NFPA 70B

Recommended Practice for Electrical Equipment Maintenance

2002 Edition

NFPA, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Codes and Standards Organization

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NFPA 70B

Recommended Practice for

Electrical Equipment Maintenance

2002 Edition

This edition of NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*, was prepared by the Technical Committee on Electrical Equipment Maintenance and acted on by NFPA at its May Association Technical Meeting held May 19–23, 2002, in Minneapolis, MN. It was issued by the Standards Council on July 19, 2002, with an effective date of August 8, 2002, and supersedes all previous editions.

This edition of NFPA 70B was approved as an American National Standard on July 19, 2002.

Origin and Development of NFPA 70B

In the fall of 1967, the Board of Directors of the National Fire Protection Association authorized the formation of an Ad Hoc Committee on Electrical Equipment Maintenance to determine the need for the development of a suitable document on this subject. The purpose of the document would be to give recommendations on the maintenance of various types of electrical installations, apparatus, and equipment usually found in industrial and large commercial-type installations. Various highly diversified interests and organizations were invited to participate.

At a meeting of the Ad Hoc Committee held January 10, 1968, in New York, with 31 representatives attending, it was pointed out that several requests had been made to the National Electrical Code Committee to include maintenance recommendations in the *National Electrical Code*®. The subject had been discussed by the Correlating Committee of the National Electrical Code Committee, and the decision was made that the Code was not the proper document in which to cover the maintenance of electrical equipment. However, the high frequency of electrical accidents that are attributed to lack of maintenance, which results annually in numerous fatalities and serious injuries as well as high monetary losses of property, caused the committee to recognize that it was a subject requiring attention.

It was noted that electrical safety information breaks down logically into four main subdivisions: (1) design or product standards, (2) installation standards (as covered by the *National Electrical Code* and the *National Electrical Safety Code*), (3) maintenance recommendations, and (4) use instructions. The problem was to explore whether something more should be done in the interest of electrical safety on the maintenance of electrical equipment and what form activity in this field should take.

It was recognized that much had been done to enunciate maintenance needs for specific types of equipment by the equipment manufacturers and that guidance was available on the general subject from a number of sources. However, it was also felt to be desirable to bring together some of the general guidelines in a single document under the NFPA procedure. The stature of the document would also be enhanced if it could in some way become associated with the *National Electrical Code*. To this end, a tentative scope was drafted for presentation to the Board of Directors of the National Fire Protection Association with a recommendation that an NFPA Committee on Electrical Equipment Maintenance be authorized.

On June 27, 1968, the NFPA Board of Directors authorized the establishment of an NFPA Committee on Electrical Equipment Maintenance with the following scope: "To develop suitable texts relating to preventive maintenance of electrical systems and equipment used in industrial-type applications with the view of reducing loss of life and property. The purpose is to correlate generally applicable procedures for preventive maintenance that have broad application to the more common classes of industrial electrical systems and equipment without duplicating or superseding instructions that manufacturers normally provide. Reports to the Association through the Correlating Committee of the National Electrical Code Committee."

The committee was formed, and an organizational meeting was held December 12, 1968, in Boston. Twenty-nine members or representatives attended. The *Recommended Practice for Electrical Equipment Maintenance* represented the cumulative effort of the entire committee.

In 1973, the committee developed Part II, which became Chapters 5 through 15, and a new addition in the Appendix, "How to Instruct."

In 1976, the committee developed the chapters on Electronic Equipment, Ground-Fault Protection, Wiring Devices, Maintenance of Electrical Equipment Subject to Long Intervals Between Shutdowns, and new additions in the Appendix, "NEMA Configurations," and "Long-Term Maintenance Guidelines."

In the 1983 edition, the committee developed the chapters on De-energizing and Grounding of Equipment to Provide Protection for Electrical Maintenance Personnel and on Cable Tray Systems, and added Appendix I, "Equipment Storage and Maintenance During Construction."

In the 1987 edition, the committee reorganized and reformatted the former Chapter 7, now Chapter 9, to include distribution transformers as well as power transformers.

In the 1990 edition, the committee developed the chapter on Uninterruptible Power Supply (UPS) Systems. This all-new chapter was developed with a significant contribution from several nonmembers who joined our Ad Hoc Technical Subcommittee to produce this new material. The committee recognized and extended its appreciation to Mr. Robert Adams, Liebert Corporation; Mr. Russ Grose, Liebert Corporation; and Mr. Ronald Mundt, U.S. Army Corps of Engineers. The chapter on Testing and Test Methods was amended by the addition of diagrams of different wave shapes for detecting problems in motors and generators using surge testing.

In the 1994 edition, the committee added three new chapters to cover power system studies that include short circuit studies, coordination studies, load-flow studies, and reliability studies; power quality and information pertaining to harmonics, the problems created by harmonic distortion, causes of harmonic distortion, harmonic surveying and testing, and recommended solutions to harmonic problems; and vibration analysis pertaining to rotating machinery. The latter chapter included a table on suggested vibration limits and a vibration severity chart for various-sized machines. In order to more closely follow the NFPA *Manual of Style*, a new Referenced Publications chapter was created. Also, the Bibliography was moved to Appendix J.

For the 1998 edition, the chapter on Power Quality was rewritten and greatly expanded. In addition, the committee updated and revised maintenance techniques for stationary batteries and infrared inspections. Special handling and disposal considerations were introduced and employee training was focused to emphasize workplace safety.

In the 2002 edition, the committee has made several enhancements to 70B. The document was restructured to comply with the NFPA *Manual of Style*. The document scope was revised to include preventive maintenance for electronic and communications equipment. A new chapter was added for grounding. This chapter provides definitions, symptoms, inspection, testing techniques, and solutions to grounding issues. A new section for Gas Insulated Substations was added to Chapter 8 to address the maintenance issues on industrial sites resulting from regulatory changes in the electrical utility industry. Charts were added in Chapter 11 for motor control troubleshooting for motor controllers, switchboards and panelboards. Chapter 27 was enhanced with the latest technology on voltage fluctuation. A new annex was added with maintenance intervals for electrical equipment.

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Committee Scope: This Committee shall have the primary responsibility for documents relating to preventive maintenance of electrical, electronic, and communications systems and equipment used in industrial and commercial type applications with the view of: (1) reducing loss of life and property, and (2) improving reliability, performance, and efficiency in a cost-effective manner. The purpose is to provide generally applicable procedures for preventive maintenance that have broad application to the more common classes of industrial and commercial systems and equipment without duplicating or superseding instructions that manufacturers normally provide. Reports to the Association through the Correlating Committee of the National Electrical Code.

This list represents the membership at the time the Committee was balloted on the final text of this edition. Since that time, changes in the membership may have occurred. A key to classifications is found at the back of the document.

NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

Changes other than editorial are indicated by a vertical rule beside the paragraph, table, or figure in which the change occurred. These rules are included as an aid to the user in identifying changes from the previous edition. Where one or more complete paragraphs have been deleted, the deletion is indicated by a bullet between the paragraphs that remain.

A reference in brackets [ ] following a section or paragraph indicates material that has been extracted from another NFPA document. As an aid to the user, Annex L lists the complete title and edition of the source documents for both mandatory and nonmandatory extracts. Editorial changes to extracted material consist of revising references to an appropriate division in this document or the inclusion of the document number with the division number when the reference is to the original document. Requests for interpretations or revisions of extracted text shall be sent to the appropriate technical committee.

Information on referenced publications can be found in Chapter 2 and Annexes K and L.

Chapter 1 Administration

1.1 Scope.

1.1.1 This recommended practice applies to preventive maintenance for electrical, electronic, and communication systems and equipment and is not intended to duplicate or supersede instructions that manufacturers normally provide. Systems and equipment covered are typical of those installed in industrial plants, institutional and commercial buildings, and large multifamily residential complexes.

1.1.2 Consumer appliances and equipment intended primarily for use in the home are not included.

1.2 Purpose. The purpose of this recommended practice is to reduce hazards to life and property that can result from failure or malfunction of industrial-type electrical systems and equipment.

1.2.1 Chapters 4, 5, and 6 of these recommendations for an effective electrical preventive maintenance (EPM) program have been prepared with the intent of providing a better understanding of benefits, both direct and intangible, that can be derived from a well-administered EPM program.

1.2.2 This recommended practice explains the function, requirements, and economic considerations that can be used to establish such an EPM program.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this recommended practice and should be considered part of the recommendations of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 70, *National Electrical Code®*, 2002 edition.

NFPA 70E, *Standard for Electrical Safety Requirements for Employee Workplaces,* 2000 edition.

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment,* 1998 edition.

2.3 Other Publications.

2.3.1 ANSI Publications. American National Standards Institute, Inc., 11 West 42nd Street, New York, NY 10036.

ANSI/AATCC-27, *Wetting Agents: Evaluation of Rewetting Agents,* 1994.

ANSI C2, *National Electrical Safety Code*, Part I, Rules for the Installation and Maintenance of Electric Supply Stations and Equipment, 1993.

ANSI/IEEE C37.13, *Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures*, 1990.

ANSI/NEMA C84.1, *Electric Power Systems and Equipment, Voltage Ratings (60 Hertz),* 1995.

ANSI Z244.1, *Personnel Protection — Lockout/Tagout of Energy Sources — Minimum Safety Requirements*, 1982.

2.3.2 ASTM Publications. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 120, *Standard Specifications for Rubber Insulating Gloves,* 1995.

ASTM D 664, *Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration,* 1995.

ASTM D 877, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes*, 1987.

ASTM D 923, *Standard Test Method for Sampling Electrical Insulating Liquids*, 1991.

ASTM D 924, *Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids*, 1992.

ASTM D 971, *Standard Test Methods for Interfacial Tension of Oil Against Water by the Ring Method*, 1991.

ASTM D 974, *Standard Test Methods for Acid and Base Number by Color-Indicator Titration*, 1992.

ASTM D 1500, *Standard Test Method for ASTM Color of Petroleum Products*, 1991.

ASTM D 1524 (Reaff. 1990), *Standard Test Method for Visual Examination of Used Electrical Insulating Oils of Petroleum Origin in the Field*, 1984.

ASTM D 1534, *Standard Test Method for Approximate Acidity in Electrical Insulating Liquids by Color-Indicator Titration*, 1990.

ASTM D 1816 REV A (Reaff. 1990), *Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes,* 1984.

ASTM D 2285 (Reaff. 1990), *Standard Test Method for Interfacial Tension of Electrical Insulating Oils of Petroleum Origin Against Water by the Drop-Weight Method*, 1985.

ASTM D 2472, *Standard Specification for Sulfur Hexaflouride*, 2000.

ASTM D 3284 REV A, *Test Methods for Combustible Gases in the Gas Space of Electrical Apparatus in the Field,* 1990.

ASTM D 3612, *Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography*, 1993.

2.3.3 IEEE Publications. Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

ANSI/IEEE 4, *Standard Techniques for High Voltage Testing. Sixth edition*, 1995.

IEEE 27, *Standard for Switchgear Assemblies including Metal-Enclosed Bus*, 1987.

ANSI/IEEE 43 (R.1991), *Recommended Practice for Testing Insulation Resistance of Rotating Machinery*, 1974.

ANSI/IEEE 62, *Guide for Diagnostic Field Testing of Electric Power Apparatus—Part 1: Oil Filled Power Transformers, Regulators, and Reactors*, 1995.

ANSI/IEEE 80, *Guide for Safety in AC Substation Grounding*, 1986.

ANSI/IEEE 95 (Reaff. 1991), *Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage*, 1977.

ANSI/IEEE 141, *Recommended Practice for Electric Power Distribution for Industrial Plants* (Red Book), 1993.

ANSI/IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems* (Green Book), 1991.

ANSI/IEEE 241, *Recommended Practice for Electric Power Systems in Commercial Buildings* (Gray Book), 1990.

ANSI/IEEE 242 (Reaff. 1991), *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems* (Buff Book), 1986.

ANSI/IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis* (Brown Book), 1990.

ANSI/IEEE 400, *Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field*, 1991.

ANSI/IEEE 493, *Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems* (Gold Book), 1990.

ANSI/IEEE 519, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, 1992.

IEEE Std C37.122.1-1993 *IEEE Guide for Gas-Insulated Substations.*

ANSI/IEEE C57.104, *Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers*, 1991.

ANSI/IEEE 1100, *Recommended Practice for Powering and Grounding Sensitive Electronic Equipment* (Emerald Book), 1992.

IEEE Std 1125-1993, *IEEE Guide for Moisture Measurement and Control in SF_6 Gas-Insulated Equipment.*

ANSI/IEEE C57.110 (Reaff. 1993), *Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents*, 1986.

2.3.4 ITI Publication. Information Technology Industry Council, 1250 Eye Street NW, Suite 200, Washington, DC 20005. 202-737-8880. http://www.itic.org

2.3.5 NEMA Publications. National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1847, Rosslyn, VA 22209.

NEMA AB 1-99, *Molded Case Circuit Breakers and Molded Case Switches*, 1999.

NEMA AB 4, *Guidelines for Inspection and Preventive Maintenance of Molded-Case Circuit Breakers Used in Commercial and Industrial Applications*, 1996.

NEMA MG 1, *Motors and Generators Standards*, 1998.

NEMA SG 6, *Power Switching Equipment*, 2000.

NEMA WD 6, *Wiring Devices — Dimensional Requirements*, 1997.

2.3.6 NETA Publication. InterNational Electrical Testing Association, P.O. Box 687, Morrison, CO 80465.

Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems, 1997.

2.3.7 UL Publications. Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062.

UL 489, *Standard for Safety, Molded-Case Circuit Breakers, Molded-Case Switches and Circuit Breaker Enclosures*, Eighth edition, 1991.

UL 1436, *UL Standard for Safety Outlet Circuit Testers and Similar Indicating Devices*, 3rd edition, 1993.

2.3.8 U.S. Government Publications. U.S. Government Printing Office, Washington, DC 20402-9328.

Federal Information Processing Standards Publication 94, *Guideline on Electrical Power for ADP Installations*, 1983.

Title 29, *Code of Federal Regulations*, Part 1910.146, "Occupational Safety and Health Standards."

Title 40, *Code of Federal Regulations*, Part 761, "Protection of Environment — Polychlorinated Biphenyls (PCBs) Manufacturing Processing, Distribution in Commerce, and Use Prohibitions."

2.3.9 Westinghouse Publication. Westinghouse Electrical Corp., Printing Division, 1 Stewart Station Drive, Trafford, PA 15085.

HB 6001-RS, *Electrical Maintenance Hints.*

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter apply to the terms used in this recommended practice. Where terms are not included, common usage of the terms applies.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

3.2.3* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.4 Recommended Practice. A document that is similar in content and structure to a code or standard but that contains only nonmandatory provisions using the word "should" to indicate recommendations in the body of the text.

3.2.5 Shall. Indicates a mandatory requirement.

3.2.6 Should. Indicates a recommendation or that which is advised but not required.

3.3 General Definitions.

3.3.1 Coordinated System. When an overcurrent (overload or fault) occurs on an electrical system, the protective device immediately on the line side of the overcurrent should open without affecting further upstream overcurrent devices.

3.3.2 Coordination Study. A study of the coordinated system to improve power system reliability.

3.3.3 Corona. An electrical discharge phenomenon occurring in gaseous substances, such as air. High electrical gradients exceeding the breakdown level of air lead to corona discharges. Mild corona will have a low sizzling sound and might not be audible above ambient noise in the substation. As the corona increases in level, the sizzling sound becomes louder and will be accompanied by popping, spitting, or crackling as flashover level nears. Corona ionizes the air, converting the oxygen to ozone, which has a distinctive, penetrating odor.

3.3.4 Duty.

3.3.4.1 Continuous Duty. Operation at a substantially constant load for an indefinitely long time.

3.3.4.2 Intermittent Duty. Operation for alternate intervals of (1) load and no load; (2) load and rest; and (3) load, no load, and rest.

3.3.4.3 Periodic Duty. Intermittent operation in which the load conditions are regularly recurrent.

3.3.4.4 Short-Time Duty. Operation at a substantially constant load for a short and definitely specified time.

3.3.4.5 Varying Duty. Operation at loads, and for intervals of time, both of which might be subject to wide variation.

3.3.5 Electrical Equipment. A general term applied to the material, fittings, devices, fixtures, and apparatus that are part of, or are used in connection with, an electrical installation. This includes the electrical power-generating system; substations; distribution systems; utilization equipment; and associated control, protective, and monitoring devices.

3.3.6 Electrical Preventive Maintenance (EPM). A managed program of inspecting, testing, analyzing, and servicing electrical systems and equipment. Its purpose is to maintain safe operations and production by reducing or eliminating system interruptions and equipment breakdowns. EPM relies on the knowledge of the electrical systems and equipment being maintained, and on knowing the operating experience, loss exposures, potential for injury, and maintenance resources.

3.3.7 Ground. A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth. [**70:**100]

3.3.7.1 Lightning Ground. See 3.3.13, Grounding Electrode System.

3.3.7.2 Noise(less) Ground. The supplemental equipment-grounding electrode installed at machines, or the isolated equipment-grounding conductor, intended to reduce electrical noise.

3.3.7.3 Personnel Protective Ground. Bonding jumper that is intentionally installed to ground de-energized, normally ungrounded circuit conductors when personnel are working on them, to minimize voltage differences between different parts of the equipment and personnel, so as to protect against shock hazard and/or equipment damage.

3.3.7.4 Safety Ground. See 3.3.7.3, Personnel Protective Ground.

3.3.8 Ground Resistance/Impedance Measurement. The use of special test equipment to measure the grounding electrode resistance or impedance to earth at a single frequency at or near power line frequency.

3.3.9 Ground Well. See 3.3.13, Grounding Electrode System.

3.3.10 Ground-Fault Circuit Interrupter (GFCI). A GFCI is designed to protect a person from electrocution when contact between a live part of the protected circuit and ground causes current to flow through a person's body. A GFCI will disconnect the circuit when a current equal to or higher than the calibration point (4 mA to 6 mA) flows from the protected circuit to ground. It will not eliminate the shock sensation since normal perception level is approximately 0.5 mA. It will not protect from electrocution on line-to-line contact since the nature of line-to-line loads cannot be distinguished.

3.3.11 Ground-Fault Protection of Equipment (GFP). There are two applications where ground-fault protection of equipment is intended to be used, where there may be excessive ground-fault leakage current from equipment, or when equipment and conductors are to be protected from damage in the event of a higher-level ground fault (either solid or arcing). These types of protective equipment are for use only on alternating-current, grounded circuits, and will cause the circuit to be disconnected when a current equal to or higher than its pickup setting or rating flows to ground. They are not designed to protect personnel from electrocution. Equipment ground-fault protective devices are intended to operate upon a condition of excessive ground-fault leakage current from equipment. The ground current pickup level of these devices is from above 6 mA to 50 mA. Circuit breakers with equipment ground-fault protection are combination circuit breaker and equipment ground-fault protective devices designed to serve the dual function of providing overcurrent protection and ground-fault protection for equipment. The ground current pickup level of these breakers is typically 30 mA. They are intended to be used in accordance with NFPA 70, *National Electrical Code*®, Articles 426 and 427. Ground-fault sensing and relaying equipment is intended to provide ground-fault protection of equipment at services and feeders. They are rated for ground current pickup levels from 4 amperes to 1200 amperes.

3.3.12 Grounded. Connected to earth or to some conducting body that serves in place of the earth. [**70:**100]

3.3.13 Grounding Electrode System. The interconnection of grounding electrodes.

3.3.14 Grounding-Type Receptacle. A receptacle with a dedicated terminal that is to be connected to the equipment grounding conductor.

3.3.15 Harmonics. Harmonic voltages or currents are those voltages or currents whose frequencies are integer multiples of the fundamental frequency.

3.3.16 Noise. Undesirable electrical signals in an electrical or electronic circuit.

3.3.16.1 Common Mode Noise. Undesirable electrical signals that exist between a circuit conductor and the grounding conductor.

3.3.16.2 Transverse Mode Noise. Transverse mode noise, sometimes referred to as normal or differential mode noise, is undesirable electrical signals that exist between a pair of circuit conductors.

3.3.17 Power Transformers. Determines the type of transformer and is defined as those larger than 500 kVA, while distribution transformers are those 500 kVA or smaller.

3.3.18 Protective Conductor. *(See 29.2.23, Equipment-Grounding Conductor.)* A conductor required by some measures for protection against electric shock for electrically connecting any of the following parts: exposed conductive parts, extraneous conductive parts, or main (grounding) earthing terminal. Also identified in some instances as the protective external (PE) conductor.

3.3.19 Qualified Person. One who has the skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training on the hazards involved.

3.3.20 Single-Point Grounding. The single-point grounding of a transformer means connecting the secondary side of the transformer to earth ground through one or more grounding electrodes. This connection should be made at any point on the separately derived system from the source to the first system-disconnecting means or overcurrent device.

3.3.21 Survey. The collection of accurate data on the electrical system and the evaluation of this data to obtain the necessary information for developing the EPM program. The systems and equipment covered in specific parts of the survey should be based on logical divisions of the electrical system.

3.3.22 Sustained Voltage Interruption. The loss of the supply voltage to less than 10 percent on one or more phases for a period greater than 1 minute.

3.3.23 System Grounding. The intentional connection of an electrical supply system to its associated grounding electrode(s).

3.3.24 Transformer. A device for changing energy in an alternating current system from one voltage to another; usually includes two or more insulated coils on an iron core.

3.3.25 Unbalanced Voltages. Unequal voltage values on three-phase circuits that can exist anywhere on the power distribution system.

3.3.26 Undervoltage. A long duration undervoltage is a decrease of the supply voltage to less than 90 percent of the nominal voltage for a time duration greater than 1 minute. *[See ANSI/NEMA C84.1, Electric Power Systems and Equipment, Voltage Ratings (60 Hertz).]*

Chapter 4 Why an Effective Electrical Preventive Maintenance (EPM) Program Pays Dividends

4.1 Why EPM?

4.1.1 Electrical equipment deterioration is normal, but equipment failure is not inevitable. As soon as new equipment is installed, a process of normal deterioration begins. Unchecked, the deterioration process can cause malfunction or an electrical failure. Deterioration can be accelerated by factors such as a hostile environment, overload, or severe duty cycle. An effective EPM program identifies and recognizes these factors and provides measures for coping with them.

4.1.2 In addition to normal deterioration, there are other potential causes of equipment failure that can be detected and corrected through EPM. Among these are load changes or additions, circuit alterations, improperly set or improperly selected protective devices, and changing voltage conditions.

4.1.3 Without an EPM program, management assumes a greatly increased risk of a serious electrical failure and its consequences.

4.2 Value and Benefits of a Properly Administered EPM Program.

4.2.1 A well-administered EPM program will reduce accidents, save lives, and minimize costly breakdowns and unplanned shutdowns of production equipment. Impending troubles can be identified — and solutions applied — before they become major problems requiring more expensive, time-consuming solutions.

4.2.2 Benefits of an effective EPM program fall into two general categories. Direct, measurable, economic benefits are derived by reduced cost of repairs and reduced equipment downtime. Less measurable but very real benefits result from improved safety. To understand fully how personnel and equipment safety are served by an EPM program, the mechanics of the program — inspection, testing, and repair procedures — should be understood. Such an understanding explains other intangible benefits such as improved employee morale, better workmanship and increased productivity, reduced absenteeism, reduced interruption of production, and improved insurance considerations. Improved morale will come with employee awareness of a conscious management effort to promote safety by reducing the likelihood of electrical injuries or fatalities, electrical explosions, and fires. Reduced personnel injuries and property loss claims can help keep insurance premiums at favorable rates.

4.2.3 Although the benefits that result from improved safety are difficult to measure, direct, measurable, economic benefits can be documented by equipment repair cost and equipment downtime records after an EPM program has been implemented.

4.2.4 Dependability can be engineered and built into equipment, but effective maintenance is required to keep it dependable. Experience shows that equipment lasts longer and performs better when covered by an EPM program. In many cases, the investment in EPM is small compared to the cost of equipment repair and the production losses associated with an unexpected equipment shutdown.

4.2.5 Careful planning is the key to the economic success of an EPM program. With proper planning, maintenance costs can be held to a practical minimum, while production is maintained at a practical maximum.

4.2.6 An EPM program requires the support of top management, because top management provides the funds that are required to initiate and maintain the program. The maintenance of industrial electrical equipment is essentially a matter of business economics. Maintenance costs can be placed in either of two basic categories: preventive maintenance or breakdown repairs. The money spent for preventive maintenance will be reflected as less money required for breakdown repairs. An effective EPM program holds the sum of these two expenditures to a minimum. Figure 4.2.6 is a typical curve illustrating this principle. According to this curve, as the interval of time between EPM inspections is increased, the cost of the EPM will diminish and the cost of breakdown repairs and replacement of failed equipment will increase. The lowest total annual expense is realized by maintaining an inspection frequency that will keep the sum of repair/replacement and EPM costs at a minimum.

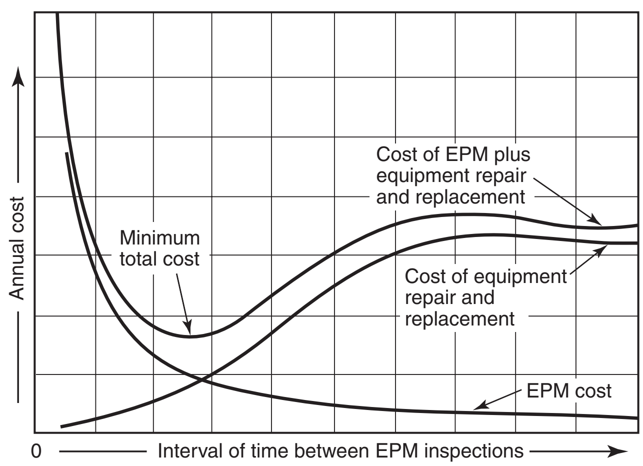


FIGURE 4.2.6 Effect of EPM Inspection Frequency on Overall Costs.

4.2.7 An EPM program is a form of protection against accidents, lost production, and loss of profit. An EPM program enables management to place a dollar value on the cost of such protection. An effective EPM program satisfies an important part of management's responsibility for keeping costs down and production up.

4.2.8* Insurance statistics document the high cost of inadequate electrical maintenance. *(See Table A.4.2.8.)*

4.3 EPM and Energy Conservation. Energy conservation is one of the worthwhile benefits associated with an EPM program — saving dollars and vital resources. Equipment that is well maintained operates more efficiently and utilizes less energy.

4.4 Case Histories.

4.4.1 The failure of a transformer in an industrial plant caused a total plant shutdown. Contamination of the transformer's insulating oil caused the failure. The contamination went undetected because the oil had not been tested for several years. Fire damage and equipment replacement costs amounted to $50,000, exclusive of the cost of plant downtime. This amount would have paid for the cost of operating an EPM program covering the entire plant's electrical distribution system for several years.

4.4.2 Damage amounting to $100,000 was attributed to the failure of the main switchgear in an industrial plant. Fouling by dirt, gummy deposits, and iron filings caused the failure. The cost of this failure would have supported a comprehensive EPM program covering all of the plant's electrical distribution system for several years.

4.4.3 McCormick Place, a large exhibition hall in Chicago, was destroyed by a fire believed to have been started because of a defective extension cord serving a display booth. Direct property loss was $60 million, and loss of the facility cost an additional $100 million to the economy in the Chicago area. This fire might have been prevented if a program had been in effect to ensure that worn cords were replaced, that only heavy-duty cords were used, and that cords and their supply circuits were not overloaded.

4.4.4 The failure of a large motor shut down an entire industrial plant for 12 days. The cause of the failure was overheating resulting from dust-plugged cooling ducts. An EPM inspection would have detected the clogged ducts and averted the failure and accompanying plant outage.

Chapter 5 What Is an Effective Electrical Preventive Maintenance (EPM) Program?

5.1 Introduction. An effective electrical preventive maintenance (EPM) program should enhance safety and also reduce equipment failure to a minimum consistent with good economic judgment.

5.1.1 An effective electrical preventive maintenance program should include the following basic ingredients:

(1) Personnel qualified to carry out the program
(2) Regularly scheduled inspection, testing, and servicing of equipment

5.1.2 A successful program should also include the following:

(1) Application of sound judgment in evaluating and interpreting results of inspections and tests
(2) Keeping of concise but complete records

5.2 Planning an EPM Program. The following basic factors should be considered when planning an EPM program.

5.2.1 Personnel Safety. Will an equipment failure endanger or threaten the safety of any personnel? What can be done to ensure personnel safety?

5.2.2 Equipment Loss. Is installed equipment — both electrical and mechanical — complex or so unique that required repairs would be unusually expensive?

5.2.3 Production Economics. Will breakdown repairs or replacement of failed equipment require extensive downtime? How many production dollars will be lost in the event of an equipment failure? Which equipment is most vital to production?

5.3 Main Parts of an EPM Program. An EPM program should consist of the following essential ingredients:

(1) Responsible and qualified personnel

(2) Survey and analysis of electrical equipment and systems to determine maintenance requirements and priorities
(3) Programmed routine inspections and suitable tests
(4) Accurate analysis of inspection and test reports so that proper corrective measures can be prescribed
(5) Performance of necessary work
(6) Concise but complete records

5.3.1 Personnel.

5.3.1.1 A well-qualified individual should be in charge of the program.

5.3.1.2 Personnel assigned to inspection and testing duties should be selected from the best maintenance personnel in the plant.

5.3.1.3 Where in-plant personnel are not qualified, a maintenance contractor should be employed.

5.3.2 Survey and Analysis.

5.3.2.1 Survey and analysis should cover equipment and systems that have been previously determined to be essential in accordance with a priority plan.

5.3.2.2 Regardless of the size of the program being contemplated, the EPM supervisor should determine the extent of the work to be done and where to begin.

5.3.2.3 All electrical equipment — motors, transformers, circuit breakers, controls, and the like — should receive a thorough inspection and evaluation to permit the EPM supervisor to make a qualified judgment as to how, where, and when each piece of equipment should be fitted into the program.

5.3.2.4 In addition to determining the physical condition, the survey should determine if the equipment is operating within its rating.

5.3.2.5 In the course of the survey, the condition of electrical protective devices such as fuses, circuit breakers, protective relays, and motor overload relays should be checked. These devices are the safety valves of an electrical system and their proper operating condition ensures the safety of personnel, protection of equipment, and reduction of economic loss.

5.3.2.6 After the survey has been completed, data should be evaluated to determine equipment condition. Equipment condition will reveal repair work to be done, as well as the nature and frequency of required inspections and tests.

5.3.3 Programmed Inspections. Inspection and testing procedures should be carefully tailored to requirements. In some plants, regularly scheduled tests will call for scheduled outages of production or process equipment. In such cases, close coordination between maintenance and production personnel is necessary.

5.3.3.1 Analysis of Inspection and Test Reports. Analysis of inspection and test reports should be followed by implementation of appropriate corrective measures. Follow-through with necessary repairs, replacement, and adjustment is in fact the end purpose of an effective EPM program.

5.3.3.2 Records.

5.3.3.2.1 Records should be accurate and contain all vital information.

5.3.3.2.2 Care should be taken to ensure that extraneous information does not become part of the record, because excessive record keeping can hamper the program.

5.3.4 EPM Support Procedures.

5.3.4.1 Design for Ease of Maintenance. Effective electrical preventive maintenance begins with good design. In design of new facilities, conscious effort is recommended to ensure optimum maintainability. Dual circuits, tie circuits, auxiliary power sources, and drawout protective devices make it easier to schedule maintenance and to perform maintenance work with minimum interruption of production. Other effective design techniques include equipment rooms to provide environmental protection, grouping of equipment for more convenience and accessibility, and standardization of equipment and components.

5.3.5 Training for Safety and Technical Skills.

5.3.5.1 Training Requirements.

5.3.5.1.1 All employees who face a risk of electrical hazard should be trained to understand the specific hazards associated with electrical energy.

5.3.5.1.2 All employees should be trained in safety-related work practices and required procedures as necessary to provide protection from electrical hazards associated with their respective jobs or task assignments.

5.3.5.1.3 Employees should be trained to identify and understand the relationship between electrical hazards and possible injury.

5.3.5.1.4 Refresher training should be provided as required.

5.3.5.2 Type of Training. The training can be classroom or on the job, or both. The type of training should be determined by the needs of the employee.

5.3.5.3 Emergency Procedures.

5.3.5.3.1 Employees working on or near exposed energized electrical conductors or circuit parts should be trained in methods of release of victims from contact with exposed energized conductors or circuit parts.

5.3.5.3.2 Employees working on or near exposed energized electrical conductors or circuit parts should be instructed regularly in methods of first aid and emergency procedures, such as approved methods of resuscitation.

5.3.5.4 Training Scope. Employees should be trained and be knowledgeable of the following:

(1) Construction and operation of equipment
(2) Specific work method
(3) Electrical hazards that can be present with respect to that equipment or work method
(4) Proper use of special precautionary techniques, personal protective equipment, insulating and shielding materials, and insulated tools and test equipment
(5) Skills and techniques necessary to distinguish exposed, energized parts from other parts of electrical equipment
(6) Skills and techniques necessary to determine the nominal voltage of exposed energized parts
(7) Decision-making process necessary to determine the degree and extent of hazard
(8) Job planning necessary to perform the task safely

5.3.5.5 Record Keeping. Records of training should be maintained for each employee.

5.3.6 Outside Service Agencies. Some maintenance and testing operations, such as relay and circuit-breaker inspection and testing, require specialized skills and special equipment. In small organizations, it might be impractical to develop the skills and acquire the equipment needed for this type of work. In such cases, it might be advisable to contract the work to firms that specialize in providing such services.

5.3.7 Tools and Instruments. Proper tools and instruments are an important part of an EPM program, and safety protective gear is an essential part of the necessary equipment. Proper tools, instruments, and other equipment should be used to ensure maximum safety and productivity from the maintenance crew. Where specialized instruments and test equipment are needed only occasionally, they can be rented from a variety of sources.

Chapter 6 Planning and Developing an Electrical Preventive Maintenance (EPM) Program

6.1 Introduction.

6.1.1 The purpose of an EPM program is to reduce hazard to life and property that can result from the failure or malfunction of electrical systems and equipment. The first part of these recommendations for an effective EPM program has been prepared with the intent of providing a better understanding of benefits — both direct and intangible — that can be derived from a well-administered EPM program. This chapter explains the function, requirements, and economic considerations that can be used to establish such a program.

6.1.2 The following four basic steps should be taken in the planning and development of an EPM program. In their simplest form, they are as follows:

(1) Compile a listing of all equipment and systems.
(2) Determine which equipment and systems are most critical and most important.
(3) Develop a system for keeping up with what needs to be done.
(4) Train people for the work that needs to be done, or contract for the special services that are needed.

6.1.3 The success of an EPM program depends on the caliber of personnel responsible for its implementation.

6.1.3.1 The primary responsibility for EPM program implementation and its success should lie with a single individual.

6.1.3.2 This individual responsible for the EPM program should be given the authority to do the job and should have the cooperation of management, production, and other departments whose operations might affect the EPM program.

6.1.3.3 Ideally, the person designated to head the EPM program should have the following qualifications.

(1) *Technical Competence.* Personnel should, by education, training, and experience, be well-rounded in all aspects of electrical maintenance.
(2) *Administrative and Supervisory Skills.* Personnel should be skilled in the planning and development of long-range objectives to achieve specific results and should be able to command respect and solicit the cooperation of all persons involved in the program.

6.1.4 The maintenance supervisor should have open lines of communication with design supervision. Frequently, an unsafe installation or one that requires excessive maintenance can be traced to improper design or construction methods or misapplication of hardware.

6.1.5 The work center of each maintenance work group should be conveniently located. This work center should contain the following:

(1) All of the inspection and testing procedures for that zone
(2) Copies of previous reports
(3) Single-line diagrams
(4) Schematic diagrams
(5) Records of complete nameplate data
(6) Vendors' catalogs
(7) Facility stores' catalogs
(8) Supplies of report forms

6.1.5.1 There should be adequate storage facilities for tools and test equipment that are common to the group.

6.1.6 In a continuously operating facility, running inspections (inspections made with equipment operating) play a very vital role in the continuity of service. The development of running inspection procedures varies with the type of operation. Running inspection procedures should be as thorough as practicable within the limits of safety and the skill of the craftsman. These procedures should be reviewed regularly in order to keep them current. Each failure of electrical equipment, be it an electrical or a mechanical failure, should be reviewed against the running inspection procedure to determine if some other inspection technique would have indicated the impending failure. If so, the procedure should be modified to reflect the findings.

6.1.7 Supervisors find their best motivational opportunities through handling the results of running inspections. When the electrical maintenance supervisor initiates corrective action, the craftsperson should be so informed. The craftsperson who found the condition will then feel that his or her job was worthwhile and will be motivated to try even harder. However, if nothing is done, individual motivation might be affected adversely.

6.1.8 Trends in failure rates are hard to change and take a long time to reverse. For this reason, the inspection should continue and resulting work orders written, even though the work force might have been reduced. Using the backlog of work orders as an indicator, the electrical maintenance supervisor can predict trends before they develop. With the accumulation of a sizable backlog of work orders, an increase in electrical failures and production downtime can be expected.

6.2 Survey of Electrical Installation.

6.2.1 Data Collection.

6.2.1.1 The first step in organizing a survey should be to take a look at the total package. Will the available manpower permit the survey of an entire system, process, or building, or should it be divided into segments?

6.2.1.2 Next, a priority should be assigned to each segment. Segments found to be sequential should be identified before the actual work commences.

6.2.1.3 The third step should be the assembling of all documentation. This might necessitate a search of desks, cabinets, and such, and might also require that manufacturers be contacted in order to replace lost documents. All of these documents should be brought to a central location and marked immediately with some form of effective identification.

6.2.2 Diagrams and Data. The availability of up-to-date, accurate, and complete diagrams is the foundation of a successful EPM program. No EPM program can operate without them, and their importance cannot be overemphasized. The diagrams discussed in 6.2.2.1 through 6.2.2.8.2 are some of those in common use.

6.2.2.1 Single-line diagrams should show the electrical circuitry down to, and often including, the major items of utilization equipment. They should show all electrical equipment in the power system and give all pertinent ratings. In making this type of diagram, it is basic that voltage, frequency, phase, and normal operating position be included. No less important, but perhaps less obvious, are items such as transformer impedance, available short-circuit current, and equipment continuous and interrupting ratings. Other items include current and potential transformers and their ratios, surge capacitors, and protective relays. If one diagram cannot cover all of the equipment involved, additional diagrams, appropriately noted on the main diagram, can be drawn.

6.2.2.2 Short-circuit and coordination studies are very important. Many managers have the misconception that these engineering studies are part of the initial facility design, after which the subject can be forgotten. However, a number of factors can affect the available short-circuit current in an electrical system. Among these are changes in the supply capacity of the utility company, changes in size or percent impedance of transformers, changes in conductor size, addition of motors, and changes in system operating conditions.

(A) In the course of periodic maintenance testing of protective equipment, such as relays and series or shunt-trip devices, equipment settings should be evaluated. Along with the proper sizing of fuses, this is part of the coordination study.

(B) In a small facility — one receiving electrical energy at utilization voltage or from a single step-down transformer — the short-circuit study is very simple. The available incoming short-circuit current can be obtained from the utility company sales engineer.

(C) In a larger system, it might be desirable to develop a computerized short-circuit study to improve accuracy and reduce engineering time. Should resources not be available within the plant organization, the short-circuit study can be performed on a contract basis. The short-circuit data are used to determine the required momentary and interrupting ratings of circuit breakers, fuses, and other equipment.

(D) Fuses are rated on the basis of their current-carrying and interrupting capacities. These ratings should be determined and recorded. Other protective devices are usually adjustable as to pickup point and time-current characteristics. The settings of such protective devices should be determined, verified by electrical tests, and recorded for future reference.

(E) Personnel performing the tests should be trained and qualified in proper test procedures. Various organizations and manufacturers of power and test equipment periodically schedule seminars where participants are taught the principles of maintenance and testing of electrical protective devices.

(F) Additional guidance on electrical systems can be found in Chapter 25.

6.2.2.3 Circuit routing diagrams, cable maps, or raceway layouts should show the physical location of conductor runs. In addition to voltage, such diagrams should also indicate the type of raceway, number and size of conductors, and type of insulation.

(A) Where control conductors or conductors of different systems are contained within the same raceway, the coding appropriate to each conductor should be noted.

(B) Vertical and horizontal runs with the location of taps, headers, and pull boxes should be shown.

(C) Access points should be noted where raceways pass through tunnels or shafts with limited access.

6.2.2.4 Layout diagrams, plot plans, equipment location plans, or facility maps should show the physical layout (and in some cases, the elevations) of all equipment in place.

(A) Switching equipment, transformers, control panels, mains, and feeders should be identified.

(B) Voltage and current ratings should be shown for each piece of equipment.

6.2.2.5 Schematic diagrams should be arranged for simplicity and ease of understanding circuits without regard for the actual physical location of any components. The schematic should always be drawn with switches and contacts shown in a de-energized position.

6.2.2.6 Wiring diagrams, like schematics, should show all components in the circuit, but they are arranged in their actual physical location.

6.2.2.6.1 Electromechanical components and strictly mechanical components interacting with electrical components should be shown. Of particular value is the designation of terminals and terminal strips with their appropriate numbers, letters, or colors.

6.2.2.6.2 Wiring diagrams should identify all equipment parts and devices by standard methods, symbols, and markings.

6.2.2.7 An effective EPM program should have manufacturers' service manuals and instructions. These manuals should include recommended practices and procedures for the following:

(1) Installation
(2) Disassembly/assembly (interconnections)
(3) Wiring diagrams, schematics, bills of materials
(4) Operation (set-up and adjustment)
(5) Maintenance (including parts list and recommended spares)
(6) Software program (if applicable)
(7) Troubleshooting

6.2.2.8 Electrical Equipment Installation Change. The documentation of the changes that result from engineering decisions, planned revisions, and so on, should be the responsibility of the engineering group that initiates the revisions.

6.2.2.8.1 Periodically, changes occur as a result of an EPM program. The EPM program might also uncover undocumented practices or installations.

6.2.2.8.2 A responsibility of the EPM program is to highlight these changes, note them in an appropriate manner, and formally submit the revisions to the organization responsible for the maintenance of the documentation.

6.2.3 System Diagrams. System diagrams should be provided to complete the data being assembled. The importance of the system determines the extent of information shown. The information can be shown on the most appropriate type of diagram but should include the same basic information, source and type of power, conductor and raceway information, and switching and protective devices with their physical locations. It is vital to show where the system might interface with another, such as with emergency power; hydraulic, pneumatic, or mechanical systems; security and fire-alarm systems; and monitoring and control systems. Some of the more common of these are described in 6.2.3.1 through 6.2.3.4.

6.2.3.1 Lighting System Diagrams. Lighting system diagrams (normal and emergency) can terminate at the branch circuit panelboard, listing the number of fixtures, type and lamp size for each area, and design lighting level. The diagram should show watchman lights and probably an automatic transfer switch to the emergency power system.

6.2.3.2 Ventilation. Ventilation systems normally comprise the heating, cooling, and air-filtering system. Exceptions include furnace, dryer, oven, casting, and similar areas where process heat is excessive and air conditioning is not practical. Numerous fans are used to exhaust the heated and possibly foul air. In some industries, such as chemical plants and those using large amounts of flammable solvents, large volumes of air are needed to remove the hazardous vapors. Basic information, including motor and fan sizes, motor or pneumatically operated dampers, and so on, should be shown. Additionally, many safety features can be involved to ensure that fans start before the process — airflow switches to shut down an operation on loss of ventilation and other interlocks of similar nature. Each of these should be identified with respect to type, function, physical location, and operating limits.

6.2.3.3 Heating and Air Conditioning. Heating and air-conditioning systems are usually manufactured and installed as a unit, furnished with diagrams and operating and maintenance manuals. This information should be updated as the system is changed or modified. Because these systems are often critical to the facility operation, additional equipment might have been incorporated: for example, humidity, lint, and dust control for textile, electronic, and similar processes and corrosive and flammable vapor control for chemical and related industries. Invariably, these systems interface with other electrical or nonelectrical systems; pneumatic or electromechanical operation of dampers, valves, and so on; electric operation for normal and abnormal temperature control; and manual control stations for emergency smoke removal are just a few. There might be others, but all should be shown and complete information given for each.

6.2.3.4 Control and Monitoring. Control and monitoring system diagrams should be provided to understand how these complicated systems function. They usually are in the form of a schematic diagram and can refer to specific wiring diagrams. Maximum benefit can be obtained only when every switching device is shown, its function indicated, and it is identified for ease in finding a replacement. These devices often involve interfaces with other systems, whether electromechanical (heating or cooling medium) pumps and valves, electro-pneumatic temperature and damper controls, or safety and emergency operations. A sequence-of-operation chart and a list of safety precautions should be included to promote the safety of personnel and equipment. Understanding these complex circuits is best accomplished by breaking down the circuits into their natural functions, such as heating, cooling, process, or humidity controls. The knowledge of how each function relates to another enables the craftsperson to have a better concept of the entire system and thus perform the assignment more efficiently.

6.2.4 Emergency Procedures. Emergency procedures should list, step by step, the action to be taken in case of emergency or for the safe shutdown or start-up of equipment or systems. Optimum use of these procedures is made when they are bound for quick reference and posted in the area of the equipment or systems. Some possible items to consider for inclusion in the emergency procedures are interlock types and locations, interconnections with other systems, and tagging procedures of the equipment or systems. Accurate single-line diagrams posted in strategic places are particularly helpful in emergency situations. The production of such diagrams in anticipation of an emergency is essential to a complete EPM program. Diagrams are a particularly important training tool in developing a state of preparedness. Complete and up-to-date diagrams provide a quick review of the emergency plan. During an actual emergency, they provide a simple, quick reference guide when time is at a premium.

6.2.5 Test and Maintenance Equipment.

6.2.5.1 All maintenance work requires the use of proper tools and equipment to properly perform the task to be done. In addition to their ordinary tools, each craftsperson (such as carpenters, pipe fitters, and machinists) uses some special tools or equipment based on the nature of the work to be performed. The electrician is no exception, but for EPM, additional equipment not found in the toolbox should be readily available. The size of the plant, nature of its operations, and extent of its maintenance, repair, and test facilities are all factors that determine the use frequency of the equipment. Economics seldom justify purchasing an infrequently used, expensive tool when it can be rented. However, a corporation having a number of plants in the area might well justify common ownership of the same device for joint use, making it quickly available at any time to any plant. Typical examples might be high-current or dc high-potential test equipment or a ground-fault locator.

6.2.5.2 Because a certain amount of mechanical maintenance is often a part of the EPM program being conducted on associated equipment, the electrical craftsperson should have ready access to such items as the following:

(1) Assorted lubrication tools and equipment
(2) Various types and sizes of wrenches
(3) Nonmetallic hammers and blocks to protect against injury to machined surfaces
(4) Wheel pullers
(5) Feeler gauges to function as inside- and outside-diameter measuring gauges
(6) Instruments for measuring torque, tension, compression, vibration, and speed
(7) Standard and special mirrors with light sources for visual inspection
(8) Industrial-type portable blowers and vacuums having insulated nozzles for removal of dust and foreign matter
(9) Nontoxic, nonflammable cleaning solvents
(10) Clean, lint-free wiping cloths

6.2.5.3 The use of well-maintained safety equipment is essential and should be mandatory when working on or near live electrical equipment. Some of the more important articles that should be provided are as follows:

(1) Heavy leather gloves
(2) Insulating gloves, mats, blankets, baskets, boots, jackets, and coats
(3) Insulated hand tools such as screwdrivers and pliers
(4) Nonmetallic hard hats with clear insulating face shields for protection against arcs
(5) Poles with hooks and hot sticks to safely open isolating switches

6.2.5.3.1 A statiscope is recommended to indicate the presence of high voltage on certain types of equipment. See NFPA 70E, *Standard for Electrical Safety Requirements for Employee Workplaces,* Parts II and III.

6.2.5.4 Portable electric lighting should be provided, particularly in emergencies involving the power supply. Portable electric lighting used for maintenance areas that are normally wet or where personnel will be working within grounded metal structures such as drums, tanks, and vessels should be operated at an appropriate low voltage from an isolating transformer or other isolated source. This voltage level is a function of the ambient condition in which the portable lighting is used. The aim is to limit the exposure of personnel to hazardous current levels by limiting the voltage. Ample supply of battery lanterns should be available with extra batteries. Suitable extension cords should be provided.

6.2.5.5 Portable meters and instruments are necessary for testing and troubleshooting, especially on circuits of 600 volts or less. These include general-purpose volt meters, voltohmmeters, and clamp-on-type ammeters with multiscale ranges. In addition to these conventional instruments, recording meters are useful for measuring magnitudes and fluctuations of current, voltage, power factor, watts, and volt-amperes versus time values. These are a definite aid in defining specific electrical problems and determining if equipment malfunction is due to abnormal electrical conditions. Other valuable test equipment includes devices to measure the insulation resistance of motors and similar equipment in the megohm range and similar instruments in the low range for determining ground resistance, lightning protection systems, and grounding systems. Continuity testers are particularly valuable for checking control circuits and for circuit identification.

6.2.5.6 Special instruments can be used to test the impedance of the grounding circuit conductor, or grounding path of energized low-voltage distribution systems and equipment. These instruments can be used to test the equipment-grounding circuit path of electrical equipment.

6.2.5.7 Insulation-resistance-measuring equipment should be used to indicate insulation values at the time equipment is put into service. Later measurements might indicate any deterioration trend of the insulation values of the equipment. High-potential ac and dc testers are used effectively to indicate dielectric strength and insulation resistance of the insulation, respectively. It should be recognized that the possibility of breakdown under test due to concealed weakness is always present. High-potential testing should be performed with caution and only by qualified operators.

6.2.5.8 Portable ground-fault locators can be used to test ungrounded power systems. Such devices will indicate ground location while the power system is energized. They thus provide a valuable aid for safe operation by indicating where to take corrective steps before an insulation breakdown occurs on another phase.

6.2.5.9 Receptacle circuit testers are devices that, by a pattern of lights, indicate some types of incorrect wiring of 15- and 20-ampere, 125-volt grounding-type receptacles.

6.2.5.9.1 Although these test devices can provide useful and easily acquired information, some have limitations, and the test results should be used with caution. For example, a high-resistance ground can give a correct wiring display, as will some multiple wiring errors. An incorrect display can be considered a valid indication that there is an incorrect situation, but a correct wiring display should not be accepted without further investigation.

6.3 Identification of Critical Equipment.

6.3.1 Equipment (electrical or otherwise) should be considered critical if its failure to operate normally and under complete control will cause a serious threat to people, property, or the product. Electric power, like process steam, water, and so forth, might be essential to the operation of a machine, but unless loss of one or more of these supplies causes the machine to become hazardous to people, property, or production, that machine might not be critical. The combined knowledge and experience of several people might be needed to make this determination. In a small plant, this determination should be able to be done by the plant engineer or master mechanic working with the operating superintendent.

6.3.1.1 A large operation should use a team comprising the following qualified people:

(1) The electrical foreman or superintendent
(2) Production personnel thoroughly familiar with the operation capabilities of the equipment and the effect its loss will have on final production
(3) The senior maintenance person who is generally familiar with the maintenance and repair history of the equipment or process
(4) A technical person knowledgeable in the theoretical fundamentals of the process and its hazards (in a chemical plant he or she should be a chemist; in a mine, a geologist, and so on)
(5) A safety engineer or one responsible for the overall security of the plant and its personnel against fire and accidents of all kinds

6.3.1.2 The team should go over the entire plant or each of its operating segments in detail, considering each unit of equipment as related to the entire operation and the effect of its loss on safety and production.

6.3.2 There are entire systems that might be critical by their very nature. Depending on the size and complexity of the operation, a plant can contain any or all of the following examples: emergency power, emergency lighting, fire-alarm systems, fire pumps, and certain communication systems. There should be no problem in establishing whether or not any of these systems is critical and in having the proper amount of emphasis placed on their maintenance.

6.3.3 More difficult to identify are the parts of a system that are critical because of the function of the utilization equipment and its associated hardware. Some examples are as follows:

(1) The agitator drive motor for a kettle-type reactor can be extremely critical in that, if it fails to run for some period of time, when the charge materials are added to the reactor, the catalyst stratifies. If the motor is then started, a rapid reaction, rather than a slow, controlled reaction, could result that might run away, overpressurize, and destroy the reactor.
(2) The cooling water source of an exothermic reactor might have associated with it some electrical equipment such as a drive motor, solenoid valves, controls, or the like. The failure of this cooling water might allow the exothermic reaction to go beyond the stable point and overpressurize and destroy the vessel.
(3) A process furnace recirculating fan drive motor or fan might fail, nullifying the effects of temperature-sensing points and thus allowing hot spots to develop with serious side reactions.
(4) The failure of gas analysis equipment and interlocks in a drying oven or annealing furnace might allow the atmosphere in the drying oven or furnace to become flammable, with the possibility of an explosion.
(5) The failure of any of the safety combustion controls on a large firebox, such as a boiler or incinerator, can cause a serious explosion.
(6) Two paralleled pump motors might be needed to provide the total requirements of a continuous process. Failure of either of these motors can cause a complete shutdown, rather than simply reduce production.

6.3.4 There are parts of the system that are critical because they reduce the widespread effect of a fault in electrical equipment. The determination of these should be primarily the responsibility of the electrical person on the team. Among the things that fall into this category are the following:

(1) Source overcurrent protective devices, such as circuit breakers or fuses. This includes the relays and control circuits. It also includes the coordination of trip characteristics of the devices.
(2) Automatic bus transfer switches or other transfer switches that would supply critical loads with power from the emergency power source if the primary source failed. This includes instrument power supplies as well as load power supplies.

6.3.5 Parts of the control system are critical because they monitor the process and automatically shut down equipment or take other action to prevent catastrophe. These items are the interlocks, cutout devices, or shutdown devices installed throughout the plant or operation. Each of these interlocks or shutdown devices should be considered carefully by the entire team to establish whether they are critical shutdowns or whether they are "convenience" shutdowns. The maintenance group should thoroughly understand which shutdowns are critical and which are convenience. The critical shutdown devices are normally characterized by a sensing device separate from the normal control device. They probably have separate, final, or end devices that cause action to take place. Once the critical shutdown systems are recognized, they should be distinctly identified on drawings, on records, and on the hardware itself. Some examples of critical shutdown devices are overspeed trips; high or low temperature, pressure, flow, or level trips; low lube-oil pressure trips; pressure-relief valves; overcurrent trips; and low-voltage trips.

6.3.6 There are parts of the system that are critical because they alert operating personnel to dangerous or out-of-control conditions. These are normally referred to as alarms. Like shutdown devices, alarms fall into at least three categories: (1) those that signify a true pending catastrophe, (2) those that indicate out-of-control conditions, and (3) those that indicate the end of an operation or similar condition. The entire team should consider each alarm in the system with the same thoroughness with which they have considered the shutdown circuits. The truly critical alarm should be characterized by its separate sensing device, a separate readout device, and preferably, separate circuitry and power source. The maintenance department should thoroughly understand the critical level of each of the alarms. The critical alarms and their significance should be distinctly marked on drawings, in records, and on the operating unit. For an alarm to be critical does not necessarily mean that it is complex or related to complex action. A simple valve position indicator can be one of the most critical alarms in an operating unit.

6.4 Establishment of a Systematic Program. The purpose of any inspection and testing program is to establish the condition of equipment to determine what work should be done and to verify that it will continue to function until the next scheduled servicing occurs. Inspection and testing is best done in conjunction with routine maintenance. In this way, many minor items that require no special tools, training, or equipment can be corrected as they are found. The inspection and testing program is probably the most important function of a maintenance department in that it establishes what should be done to keep the system in service to perform the function for which it is required.

6.4.1 Atmosphere or Environment.

6.4.1.1 The atmosphere or environment in which electrical equipment is located has a definite effect on its operating capabilities and the degree of maintenance required. An ideal environment is one in which the air is (1) clean or filtered to remove dust, harmful vapor, excess moisture, and so on; (2) maintained in the temperature range of 15°C to 29°C (60°F to 85°F); and (3) in the range of 40 percent to 70 percent humidity. Under such conditions, the need for maintenance will be minimized. Where these conditions are not maintained, the performance of electrical equipment will be adversely affected. Good housekeeping contributes to a good environment and reduced maintenance.

6.4.1.2 Dust can foul cooling passages and thus reduce the capabilities of motors, transformers, switchgear, and so on, by raising their operating temperatures above rated limits, decreasing operating efficiencies, and increasing fire hazard. Similarly, chemicals and vapors can coat and reduce the heat transfer capabilities of heating and cooling equipment. Chemicals, dusts, and vapors can be highly flammable, explosive, or conductive, increasing the hazard of fire, explosion, ground faults, and short circuits. Chemicals and corrosive vapors can cause high contact resistance that will decrease contact life and increase contact power losses with possible fire hazard or false overload conditions due to excess heat. Large temperature changes combined with high humidity can cause condensation problems, malfunction of operating and safety devices, and lubrication problems. High ambient temperatures in areas where thermally sensitive protective equipment is located can cause such protective equipment to operate below its intended operating point. Ideally, both the electrical apparatus and its protective equipment should be located within the same ambient temperature. Where the ambient-temperature difference between equipment and its protective device is extreme, compensation in the protective equipment should be made.

6.4.1.3 Electrical equipment installed in hazardous (classified) locations as described in NFPA 70, *National Electrical Code (NEC)*, requires special maintenance considerations. *(See Section 6.7.)*

6.4.2 Load Conditions.

6.4.2.1 Equipment is designed and rated to perform satisfactorily when subjected to specific operating and load conditions. A motor designed for safe continuous operation at rated load might not be satisfactory for frequent intermittent operation, which can produce excessive winding temperatures or mechanical trouble. The resistance grid or transformer of a reduced-voltage starter will overheat if left in the starting position. So-called "jogging" or "inching" service imposes severe demands on equipment such as motors, starters, and controls. Each type of duty influences the type of equipment used and the extent of maintenance required. The five most common types of duty are defined in NFPA 70, *National Electrical Code*, and they are repeated in 6.4.2.2.

6.4.2.2 The following definitions can be found in Chapter 3 and are unique to this chapter:

(1) Continuous duty *(See 3.3.4.1.)*
(2) Intermittent duty *(See 3.3.4.2.)*
(3) Periodic duty *(See 3.3.4.3.)*
(4) Short-time duty *(See 3.3.4.4.)*
(5) Varying duty *(See 3.3.4.5.)*

6.4.2.3 Some devices used in establishing a proper maintenance period are running-time meters (to measure total "on" or "use" time); counters to measure number of starts, stops, or load-on, load-off, and rest periods; and recording ammeters to graphically record load and no-load conditions. These devices can be applied to any system or equipment and will help classify the duty. They will help establish a proper frequency of preventive maintenance.

6.4.2.4 Safety and limit controls are devices whose sole function is to ensure that values remain within the safe design level of the system. Each device should be periodically and carefully inspected, checked, and tested to be certain that it is in reliable operating condition because it functions only during an abnormal situation where an undesirable or unsafe condition is reached.

6.4.3 Wherever practical, a history of each electrical system should be developed for all equipment or parts of a system vital to a plant's operation, production, or process. The record should include all pertinent information for proper operation and maintenance. This information is useful in developing repair cost trends, items replaced, design changes or modifications, significant trouble or failure patterns, and replacement parts or devices that should be stocked. System and equipment information should include the following:

(1) Types of electrical equipment, such as motors, starters, contactors, heaters, relays
(2) Types of mechanical equipment, such as valves, controls, and so on, and driven equipment, such as pumps, compressors, fans — and whether they are direct, geared, or belt driven
(3) Nameplate data
(4) Equipment use
(5) Installation date
(6) Available replacement parts
(7) Maintenance test and inspection date — type and frequency of lubrication; electrical inspections, test, and repair; mechanical inspections, test, and repair; replacement parts list with manufacturer's identification; electrical and mechanical drawings for assembly, repair, and operation

6.4.4 Inspection Frequency. Those pieces of equipment found to be critical should require the most frequent inspections and tests. Depending on the degree of reliability required, other items can be inspected and tested much less frequently.

6.4.4.1 Manufacturers' service manuals should have a recommended frequency of inspection. The frequency given is based on standard or usual operating conditions and environments. It would be impossible for the manufacturer to list all combinations of environmental and operating conditions. However, the manufacturers' service manual is a good basis from which to begin considering the frequency for inspection and testing.

6.4.4.2 There are several points to consider in establishing the initial frequency of inspections and tests. Electrical equipment located in a separate air-conditioned control room or switch room certainly would not be considered normal, so the inspection interval might be extended 30 percent. However, if the equipment is located near another unit or operating plant that discharges dust or corrosive vapors, this time might be reduced by as much as 50 percent.

6.4.4.3 Continuously operating units with steady loads or with less than the rated full load would tend to operate much longer, and more reliably, than intermittently operated or standby units. For this reason, the interval between inspections might be extended 10 to 20 percent for continuously operating equipment and possibly reduced by 20 to 40 percent for standby or infrequently operated equipment.

6.4.4.4 Once the initial frequency for inspection and tests has been established, this frequency should be adhered to for at least four maintenance cycles unless undue failures occur. For equipment that has unexpected failures, the interval between inspections should be reduced by 50 percent as soon as the trouble occurs. On the other hand, after four cycles of inspections have been completed, a pattern should have developed. If equipment consistently goes through more than two inspections without requiring service, the inspection period can be extended by 50 percent. Loss of production due to an emergency shutdown is almost always more expensive than loss of production due to a planned shutdown. Accordingly, the interval between inspections should be planned to avoid the diminishing returns of either too long or too short an interval.

6.4.4.5 This adjustment in the interval between inspections should continue until the optimum interval is reached. This adjustment time can be minimized and the optimum interval approximated more closely initially by providing the person responsible for establishing the first interval with as much pertinent history and technology as possible.

6.4.4.6 The frequency of inspection for similar equipment operating under differing conditions can be widely different. Typical examples illustrating this are as follows:

(1) In a continuously operating plant having a good load factor and located in a favorable environment, the high-voltage oil circuit breakers might need an inspection only

every two years. On the other hand, an electrolytic process plant using similar oil circuit breakers for controlling furnaces might find it necessary to inspect and service them as frequently as every 7 to 10 days.

(2) An emergency generator to provide power for noncritical loads can be tested on a monthly basis. Yet the same generator in another plant having processes sensitive to explosion on loss of power might need to be tested during each shift.

6.5 Methods and Procedures.

6.5.1 General.

6.5.1.1 If a system is to operate without failure, not only should the discrete components of the system be maintained, but the connections between these components should also be covered by a thorough set of methods and procedures. Overlooking this important link in the system causes many companies to suffer high losses every year.

6.5.1.2 Other areas where the maintenance department should develop their own procedures are shutdown safeguards, interlocks, and alarms. Although the individual pieces of equipment can have testing and calibrating procedures furnished by the manufacturer, the application is probably unique, so that the system, per se, should have an inspection and testing procedure developed for it.

6.5.2 Forms.

6.5.2.1 A variety of forms can go along with the inspection, testing, and repair (IT&R) procedure; these forms should be detailed and direct, yet simple and durable enough to be used in the field. Field notes taken should be legibly transcribed. One copy of reports should go in the working file of the piece of equipment and one in the master file maintained by first line supervision. These forms should be used by the electrical maintenance personnel; they are not for general distribution. If reports to production or engineering are needed, they should be separate, and inspection reports should not be used.

6.5.2.2 The IT&R procedure folder for a piece of equipment should have the following listed in it:

(1) All the special tools, materials, and equipment necessary to do the job
(2) The estimated or actual average time to do the job
(3) Appropriate references to technical manuals
(4) Previous work done on the equipment
(5) Points for special attention indicated by previous IT&R

6.5.2.2.1 If major work was predicted at the last IT&R, the procedure folder should contain a copy of the purchase order and receiving reports for the parts to do the work. It should contain references to unusual incidents reported by production that might be associated with the equipment.

6.5.2.3 Special precautions relative to operation, such as the following, should be part of the IT&R document:

(1) What other equipment is affected and in what way?
(2) Who has to be informed that the IT&R is going to be done?
(3) How long will the equipment be out of service if all goes well and also if major problems are uncovered?

6.5.3 Planning.

6.5.3.1 After the IT&R procedures have been developed and the frequency has been established (even though preliminary), the task of scheduling should be handled. Scheduling in a continuous-process plant (as opposed to a batch-process plant) is most critically affected by availability of equipment in blocks consistent with maintenance manpower capabilities. In general, facilities should be shut down on some regular basis for overall maintenance and repair. Some of the electrical maintenance items should be done at this time. IT&R that could be done while equipment is in service should be done prior to shutdown. Only work that needs to be done during shutdown should be scheduled at that time; this will level out manpower requirements and limit downtime.

6.5.3.2 The very exercise of scheduling IT&R will point out design weaknesses that require excessive manpower during critical shutdown periods or require excessive downtime to do the job with the personnel available. Once these weaknesses have been uncovered, consideration can be given to rectifying them. For example, the addition of one circuit breaker and a little cable can change a shutdown from three days to one day.

6.5.3.3 Availability of spare equipment affects scheduling in many ways. Older facilities might have installed spares for a major part of the equipment, or the facility might be made up of many parallel lines so that they can be shut down, one at a time, without seriously curtailing operations. This concept is particularly adaptable to electrical distribution. The use of a circuit breaker and a transfer bus can extend the interval between total shutdown on a main transformer station from once a year to once in 5 years or more.

6.5.3.4 In many continuous-process plants, particularly the newer ones, the trend is toward a large single-process line with no installed spares. This method of operation requires performing inspections and tests, since there will be a natural desire to extend the time between maintenance shutdowns. Downtime in such plants will be particularly costly, so it is desirable to build as much monitoring into the electrical systems as possible.

6.5.3.5 Planning running inspections can vary from a simple desk calendar to a computer program. Any program for scheduling should have the following four facets:

(1) A reminder to order parts and equipment with sufficient lead time to have them on the job when needed
(2) The date and man-hours to do the job
(3) A check to see that the job has been completed
(4) Noticing if parts are needed for the next IT&R and when they should be ordered

6.5.3.6 Planning shutdown IT&R is governed by the time between shutdowns, established by the limitations of the process or production units involved. Reliability of electrical equipment can and should be built in to correspond to almost any length of time.

6.5.3.7 Small plants should use, in a much abbreviated form, the following shutdown recommendations of a large plant IT&R:

(1) Know how many personnel-shifts the work will take.
(2) Know how many persons will be available.
(3) Inform production of how many shifts the electrical maintenance will require.
(4) Have all the tools, materials, and spare parts that are necessary assembled on the job site. Overage is better than shortage.
(5) Plan the work so that each person is used to best suit his or her skills.

(6) Plan what each person will be doing during each hour of the shutdown. Allow sufficient off time so that if a job is not finished as scheduled, the person working on that job can be held over without becoming overtired for the next shift. This procedure will allow the schedule to be kept.
(7) Additional clerical people during shutdown IT&R will make the job go more smoothly, help prevent missing some important function, and allow an easier transition back to normal.
(8) Supply copies of the electrical group plan to the overall shutdown coordinator so that it can be incorporated into the overall plan. The overall plan should be presented in a form that is easy to use by all levels of supervision. In a large, complex operation, a critical path program or some similar program should be used.

6.5.3.8 Automatic shutdown systems and alarm systems that have been determined as critical should be designed and maintained so that nuisance tripping does not destroy operator confidence. Loss of operator confidence can and will cause these systems to be bypassed and the intended safety lost. Maintenance should prove that each operation was valid and caused by an unsafe condition.

6.5.3.9 A good electrical preventive maintenance program should identify the less critical jobs, so it will be clear to first-line supervision which EPM can be delayed to make personnel available for emergency breakdown repair.

6.5.4 Analysis of Safety Procedures.

6.5.4.1 It is beyond the scope of this recommended practice to cover the details of safety procedures for each of the IT&R activities. Manufacturers' instructions contain safety procedures required in using their test equipment.

6.5.4.2 The test equipment (high voltage, high current, or other uses) should be inspected in accordance with vendor recommendations before the job is started. Any unsafe condition should be corrected before proceeding.

6.5.4.3 The people doing the IT&R should be briefed to be sure that all facets of safety before, during, and after the IT&R are understood. It is important that all protective equipment is in good condition and is on the job.

6.5.4.4 Screens, ropes, guards, and signs needed to protect people other than the IT&R team should be provided and used.

6.5.4.5 A procedure should be developed, understood, and used for leaving the test site in a safe condition when unattended at times such as a smoke break, a lunch break, or even overnight.

6.5.4.6 A procedure should be developed, understood, and used to ensure safety to and from the process before, during, and after the IT&R. The process or other operation should be put in a safe condition for the IT&R by the operating people before the work is started. The procedure should include such checks as are necessary to ensure that the unit is ready for operation after the IT&R is completed and before the operation is restarted.

6.5.5 Records.

6.5.5.1 Sufficient records should be kept by maintenance management to evaluate results. Analysis of the records should guide the spending level for EPM and breakdown repair.

6.5.5.2 Figures should be kept to show the total cost of each breakdown. This should be the actual cost plus an estimated cost of the business interruption. This figure is a powerful indicator for the guidance of expenditures for EPM.

6.5.5.3 Records Kept by First-Line Supervisor of EPM. Of the many approaches to this phase of the program, the following is a typical set that fulfills the minimum requirements.

(A) Inspection Schedule. The first-line supervisor should maintain, in some easy-to-use form, a schedule of inspections so that he or she can plan manpower requirements.

(B) Work Order Log. An active log should be kept of unfinished work orders. A greater susceptibility to imminent breakdown is indicated by a large number of outstanding work orders resulting from the inspection function.

(C) Unusual Event Log. As the name implies, this lists unusual events that affect the electrical system in any way. This record is derived from reports of operating and other personnel. This is a good tool for finding likely problems after the supervisor has learned to interpret and evaluate the reports. This is the place where near misses can be recorded and credit given for averting trouble.

6.5.6 Emergency Procedures. It should be recognized that properly trained electrical maintenance personnel have the potential to make a very important contribution in the emergency situations that are most likely to occur. However, most such situations will also involve other crafts and disciplines, such as operating personnel, pipe fitters, and mechanics. An overall emergency procedure for each anticipated emergency situation should be developed cooperatively by the qualified personnel of each discipline involved, detailing steps to be followed, sequence of steps, and assignment of responsibility. The total procedure should then be run periodically as an emergency drill to ensure that all involved personnel are kept thoroughly familiar with the tasks they are to perform.

6.6 Maintenance of Imported Electrical Equipment. Imported equipment poses some additional maintenance considerations.

6.6.1 Quick delivery of replacement parts cannot be taken for granted. Suppliers should be identified, and the replacement parts problem should be reflected in the in-plant spare parts inventory. In addition to considering possible slow delivery of replacement parts, knowledgeable outside sources of engineering services for the imported equipment should be established.

6.6.2 Parts catalogs, maintenance manuals, and drawings should be available in the language of the user. Documents created in a different language and then translated should not be automatically presumed to be understandable. Problems in translation should be identified as soon as literature is received to ensure that material will be fully understood later, when actual maintenance must be performed.

6.7 Maintenance of Electrical Equipment for Use in Hazardous (Classified) Locations.

6.7.1 Electrical equipment designed for use in hazardous (classified) locations should be maintained through periodic inspections, tests, and servicing as recommended by the manufacturer. Electrical preventive maintenance documentation should define the classified area (the class, group, and division specification, and the extent of the classified area) and the equipment maintenance required. Electrical preventive maintenance documentation should identify who is authorized to work on this equipment, where this maintenance is to be performed, and what precautions are necessary. Although repairs to certain equipment should be done by the manufacturer or authorized representatives, inspection and servicing that can be performed in house should be clearly identified.

6.7.2 Maintenance should be performed only by qualified personnel who are trained in safe maintenance practices and the special considerations necessary to maintain electrical equipment for use in hazardous (classified) locations. These individuals should be familiar with requirements for obtaining safe electrical installations. They should be trained to evaluate and eliminate ignition sources, including high surface temperatures, stored electrical energy, and the buildup of static charges, and to identify the need for special tools, equipment, tests, and protective clothing.

6.7.3 Where possible, repairs and maintenance should be performed outside the hazardous (classified) area. For maintenance involving permanent electrical installations, an acceptable method of compliance can include de-energizing the electrical equipment and removing the hazardous atmosphere for the duration of the maintenance period. All sources of hazardous vapors, gases, and dusts should be removed, and enclosed, trapped atmospheres should be cleared.

6.7.4 Electrical power should be disconnected and all other ignition sources abated before disassembling any electrical equipment in a hazardous (classified) location. Time should be allowed for parts to cool and electrical charges to dissipate, and other electrical maintenance precautions followed.

6.7.5 Electrical equipment designed for use in hazardous (classified) locations should be fully reassembled with original components or approved replacements before the hazardous atmosphere is reintroduced and before restoring power. Special attention should be given to joints and other openings in the enclosure. Cover(s) should not be interchanged unless identified for the purpose. Foreign objects, including burrs, pinched gaskets, pieces of insulation, and wiring, will prevent the proper closure of mating joints designed to prevent the propagation of flame upon explosion.

6.7.6 An approved system of conduit and equipment seals conforming to NEC requirements and manufacturer's specifications should be maintained. Corrective action should be taken upon maintenance actions that damage or discover damage to a seal. Damage to factory-installed seals within equipment can necessitate replacing the equipment.

6.7.7 Wherever electrical equipment cover bolts or screws require torquing to meet operating specifications, these bolts or screws should be maintained with the proper torque as specified by the manufacturer. Electrical equipment should not be energized when any such bolts or screws are missing. All bolts and screws should be replaced with original components or approved replacements.

6.7.8 Special care should be used in handling electrical devices and components approved for use in hazardous (classified) locations. Rough handling, and the use of tools that pry, impact, or abrade components, can dent, scratch, nick, or otherwise mar close-tolerance, precision-machined joints and make them unsafe.

6.7.8.1 Grease, paint, and dirt should be cleaned from machined joints using a bristle (not wire) brush, an acceptable noncorrosive solvent, or other methods recommended by the manufacturer.

6.7.8.2 Prior to replacing a cover on an enclosure designed to prevent flame propagation upon an explosion, mating surfaces should be cleaned and lubricated in accordance with the manufacturer's instructions.

6.7.9 Field modifications of equipment and parts replacement should be limited to those changes acceptable to the manufacturer and approved by the authority having jurisdiction. Normally, modifications to equipment will void any listing by nationally recognized testing laboratories.

6.7.10 The requirements of NFPA 70, *National Electrical Code*, should be followed.

6.7.10.1 Explosionproof enclosures, dust-ignitionproof enclosures, dusttight enclosures, raceway seals, vents, barriers, and other protective features are required for electrical equipment in certain occupancies. Equipment and facilities should be maintained in a way that will not compromise equipment performance or safety.

6.7.10.2 Intrinsically safe equipment and wiring is permitted in locations for which specific systems are approved. Such wiring should be separate from the wiring of other circuits. Article 504, Intrinsically Safe Systems, of NFPA 70, *National Electrical Code,* describes control drawings, grounding, and other features involved in maintenance programs.

6.7.10.3 Purged and pressurized enclosures can be used in hazardous (classified) areas. NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment,* provides guidance useful to maintenance personnel.

Chapter 7 Fundamentals of Electrical Equipment Maintenance

7.1 Design to Accommodate Maintenance.

7.1.1 Equipment should be de-energized for inspections, tests, repairs, and other servicing. Such maintenance tasks can be performed when the equipment is energized provided provisions are made to allow maintenance to be performed safely. For the purpose of this chapter, de-energized means locked and tagged out in accordance with 7.3.4. See 7.3.3 for examples of typical safety-related work practices that might need to be implemented.

7.1.1.1 Many maintenance tasks require equipment to be shut down and de-energized for effective results.

7.1.1.2 Other maintenance tasks might specifically require or permit equipment to be energized and in service while the tasks are performed. Examples include taking transformer oil samples and observing and recording operating temperatures, load conditions, corona, noise, or lamp output.

7.1.1.3 Coordinating maintenance with planned production outages and providing system flexibility such as by duplication of equipment and processes are two recommended means to avoid major disruptions of operations. An example of flexibility is a selective radial distribution system incorporating double-ended low-voltage substations. This system permits maintenance and testing to be performed on equipment such as the primary feeders, transformers, and main and tie circuit breakers during periods of light loads.

7.1.2 Larger production equipment, such as air compressors, air-conditioning units, pumps, and so forth, that can be difficult to repair or replace quickly, are often installed in multiples to provide reserve capacity. Duplication of equipment enables maintenance to be performed economically without costly premium time and ensures continuous production in the event of an accidental breakdown.

7.1.3 Selection of quality equipment, adequate for the present and projected load growth, is a prime factor in reducing maintenance cost. Overloaded equipment or equipment not suited for the application will have a short service life and will be costly to maintain. Abnormal conditions, such as a corrosive atmosphere, excessive temperature, high humidity, abrasive or conducting particles, and frequent starting and stopping, require special consideration in the selection of the equipment in order to minimize maintenance cost.

7.1.4 Too often, installation cost, without sufficient regard for performing efficient and economic maintenance, influences system design. Within a few years, the added cost of performing maintenance plus production loss from forced outages due to lack of maintenance will more than offset the savings in initial cost.

7.1.5 As equipment grows older, and is possibly worked harder, scheduling outages to perform accelerated maintenance could become a major problem.

7.2 Scheduling Maintenance.

7.2.1 In the larger plants, routine maintenance scheduling is often done on a computer. The computer is programmed to print out the work orders for the projects to be accomplished on a weekly or monthly basis. To the opposite extreme, in smaller plants, the maintenance schedule is often carried in the maintenance supervisor's head. It goes without saying that an effective maintenance program requires a positive mechanism for scheduling and recording the work that has been accomplished.

7.2.2 A most thankless task is that of working with production management in attempting to obtain production outages necessary to accommodate maintenance. As yet, most production managers look at maintenance as a necessary evil. Maintenance outages, particularly in plants that operate 24 hours a day, 7 days a week, are difficult to come by; however, there are some areas that can be relieved with a nominal investment.

7.2.2.1 For example, low-voltage power circuit breakers should be inspected on an annual basis and tested under simulated overload and fault conditions every 3 to 5 years. An investment in a few spare circuit breakers, one or two of each make and size in use, would allow them to be inspected, overhauled, and tested at almost any convenient time. The in-service breakers could then be exchanged with spares at an opportune time, with negligible production downtime.

7.2.3 Many plants schedule vacation shutdowns of one to three weeks duration to perform needed periodic maintenance on vital production apparatus that cannot be taken out of service at any other time. A total plant shutdown resolves the problem of scheduling partial outages around limited production operations. Even so, some difficulty might be encountered in providing power requirements for maintenance operations and still performing the needed maintenance on the electrical system.

7.2.4 The scope of the work should be confined to the limited time and available personnel. Contracting out preventive maintenance to qualified electrical contractors can relieve these and other problems associated with preventive maintenance. Electrical contractors who specialize in this type of work have trained mechanics and the proper tools and equipment. Many of them carry inventories of spare electrical equipment.

7.2.5 It is necessary to establish intervals for performing specific tasks when scheduling maintenance. The following considerations should be reviewed upon developing a routine maintenance schedule:

(1) Equipment failure's potential to endanger or threaten personnel safety *(See 5.2.)*
(2) Manufacturers' service manual recommended practices and procedures *(See 6.4.4.2.)*
(3) Operating environment *(See 5.3.3, 6.4.1, 6.4.3.)*
(4) Operating load conditions and equipment rating *(See 5.3.4, 6.4.2, 6.4.4.4.)*
(5) Equipment repairs unusually expensive *(See 5.2.)*
(6) Failure and repair of failed equipment causing extensive downtime and production dollars lost *(See 5.2.)*
(7) Equipment condition *(See 6.3.3, 6.3.5.)*
(8) Operating load conditions and equipment rating *(See 5.3.4, 5.3.5, 5.4.4.4.)*
(9) Production and operating schedules *(See 6.1.6, 6.5.3.)*
(10) Ability to take equipment out of service *(See 6.1.6.)*
(11) Failure history *(See 6.1.6, 6.4.4.5.)*
(12) Inspection history *(See 6.4.4.5.)*

7.2.5.1 A guide for maintenance intervals is included in Annex I.

7.3 Personnel and Equipment Safety.

7.3.1 Personnel safety, in addition to equipment safety, should be given prime consideration in system design and in establishing adequate maintenance practice. The principal personnel danger from electricity is that of shock, electrocution, and/or severe burns from the electrical arc or its effects, which can be similar to that of an explosion. It should be of interest to know that the small current drawn by a 7.5-watt, 120-volt lamp, if passed from hand to hand or hand to foot, could be fatal.

7.3.2 Destructive energy, capable of disintegrating an entire switchgear assembly in a matter of a few minutes, can be released in a low-voltage phase-to-phase or phase-to-enclosure, sustained arcing fault. The fault current, in the order of thousands of amperes, multiplied by the arc voltage drop (approximately 100 volts on a 480Y/277 system) multiplied by the duration of the arc in seconds is a measure of the energy released (watt-seconds).

7.3.2.1 Switchboards, panelboards, industrial control panels, and motor control centers that are likely to require examination, adjustment, servicing, or maintenance while energized, should be field marked to warn qualified persons of potential electric arc flash hazards. The marking should be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

7.3.3 Personnel safety should be an integral part of maintenance practices. As a general rule, no electrical apparatus should be worked on while it is energized. Work on or near energized conductors or equipment rated over 50 volts should be performed only when it is not feasible to de-energize, or when it would create a greater hazard to perform the work in a de-energized condition. When it is necessary to work in the vicinity of energized equipment, all safety precautions should be followed, such as roping off the dangerous area, using rubber blankets for isolation, and using rubber gloves and properly insulated tools and equipment. All insulating tools such as rubber gloves and blankets should be tested periodically. See 29 CFR 1910.137 "Electrical Protective Devices," for the testing, care, marking, and use of rubber goods, such as insulating blankets, matting, covers, line hose, gloves, and sleeves.

7.3.3.1 Prior to performing maintenance on or near live electrical equipment, NFPA 70E, *Standard for Electrical Safety Requirements for Employee Workplaces,* should be used to identify the degree of personal protective equipment (PPE) required.

7.3.4 Switches or circuit breakers should be locked in an open position and tagged to provide information as to why the circuit is open and the name of the person having the key for the lock. Reference should be made to 29 CFR 1910, "Occupational Safety and Health Standards." See Section 1910.147, "The Control of Hazardous Energy (Lockout/Tagout)," dated September 1, 1989, and Sections 1910.331 through 1910.335, "Safety Related Work Practices," dated August 6, 1990. ANSI Z244.1, *Personnel Protection — Lockout/Tagout of Energy Sources — Minimum Safety Requirements,* and NFPA 70E, *Standard for Electrical Safety Requirements for Employee Workplaces,* are also suggested as guides in developing an effective lockout/tagout for electrical and other energy sources. Where the practice of utilizing a protective ground is employed, Section 23.3 details five major considerations for selecting the grounding equipment, including protective ground cables and clamps. All of these factors should be considered to ensure that the protective ground facilitates the operation of the protective device in the event that the circuit is accidentally energized.

7.3.5 Equipment safety demands sensitive and effective protection. The protective device should be capable of immediately sensing the abnormality and causing it to be isolated with the least destruction and minimum disturbance to the system. The degree of sensitivity and speed of response is most vital to the effectiveness of the protection.

7.3.6 The protective device, fuse, relay, and series or static trip on low-voltage breakers generally sense overcurrent. Ideally, the device should not be applied or set to respond to normal load excursions, yet it should function on a low-level fault. This is an impossible situation unless ground-fault protection is utilized, since the magnitude of a phase-to-ground fault could be less than normal load current.

7.4 Protective Scheme.

7.4.1 While the application of circuit protection, as developed in a short-circuit and coordination study, is an engineering function and hence recognized as a facet of system design, assurance that this designed protection remains in operation is a maintenance responsibility. Applying the settings and periodic testing of the protective devices, relays, and series and static trip elements is definitely a maintenance function. Similarly, the checking of the proper type and ampere rating of the fuses used in the system is part of the maintenance function.

7.4.2 In the larger plants, the interpretation of the short-circuit and coordination study is generally made by plant engineering, and the settings and test points for the adjustable protective devices are furnished by the maintenance department, as are the type and ampere rating of the fuses. While the maintenance personnel need not be able to formulate the engineering study, they should be able to interpret the time-current curves in understanding the performance of the protective device being tested.

7.4.3 An up-to-date short-circuit and coordination study is essential for the safety of personnel and equipment. The momentary and interrupting rating requirements of the protective devices should be analyzed, that is, will the circuit breaker or fuse safely interrupt the fault or explode in attempting to perform this function?

7.4.3.1 Another phase of the study is that of developing the application of the protective device to realize minimum equipment damage and the least disturbance to the system in the event of a fault.

7.5 Acceptance Testing. The initial acceptance testing of the electrical system is part of design and plant construction and hence not part of maintenance. However, the acceptance test data do provide the benchmarks for the subsequent maintenance testing. The acceptance testing should be witnessed by the owner's representative, and a copy of the test reports should be forwarded to the plant engineer for the maintenance records.

7.6 Equipment Cleaning.

7.6.1 General. Various methods for cleaning are available, and the method used should be determined by the kind of contamination to be removed and whether or not the apparatus is to be returned to use immediately. Drying is necessary after a solvent or water cleaning, and insulation testing might be required to determine whether the insulation has been properly reconditioned. Enclosure filters, where used, should be cleaned at regular intervals and replaced when damaged or clogged. Loose hardware and debris should be removed from the enclosures so that any new or unusual wear or loss of parts occurring after the cleaning can be detected during subsequent maintenance.

7.6.2 Methods of Cleaning.

7.6.2.1 Wiping off dirt with a clean, dry, lint-free cloth or soft brush is usually satisfactory if the apparatus is small, the surfaces to be cleaned are accessible, and dry dirt only is to be removed. Waste rags should not be used because lint will adhere to the insulation and act as a further dirt-collecting agent. Care should be used to avoid damage to delicate parts.

7.6.2.2 To remove loose dust, dirt, and particles, suction cleaning methods should be used. Blowing out with compressed air is likely to spread contamination and damage insulation.

7.6.2.3 Where dirt cannot be removed by vacuuming or wiping, compressed-air blowing might be necessary. Care should be taken that dirt is not blown out of the equipment being cleaned into other equipment. Air should be dry and directed in such a manner as to avoid further closing ventilation ducts and recesses in insulations.

CAUTION: Cleaning with compressed air can create a hazard to personnel and equipment.

7.6.2.3.1 If compressed air is used, protection should be provided against injury to workers' faces and eyes by flying debris and to their lungs by dust inhalation. The use of compressed air should comply with OSHA 29 CFR 1910.242(b). This includes limiting air pressure for such cleaning to less than a gauge pressure of 208.85 kPa (30 psi) and the provision of effective chip guarding and appropriate personal protective equipment.

7.6.2.3.2 Protection might also be needed against contamination of other equipment if the insulation is cleaned in place with compressed air. Equipment should be removed to a suitable location for cleaning, or other exposed equipment should be covered before cleaning starts to keep the debris out.

7.6.2.4 Accumulated dirt containing oil or grease might require a solvent to remove it. A rag barely moistened (not wet) with a nonflammable solvent can be used for wiping. Solvents used for cleaning of electrical equipment should be selected carefully to ensure compatibility with materials being cleaned. Liquid cleaners, including spray cleaners, are not recommended unless specified by the equipment manufacturer because of the risk of residues causing damage or interfering with electrical or mechanical functions or introducing conducting contaminants into critical areas to produce short circuits and ground faults.

7.6.2.5 Equipment might require cleaning by nonconductive sandblasting.

7.6.2.5.1 Shot blasting should not be used.

CAUTION: Cleaning with abrasives or sandblasting can create a hazard to personnel and equipment.

7.6.2.5.2 Abrasive blasting operations should comply with OSHA 29 CFR 1910.94(a). Protection should be provided against injury to workers' faces and eyes by abrasives and flying debris and to their lungs by dust inhalation.

7.6.2.6 Asbestos is subject to government regulations as a toxic substance. A knowledge of government regulations is required in handling such materials. (One reference is the Toxic Substances Control Act as defined in the U.S. Code of Federal Regulations. Copies can be obtained from the Industry Office of Toxic Substances, Environmental Protection Agency, Washington, DC 20460. Call 202-554-1404.)

7.7 Special Handling and Disposal Considerations.

7.7.1 The handling and disposal of certain electrical equipment, components, and materials can present special maintenance obligations. Examples of such materials include the following:

(A) Asbestos. Asbestos-containing materials can be present in equipment such as wire, switches, circuit protectors, panelboards and circuit breakers, particularly in various arc chute constructions. Airborne asbestos fibers can endanger health. *(See 7.6.2.6.)*

(B) Polychlorinated Biphenyls (PCBs). Askarels and other PCBs were previously used as a noncombustible dielectric fluid or were added to transformer oil. Although PCBs are no longer manufactured in the United States and are no longer put in new equipment, PCBs might still exist in older transformers, power capacitors, oil insulated cables, and fluorescent lighting ballasts. *(See 9.2.1.3.)*

(C) Lead. The disposal of paper-insulated, lead-covered cables can be an environmental concern. Abandoning a lead product, like a lead-covered cable, in the ground is prohibited in some jurisdictions. The lead can leach soluble lead salts into the environment. Reclaiming and reusing the lead or treating the lead to curtail leaching are two means of handling the environmental threat.

(D) Mineral Oil. The disposal of ordinary transformer oil can be an environmental concern. Spent oil should be sent to a manufacturer or processor for recycling. In the U.S., certain oil spills can require state and regional EPA notification.

(E) Tetrachlorethylene. Some transformers contain tetrachlorethylene, a toxic substance. Where possible, recycling should be considered.

(F) Trichloroethane. Vapors from trichloroethane, an electrical cleaning and degreasing solvent, are toxic and an environmental threat. Handling and disposal of the liquid require special precautions because trichloroethane is an ozone-depleting chemical. Some jurisdictions have already banned the use of trichlor products.

(G) Mercury Vapor and Phosphor Coatings. Fluorescent lamps and similar gas tubes can contain mercury vapor and phosphor coatings. If the tube breaks, these materials can escape into the environment. The disposal of large quantities of tubes warrants capturing these materials.

(H) Radioactive Materials. Devices containing radioactive materials can require special precautions.

(I) Other Harmful Agents. Hazards presented by materials and processes should be reviewed whenever changes are planned. For example, a substitute cleaning agent might be more hazardous than the old cleaner; special handling precautions might be needed for the new cleaner. Or, because of a planned change in operations, a fabric filter might soon be collecting a toxic chemical; new procedures for filter replacement and disposal might be needed.

7.7.2 Those responsible for establishing and sustaining maintenance programs should keep abreast of relevant materials handling and disposal issues, including knowledge of toxic substances, environmental threats, and the latest technologies for waste handling and salvage. Testing might be required to determine the presence of toxic substances.

7.7.3 Health and environmental issues, governmental regulations, and salvage values should all be addressed in disposal planning programs.

7.8 Lubrication. Lubrication refers to the application of grease or oil to bearings of motors, rotating shafts, gears, and so on. This can also include light lubrication to door hinges or other sliding surfaces on the equipment. Some special parts are identified as being prelubricated for life and should require no further lubrication.

Chapter 8 Substations and Switchgear Assemblies

8.1 Substations.

8.1.1 Introduction.

8.1.1.1 Substations in an electrical system perform the functions of voltage transformation, system protection, power factor correction metering, and circuit switching. They are comprised of electrical power products, such as transformers, regulators, air switches, circuit breakers, capacitors, and lightning arresters.

8.1.1.2 Maintenance of the substation is of a general nature. Maintenance of the individual power products will be discussed under the appropriate heading. *(See Section 8.8 for additional consideration in the maintenance of gas-insulated substations and gas-insulated equipment.)*

8.1.1.3 The recommended frequency of maintenance will depend on the environment in which the substation is operating. In many cases, it is an outdoor installation and exposed to the atmospheric contaminations in the neighborhood. In areas of industrial contamination or in coastal areas where ocean vapors are prevalent, inspections are recommended at intervals of between 6 weeks and 2 months. Less frequent inspections are recommended in areas of relatively clean atmosphere.

8.1.2 Insulators.

8.1.2.1 Insulators should be inspected for evidence of contaminated surfaces or physical damage, such as cracked or broken segments. Contaminated insulator surfaces should be cleaned, and damaged insulators replaced.

8.1.2.2 Evidence of violent corona when the substation is energized should be reported. (Refer to 3.3.6 for definition.) Ultrasonic detection and light amplification (night vision) equipment are useful for detecting corona.

8.1.2.3 Mild corona might be normal and will be more pronounced when humidity is high.

8.1.3 Conductors. All exposed conductors should be inspected for evidence of overheating at bolted joints. Extreme overheating will discolor copper conductors. If the substation is de-energized, bolted connections should be checked for tightness. Bolts should be tightened where required, being careful not to overstress the bolts. There are infrared detectors that can be used on energized systems to check for overheating by scanning from a distance. Where aluminum-to-copper joints exist, they should be inspected carefully for evidence of corrosion, overheating, or looseness.

8.1.4 Air-Disconnecting Switches.

8.1.4.1 Air-disconnecting switches are normally operated infrequently in service and will usually be energized during routine substation maintenance. In this case, maintenance of the switch will be limited to those areas that can be approached safely. The insulators and conducting parts should be examined as described earlier under these subjects. Interphase linkages and operating rods should be inspected to make sure that the linkage has not been bent or distorted and that all fastenings are secure. The position of the toggle latch of the switch-operating linkage should be observed on all closed switches to verify that the switch is mechanically locked in a closed position.

8.1.4.2 Power-operated switches should be operated periodically to ensure that the switches and their mechanism and control features are functioning properly. When the circuit condition will not permit operating the switch while energized and the circuit cannot be de-energized for routine maintenance, the operating mechanism should be disengaged from the linkage to allow the control circuits and mechanism to be checked, provided that this method does not adversely affect the overall adjustment.

8.1.4.2.1 The maintenance instructions of the particular manufacturer of each mechanism should be followed.

8.1.4.2.2 In addition, the following features should be checked:

(1) Limit switch adjustment
(2) Associated relays for poor contacts, burned-out coils, and inadequate supply voltage
(3) Any other condition that might prevent proper functioning of the switch assembly

8.1.4.3 If the switches cannot be de-energized during routine maintenance, a scheduled outage should be planned periodically and thorough maintenance performed as follows:

(1) The switch should be operated several times manually and checked for approximate simultaneous closing of all blades and for complete contact closing.
   (a) The blade lock or latch should be checked in the fully closed position.
(2) If so equipped, the switch should be power operated and checked in accordance with the previously described procedure.
(3) Contacts should be inspected for alignment, pressure, burns, or corrosion.
   (a) Pitted or badly burned contacts should be replaced.
   (b) If pitting is of a minor nature, the surface should be smoothed down with clean, fine sandpaper.
   (c) Arcing horns should be inspected for signs of excessive burning and should be replaced if necessary.
(4) Insulation should be inspected for breaks, cracks, or burns.
   (a) Insulation should be cleaned where abnormal conditions, such as salt deposits, cement dust, or acid fumes, prevail.
(5) Gear boxes should be checked for moisture that could cause corrosion or difficulty in the switch due to ice formation.
(6) Flexible braids or slip ring contacts commonly used for grounding the operating handle should be inspected.
   (a) Braids showing signs of corrosion, wear, or broken strands should be replaced.
(7) All safety interlocks should be inspected, checked, and tested for proper operation.

8.1.4.4 If it is known that a switch has carried heavy short-circuit current, special effort should be made to inspect it at the earliest possible time, since the ability of the switch to carry rated load current or fault current might be seriously impaired if the contacts are not maintained properly.

8.1.5 Grounding Equipment. All of the station grounds, enclosure grounds, and apparatus grounds should be inspected and tested (when possible). All grounding connections should be inspected for tightness and absence of corrosion.

8.1.6 Enclosures. The security of fences or other enclosures should be checked to ensure against entry of animals or unauthorized personnel. The gates or doors, especially where equipped with panic hardware, should be checked for security and proper operation. The enclosed area should not be used for storage of anything other than the most frequently used spare parts directly associated with the enclosed equipment.

8.1.7 Miscellaneous Equipment.

8.1.7.1 The availability and condition of rack-out devices, hoisting or handling apparatus, grounding equipment, hot sticks, rubber gloves, statiscopes, and other test equipment should be checked.

8.1.7.2 The proper operation of floodlights and other auxiliary apparatus, such as cooling fans on transformers, should be checked.

8.1.7.3 Any indication of warning lights or warning flags on temperature gauges, pressure gauges, or liquid level gauges should be reported.

8.2 Switchgear Assemblies.

8.2.1 Introduction.

8.2.1.1 A switchgear assembly is an assembled equipment (indoor or outdoor) including, but not limited to, one or more of the following: switching, interrupting, control, metering, protective, and regulating devices together with their supporting structure, enclosure, conductors, electric interconnections, and accessories.

8.2.1.2 A switchgear assembly can be an open type, as part of a substation assembly, or an enclosed type. The open type was covered under the section on substations. This section will cover enclosed-type assemblies and, more specifically, metal-enclosed assemblies, because other types of enclosures are rarely found.

8.2.1.3 Metal-enclosed switchgear assemblies are enclosed on all sides and the top with sheet metal. Access into the enclosure is provided by doors or a removable cover. The bus and bus connections are bare in all except metal-clad-type switchgear assemblies. Although the bus and connections are insulated in metal-clad switchgear assemblies, the insulation is not designed to protect against electrical shock. Contact with the bus or its connections should be avoided when the switchgear is energized.

8.2.1.4 Low-voltage metal-enclosed switchgear assemblies have a maximum nominal voltage rating of 600 volts. Medium- and high-voltage metal-enclosed switchgear assemblies have nominal voltage ratings from 5,000 volts to 69,000 volts inclusive.

8.2.1.5 These switchgear assemblies are normally constructed in modules or cubicles, each of which contains either one or more interrupting devices (low-voltage cubicles usually contain two or more interrupting devices whereas medium- and high-voltage cubicles contain only one device) or auxiliary equipment, such as metering transformers, auxiliary power transformer, control relaying, and battery chargers. Power is fed throughout the assembly by the main power bus.

8.2.1.6 Metal-enclosed switchgear assemblies are normally connected to one or more supply transformers, either closely connected to the transformer throat or remotely connected by cable or metal-enclosed bus. They might be found outdoors as a part of a substation or indoors as a power distribution center.

8.2.2 Frequency of Maintenance.

8.2.2.1 Recommended frequency of maintenance will depend on environmental and operating conditions, so that no fixed rule can govern all applications.

8.2.2.1.1 An annual inspection of the entire switchgear assembly, including withdrawable elements during the first three years of service, is usually suggested as a minimum when no other criteria can be identified.

8.2.2.1.2 Inspection frequency can be increased or decreased depending on observations and experience. It is good practice to follow specific manufacturers' recommendations regarding inspection and maintenance until sufficient knowledge is accumulated that permits modifying these practices based on experience. It is recommended that frequent inspections be made initially; the interval can then be gradually extended as conditions warrant.

8.2.2.2 The following factors will affect the decision on when to inspect:

(1) Scheduled shutdowns
(2) Emergency shutdowns
(3) Periods of sustained unusual or abnormal operating conditions (for example, switching or lightning surges and sustained overloads)
(4) Feeder, bus, or system fault occurrence
(5) Extremes in atmospheric conditions, such as heat, cold, heavy dust, high winds, rain, snow, fog, smog, fumes of many kinds, fly ash, salt spray, high humidity, unusual temperature changes, and lightning
(6) Maintenance requirements and schedules for related equipment — either component parts of the switchgear assembly or items apart from but connected to the switchgear circuits (Time is the most universal criterion, but other indicators, such as number of operations, can be used as a guide.)

8.2.2.3 Partial inspections can be made even when the entire switchgear assembly cannot be de-energized.

8.2.2.4 Specific circuits can be taken out of service even though the main bus is not de-energized. This permits an insulation inspection of bus risers and supports in the load side or "off" side of the switchgear unit.

8.2.2.5 Where operating conditions are such that a full shutdown of an entire switchgear assembly for inspection of insulation is impractical, partial inspections can dictate a decision on whether or not a full shutdown is mandatory to avoid a potential developing failure. Conditions in those areas accessible for partial inspection, however, cannot be guaranteed to be indicative of conditions in areas not accessible for inspection under energized conditions.

8.2.3 Enclosure. The function of the enclosure is twofold:

(1) Prevent exposure of live parts and operating mechanisms.
(2) Protect the equipment from exposure to moisture and air contaminants outside the enclosure. A good maintenance program will ensure the continuation of these two functions.

8.2.4 Security. All doors and access panels should be inspected to ensure that all hardware is in place and in good condition. Hinges, locks, and latches should be lubricated. Check for removal of screens from ventilation openings that might permit entry of rodents or small animals.

8.2.5 Leakage. On outdoor assemblies, roof or wall seams should be checked for evidence of leakage, and any leaking seams should be caulked. Although leakage might not be prevalent at the time of inspection, prior leakage can be identified by rust or water marks on surfaces adjacent to and below leaky seams. Check around the base for openings that could permit water draining into the interior. Caulk or grout any such openings.

8.2.6 Moisture.

8.2.6.1 Moisture accumulation might occur on internal surfaces of enclosures even though they are weathertight. The source of this moisture is condensation. When the temperature of any surface drops below the dew point of the air with which it is in contact, condensation will occur. Humidity of the outside atmosphere is uncontrollable as it enters the enclosure. However, water vapor can be added to the internal atmosphere if there are pools of water at the base of the enclosure in the vicinity of floor openings or bottom wall ventilation openings. All floor openings, other than those specifically provided for drainage purposes, should be effectively sealed. All unused conduits or openings around cables at entrance ducts should be sealed with an electrical grade of caulking compound. Water pools should be eliminated permanently.

8.2.6.2 Conditions causing condensation are intermittent and might not be prevalent at the time of inspection. All internal surfaces should be examined for signs of previous moisture such as the following:

(1) Droplet depressions or craters on heavily dust-laden surfaces
(2) Dust patterns, such as those that occur if an auto is subjected to a light rain shower shortly after it has been driven on a dusty road
(3) Deposit patterns, such as those that might occur where a film of dirty water was left to evaporate on a flat surface
(4) Excessive rust anywhere on the metal housing

8.2.6.3 Moisture accumulation is prevented by heat and air circulation. It is very important, therefore, to make sure the heating and ventilating systems are functioning properly.

8.2.7 Heating. Heat losses in switchgear assemblies carrying not less than 75 percent full load will probably prevent condensation except in those cubicles containing auxiliary equipment. Where space heaters are provided in each cubicle and in outdoor metal-enclosed bus runs to supply supplementary heat, they should be checked to ensure that they are in good condition and are operating properly. If they are thermostatically controlled, the thermostat should be checked for proper operation and setting. A thermostat set too low will not control the heaters properly under all climatic conditions.

8.2.8 Ventilation. Where ventilators are supplied on enclosures, including metal-enclosed bus enclosures, they should be checked to ensure that they are clear of obstructions and that the air filters are clean and in good condition. Base foundations should be examined to ensure that structural members have not blocked floor ventilation.

8.2.9 Lighting and Housekeeping. All interior and exterior lighting should be checked for proper operation. Availability of spare equipment and handling devices should be checked. They should be stored in such a manner as to be readily available yet not hamper normal manual operation or block ventilation passages.

8.2.10 Insulation.

8.2.10.1 With proper maintenance, the insulation of metal-enclosed switchgear assemblies is designed and expected to withstand operating voltages for periods on the order of 20 years to 30 years. During this time, the insulation will be subject to an accumulation of deteriorating conditions that detract from its voltage- withstanding capability.

8.2.10.2 Moisture combined with dirt is the greatest deteriorating factor for insulation. Perfectly dry dirt is mostly harmless, but even small amounts of moisture, such as condensation, will result in electrical leakage that leads to tracking and eventual flashover if allowed to continue to accumulate. It is important in the maintenance of switchgear to know the condition of the insulation. This is especially true in the older installations in unfavorable locations where deteriorating effects might be significant.

8.2.10.3 The surfaces of all insulating members should be inspected before any cleaning or dust removal and repeated after cleaning. Moisture droplets often leave little craters or depressions in a heavy dust layer without staining the member under the dust. Conversely, a carbon track starting to form on a bus support sometime prior to inspection might be completely masked by later deposits of dust.

8.2.11 Electrical Distress. The following are specific areas in which electrical distress is more likely to occur, and they should be given special attention:

(1) Boundaries between two adjoining insulators
(2) Boundaries between an insulating member and the grounded metal structure
(3) Taped or compounded splices or junctions
(4) Bridging paths across insulating surfaces, either phase-to-phase or phase-to-ground
(5) Hidden surfaces such as the adjacent edges between the upper and lower member of split-type bus supports or the edges of a slot through which a busbar protrudes
(6) Edges of insulation surrounding mounting hardware either grounded to the metal structure or floating within the insulating member

8.2.11.1 Damage caused by electrical distress will normally be evident on the surface of insulating members in the form of corona erosion or markings or tracking paths.

8.2.12 Corona.

8.2.12.1 If corona occurs in switchgear assemblies, it is usually localized in thin air gaps that exist between a high-voltage bus bar and its adjacent insulation or between two adjacent insulating members. It might form around bolt heads or other sharp projections if not properly insulated or shielded. Corona in low-voltage switchgear is practically nonexistent.

8.2.12.2 Organic insulating materials, when exposed to corona discharge, will initially develop white powdery deposits on their surface. These deposits can be wiped off with solvent. If the surface has not eroded, further maintenance is not required. Prolonged exposure to corona discharge will result in erosion of the surface of the insulating material. In some materials, corona deterioration has the appearance of worm-eaten wood. If the corrosion paths have not progressed to significant depths, surface repair can probably be accomplished. Manufacturers' recommendations should be followed in this repair.

8.2.13 Tracking.

8.2.13.1 Tracking is an electrical discharge phenomenon caused by electrical stress on insulation. This stress can occur phase-to-phase or phase-to-ground. Although tracking can occur internally in certain insulating materials, these materials as a rule are not used in medium- or high-voltage switchgear insulation. Tracking, when it occurs in switchgear assemblies, will normally be found on insulation surfaces.

8.2.13.2 Tracking develops in the form of streamers or sputter arcs on the surface of insulation, usually adjacent to high-voltage electrodes. One or more irregular carbon lines in the shape of tree branches is the most common sign of tracking.

8.2.13.3 Surface tracking can occur on the surfaces of organic insulation or on contaminated surfaces of inorganic insulation. The signs of tracking on organic materials are eroded surfaces with carbon lines. On track-resistant organic materials, these erosion patterns will be essentially free of carbon.

8.2.13.3.1 Tracking can propagate from either the high-voltage or ground terminal. It will not necessarily progress in a regular pattern or by the shortest possible path.

8.2.13.4 Tracking conditions on surfaces of inorganic material can be completely removed by cleaning its surfaces, because no actual damage to the material occurs. In the case of organic material, the surface is damaged in varying degrees depending on the intensity of the electric discharge and the duration of exposure. If the damage is not too severe, it can be repaired by sanding and application of track-resistant varnish in accordance with the manufacturers' instructions.

8.2.14 Thermal Damage.

8.2.14.1 Temperatures even slightly over design levels for prolonged periods can significantly shorten the electrical life of organic insulating materials. Prolonged exposure to higher than rated temperatures can cause physical deterioration of these materials, resulting in lowered mechanical strength.

8.2.14.2 Localized heating (hot spots) can sometimes occur but can be masked because the overall temperature of the surroundings is not raised appreciably. Loosely bolted connections in a bus bar splice or void spaces (dead air) in a taped assembly are examples of this difficult problem.

8.2.14.3 Since power should be removed prior to inspection, it is relatively unlikely that temperature itself can be relied on to signal potentially damaging heat. Other external conditions, therefore, form the basis for detecting heat damage, including the following:

(1) Discoloration — usually a darkening — of materials or finishes
(2) Crazing, cracking, and flaking of varnish coatings
(3) Embrittlement of tapes and cable insulation
(4) Delamination
(5) Generalized carbonization of materials or finishes
(6) Melting, oozing, or exuding of substances from within an insulating assembly

8.2.14.3.1 Insulating materials that have been physically damaged should be replaced. Mild discoloration is permissible if the cause of overheating is corrected.

8.2.14.3.2 In summary, there are two important things to remember in maintenance of insulation: KEEP IT CLEAN and KEEP IT DRY.

8.3 Circuit Interrupters. Circuit interrupters in switchgear assemblies are either circuit breakers or interrupter switches. Fuses are technically interrupters, but they will be covered as an item of auxiliary equipment.

8.4 Air Circuit Breakers.

8.4.1 Introduction.

8.4.1.1 Before any maintenance work is performed, manufacturers' instruction manuals should be obtained and read carefully. If it is a drawout-type breaker, it should be removed from its cubicle and placed in a secure, convenient location for maintenance. A stored-energy-type circuit breaker or its mechanism should never be worked on while its closing spring is charged.

8.4.1.2 Maintenance on fixed- or bolted-type circuit breakers should normally be performed with the breaker in place inside its cubicle. Special precaution should therefore be exercised to ensure that the equipment is de-energized and the circuit in which it is connected is properly secured from a safety standpoint. All control circuits should be de-energized. Stored-energy closing mechanisms should be discharged.

8.4.1.3 Subsections 8.4.2 through 8.5.3 break down maintenance operations on air circuit breakers into five categories.

8.4.2 Insulation. Interphase barriers should be removed and then cleaned along with all other insulating surfaces with a vacuum cleaner or clean lint-free rags and solvents as recommended by the manufacturer, if needed, to remove hardened or encrusted contamination. An inspection should be made for signs of corona, tracking, or thermal damage as described in 8.2.12 through 8.2.14. The maintenance theme here again is KEEP IT CLEAN and KEEP IT DRY.

8.4.3 Contacts.

8.4.3.1 General. The major function of the air circuit breaker depends among other things on correct operation of its contacts. These circuit breakers normally have at least two distinct sets of contacts on each pole, main and arcing. Some have an intermediate pair of contacts that open after the main current-carrying contacts and before the arcing contacts. When closed, practically the entire load current passes through the main contacts. Also, high-overload or short-circuit current pass through them during opening or closing faulted lines. If the resistance of these contacts becomes high, they will overheat. Increased contact resistance can be caused by pitted contact surfaces, foreign material embedded on contact surfaces, or weakened contact spring pressure. This resistance will cause excessive current to be diverted through the arcing contacts, with consequent overheating and burning. The pressure should be kept normal, which is usually described in the manufacturer's instructions.

8.4.3.2 Arcing contacts are the last to open; any arcing normally originates on them. In circuit interruption they carry current only momentarily, but that current might be equal to the interrupting rating of the breaker. In closing against a short circuit, they can momentarily carry considerably more than the short-circuit interrupting rating. Therefore, there must be positive contact when they are touching. If not, the main contacts can be badly burned, interrupting heavy faults. Failure to interrupt might also result.

8.4.3.2.1 On magnetic blow-out air breakers, the arc is quickly removed from the arcing contacts by a magnetic blow-out field and travels to arcing horns, or runners, in the arc interrupter. The arcing contacts are expendable and will eventually burn enough to require replacement.

8.4.3.3 The general rules for maintaining contacts on all types of breakers are as follows:

(1) They should be kept clean, smooth, and in good alignment.
(2) The pressure should be kept normal, as prescribed in the manufacturers' literature.

8.4.3.4 The main contact surfaces should be clean and bright. Discoloration of the silvered surfaces, however, is not usually harmful unless caused by insulating deposits. Insulating deposits should be removed with alcohol or a silver cleaner. Slight impressions on the stationary contacts will be caused by the pressure and wiping action of the movable contacts. Minor burrs or pitting can be allowed, and projecting burrs can be removed by dressing. Nothing more abrasive than crocus cloth should be used on the silvered contact surfaces. Where serious overheating is indicated by the discoloration of metal and surrounding insulation, the contacts and spring assemblies should be replaced in line with the manufacturers' instructions.

8.4.3.5 The circuit breaker should be closed manually to check for proper wipe, pressure, and contact alignment, and to ensure that all contacts make at approximately the same time. The spacing between stationary and movable contacts should be checked in the fully open position. Adjustments should be made in accordance with the manufacturers' recommendations.

8.4.3.6 Laminated copper or brush-style contacts found on older circuit breakers should be replaced when badly burned. Repairs are impractical because the laminations tend to weld together when burning occurs, and contact pressure and wipe are greatly reduced. They can be dressed with a file to remove burrs or to restore their original shape. They should be replaced when they are burned sufficiently to prevent adequate circuit-breaker operation or when half of the contact surface is burned away. Carbon contacts, used on older circuit breakers, require very little maintenance. However, inadequate contact pressure caused by erosion or repeated dressing might cause overheating or interfere with their function as arcing contacts.

8.4.3.7 The drawout contacts on the circuit breaker and the stationary contacts in the cubicle should be cleaned and inspected for overheating, proper alignment, and broken or weak springs. The contact surfaces should be lightly coated with a contact lubricant to facilitate ease of the mating operation.

8.4.4 Arc Interrupters.

8.4.4.1 General. Modern arc interrupters of medium-voltage magnetic blow-out air circuit breakers are built with only inorganic materials exposed to the arc. Such materials line the throats of the interrupter and constitute the interrupter plates or fins, which act to cool and disperse the arc. The insulation parts of the interrupter remain in the circuit across contacts at all times. During the time that the contacts are open, these insulating parts are subject to full potential across the breaker. The ability to withstand this potential depends on the care given the insulation.

8.4.4.2 Particular care should be taken at all times to keep the interrupter assembly dry. The materials are not affected much by humidity, but the ceramic material especially will absorb water.

8.4.4.3 The interrupters should be inspected each time the contacts are inspected. Any residue, dirt, or arc products should be removed with a cloth or by a light sanding. A wire brush or emery cloth should not be used for this purpose because of the possibility of embedding conducting particles in the ceramic material.

8.4.4.4 An interrupter should be inspected for the following:

(A) Broken or Cracked Ceramic Parts. Small pieces broken from the ceramics or small cracks are not important. Large breaks or expansive cracks, however, can interfere with top performance of the interrupter. Hence, if more than one or two broken or badly cracked plates are apparent, renewal of the ceramic stack is indicated.

(B) Erosion of Ceramics. When an arc strikes a ceramic part in the interrupter, the surface of the ceramic will be melted slightly. When solidified again, the surface will have a glazed, whitish appearance. At low and medium currents, this effect is very slight. However, large-current arcs repeated many times can boil away appreciable amounts of the ceramic. When this happens, the ceramic stack assembly should be replaced.

(C) Dirt in Interrupter. While in service, the arc chute assembly can become dirty. Dust or loose soot deposited on the inside surface of the arc chute can be removed by vacuuming or by wiping with cloths that are free of grease or metallic particles. Deposits can accumulate on ceramic arc shields from the arcing process. These deposits, from the metal vapors boiled out of the contacts and arc horns, can accumulate to a harmful amount in breakers that receive many operations at low- or medium-interrupting currents. Particular attention should be paid to any dirt on the plastic surfaces below the ceramic arc shield. These surfaces should be wiped clean, if possible, especially if the dirt contains carbon or metallic deposits. On breakers that operate thousands of times at low and medium currents, sufficient tightly adhering dirt can accumulate on the ceramic arc shields to impair proper interrupting performance. These arc chutes are of a very hard material, and a hard nonconducting abrasive is necessary for cleaning. A flexible, abrasive aluminum oxide disc on an electric drill can be useful in cleaning arc chutes. The ceramic arc shields might appear dirty and yet have sufficient dielectric strength. The following insulation test can be used as a guide in determining when this complete or major cleaning operation is required. The arc chutes of medium-voltage circuit breakers should withstand the 60-Hz-rated maximum voltage for one minute between the front and rear arc horns. In some applications, circuit breakers can be exposed to overvoltages, in which case such circuit breakers should have an appropriate overpotential test applied across the open contacts. Some manufacturers also recommend a surface dielectric test of the ceramic surfaces near the contacts to verify adequate dielectric strength of these surfaces.

8.4.4.5 Air-puffer devices used to blow the arc up into the interrupter should be checked for proper operation. One accepted method is as follows. With the interrupter mounted on the breaker in its normal position, a piece of tissue paper is placed over the discharge area of the interrupter and observed for movement when the breaker is opened. Any perceptible movement of the paper indicates that the puffer is functioning properly.

8.4.4.6 Low-voltage air circuit-breaker arc chutes are of relatively simple construction, consisting primarily of a wedge-shaped vertical stack of splitter plates enclosed in an insulating jacket. An arc chute is mounted on each pole unit directly above the main contacts. Arc interruptions produce erosion of the splitter plates. The lower inside surfaces of the insulating jackets will also experience some erosion and sooty discoloration.

8.4.4.6.1 The arc chutes should be removed and examined as part of routine maintenance. If the splitter plates are seriously eroded, they should be replaced. If the interior surfaces of the enclosing jackets are discolored or contaminated with arc products, they should be sanded with sandpaper or replaced. Occasionally, the whole arc chute might need replacing, depending on the severity of the duty.

8.4.5 Operating Mechanism.

8.4.5.1 General. The purpose of the operating mechanism is to open and close the contacts. This usually is done by linkages connected, for most power breakers, to a power-operating device such as a solenoid or closing spring for closing, and that contains one or more small solenoids or other types of electromagnets for tripping. Tripping is accomplished mechanically, independently from the closing device, so that the breaker contacts will open even though the closing device still might be in the closed position. This combination is called a mechanically trip-free mechanism. After closing, the primary function of the operating mechanism is to open the breaker when it is desired, which is whenever the tripping coil is energized at above its rated minimum operating voltage.

8.4.5.2 The operating mechanism should be inspected for loose or broken parts, missing cotter pins or retaining keepers, missing nuts and bolts, and binding or excessive wear. All moving parts are subject to wear. Long-wearing and corrosion-resistant materials are used by manufacturers, and some wear can be tolerated before improper operation occurs.

8.4.5.2.1 Excessive wear usually results in the loss of travel of the breaker contacts. It can affect operation of latches; they could stick or slip off and prematurely trip the breaker. Adjustments for wear are provided in certain parts. In others, replacement is necessary.

8.4.5.2.2 The closing and tripping action should be quick and positive. Any binding, slow action, delay in operation, or failure to trip or latch must be corrected prior to returning to service.

8.4.5.3 The two essentials to apply in maintenance of the operating mechanism are KEEP IT SNUG and KEEP IT FRICTION FREE.

8.4.6 Breaker Auxiliary Devices.

8.4.6.1 The closing motor or solenoid, shunt trip, auxiliary switches, and bell alarm switch should be inspected for correct operation, insulation condition, and tightness of connections.

8.4.6.2 On-off indicators, spring-charge indicators, mechanical and electrical interlocks, key interlocks, and padlocking fixtures should be checked for proper operation, and should be lubricated where required. In particular, the positive interlock feature that prevents the insertion and withdrawal of the circuit breaker should be tested while it is in the closed position.

8.4.6.3 The protective relay circuits should be checked by closing the breaker in the test position and manually closing the contacts of each protective relay to trip the circuit breaker. Test procedures are given in 20.10.3.

8.4.6.4 Trip devices on low-voltage breakers might be the electromechanical series overcurrent type with an air or fluid dashpot for time delay. These devices should be tested periodically for proper calibration and operation with low-voltage/high-current test devices. Calibration tests should be made to verify that the performance of the breaker is within the manufacturer's published curves. It is very important that manufacturers' calibration curves for each specific breaker rating be used. The fact that current-time curves are plotted as a band of values rather than a single line curve should be taken into account. It should be realized that short-time calibration cannot be checked accurately because factory calibration equipment has synchronized timing devices to ensure symmetrical currents, whereas field-test equipment features random closing and might produce asymmetrical currents that result in faulty readings. If the trip devices do not operate properly, the calibration and timing components should be repaired or replaced in line with the manufacturer's recommendations.

8.4.6.5 If the breakers are equipped with static-tripping devices, they should be checked for proper operation and timing in line with the manufacturer's recommendations. Some manufacturers recommend replacement of electromagnetic devices with static devices in the interest of realizing more precision and a higher degree of reliability with the latter devices.

8.5 Vacuum Circuit Breakers.

8.5.1 The principal difference between vacuum circuit breakers and air circuit breakers is in the main contact and interrupter equipment. In the vacuum circuit breaker, these components are in the vacuum bottle and are not available for cleaning, repair, or adjustment. Contact-wear indicators are available for measuring contact wear.

8.5.2 Vacuum integrity is checked by application of test voltage across the open contacts of the bottle. This test should be performed strictly in accordance with the manufacturer's instructions.

CAUTION: Application of high voltage across an open gap in vacuum can produce x-ray emission.

8.5.2.1 The level of x-ray emission from a vacuum breaker with proper contact spacing and subjected to standard test voltages is extremely small and well below the maximum level permitted by standards. In view of the possibility that the contacts are out of adjustment or that the applied voltage is greater than prescribed, it is advisable that during the overvoltage test all personnel stand behind the front steel barrier and remain further from the breaker than would otherwise be necessary for reasons of electrical safety. During this high-voltage test, the vapor shield inside the interrupter can acquire an electrostatic charge. This charge should be bled off immediately after the test.

8.5.3 All other maintenance on vacuum circuit breakers should be performed in accordance with that recommended on air circuit breakers.

8.6 Oil Circuit Breakers.

8.6.1 Introduction.

8.6.1.1 Oil circuit breakers are seldom found in modern metal-enclosed switchgear assemblies. They are prevalent in older metal-enclosed switchgear assemblies and in open-type outdoor substations.

8.6.1.2 Although oil circuit breakers perform the same function in switchgear assemblies as air circuit breakers, they are quite different in appearance and mechanical construction. The principal insulating medium is oil rather than air.

8.6.2 Insulation.

8.6.2.1 External insulation is provided by insulating bushings. Outdoor oil circuit breakers have porcelain bushings, whereas indoor breakers can have either porcelain bushings or organic tubing. The bushings should be examined for evidence of damage or surface contamination. If they are damaged to the extent that the electrical creepage path has been reduced or the glazed surface on porcelain bushings damaged, they should be replaced. Otherwise they should be cleaned thoroughly as required to remove all surface contamination.

8.6.2.2 The oil, in addition to providing insulation, acts as an arc-extinguishing medium in current interrupters. In this process, it absorbs arc products and experiences some decomposition in the process. Thus, maintenance of the oil is of great importance. Oil maintenance involves detection and correction of any condition that would lower its quality. The principal contaminants are moisture, carbon, and sludge. Moisture will appear as droplets on horizontal members, while free water will accumulate in the bottom of the tank. Sludge caused by oxidation will appear as a milky translucent substance. Carbon initially appears as a black trace. It eventually will disperse and go into suspension, causing the oil to darken.

8.6.2.3 A dielectric breakdown test is a positive method of determining the insulating value of the oil. Samples can be taken and tested as covered in ASTM D 877, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes,* and as outlined in 9.2.8.1 and 9.2.8.2. Oil that tests too low should be immediately reconditioned and retested or replaced with new oil. Oil should be tested periodically or following a fault interruption.

8.6.2.4 In replacing the oil, only the oil recommended by the manufacturer should be used and it should have been stored in sealed containers. In addition, the oil should be given a dielectric breakdown test immediately prior to use and to avoid air entrapment when adding oil. An oil pump or other means should be used to avoid aeration.

8.6.2.5 In the event entrapment of air cannot be avoided, the entrapped air should be removed by application of vacuum or the equipment should be allowed to stand for 8 hours to 12 hours prior to being energized.

8.6.3 Contacts. The main contacts of an oil circuit breaker are not readily accessible for routine inspection. Contact resistance should be measured. Contact engagement can be measured by measuring the travel of the lift rod from the start of contact opening to the point where contacts separate as indicated by an ohmmeter.

8.6.3.1 More extensive maintenance on main contacts might require removal of the oil and lowering the tank and should therefore be performed less frequently than routine maintenance. The frequency should be determined by the severity of the breaker duty, for example, the number of operations and operating current levels. Any time the breaker has interrupted a fault current at or near its maximum rating, this type of maintenance should be performed. The contacts should be inspected for erosion or pitting. Contact pressures and alignment should be checked. All bolted connections and contact springs should be inspected for looseness.

8.6.4 Arc-Quenching Assemblies.

8.6.4.1 Arc-quenching assemblies should be inspected for carbon deposits or other surface contamination in the areas of arc interruption.

8.6.4.2 If cleaning of these surfaces is necessary, manufacturers' instructions should be followed.

8.6.5 Operating Mechanism. Maintenance of the operating mechanism should follow the same procedure as recommended for air circuit breakers. *(See 8.4.5.)*

8.6.6 Breaker Auxiliary Devices. Breaker-auxiliary-device maintenance should follow the same procedure as recommended for air circuit breakers *(see 8.4.6)* when applicable. Other accessories, such as oil level gauges, sight glasses, valves, gaskets, breathers, oil lines, and tank lifters should be inspected. The breaker should be taken out of service immediately if the oil level is below the level gauge or sight glass.

8.7 Interrupter Switches.

8.7.1 A medium-voltage interrupter switch is an air switch equipped with an interrupter for making or breaking specified currents, or both. It can be either the fixed mounted or draw-out type and can be either manually or electrically operated. If fixed mounted, it will be interlocked with access doors or panels to prevent access to closed switches.

8.7.2 Maintenance procedures should correspond to those recommended for air circuit breakers except as regards the interrupter device. This device, on most interrupter switches, is of very simple open-type construction and can be inspected and cleaned easily without removal from the switch. Enclosed interrupters should be removed from the switch and disassembled for maintenance in accordance with the manufacturer's recommendation. Dielectric tests are not required as a part of maintenance. Air puffers are not employed in this type of interrupter.

8.8 Gas-Insulated Substations and Gas-Insulated Equipment.

8.8.1 Introduction. A gas-insulated substation (GIS) is a manufactured assembly of gas-insulated equipment (GIE) typically installed on electric systems rated 72.5 kV and above. While a few gas-insulated substations are operated by industrials, most GIS are operated by utilities. A GIS may include such GIE as circuit breakers, disconnect switches, ground switches, voltage transformers, current transformers, capacitors, gas-to-air bushings, gas-to-cable terminations, buses, associated enclosures, and control and monitoring equipment.

8.8.1.1 Gas-insulated equipment is installed as components such as circuit breakers for application on industrial medium- and high-voltage electrical systems. In addition to the general guidelines provided in this document, manufacturer maintenance procedures for GIE should be followed.

8.8.1.2 Some circuit-interrupting devices are inside a hermetically sealed enclosure containing a prescribed amount of SF_6 gas and are not serviceable. These devices are typically found in some medium-voltage metal-enclosed switchgear and medium-voltage outdoor power circuit breakers, and they are also used in some medium- and high-voltage interrupter switches. Generally, this equipment utilizes devices that provide a visual indication of loss of gas. Replacement of the entire sealed unit is required when this occurs.

8.8.1.3 Other GIE units contain gas density gauges to monitor temperature and pressure, providing indication of sufficient gas to maintain the equipment ratings.

8.8.2 Sulfur Hexafluoride (SF_6) Gas.

8.8.2.1 SF_6 gas, under pressure, is used as the dielectric and interrupting medium in circuit breakers and switches. SF_6 has been identified as a "greenhouse gas" whose release to the environment could contribute to global warming. Therefore, SF_6 gas should be reused and recycled whenever possible, and should never be released into the atmosphere unnecessarily. SF_6, in its pure state, is odorless, colorless, tasteless, nonflammable, noncorrosive, and nontoxic. It is five times heavier than air and will settle to the bottom of an enclosed vessel, displacing any breathable air to the top of the vessel. Although nontoxic, SF_6 gas will not support life by itself and will result in asphyxiation. For this reason, do not enter any vessel previously containing SF_6 gas unless thorough ventilation is achieved and until the oxygen content is verified. See OSHA 29 CFR 1910.146 for practices and procedures to protect employees from the hazards of entry into permit-required confined spaces and Part 7 of OSHA 29 CFR 1910.269(e) for enclosed space entry.

8.8.2.2 SF_6 gas used in GIE can be tested and should conform to ASTM D 2472, *Standard for Sulfur Hexafluoride*.

8.8.3 Causes of SF_6 Decomposition.

8.8.3.1 SF_6 decomposes as a result of excessive heating, electric sparks, power arcs, and partial discharges. The rate of decomposition of the gas during operation is determined by the equipment design and the inclusion of desiccants and adsorbents within the equipment. A power arc associated with a fault within the equipment results in a decomposition of SF_6 within a compartment and the generation of gaseous and solid by-products.

8.8.4 Decomposition By-Products.

8.8.4.1 Gaseous By-Products. The major gaseous by-products include S_2F_2, SOF_2, SO_2F_2, SF_4, SO_2, and HF. Some of these gases are highly toxic. The reaction of some of these gases with available moisture produces additional quantities of toxic gases. Arcing causes SF_6 to decompose into other sulfur fluorides and, in the presence of moisture, hydrogen fluoride. These decomposition products are toxic and harmful to the eyes, nose, and lungs. When arcing has occurred, avoid breathing any of the SF_6 by-products. Any rotten egg odor in the vicinity of the equipment is indicative of contaminated SF_6.

8.8.4.1.1 DO NOT vent gas from the equipment or attempt to sniff it.

8.8.4.2 Solid Arcing By-Products. Solid decomposition by-products are produced in the form of a fine (talcum-like) powder. This powder is a metal fluoride and is white or tan in color. The danger from solid arcing by-products comes more from the gases adsorbed on the surface area of the powder than from the toxicity of the base material. The aluminum fluoride (AlF_3) powder that normally dominates solid arcing by-products is so fine that the lungs do not easily expel it.

8.8.5 Maintenance and Repair of GIS and GIE.

8.8.5.1 General.

8.8.5.1.1 Instruction books or equipment manuals furnished with the GIS or GIE are necessary for operating and maintenance personnel. This instructional literature should include information pertaining to safe operating and maintenance procedures.

8.8.5.1.2 Safety during maintenance and repair requires that the components on which work is to be performed are electrically isolated, de-energized, grounded, and locked/tagged out.

8.8.5.1.3 Equipment should never be depressurized until it is de-energized and grounded.

8.8.5.1.4 Cleanliness, in accordance with manufacturer's instructions, should be observed at all times. The area around the access point to be opened, including supporting steel and other parts from which dirt or contaminants could fall or be blown into the enclosure, should be vacuumed and wiped with lint-free cloths.

8.8.5.1.5 Do not stand or step on small piping or connections.

8.8.5.1.6 Gas is handled through commercially available gas-processing trailers (carts) that contain vacuum-pumping equipment, gas storage tanks, compressors, filters, and dryers. Suitable evacuating equipment and a heat source to counteract the chilling effect of the expanding gas can permit filling directly from gas cylinders or gas-handling equipment. The specific requirements for gas purity, handling, processing, filling, and refilling that the equipment manufacturer provides should be followed to ensure proper equipment operation.

8.8.5.1.7 Evacuate to 133 Pa (Pascals) all gas from the compartment by a closed evacuation system and pass it through a filter capable of removing arc decomposition by-products. Allow dry air to enter and refill the compartment to atmospheric pressure (101 kPa) before opening the access port.

8.8.5.1.8 Upon opening of the compartment, assure proper ventilation and oxygen content of enclosure prior to personnel entry.

8.8.5.1.9 Maintenance workers who conduct the initial opening of the faulted gas compartment and removal of the solid arcing by-products should employ air respirators and wear disposable protective clothing covering all garments, boots, hair, and hands. Avoid direct contact with arc decomposition by-products (fine powder).

8.8.5.1.10 Work quickly because the exposure of the solid arcing by-products to moist air will result in toxic fumes with a strong rotten egg odor. Immediate removal of the solid by-products should be the first priority, as they will become sticky and more difficult to remove with continued exposure to moist air.

8.8.5.1.11 A commercial-type vacuum cleaner with high-efficiency particulate air (HEPA) filters and nonmetallic accessories should be used to remove the arc solid by-products. Precautions should be taken to avoid breathing the exhaust air from the vacuum cleaner, since dust particles might go through the collection system. Following vacuuming, the affected area should be wiped down using a solvent (typically ethyl alcohol denatured with 5 percent or 10 percent methyl alcohol) by workers continuing to wear respirators, appropriate personal protective equipment, and disposable clothing.

8.8.5.1.12 All work should be completed safely and as quickly as possible. When delays are encountered, any open sections should be covered immediately with suitable seals. It might also be necessary to add heat to prevent condensation. When any section is left overnight or longer, it should be pressurized with dry air to a pressure of approximately 136 kPa to avoid condensation or entrance of moist air.

8.8.5.1.13 Recharging. To achieve the required fill density, it is important that the gas pressure and temperature curve from the manufacturer's instruction book be used. Sufficient time should be allowed for equalization of the gas temperature.

8.8.5.1.14 Moisture Tests. After recharging, several measurements of the moisture content of the gas within the equipment should be taken to ensure that the moisture content of the SF_6 remains within acceptable limits. If the moisture content of the gas rises to an unacceptable level, recirculation through the dehydration portion of the gas-processing trailer (cart) is required to remove the excess moisture. *(See IEEE Std 1125-1993 IEEE Guide for Moisture Measurement and Control in SF_6 Gas-Insulated Equipment.)*

8.8.5.2 References. The equipment manufacturer's instructions, NETA *Maintenance Testing Specifications for Electrical Power*

Distribution Equipment and Systems, SF_6 Switches Section 7.5.4 and SF_6 HV Circuit Breakers 7.6.3.2, and the following clauses of IEEE Std C37.122.1-1993, *IEEE Guide for Gas-Insulated Substations,* should be consulted for specific maintenance, repair considerations, and procedures:

(1) 4.2, Installation and equipment handling
(2) 4.4, Gas handling-SF_6 and GIS
(3) 4.5, Safe operating procedures
(4) 4.8, Partial discharge (PD) testing
(5) 4.10, Field dielectric testing
(6) 4.11, Maintenance and repair

8.9 Auxiliary Equipment.

8.9.1 Fuses. Fuse maintenance is covered as a separate category of electrical equipment in Chapter 15.

8.9.2 Surge Arresters.

8.9.2.1 Surge arresters should be inspected periodically for evidence of damage to the porcelain housing or surface contamination. If the porcelain is damaged to the extent that the creepage path over its surface is reduced or the porcelain glazed surface is seriously damaged, the arrester should be replaced. Otherwise, the porcelain surface should be cleaned thoroughly as required to remove all surface contamination.

8.9.2.2 There are no simple practical field tests that will determine the complete protective characteristics of lightning arresters. There are, however, certain tests that can be made with apparatus usually available that will give sufficient information to determine whether the arrester can be relied on to be an insulator under normal conditions. These tests are 60-cycle spark-over and hold tests, watts-loss and leakage-current tests, insulation resistance tests, and grounding-electrode circuit-resistance tests. These tests should be done strictly in accordance with the manufacturers' recommendations and the results interpreted in line with manufacturers' criteria.

8.9.3 Capacitors.

8.9.3.1 Capacitors should always be discharged before handling or making connections by closing the ground devices that are usually installed with large capacitor banks. An insulated short-circuit jumper should be used for dissipating the charge; however, it should only be applied with full knowledge of the circuit and with the use of appropriate protective equipment.

> **CAUTION:** Capacitors, even though they have discharge resistors, might possess a stored charge that is capable of injuring a person coming into contact with the terminals.

8.9.3.2 The capacitor case, the insulating bushings, and any connections that are dirty or corroded should be cleaned. Each capacitor case should be inspected for leaks, bulges, or discoloration. Any liquid-filled capacitor found to be bulging or leaking should be replaced. *(See Section 9.2 on liquid-filled transformers.)*

8.9.3.3 Power capacitors are generally provided with individual fuses to protect the system in case of a short circuit within the capacitor. In addition to a faulty capacitor, a fuse can also be blown by an abnormal voltage surge. A check should be made for blown fuses, and they should be replaced with the type recommended by the manufacturer. Fuses should not be removed by hand until the capacitor has been discharged completely.

8.9.3.4 Adequate ventilation is necessary to remove the heat generated by continuous full-load duty. Any obstructions at ventilation openings in capacitor housings should be removed, and adequate ventilation must be provided and maintained.

8.9.4 Stationary Batteries and Battery Chargers.

8.9.4.1 General. Stationary batteries are a primary power source for critical systems, ac power generation equipment, switchgear, and control circuits. Stationary batteries also provide backup power for essential equipment during outages of the primary power supply. These applications require reliable service; therefore, stationary batteries should be serviced regularly. The maintenance required depends on each battery's application, type, construction features and materials, and environment.

8.9.4.1.1 Lead–acid batteries are of two technologies: flooded wet cell, and sealed valve regulated lead–acid (VRLA) designs. Stationary batteries are typically lead–acid batteries with lead–antimony or lead–calcium grids. Some stationary batteries are nickel–cadmium (Ni-Cad) units. VRLA batteries have a shorter service life than flooded cells, cannot be tested in the same manner, and are not addressed in this document.

8.9.4.1.2 Battery chargers play a critical role in battery maintenance because they supply normal dc requirements and maintain batteries at appropriate levels of charge. Chargers should be set and maintained according to manufacturers' instructions.

8.9.4.2 Maintenance Program. Battery maintenance normally consists of periodic inspections and tests. Visual inspections include checking electrolyte level and internal conditions in jar-type cells. Many battery problems can be detected by visual inspections. Tests aid in evaluating performance and permit comparisons with standards and with historical test results. Battery manufacturers are good sources of information for maintenance programs.

8.9.4.3 Safety Guidelines. Personnel should be aware of the hazards associated with stationary batteries. A battery can produce and emit a mixture of hydrogen and oxygen gas that is very explosive. Exposing skin and eyes to electrolyte can cause severe burns and blindness. Voltages present can cause injury and death. As a minimum, the following safety precautions should be observed.

8.9.4.3.1 Maintenance personnel should be trained to perform the tasks properly. This training should include using personal protective equipment, handling the electrolyte safely, using the proper tools, and following the battery manufacturer's service and maintenance instructions.

8.9.4.3.2 The room or compartment in which operating lead–acid batteries are located should be ventilated adequately.

8.9.4.3.3 Appropriate safety equipment should be worn, including goggles, gloves, and aprons when working with the batteries. Eyewash and quick drench facilities should be provided near the batteries.

8.9.4.3.4 Open flames, sparks, hot plates, and other ignition sources should be kept away from storage batteries, gas ventilation paths, and places where hydrogen can accumulate.

8.9.4.3.5 Metal objects should not be placed on battery cells. Insulated tools should be used to protect against shorting of cells.

8.9.4.3.6 When electrolyte is being prepared, personal protective equipment should include a full face shield. POUR ACID INTO WATER, NOT WATER INTO ACID. If the electrolyte comes in contact with skin or eyes, the affected area should be immediately flushed with water and medical assistance obtained.

8.9.4.3.7 Unauthorized access to the battery area should be prohibited.

8.9.4.4 Guide for Visual Inspections and Associated Servicing.

8.9.4.4.1 Jars and covers should be checked for cracks and structural damage. Maintenance of flame arrestor–type vent caps should consist of rinsing them in clear water and air drying. Damaged units and vent caps should be replaced.

8.9.4.4.2 Plates of clear jars should be checked for buckling, warping, scaling, swelling, or cracking, and for changes in color. Damaged cells should be replaced.

8.9.4.4.3 The charger should be checked for proper operation. Interconnection cables, cell connectors, and other conductors should be examined for wear, contamination, corrosion, and discoloration. Racks should be checked for corrosion, cleanliness, and structural integrity.

8.9.4.4.4 A check should be made for spilled electrolyte. Bicarbonate of soda solution should be used to neutralize lead–acid battery spills and boric acid solution should be used for Ni-Cad spills.

8.9.4.4.5 The electrolyte level should be checked. It should be determined that electrolyte and cells are clear, with minimal deposits, gassing, or rings, and that there is only minor sediment below the plates. The amounts of water added to the cells should be recorded. Excessive water consumption can be a sign of overcharging. For lead–antimony batteries, water consumption increases gradually with age. Distilled water should be used unless otherwise recommended by the battery manufacturer.

CAUTION: Never add acid to a battery when refilling.

8.9.4.4.6 Ventilation and the suitability and condition of electrical equipment in the area should be checked. Battery proximity to combustibles and ignition sources should be evaluated. Local sources of heat can create cell temperature differentials that cause battery damage.

8.9.4.4.7 Ambient temperature should be checked. The optimum ambient operating temperature for lead–acid batteries is 25°C (77°F). Ni-Cad batteries can operate satisfactorily over a range of temperatures, generally from 25°C to 45°C (77°F to 113°F). High ambient temperatures reduce cell life. Every 9°C (15°F) increase in temperature above 25°C (77°F) reduces lead–acid cell life 50 percent and Ni-Cad cell life 20 percent. Lower ambient cell temperatures reduce cell capacity. A battery operating at 16°C (60°F) loses about 10 percent of its designed capacity.

8.9.4.4.8 Area heating, air conditioning, seismic protection, dc circuit overcurrent protection, distilled water supply, alarm circuits, grounding connections, cable clamps, and all other installed protective systems and devices should be checked.

8.9.4.5 Mechanical and Miscellaneous Investigation Guidelines.

8.9.4.5.1 Terminal connectors, battery posts, and cable ends should be checked and all corrosion and dirt removed. Battery posts should be cleaned according to manufacturers' recommendations.

8.9.4.5.2 Lead–acid battery surfaces should be cleaned with water and sodium bicarbonate to avoid leakage currents caused by electrolyte on the battery. Ni-Cad battery surfaces should be cleaned with a boric acid solution. Cleaners, soaps, or solvents should not be used to clean battery jars and covers, as damage can result.

8.9.4.5.3 The intercell connectors (links) should be checked annually and torqued to specified values.

8.9.4.5.4 Alarm relays, lights, and horns should be checked for proper operation. The battery room emergency light should be checked.

8.9.4.5.5 Ventilation openings should be checked to be sure they are clear of obstructions.

8.9.4.6 General Observations.

8.9.4.6.1 Excessive gassing can result from overcharging.

8.9.4.6.2 Vibration reduces battery life. Excessive vibration can be detected by observing vibration of plates and sediment in the jar.

8.9.4.6.3 A lead–acid battery electrolyte begins to freeze at –29°C (–20°F), but it can freeze at warmer temperatures if its specific gravity is low. Once ice crystals form, damage to the cell is irreparable.

8.9.4.6.4 Hydration occurs when a lead–acid battery is overdischarged without an immediate recharge, or when a dry-charge battery is accidentally filled with water. A sign of hydration is a whitish ring in the jar, which eventually shorts the positive and negative plates. Hydration is an irreversible condition.

8.9.4.6.5 Overcharging of lead–acid cells or charging at excessive rates leads to mossing. Mossing is the development of sponge-like material high on the negative plates and the resulting sedimentation in the cells. Continued mossing shorts out the plates.

8.9.4.6.6 The average battery tolerates approximately 50 full discharges in its life. Fully discharging a stationary battery more than twice in one year can reduce its life.

8.9.4.7 Battery Test and Measurement Guidelines. Tests should be performed and results recorded to establish trends that can be used in predicting battery life. For lead–acid batteries, a pilot cell from each group of six cells should be selected to obtain a representative temperature while the recommended voltage and specific gravity measurements are made. Alternate pilot cells should be chosen quarterly to minimize cell electrolyte loss and contamination during testing.

8.9.4.7.1 Pilot cell voltage, specific gravity, and electrolyte temperature should be measured and recorded monthly. Common float voltage range for lead–calcium cells is 2.20 volts to 2.30 volts per cell. Lead–antimony cells float at about 2.17 volts to 2.21 volts per cell. Ni-Cad cells charge at approximately 1.42 volts per cell. Manufacturers' literature should be referred to for specific charge potentials.

8.9.4.7.2 For lead–acid batteries, the specific gravity of electrolyte in all pilot cells should be measured and recorded monthly. The specific gravity of electrolyte in all cells should be measured and recorded quarterly. Specific gravity readings should be adjusted for pilot cell temperature. Test results should be as indicated by the manufacturer, usually between 1.205 and 1.225. For accurate results, specific gravity should not be measured within 72 hours after applying an equalizing charge or after adding water to the battery. Specific gravity readings are not required for Ni-Cad batteries.

8.9.4.7.3 A capacity test should be performed within the first 2 years of installation and every 3 to 5 years thereafter, depending on the load reliability requirements and environmental conditions of the installation. The frequency of battery tests should be increased to yearly when the battery reaches 85 percent of its service life or when it shows signs of deterioration. Once the capacity drops by 20 percent in extended operation, however, the cell should be replaced.

8.9.4.7.4 A sample (for example, 25 percent) of intercell connectors and terminal connection resistances should be measured quarterly, in accordance with the manufacturers' instructions.

8.9.4.7.5 Batteries should be examined under load with an infrared scanning device. The abnormal temperature of a cell; a poor connection at a battery post; and a deteriorated link, strap, or conductor are some of the problems that can be readily identified by thermographic surveys.

8.9.4.8 Other Tests. Test readings should be recorded for future reference along with log notations of the visual inspection and corrective action. A copy of the battery record is included as Figure F.11.

8.9.5 Instrument Transformers and Auxiliary Transformers.

8.9.5.1 Instrument transformers and auxiliary transformers might be the outdoor type, although in some cases they can be mounted inside metal-enclosed switchgear assemblies. These transformers are similar to other outdoor transformers in that they are liquid filled and equipped with outdoor bushings. All recommendations for maintenance of outdoor transformers therefore apply.

8.9.5.2 Indoor-type instrument and auxiliary transformers are normally dry type, except that potential transformers might be enclosed in compound-filled metal cases. All of the transformers above are of the completely molded type, with only the terminals exposed. Maintenance recommendations for these indoor transformer types are the same as those for metal-enclosed switchgear assemblies insulation *(see 8.2.10)*. The same conditions of environment and electrical and thermal distress prevail. In other words, KEEP THEM CLEAN and KEEP THEM DRY.

8.9.6 Alarm and Indicators.

8.9.6.1 Alarms. Alarms associated with transformer overtemperature, high or low pressure, circuit-breaker trip, accidental ground on an ungrounded system, cooling waterflow or overtemperature, or other system conditions should be tested periodically to ensure proper operation.

8.9.6.2 Indicators. Circuit-breaker "open-close" indicators can be checked during their regular maintenance.

8.9.6.2.1 Ground indicator lamps for ungrounded electric systems should be checked daily or weekly for proper operation. Other miscellaneous indicators such as flow, overtemperature, and excess pressure, should be checked or operated periodically to ensure proper operation.

8.9.7 Protective Relays, Meters, and Instruments.

8.9.7.1 The current elements of protective relays, meters, and instruments are usually connected in the secondary circuit of current transformers.

> **CAUTION:** Opening the secondary circuit of an energized current transformer will produce a very high voltage that can be fatal.

8.9.7.1.1 Therefore, the secondary terminals of an energized current transformer are required to be short-circuited before opening the secondary circuit. Some relays and instruments have special test terminals or test switches that make a closed circuit in the current transformer secondaries during test. Upon completion of tests, it is necessary to remove the short-circuit jumper to permit the current transformer to function.

8.9.7.2 Since protective relays and instruments play such an important role in the prevention of hazard to personnel and plant equipment, they should be given first line maintenance attention. Furthermore, since the only time they operate is during an abnormal electric power system condition, the only way to ensure correct operation is by a comprehensive inspection, maintenance, and testing program.

8.9.7.3 Meters, instruments, and relays should be examined to ensure that all moving parts are free of friction or binding. Wiring should be checked for loose connections. Contacts should be inspected for pitting or erosion. Evidence of overheating should be looked for in solenoid coils or armatures. Cracked glass or damaged covers or cases should be replaced. *(See 20.10.3 for testing recommendations.)*

8.9.8 Interlocks and Safety Devices. Interlocks and safety devices are employed for the protection of personnel and equipment and should, therefore, never be made inoperative or bypassed. Proper functions of these devices should be ensured by the following procedures.

(1) The adjustments and operation of the devices should be checked as follows:
   (a) Mechanical interlocks on draw-out mechanisms should prevent withdrawal or insertion of circuit breakers in the closed position.
   (b) Safety shutters, where provided, should automatically cover the "stab-in" ports.
   (c) Limit switches should prevent overtravel of motorized lifting devices.
(2) Key interlock systems should be operated in proper sequence, and suitable operation ensured by the following:
   (a) Adjustments should be made and the system lubricated as necessary.
   (b) Instructions should be posted on complicated systems, especially where the interlocks might only be operated annually or in emergencies.
(3) Spare keys should be identified and stored in the custody of the supervisor.
(4) Grounding switches used in medium-voltage switchgear should be maintained to the same degree as the circuit breaker itself.
   (a) If they are stored indoors, they should be covered to prevent dust accumulation.
   (b) If stored outdoors, they should be stored in a weatherproof covering.

8.9.9 Grounding.

8.9.9.1 Equipment-grounding circuits are not inherently self-monitoring as are circuits that normally carry current. To ensure that the equipment-grounding conductors continue to be effective when called upon to carry ground-fault current, they should be checked periodically.

8.9.9.2 Checking a system to determine the adequacy of the equipment ground involves inspection of connections that can be supplemented by an impedance test to enable an evaluation of those parts of the system not accessible for inspection. *(See Section 20.13.)*

8.9.9.3 Terminal connections of all equipment-grounding conductors and bonding jumpers should be checked to see that they are tight and free of corrosion. Bonding jumpers should also be examined for physical abuse, and those with broken strands should be replaced. Where metal raceway is used as the equipment-grounding path, couplings, bushings, set-screws, and locknuts should be checked to see that they are tight and properly seated. Any metal raceway used as the equipment-grounding path should be examined carefully for rigid mounting and secure joints; screws and bolts should be retightened.

8.9.10 Ground-Fault Indicators.

8.9.10.1 Ground-fault indicators can be installed on all ungrounded or resistance-grounded low-voltage systems. The indicator can consist of a simple set of lamps wired phase-to-ground. A ground on one phase will cause the lamp on that phase to be dark, while the other two lamps will have increased brilliancy.

8.9.10.2 A more elaborate system provides audible as well as visual indication so the ground is more readily detected.

8.9.10.3 Once a ground has been detected, prompt location and correction are important, since the system is now highly vulnerable in the event of a ground on another phase. Through the process of elimination, searching for the ground requires circuit or system interruptions and isolation of the circuit(s) until the ground fault is located and eliminated. The use of an instrument that permits location of such ground faults without power interruptions is recommended.

8.9.10.4 Maintenance of ground fault detectors should include a complete inspection of the signal elements such as lamps, horns, or buzzers. Audible devices should be operated to ensure that they are in operable condition. Wiring should be checked for loose connections or damaged wiring.

8.9.10.5 Summary. A complete, effective maintenance program for substations and assembled switchgear will result if the four "keepers" are observed.

8.9.10.5.1 If it's insulation, KEEP IT CLEAN and KEEP IT DRY.

8.9.10.5.2 If it's mechanical, KEEP IT SNUG and KEEP IT FRICTION FREE.

8.9.11 Network Protectors.

8.9.11.1 A network protector is an air circuit breaker equipped with specialized relays that sense network circuit conditions and command the circuit breaker to either open or close. There is no separate power source for control. All control power is taken from the system.

8.9.11.1.1 A routine maintenance schedule for network protectors should be observed. Frequency of inspection will vary to a great extent depending on the location and environment in which a protector is installed.

8.9.11.1.2 Maintenance should include cleaning any accumulation of dust from the unit, a thorough visual inspection, and overall operational test. Should any part look suspicious, the manufacturers' instructions describing operation, adjustment, and replacement of these parts should be consulted. If relays are out of calibration, they should be recalibrated by competent personnel.

8.9.11.2 Safety. Network protectors are used where a large amount of power is distributed to high-load-density areas. As a result, any short circuit at any point in the system involves very high fault currents. Due to the nature of a secondary network, some maintenance might be necessary to be performed while the system is energized.

> **CAUTION:** In this work, always use insulated tools and wear safety gloves. Rigid clearance procedures have to be observed.

8.9.11.2.1 Extensive use of barriers has been a salient feature in the design of this equipment. These barriers should be kept in place, and any that have been broken should be replaced immediately. Only skilled maintenance personnel who are thoroughly familiar with the construction and operation of network protectors should be permitted to perform any maintenance on an energized unit. The first procedure in performing maintenance is to trip the protector to the open position.

8.9.11.3 Maintenance. The circuit-breaker mechanism and relay panel assembly are usually constructed as an integral draw-out unit that should be withdrawn from the housing for maintenance. Removal of the fuses at the top and the disconnecting links at the bottom (some modern protectors have bolt-actuated disconnecting fingers at the bottom) isolates the unit electrically from the system. Although this procedure provides comparative safety, work should be done cautiously, since it might be assumed that normally there is voltage on the transformer and the network leads. With the draw-out unit outside the enclosure on the extension rails, the following inspection and maintenance operations should be performed on the draw-out unit. (8.9.11.3.11 applies only to the containing structure, not the draw-out unit.)

8.9.11.3.1 The complete unit should be cleaned. Use of a vacuum-type cleaner is preferred. Use cloth rags free of oil or greases for removing clinging dirt.

8.9.11.3.2 Arc chutes should be removed. Any broken splitter plates should be replaced.

8.9.11.3.3 Main contacts should be inspected.

(A) Any heavily frosted area should be smoothed with a fine file, stone, crocus cloth, or other suitable abrasive that does not shed abrasive particles.

(B) The hinge joint should be protected from falling particles during dressing.

8.9.11.3.4 During normal operation, arcing contacts become rough due to arcing. Any especially high projections of metal should be filed smooth.

8.9.11.3.5 All electrical connections should be checked to see that they are tight.

8.9.11.3.6 Any abrasion of wire insulation should be observed.

8.9.11.3.7 Control wire and current-carrying parts should be checked for overheating.

8.9.11.3.8 All springs should be checked to see that they are in place and not broken.

8.9.11.3.9 All nuts, pins, snap rings, and screws should be checked to see that they are in place and tight.

8.9.11.3.10 Any broken barriers should be replaced.

8.9.11.3.11 With the rollout unit removed, the following maintenance operations should be performed inside the enclosure.

> **CAUTION:** Both network and transformer connections should be treated as though they are energized. When working in housing or on frame, use only insulated tools and wear safety protective equipment. Do not remove any barriers from enclosure.

(A) Loose hardware should be looked for on the floor or beneath the frame. If any is found, it should be traced to its source.

(B) Stand-off bus insulators should be cleaned.

(C) Any oxide film should be removed from terminal contacts if necessary.

8.9.11.3.12 The protector should be closed manually in accordance with the manufacturer's instructions.

(A) It should close with a definite snap action. Sluggish closing indicates excessive friction.

(B) The trip level should be moved to "tripped" position.

(C) The breaker should snap open.

8.9.11.3.13 An operational test is best performed using a network protector test kit.

8.9.11.3.14 An insulation resistance test, a dielectric test, and electrical operating tests should be performed strictly in accordance with the manufacturers' recommendations.

Chapter 9 Power and Distribution Transformers

9.1 Introduction.

9.1.1 In industrial installations, transformers are usually used to transform or step down a higher distribution level voltage to a lower utilization level. They are vital links in electrical power systems and are among the most reliable components in the system. If they are not overloaded or otherwise abused, they should provide long, trouble-free service. Established records of reliable performance, coupled with a lack of movement, noise, or other sign of action, often result in general disregard and neglect. Because a transformer failure is usually of a very serious nature, requiring extensive repair and long downtime, regular maintenance procedures are the best assurance of continued high reliability.

9.1.2 Power and distribution transformers require regular maintenance if they are to have a normal service life. The extent and frequency of maintenance should be based not only on size or voltage but also on the relative importance of the transformer in the system. The failure of a small distribution transformer serving a critical load can have more impact on an operation than the failure of a larger or higher-voltage unit. Also, on some smaller systems, the failure of a distribution transformer can result in an outage of the complete system. When planning the level of maintenance on a transformer, consideration should also be given to other factors, such as replacement lead time.

9.1.3 Transformers can be divided into two general categories in accordance with their insulating medium and construction: liquid-filled and dry type. Each has several variations listed under the specific maintenance recommendations, and each requires different maintenance techniques. In general, insulation tests, such as power-factor testing and insulation-resistance testing, and diagnostic tests, such as turns-ratio testing and exciting-current testing, are the major maintenance tests for all transformers. In addition, liquid-filled transformers should be tested to determine the quality of the insulating liquid.

9.2 Liquid-Filled Transformers.

9.2.1 Introduction.

9.2.1.1 The core and coils of liquid-filled transformers are immersed in a liquid. The liquid serves two purposes. It is an important part of the insulating medium, and it serves to transfer heat away from the windings to be dissipated by the cooling fins, tank surface, or radiator.

9.2.1.2 Two types of insulating liquid in common use are mineral-insulating oil and askarel. Other types of liquids used are less-flammable liquids, such as silicone or stabilized hydrocarbon liquids. Each liquid has definite characteristics and THEY SHOULD NOT BE MIXED. Manufacturers' instructions should be carefully followed with all insulating liquids.

9.2.1.3 Askarel is identified by various brand names and consists largely of polychlorinated biphenyls (PCBs). It is subject to strict government regulation as a toxic substance. A knowledge of government regulations is necessary because any liquid-filled transformer might contain some level of PCBs. (One reference is the Toxic Substances Control Act as defined in 40 CFR 761. Copies can be obtained from the Industry Office of Toxic Information Service operated by the Environmental Protection Agency, Washington, DC 20460. Call 202-554-1404.)

9.2.1.4 There are several types of transformer construction regarding the preservation of the liquid. Preservation means minimizing exposure of the insulating liquid to the atmosphere. The types are as follows:

(1) Free breathing (open to the atmosphere)
(2) Restricted breathing (open to the atmosphere through dehydrating compounds)
(3) Conservator or expansion tank (exposure to air limited to the liquid in the conservator tank)
(4) Sealed tanks (a gas space above the liquid serves as a cushion for internal pressure)
(5) Gas-oil seal (exposure to air limited to the oil in the auxiliary tank)
(6) Inert gas (gas space above liquid maintained under positive pressure by gas supplied from a nitrogen cylinder)

9.2.1.5 Some common cooling methods are as follows:

(1) Self-cooled (OA or OISC) — heat is dissipated by the tank surface and cooling fins or tubes

(2) Forced-air cooled (FA) — fans are employed to force air over the cooling surfaces to augment the self-cooled rating
(3) Forced-air cooled/forced-oil cooled (FA/FOA) — an oil pump circulates oil through a fan-blown oil-to-air heat exchanger
(4) Water cooled (FOW) — heat exchange by means of water pumped through a pipe coil installed inside or outside the transformer tank

9.2.2 Regular Inspections.

9.2.2.1 Inspections of transformers should be made on a regular basis. The frequency of inspection should be based on the importance of the transformer, the operating environment, and the severity of the loading conditions. Typical regular inspection data can include load current, voltage, liquid level, liquid temperature, winding hot-spot temperature, ambient temperature, leaks, and general condition.

9.2.2.2 The current, voltage, and temperature readings should be taken at the time of peak load and the liquid level reading at the end of a low-load period. Permanent records should be kept of the readings. Keeping such records helps ensure that the readings will be made and provides a means of ready comparison with previous conditions. Further explanations are covered in the following sections.

9.2.3 Current and Voltage Readings.

9.2.3.1 Load currents are a very important part of the recommended regular inspections. If the observed current in any phase exceeds the rated full-load value, and the rated maximum temperature is exceeded, steps should be taken to reduce the load.

9.2.3.2 Overvoltages and undervoltages can be detrimental to the transformer and the load it serves. The cause should be investigated immediately and corrective action taken to bring the voltage within acceptable limits.

9.2.4 Temperature Readings.

9.2.4.1 Transformers are rated to carry their nameplate load in kVA with a given heat rise when the ambient temperature is at a standard level. Exact values are stated on the nameplate. For instance, a liquid-filled transformer might be rated to deliver nameplate capacity with a 65°C (149°F) temperature rise above a 30°C (86°F) ambient temperature (24-hour average).

9.2.4.2 If transformers have temperature gauges, readings should be regularly taken and recorded. If the gauge is also equipped with a maximum-temperature indicator, readings from both indicators should be recorded and the maximum-temperature indicator should be reset. Excessive temperature indicates an overload or perhaps some interference with the normal means of cooling. Prolonged operation at overtemperature will accelerate the deterioration of the liquid and result in reduced life expectancy of the solid insulation. Either will greatly increase the risk of failure. In some installations, constant monitoring against overtemperature is provided by special alarm contacts on the temperature gauge.

9.2.5 Liquid-Level Indicator and Pressure/Vacuum Gauges.

9.2.5.1 The liquid level should be checked regularly, especially after a long period of low load at low ambient temperature when the level should be at its lowest point. It is important that liquid be added before the level falls below the sight glass or bottom reading of the indicator. If a transformer is not equipped with a liquid-level indicator, the liquid level can be checked by removing the inspection plate on the top of the transformer or by removing the top if no inspection plate is available. It is necessary to de-energize the transformer prior to either of the above two procedures. *(See 9.2.7 for precautions relative to de-energizing the transformer and for the recommended procedures for adding liquid.)*

9.2.5.2 Pressure/vacuum gauges are commonly found on sealed-type transformers and are valuable indicators of the integrity of the sealed construction. Most sealed transformers have provisions for adding a pressure/vacuum gauge, and, if feasible, the gauge should be added. The readings should be compared to the recommendations of the manufacturer as to the normal operating ranges. High pressures indicate an overload or internal trouble and should be investigated immediately. A sustained zero pressure reading indicates a leak or a defective gauge.

9.2.6 Miscellaneous. The features of special types of transformer construction that should be included in regular inspections include the following:

(1) The water-in and water-out temperatures of water-cooled transformers.
(2) The oil-in and oil-out temperatures of forced-oil-cooled transformers with oil-to-air or oil-to-water heat exchangers.
(3) The pressure in the nitrogen cylinder for a transformer equipped with an automatic gas-pressure system — if the pressure drops below the manufacturer's recommended value [usually about 1034 kPa (150 psi)], the cylinder should be replaced, and leaks repaired.
(4) Dehydrating breathers should be checked to ensure that they are free from restriction and have not absorbed excessive moisture.

9.2.7 Special Inspections and Repairs.

9.2.7.1 Because of the wide variety of liquid-filled transformer types, sizes, and uses, as previously listed, the special inspection and repair recommendations will be general in nature. For specific directions, the manufacturer's recommendations should be followed.

9.2.7.2 If a transformer is given an external visual examination, the case of the transformer should be regarded as energized until the tank ground connection is inspected and found to be adequate. If any procedure more extensive than an external visual examination is to be performed, the first precaution that should always be observed is to de-energize the transformer. De-energization should always be accompanied by approved positive lockout or lockout/tagout procedures to ensure against an unexpected re-energization and resulting hazard to personnel or equipment. De-energization should be immediately followed by a test to ensure that the equipment is de-energized. The equipment should be grounded prior to the start of any work. *(See Chapter 23.)*

9.2.7.3 All connections should be inspected for signs of overheating and corrosion. Insulators and the insulating surfaces of bushings should be inspected for tracking, cracks, or chipped skirts, and the gasketed bases should be checked for leaks. The insulating surfaces should be cleaned of any surface contamination. Damaged insulators or bushings should be replaced. Leaks should be repaired. Pressure-relief devices should be inspected to ensure that there are no leaks or corrosion and that the diaphragm or other pressure-relief device is intact and ready to function. A cracked or leaking diaphragm should be replaced at once.

9.2.7.4 The tank, cooling fins, tubes, radiators, tap changer, and all gasketed or other openings should be inspected for leaks, deposits of dirt, or corrosion. Leak repair, cleaning, and painting should be done as required. Infrared inspection can be used to detect fluid levels as well as flow restrictions in cooling tubes.

9.2.7.5 The tank ground should be inspected for corrosion or loose connections. A grounding-electrode resistance test should be made, as covered in Section 20.15.

9.2.7.6 Cooling fans, circulating oil pumps, and protective relays (for example, Bucholtz relays and sudden-gas relays) should be inspected regularly in accordance with manufacturers' recommended practices.

9.2.7.7 The conservator tank, inert gas atmosphere, and dehydrating breather equipment should be inspected and tested according to the manufacturer's instructions. Since most modern, large, liquid-filled power transformers have features to minimize exposure of the liquid to air, opening of this type of transformer for internal inspection is recommended only when the need is positively indicated, and then the manufacturer's instructions should be carefully followed or technical assistance employed.

9.2.7.7.1 Contamination or impairment of the insulating liquid should be carefully avoided. If the humidity is high, exposure should be avoided entirely unless the work is absolutely necessary and cannot be postponed, in which case special humidity-control steps should be taken.

9.2.7.8 If liquid is to be added, it should be given a dielectric-breakdown test. The liquid to be added should be at least as warm as the liquid in the transformers. If a large amount of liquid is added, the transformer should remain de-energized for 12 hours or more to permit the escape of entrapped air bubbles. A desirable method is to add the liquid with the transformer tank under a vacuum. (Check the manufacturer's instructions for further information.)

9.2.8 Liquid Maintenance and Analysis.

9.2.8.1 Liquid Analysis. For insulating oils, the tests routinely performed are dielectric breakdown, acidity, color, power factor, interfacial tension, and visual examination. These tests are covered in Section 20.19. For other insulating liquids, the manufacturers' recommendations should be followed.

9.2.8.1.1 Tests can also be performed to determine levels of PCBs. Test results might require service or replacement of the transformer tested as specified by government regulations. *(See 9.2.1.3.)*

9.2.8.1.2 Samples should never be taken from energized transformers except by means of an external sampling valve. If the transformer has no external sampling valve, the unit should first be de-energized and a sample taken internally. *(See ASTM D 923, Standard Test Method for Sampling Electrical Insulating Liquids.)*

9.2.8.2 Maintenance. If any of the tests indicate that an insulating liquid is not in satisfactory condition, it can be restored by reconditioning or reclaiming or it can be completely replaced. Reconditioning is the removal of moisture and solid materials by mechanical means such as filter presses, centrifuges, or vacuum dehydrators. Reclaiming is the removal of acidic and colloidal contaminants and products of oxidation by chemical and absorbent means such as processes involving fuller's earth, either alone or in combination with other substances. Replacing the liquid involves draining, flushing, testing, and proper disposal of materials removed.

9.2.9 Other Tests.

9.2.9.1 In addition to the tests of the insulating liquid, tests should also be made of the dielectric properties of the solid insulation. Several commonly used tests are the insulation-resistance test and the dielectric-absorption test. A power-factor test can be used to record the trend of insulation condition. These are nondestructive tests, which means that they can be performed without the risk of damage to the insulation. All of these tests are discussed in Chapter 20.

9.2.9.2 Turns-Ratio and Polarity Tests. The turns-ratio test is used to determine the number of turns in one winding of a transformer in relation to the number of turns in the other windings of the same phase of the transformer. The polarity test determines the vectoral relationships of the various transformer windings. The turns-ratio test is used as both an acceptance and a maintenance test, while the polarity test is primarily an acceptance test.

9.2.9.2.1 The test equipment used will ordinarily be a turns-ratio test set designed for the purpose. If not available, input and output voltages can be measured, with at least 0.25 percent full-scale accuracy voltmeters, for approximation.

9.2.9.2.2 When a turns-ratio test is performed, the ratio should be determined for all no-load taps. If the transformer is equipped with a load-tap changer (LTC), the ratio should be determined for each LTC position. If the transformer has both an LTC and a no-load-tap changer, then the ratio should be determined for each position of the LTC to one position of the no-load-tap changer and vice versa.

9.2.9.2.3 This test is useful in determining whether a transformer has any shorted turns or improper connections and, in acceptance testing, to verify nameplate information.

9.2.9.3 Fault-Gas Analysis. *(See ASTM D 3284, Test Methods for Combustible Gases in the Gas Space of Electrical Apparatus in the Field.)* The determination of the percentage of combustible gases present in the nitrogen cap of sealed, pressurized oil–filled transformers can provide information as to the likelihood of incipient faults in the transformer. When arcing or excessive heating occurs below the top surface of the oil, insulation decomposition can occur. Some of the products of the decomposition are combustible gases that rise to the top of the oil and mix with the nitrogen above. A small sample of nitrogen is removed from the transformer and analyzed. The test set has a direct reading scale calibrated in percent of combustible gas. Ordinarily, the nitrogen cap in a transformer will have less than one-half percent combustible content. As a problem develops over a period of time, the combustible content can rise to 10 or 15 percent. A suggested evaluation of the test results is as shown in Table 9.2.9.3.

9.2.9.4 Dissolved-Gas-in-Oil Analysis. A refinement of the fault-gas analysis is the dissolved-gas-in-oil test. *(See ASTM D 3612, Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography.)* In this test, an oil sample is withdrawn from the transformer, and the dissolved gases are extracted from the oil. A portion of the gases are then subjected to chromatographic analysis. This analysis determines the exact gases present and the amount of each. Different types of incipient faults have different patterns of gas evolution. With this test, the nature of the problems can often be diagnosed. *(See ANSI/IEEE C57.104, Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers.)*

Table 9.2.9.3 Sample Test Results Evaluation

Percentage of Combustible Gas	Gas Evaluation
0.0 to 1.0	No reason for concern. Make tests at regularly scheduled intervals.
1.0 to 2.0	Indication of contamination or slight incipient fault. Make more frequent readings and watch trends.
2.0 to 5.0	Begin more frequent readings immediately. Prepare to investigate cause by internal inspection.
over 5.0	Remove transformers from service and make internal inspection.

9.3 Dry-Type Transformers.

9.3.1 Introduction.

9.3.1.1 Dry-type transformers operate in air or gas rather than being liquid filled. The two general types of construction are the open or ventilated dry-type transformer and the sealed or closed tank type. Dry transformers are usually varnish impregnated or cast coil construction. Sealed transformers are cooled and insulated by a high-dielectric inert gas, such as nitrogen, sulfur hexafluoride, or perfluoropropane.

9.3.1.2 The air or gas serves as an insulating medium and also to dissipate heat from the windings. Standard insulation classes are 80°C (176°F) rise, 115°C (239°F) rise, and 150°C (302°F) rise.

9.3.2 Regular Inspections. The recommendations in 9.2.2 regarding regular inspections of liquid-filled transformers also apply to dry-type transformers, with the exception of those that obviously pertain strictly to liquid-filled construction.

9.3.3 Current and Voltage Readings. The recommendations in 9.2.3 regarding current and voltage readings also apply to dry-type transformers.

9.3.4 Temperature Readings. The recommendations in 9.2.4 regarding temperature readings also apply to dry-type transformers. However, dry-type transformers usually have high-temperature insulation and might operate at higher temperatures than liquid-filled units.

9.3.5 Pressure/Vacuum Gauge.

9.3.5.1 Sealed dry-type transformers are usually equipped with pressure/vacuum gauges. The gauge should be read periodically and the readings recorded. The readings should be compared to the manufacturer's recommended normal operating range. Lower-than-normal or zero readings are an indication of a leak in the tank. If the leak is not severe, it might be desirable to periodically replace the gas or recharge the transformer instead of locating and sealing the leak. The replacement gas should be either the same as the original or an approved substitute. *(See 9.3.7 for recommendations covering severe leaks.)*

9.3.5.2 High pressures are an indication of electrical overload or internal trouble; they should be investigated immediately, and corrective action should be taken. Excessive pressure can result in distortion or rupture of the tank.

9.3.6 Miscellaneous. The louvers in the enclosures of ventilated dry-type transformers should be inspected to see that they are not clogged with dirt or otherwise obstructed. Also, the operation of integral ventilating fans should be checked. Dry-type transformers are usually installed indoors and sometimes in a vault. The temperature of the vault or room should be measured regularly and recorded. Proper ventilation is essential to the operation of a transformer. Any material or obstruction that might prevent the free circulation of air around a transformer should be removed. If the room or vault has power-driven ventilating fans, their correct operation [air velocity should not exceed 122 m/min (400 ft/min)] should be determined and overtemperature alarms, if provided, should be tested. Corrosion of the transformer enclosure, the intrusion of dirt, as well as evidence of water leaks into the room or vault, should also be carefully checked and corrective measures taken as required. A high noise level or change in level could indicate improper installation or loose windings or barriers.

9.3.7 Special Inspections and Repairs.

9.3.7.1 When a transformer is given an external visual examination, the transformer case should be regarded as energized until the case-ground connection is inspected and found to be adequate. If any procedure more extensive than an external visual examination is to be performed, the first precaution that should always be observed is to de-energize the transformer. De-energization should be accompanied by approved positive lockout procedures to ensure against an unplanned re-energization and resulting hazard to personnel or equipment. De-energization should be followed immediately by a test to ensure that the equipment is de-energized. The equipment should be grounded prior to the start of any work. *(See Chapter 23.)*

9.3.7.2 Enclosure covers of ventilated dry-type transformers should be removed carefully. An inspection for the following problems should be made:

(1) Accumulations of dirt on windings, insulators, and where cooling airflow might be restricted
(2) Discoloration caused by overheating
(3) Tracking and carbonization
(4) Cracked or chipped insulators
(5) Loose insulators, clamps, or coil spacers
(6) Deterioration of barriers
(7) Corroded or loose electrical connections.

9.3.7.2.1 In addition, the equipment ground should be inspected for corrosion or loose connections. A grounding-electrode resistance test should be made, as covered in Section 20.15.

9.3.7.3 Dirt and dust should be cleaned from the windings with a vacuum cleaner. After vacuum cleaning, compressed air can be used, only if it is clean and dry and applied at a low pressure to avoid damage to windings. In particular, ventilating ducts and the top and bottom of the windings should be cleaned. The use of liquid cleaners should be employed only when it is known that they will not have a deteriorating effect on the insulation.

9.3.7.4 Best service life will result if the windings are maintained above the ambient-temperature level. For this reason, transformers operating in high humidity should be kept energized, if feasible. If a transformer is to be de-energized long enough for it to cool, special drying procedures might be necessary before the transformer is re-energized. Refer to the manufacturers' recommendations for drying procedures to be followed.

9.3.7.5 Sealing severe leaks or opening and resealing the tanks of sealed dry-type transformers requires special procedures and equipment. The manufacturer of the transformer, an experienced transformer repair facility, or a qualified electrical maintenance contractor should perform this work. In addition, special procedures covering drying out of the windings, plus purging and refilling of the tank, might be necessary.

9.3.8 Insulation Tests. The insulation tests covered in 9.2.9.1 and 9.2.9.2 can also be applied to dry-type transformers.

Chapter 10 Power Cables

10.1 Introduction. Preventive maintenance is the best way to ensure continued reliable service from electrical cable installations. Visual inspection and electrical testing of the insulation are the major maintenance procedures. However, it should be stressed that no amount of maintenance can correct improper application or physical damage done during installation.

10.2 Visual Inspection.

10.2.1 If, in addition to the visual inspection, cables are to be touched or moved, they should be de-energized.

10.2.2 Cables in manholes should be inspected for sharp bends, physical damage, excessive tension, oil leaks, pits, cable movement, insulation swelling, soft spots, cracked jackets in nonlead cables, damaged fireproofing, poor ground connections, deterioration of metallic sheath bonding, as well as corroded and weakened cable supports and the continuity of any main grounding system. Terminations and splices of nonlead cables should be squeezed in search of soft spots and inspected for tracking or signs of corona. The ground braid should be inspected for corrosion and tight connections. The bottom surface of the cable should be inspected for wear or scraping, due to movement, at the point of entrance into the manhole and also where it rests on the cable supports.

10.2.3 The manhole should be inspected for spalling concrete or deterioration of the aboveground portion. In some instances, the manhole can be equipped with drains, and these might require cleaning. In some instances, it might be necessary to pump water from the manhole prior to entrance. Do not enter a manhole unless a test for dangerous gas has been made and adequate ventilation is provided. The inspection crew should always consist of two or more persons with at least one remaining outside of the manhole. *(See OSHA 29 CFR 1910.146, for confined space entry and Part 7 1910.269(e) for enclosed space entry.)*

10.2.4 Potheads should be inspected for oil or compound leaks and cracked or chipped porcelain. The porcelain surfaces should be cleaned and, if the connections are exposed, their tightness should be checked.

10.2.5 Cable identification tags or marking should be checked.

10.2.6 Since inspection intervals are normally one year or more, comprehensive records are an important part of any maintenance program. Comprehensive records should be arranged to facilitate comparison from year to year.

10.3 Aerial Installations. Aerial cable installations should be inspected for mechanical damage due to vibration, deteriorating supports, or suspension systems. Special attention should be given to the dead-end supports to ensure that the cable insulation is not abraded, pinched, or bent too sharply. Terminations should be inspected as covered in 10.2.2.

10.4 Raceway Installations. Since the raceway is the primary mechanical support for the cable, it should be inspected for signs of deterioration or mechanical damage or if the cable jacket is being abraded or mechanically damaged. In many installations, the raceway serves as a part of the ground-fault current circuit. Joints should be inspected for signs of looseness or corrosion that could result in a high resistance. The other recommendations for splices and terminations covered in 10.2.2 should also apply in this section.

10.5 Testing. *(See Chapter 20.)* The two most commonly used tests for cable insulation are insulation resistance testing and dc over-potential testing. Other tests are listed in ANSI/IEEE 62, *Guide for Diagnostic Field Testing of Electric Power Apparatus.*

Chapter 11 Motor Control Equipment

11.1 Introduction.

11.1.1 There are many varieties of motor controllers, motor control centers, switchboards and power panels. Following are some of the more common motor starters:

(1) Manual across-the-line starters
(2) Magnetic across-the-line starters
(3) Combination starters
  (a) Breaker-protected starters
  (b) Fuse-protected starters
  (c) Fused breaker-protected starters
(4) Reduced voltage starters
  (a) Autotransformer starters
  (b) Resistance starters
  (c) Part-winding starters
  (d) Wye-delta starters
  (e) Solid-state starters
(5) Two-speed starters
(6) Starters and speed regulators for AC wound rotor and DC motors
(7) Adjustable speed/frequency starters
(8) Miscellaneous types
  (a) Reversing starter
  (b) Motor control center

11.1.2 These maintenance recommendations are general in nature and can be adapted to a wide variety of product types.

11.2 Components and Maintenance of Motor Controls. Motor control equipment should be inspected and serviced simultaneously with the motors. As a general rule, overhaul procedures for control equipment are less involved than motor overhauling. Most repairs can be made on-site. Motor starters represent one area in which the manufacturers have emphasized simplicity of construction and wiring. Improvements have resulted in starters that are simple to install, maintain, and operate. Connections are readily accessible. Some parts are of plug-in type and can be easily replaced. Coils are often encapsulated in epoxy compounds and are less likely to burn out. Practically all newer starters have provisions for adding several auxiliary contacts with very little effort. Spare parts for starters are usually available from local suppliers. Spare starters, as well as spare parts, for the most used types and sizes should be stocked in the regular shop supply channels.

11.2.1 See Table 11.2.1 for motor control equipment troubleshooting guidance.

11.2.2 Table 11.2.2 provides motor control preventive maintenance and guidance.

Table 11.2.1 Motor Control Equipment Troubleshooting Chart

Cause	Remedy
(1) Contactor or relay does not close.	
No supply voltage.	Check fuses and disconnect switches.
Low voltage.	Check power supply. Wire may be too small.
Coil open or shorted.	Replace.
Wrong coil.	Check coil number.
Mechanical obstruction.	With power off, check for free movement of contact and armature assembly.
Pushbutton contacts not making.	Clean or replace if badly worn.
Interlock or relay contact not making.	Adjust or replace if badly worn.
Loose connection.	Turn power off first, then check the circuit visually with a flashlight.
Overload relay contact open.	Reset.
(2) Contactor or relay does not open.	
Pushbutton not connected correctly.	Check connections with wiring diagram.
Shim in magnetic circuit (DC only) worn, allowing residual magnetism to hold armature closed.	Replace.
Interlock or relay contact not opening circuit.	Adjust contact travel.
"Sneak"circuit.	Check control wiring for insulation failure.
Gummy substance on pole faces.	Clean with solvent.
Worn or rusted parts causing burning.	Replace parts.
Contacts weld shut.	See Item 3.
(3) Contacts weld shut or freeze.	
Insufficient contact spring pressure causing contacts to burn and draw arc on closing.	Adjust, increasing pressure. Replace if necessary.
Very rough contact surface causing current to be carried by too small an area.	Smooth surface or replace if badly worn.
Abnormal inrush of current.	Use larger contactor or check for grounds, shorts, or excessive motor load current.
Rapid jogging.	Install larger device rated for jogging service or caution operator.
Low voltage preventing magnet from sealing.	Correct voltage condition. Check momentary voltage dip during starting.
Foreign matter preventing contacts from closing.	Clean contacts with approved solvent.
Short circuit.	Remove short-circuit fault and check to be sure fuse or breaker size is correct.
(4) Contact chatter.	
Broken pole shader.	Replace.
Poor contact in control circuit.	Improve contact or use holding circuit interlock (3-wire control).
Low voltage.	Correct voltage condition. Check voltage condition. Check momentary voltage dip during starting.
(5) Arc lingers across contacts.	
If blowout is series, it might be shorted.	Check wiring diagram to see kind of blowout.
If blowout is shunt, it might be open circuited.	Check wiring diagram through blowout.
Arc box might be left off or not in correct place.	See that arc box is on contactor as it should be.
If no blowout used, note travel of contacts.	Increasing travel of contacts increases rupturing capacity.

Table 11.2.1 ***Continued***

Cause	Remedy
(6) Excessive corrosion of contacts.	
Chattering of contacts as a result of vibration outside the control cabinet.	Check control spring pressure and replace spring if it does not give rated pressure. If this does not help, move control so vibrations are decreased.
High contact resistance because of insufficient contact spring pressure.	Replace contact spring.
(7) Abnormally short coil life.	
High voltage.	Check supply voltage and rating of controller.
Gap in magnetic circuit (alternating current only).	Check travel of armature. Adjust so magnetic circuit is completed.
Ambient temperature too high.	Check rating of contact. Get coil of higher ambient rating from manufacturer, if necessary.
Filing or dressing.	Do not file silver-faced contacts. Rough spots or discoloration will not harm contacts.
Interrupting excessively high currents.	Install larger device or check for grounds, shorts, or excessive motor currents. Use silver-faced contacts.
Excessive jogging.	Install larger device rated for jogging or caution operator.
Weak contact pressure.	Adjust or replace contact springs.
Dirt on contact surface.	Clean contact surface.
Short-circuits.	Remove short-circuit fault and check for proper fuse or breaker size.
Loose connections.	Clean and tighten.
Sustained overload.	Install larger device or check for excessive load current.
(8) Panel and apparatus burned by heat from resistor.	
Motor being started frequently.	Use resistor of higher rating.
(9) Coil overheating.	
Overheating or high ambient temperature.	Check application and circuit.
Incorrect coil.	Check rating and replace with proper coil if incorrect.
Shorted turns caused by mechanical damage or corrosion.	Replace coil.
Undervoltage, failure of magnet to seal in.	Correct pole faces.
Dirt or rust on pole faces increasing air gap.	Clean pole faces.
(10) Overload relays tripping.	
Sustained overload.	Check for grounds, shorts, or excessive motor currents.
Loose connection on load wires.	Clean and tighten.
Incorrect heater.	Relay should be replaced with correct size heater unit.
(11) Overload relay fails to trip.	
Mechanical binding, dirt, corrosion, etc.	Clean or replace.
Wrong heater or heaters omitted and jumper wires used.	Check ratings. Apply proper heaters.
Motor and relay in different temperatures.	Adjust relay rating accordingly or make temperature the same for both.
(12) Noisy magnet (humming).	
Broken shading coil.	Replace shading coil.
Magnet faces not mating.	Replace magnet assembly or realign.
Dirt or rust on magnet faces.	Clean and realign.
Low voltage.	Check system voltage and voltage dips during starting.

Table 11.2.2 Motor Control Preventive Maintenance Guide

What to Inspect	What to Inspect For
(1) Exterior and surroundings	Dust, grease, oil; high temperature; rust and corrosion; mechanical damage; condition of gaskets, if any.
(2) Interior of enclosure, nuts, and bolts	Same as for No. 1 plus excess vibration, which may have loosened nuts, bolts, or other mechanical connections.
(3) Contactors, relays, solenoids	
(a) General	Check control circuit voltage; inspect for excess heating of parts evidenced by discoloration of metal, charred insulation or odor; freedom of moving parts; dust, grease, and corrosion; loose connections.
(b) Contact tips	Check for excessive pitting, roughness, copper oxide; do not file silver contacts.
(c) Springs	Check contact pressure; is pressure same on all tips?
(d) Flexible leads	Look for frayed or broken strands; be sure lead is flexible — not brittle.
(e) Arc chutes	Check for breaks or burning.
(f) Bearings	Check for freedom of movement; do not oil.
(g) Coils	Look for overheating, charred insulation, or mechanical injury.
(h) Magnets	Clean faces; check shading coil; inspect for misalignment, bonding.
(4) Fuses and fuse clips	Check for proper rating, snug fit; if copper, polish ferrules; check fuseclip pressure.
(5) Overload relays	Check for proper heater size; trip by hand; check heater coil and connection; inspect for dirt, corrosion.
(6) Pushbutton station and pilot devices	Check contacts; inspect for grease and corrosion.
(7) Dashpot-type timers and overload relays	Check for freedom of movement; check oil level.
(8) Resistors	Check for signs of overheating, loose connections; tighten sliders.
(9) Connections	Tighten main line and control conductor connections; look for discoloration of current-carrying parts.
(10) Control operation	Check sequence of operation of control relays; check relay contacts for sparking on operation; check contacts for flash when closing; if so, adjust to eliminate contact bounce; check light switches, pressure switches, temperature switches, and other sensing devices.

11.3 Enclosures.

11.3.1 External Care.

11.3.1.1 An enclosure located in a clean, dry, and noncorrosive atmosphere, and where it is not likely to incur physical damage, does not require scheduled maintenance. However, internal components should be inspected and serviced as necessary.

11.3.1.2 Enclosures in a marginal atmosphere should be inspected periodically for excessive dust and dirt accumulation as well as corrosive conditions. The more contaminated the atmosphere, the more frequently the inspections should be conducted. Any accumulation should be removed with a vacuum cleaner or manually during equipment maintenance shutdown periods.

11.3.1.3 Badly corroded enclosures should be properly cleaned and refinished, or replaced.

11.3.2 Opening Enclosures. Compliance with Section 7.3 is essential before opening the door or cover of a cabinet or enclosure. Foreign material, dirt, hardware, and debris should be removed from the outside top surfaces to avoid the risk of anything falling into the equipment.

11.3.3 Internal Inspection. Upon opening the cabinet or enclosure, equipment should be inspected for any dust, dirt, moisture or evidence of moisture, or other contamination. If any is found, the cause should be eliminated. Internal contamination could indicate an incorrectly selected, deteriorated, or damaged enclosure; unsealed enclosure openings; internal condensation; condensate from an unsealed conduit; or improper operating procedures (for example, operating with enclosure door or cover open).

11.3.3.1 Ventilation passages should be checked for obstructions.

11.3.3.2 If equipment depends on auxiliary cooling or heating, the temperature control system should be checked and repaired if necessary to ensure proper functioning.

11.3.4 Internal Environment. If a cooling, heating, or air-conditioning system is installed to maintain a safe environment inside an enclosure, it should be verified that the system functions as designed. As appropriate, air temperatures, air pressures, air quality, heat exchanges, fans, pumps, filters, and power supplies should be checked. For instance, a compressed air cooling system might be installed on a cabinet to provide a positive pressure enclosed environment, component cooling, and continual fresh air purging. A simple, periodic check of the filter, exhaust port opening, and the air supply helps determine that heat from normal operations is satisfactorily and reliably dissipated, and that a clean, dry atmosphere is being maintained in the enclosure.

11.3.5 Cleaning. Cleaning should be done in accordance with the appropriate recommendations of Section 7.6, Equipment Cleaning.

11.4 Bus Bar, Wiring, and Terminal Connections.

11.4.1 Introduction. Any loose bus bar or terminal connection will cause overheating that will lead to equipment malfunction or failure. Loose bonding or grounding can compromise safety and function. Overheating in a bus or terminal connection will cause a discoloration in the bus bar, which can easily be spotted where connections are visible, oftentimes too late to avoid replacement. An overheating bus bar condition will feed on itself and eventually lead to deterioration of the bus system as well as the equipment connected to the bus, such as protective devices, bus stabs, and insulated leads. Aluminum connections usually utilize plated parts that should not be cleaned with abrasives.

11.4.2 Loose Connections. Bus bar and terminal connections should be inspected periodically to ensure that all joints are properly tightened. Proper torque is a function of bolt size, bolt type, terminal material, washer type, and type of bus bar. Proper bolt torque values for all types of joints involved should be available in manufacturers' maintenance and instructional literature. It should not be assumed that bus bar and terminal hardware, once tightened to proper torque values, remains tight indefinitely. *(See Section 20.17, which describes one method of detecting loose connections during the periods between shutdowns.)*

11.4.3 Special Operating Environments. Special attention should be given to bus bars and terminal connections in equipment rooms where excessive vibration or heating/cooling cycles can cause more than normal loosening of bolted bus and terminal connections.

11.4.4 Bus Bar Support Insulators. Bus bar support insulators and barriers should be inspected to ensure that they are free of contamination. Insulators should be checked periodically for cracks and signs of arc tracking. Defective units should be replaced. Loose mounting hardware should be tightened.

11.4.5 Power and Control Wiring. Insulation on conductors should be examined for overheating or chafing that could progress into an insulation failure. Damaged conductors should be replaced. Replacement conductors should be rerouted, braced, or shielded as needed to avoid similar damage in future operation. Temporary wiring should be removed or replaced by permanent wiring.

11.5 Disconnects.

11.5.1 Introduction. Disconnects should be examined on both the line and load side for proper maintenance evaluation. Prior to initiating such an evaluation, the source side disconnect device should be opened and padlocked and tagged to avoid accidental energization by other personnel during maintenance operations. Items that can cause a load side voltage, such as an alternate power source or a charged capacitor, should be disconnected or discharged.

11.5.1.1 Switches used in draw-out units normally supplied in motor control centers can be opened and safely withdrawn and examined on a workbench, thus avoiding this potential hazard.

11.5.2 Safety. It should never be assumed that a disconnect is in the open position because the handle mechanism is in the open position. Always double check for safety. Compliance with Section 7.3 is essential.

11.5.3 Inspection and Cleaning. Routine maintenance should include a procedure for inspecting and removing excessive dust accumulations. *(See Section 7.6.)*

11.5.4 Loose Connections. Loose connections are the major source of excessive heat, which can lead to deterioration of the insulation and eventual failure of the device. Terminal and bus bar connections as well as cable connections should be examined and tightened as required using the manufacturer's torque recommendations. Any device that has evidence of overheated conductors and carbonized insulation should be repaired or replaced. Disconnects showing any evidence of damage and contacts showing evidence of welding or excessive pitting should be repaired or replaced.

11.5.5 Mechanical Operation. Mechanisms should be operated manually to ensure proper working condition. Factory-lubricated mechanisms will sometimes dry out after a period of time in dry, heated atmospheres as in motor control center enclosures. Manufacturers' maintenance literature should be followed for proper lubrication instructions.

11.6 Molded Case Breakers. A wide variety of circuit breakers are used with motor control equipment. Molded case breaker maintenance is covered in Chapter 13.

11.7 Fuses. Fuses are normally used in conjunction with disconnect switches. A dummy fuse, copper slug, or length of wire should never be used as a fuse substitute. Fuse and fuseholder maintenance is covered in Chapter 15.

11.8 Contactors.

11.8.1 Introduction. Because contactors are the working portion of a motor controller, normal wear can be expected.

11.8.2 Contacts and Arc Chutes.

11.8.2.1 Inspection. Contacts and arc chutes of electromechanical contactors should be checked for excessive burning, beads of molten material, and unusual erosion of the contact faces.

11.8.2.2 Servicing. Excessively worn or pitted contacts should be replaced with manufacturer-recommended renewal parts, or the contactor should be replaced. All contacts of multipole devices should be replaced simultaneously to avoid misalignment and uneven contact pressure. Contacts should not be filed or dressed unless recommended by the manufacturer.

11.8.2.2.1 Arc chutes and arc hoods should be replaced if they are broken or deeply eroded.

11.8.2.2.2 Easily dislodged dust or granules should be removed by vacuuming, wiping, or light brushing. Insulating surfaces should not be scraped, sandpapered, or filed.

11.8.3 Alternating Current (ac) Magnet Solenoids. A noisy solenoid in a relay or contactor indicates failure to seat properly or a broken or loose shading coil. The cause should be determined and corrected to avoid overheating and coil damage. If a coil exhibits evidence of overheating (cracked, melted, or burned insulation), it should be replaced, after the cause of overheating has been detected and corrected. This could include the ac magnet symptoms described above, binding that keeps the magnet from seating properly, and overvoltage and undervoltage conditions. If melted coil insulation has flowed onto other parts, they should be cleaned or replaced.

11.9 Motor Overload Relays — Thermal Types.

11.9.1 Introduction. Motor overload relays perform the vital supervisory function of monitoring the overload current conditions of the associated motor. The most commonly used overload relays employ a thermal element designed to interpret the overheating condition in the motor windings by converting the current in the motor leads to heat in the overload relay element. As the heat in the thermal element reaches a predetermined amount, the control circuit to the magnetic contactor holding coil is interrupted and the motor branch circuit is opened. The two most common types of thermal elements in overload relays employ either a bimetal or a melting alloy joint to initiate the opening action of the contactor.

11.9.1.1 Overload relays that trip during operation are usually resettable. The cause of the trip should be identified before resetting. Some overload relays are adjustable.

11.9.1.2 Failure of the thermal element can occur when subjected to short-circuit conditions. The cause should be identified and corrected.

11.9.1.3 Replacement or adjustment of the heater element to a higher rating should not be done without full consideration of the ambient temperatures in which the motor and controller operate, as well as all of the factors in 11.9.3.

11.9.2 Other Types. The manufacturers' literature should be consulted for maintenance of other types of overload devices.

11.9.3 Motor Data. Overload thermal elements are applied on the basis of motor full-load current and the motor service factor found on the motor rating nameplate. Complete records on all motors, including motor full-load amps together with proper manufacturer's heater selection and application charts, should be included as a part of any maintenance file on motor starters. General heater application charts are usually secured inside the starter enclosure.

11.9.4 Inspection and Replacement. Routine maintenance should include a check for loose terminal or heater connections and signs of overheating. Overheating can cause carbonization of the molding material, creating potential dielectric breakdowns as well as possibly altering the calibration of the overload relay. Overload elements can be tested with primary injection current and compared to the manufacturer's curve for performance. Overload elements operating outside the manufacturer's curve or showing signs of excessive heating should be replaced.

11.10 Pilot and Miscellaneous Control Devices.

11.10.1 Introduction. Pilot and other control devices consist of the control accessories normally employed with motor starters, such as push buttons, selector switches, indicating lights, timers, and auxiliary relays.

11.10.2 Inspection. Routine maintenance checks on these types of devices should generally include the following:

(1) Check for loose connections
(2) Check for proper mechanical operation of operators and contact blocks
(3) Inspection of contacts (when exposed)
(4) Check for signs of overheating
(5) Replacement of pilot lamps

11.11 Interlocks.

11.11.1 Electrical Interlocks.

11.11.1.1 A contactor or starter could be provided with auxiliary contacts that permit interlocking with other devices.

11.11.1.2 Inspection. Proper maintenance of these electrical auxiliary contacts should include the following:

(1) Check for loose connections
(2) Check for proper mechanical operation and alignment with the contactor
(3) Inspection of contacts (when exposed)

11.11.2 Mechanical Interlocks. Mechanical interlocks can be classified into two categories according to their application: safety and functional performance. Safety interlocks are designed to protect operating personnel by preventing accidental contact with energized conductors and the hazards of electrical shock. Functional interlocks, such as those found on reversing contactors, are designed to prevent the inadvertent closing of parallel contactors wired to provide alternate motor operating conditions. A mechanical interlock should be examined to ensure that the interlock is free to operate and that bearing surfaces are free to perform their intended function. Interlocks showing signs of excessive wear and deformation should be replaced. Several types of locking or interlocking features are used, including the following.

(A) Primary Disconnect Mechanism. This device is usually mounted directly on the disconnect device. It is mechanically interlocked with the door to ensure that the door is held closed with the disconnect in the "on" position. A maintenance check should be made to ensure that the adjustment is correct and that the interlock is providing proper engagement.

(B) Padlock Mechanism. Disconnect operating mechanisms are usually provided with padlocking means whereby the mechanism can be padlocked "off." During maintenance checks of the equipment and the motor, these mechanisms should be padlocked in the "off" position for personnel safety.

(C) Defeat Mechanisms. Most disconnects are equipped with defeater mechanisms that can be operated to release door interlock mechanisms with the disconnect device in the "on" position. The use of this release mechanism should be limited to qualified maintenance and operating personnel.

(D) Unit Lock. Motor control centers can be provided with plug-in starters for ease of inspection and interchangeability. Plug-in motor-starter units are normally held locked in their connected positions by a unit latch assembly. Maintenance on this assembly is not normally required but should be understood by maintenance personnel.

Chapter 12 Electronic Equipment

12.1 Introduction. This chapter describes the maintenance of electronic equipment in general terms. Specific maintenance procedures normally are available from the equipment manufacturer or are contained in the instruction book supplied with the apparatus. In some cases, these procedures require the services of trained specialists.

12.2 Reasons for Maintenance.

12.2.1 Maintenance procedures are designed to provide the following:

(1) Protect the equipment from adverse effects of heat, dust, moisture, and other contaminants
(2) Maintain top reliability and minimize costly downtime
(3) Prolong the useful life of the equipment
(4) Recognize incipient problems and take corrective action

12.2.2 The importance of maintenance cannot be overemphasized. Equipment should be kept operating efficiently to contribute to the success of the process or operation in which the equipment is used. Apparatus that is improperly maintained can become unreliable.

12.2.3 Persons charged with maintenance responsibility should have a keen appreciation as to why the work is required and the importance of even routine aspects of maintenance to the overall performance of the equipment.

12.3 Special Precautions.

12.3.1 Special safety precautions should be observed before and during the preventive maintenance operation. Extreme care should be taken to ensure that all power is removed from the apparatus before servicing. To prevent accidental shock from stored energy in capacitors, they should be discharged in accordance with the equipment manufacturer's instructions. Capacitors having high stored energy can be lethal or could be damaged by the application of a direct short circuit. Discharging the capacitor through a resistor followed by a direct short circuit might be required. Connecting charged capacitors to earth ground will not discharge capacitors that are used in circuits that are normally isolated from ground. After power has been removed, parts, such as tubes, resistors, and heat sinks, can remain extremely hot and cause very painful burns.

12.3.2 Occasionally, some equipment requires troubleshooting while the circuits are energized. If so, it should be ensured that the insulation on test equipment leads is fully rated for the operating voltage under test and in good mechanical condition. Special care should be observed when using or servicing equipment that employs the chassis as one side of the circuit. Such equipment can be hazardous in the presence of grounded or some ungrounded 3-phase circuits.

12.3.3 In the absence of other instructions, it should be assumed that all electronic equipment is electrostatic discharge (ESD) sensitive. Industry standard ESD procedures should be followed.

12.4 Preventive Maintenance Operations. Actual work performed during maintenance of electronic equipment should include the following operations:

(1) Inspection
(2) Cleaning
(3) Adjustments
(4) Testing
(5) Servicing

12.4.1 Inspection. Inspection is most important in the maintenance program. Slight abnormalities might not immediately interfere with the equipment performances, but deviations from normal should be discovered early. Time and effort can be saved if defects are corrected before they lead to major breakdowns. Inspections consist of careful observation of all parts of equipment, noticing their color, placement, state of cleanliness, and so on. Inspection should be made for conditions such as the following:

(1) Overheating — indicated by discoloration or other visual characteristics. Infrared inspection can reveal abnormal temperatures and possible problem areas and should be performed in accordance with 20.17.
(2) Placement — Leads and cable clearances, rub points, and so on should be observed.
(3) Cleanliness — Recesses should be examined for accumulation of dust, especially between connecting terminals. Parts, connections, and joints should be free of dust, corrosion, and other foreign material.
(4) Tightness — Soldered or screw terminal connections and mountings should be tested by slightly pulling on the wire or feeling the lug or terminal screw. Printed circuit boards should be inspected to determine that they are fully inserted into the edge board connectors. Board locking tabs should also be engaged. Unless connector malfunctions are suspected, routine unplugging and replugging of connectors to verify seating is not recommended, as this can shorten the useful life of the connectors.

(5) Moisture — Look for evidence of moisture or corrosion. Consider a space heater if the surrounding air is repeatedly or continuously high in humidity. If equipped with space heaters, verify their operation.
(6) Blockages — Keep air passages, fans, and ducting clear and clean to prevent overheating. Check fans for proper direction of rotation.

12.4.2 Cleaning. Cleaning the apparatus, both inside and out, is essential for good operation. Dust, and the like, will increase chances of current leakage or flashover with resultant malfunction or damage to critical parts. Any accumulation of dust should be removed with a vacuum cleaner, if possible, or manually cleaned during maintenance shutdown periods. Enclosure filters should be cleaned at regular intervals and replaced when damaged or clogged. Solvents should not be used on printed circuit boards.

12.4.3 Adjustments. Adjustments should be made only when performance indicates that they are required in order to maintain normal operating conditions. Specific adjustments vary with each type of equipment and will be described in the instruction booklets supplied with the apparatus. Equipment calibrations should be scheduled on a routine basis, with the frequency depending on individual operating conditions particular to the process or equipment.

12.4.4 Testing. Reference to manufacturers' instructions is recommended.

12.4.5 Servicing. Necessary replacements should be made only at the printed circuit board or plug-in component level unless otherwise recommended by the equipment manufacturer. Manufacturers' recommendations should be followed for removal, handling, packaging, shipping, and replacement of such components or modules. Unnecessary strains on wires, cables, and connections should be avoided.

Chapter 13 Molded-Case Circuit-Breaker Power Panels

13.1 Introduction.

13.1.1 A molded-case circuit breaker consists of two basic parts. One part consists of the current-carrying conductors, contacts, and appropriate operating mechanism necessary to perform the circuit-switching functions. The second part consists of the protective element, including the tripping mechanism associated therewith.

13.1.2 Molded-case circuit breakers undergo extensive production testing and calibration at the manufacturers' plants. These tests are based on UL 489, *Standard for Safety, Molded-Case Circuit Breakers, Molded-Case Switches and Circuit Breaker Enclosures*. Circuit breakers carrying the UL label have factory-sealed, calibrated elements; an unbroken seal ensures that the mechanism has not been subjected to alteration or tampering and that the breaker can be expected to perform according to UL specifications. A broken seal voids the UL label and jeopardizes the manufacturer's warranty.

13.2 Application Considerations. Molded-case circuit breakers will trip from exposure to continuous currents beyond their ratings, and many trip from unduly high ambient temperatures, from poor or improper connections, from damaged plug-in members, and from other conditions that transfer undue heat to the breaker mechanism. Some of these conditions violate application specifications. A molded-case circuit breaker applied in a panelboard should not be loaded in excess of 80 percent of its continuous current rating, where in normal operation the load will continue for three hours or more.

13.3 Phase-Fault Current Conditions. A typical molded-case circuit breaker is equipped with both time-delay and instantaneous tripping devices. Time-delay tripping has inverse time characteristics that provide a shorter tripping time for higher overloads. Under moderate, short-duration overloads, the circuit breaker allows sufficient time for applications such as motor starting. Under severe overloads, the circuit breaker will trip quickly, providing adequate protection for conductors and insulation. For high-fault currents, the magnetic tripping device responds to open the circuit breaker immediately.

13.4 Ground-Fault Tripping. It should be recognized that standard molded-case circuit breakers are not generally equipped with ground-fault sensing and protection devices and, therefore, will not normally trip and clear low-level ground faults that can do immense damage. Special ground-fault sensing and protective devices should be specified to achieve this type of equipment protection where necessary. *(See Section 14.3.)*

13.5 Types of Molded-Case Circuit Breakers.

13.5.1 Molded-case circuit breakers can generally be divided into three major categories depending on the type of trip unit employed:

(1) Factory sealed, noninterchangeable trip
(2) Interchangeable trip
(3) Solid state

13.5.2 The most common type of trip unit under (1) and (2) is the standard time-limit or thermal-magnetic trip. This type of trip unit employs a thermal element to provide inverse characteristics giving overload protection and a magnetic circuit to provide short-circuit protection. Another common type of trip under type (1) is the hydraulic-magnetic trip, where a dashpot is used to achieve the inverse time delay. These functions are accomplished with the use of solid-state circuitry in type (3), as well as other functions including ground-fault protection not normally available as an integral part of breakers under types (1) and (2).

13.6 Special-Purpose Breakers. A special design of an instantaneous-only circuit breaker having an adjustable instantaneous pickup is utilized in motor-circuit protection schemes.

13.7 Types of Maintenance. Maintenance of molded-case circuit breakers can generally be divided into two categories: mechanical and electrical. Mechanical maintenance consists of inspection involving good housekeeping, maintenance of proper mechanical mounting and electrical connections, and manual operation as outlined in the following paragraphs. Electrical testing under field test conditions is covered in 20.10.2.4.

13.8 Inspection and Cleaning. Molded-case circuit breakers should be kept clean of external contamination so that internal heat can be dissipated normally. Further, a clean case will reduce potential arcing conditions between live conductors, and between live conductors and ground. The structural strength of the case is important in withstanding the stresses imposed during fault-current interruptions. Therefore, an inspection should be made for cracks in the case, and replacements should be made if necessary.

13.9 Loose Connections. Excessive heat in a circuit breaker can cause a malfunction in the form of nuisance tripping and possibly an eventual failure. Loose connections are the most common cause of excessive heat. Periodic maintenance checks should involve checking for loose connections or evidence of overheating. Loose connections should be tightened as required, using manufacturers' recommended torque values. Molded-case circuit breakers having noninterchangeable trip units are properly adjusted, tightened, and sealed at the factory. Those having interchangeable trip units installed away from the factory could overheat if not tightened properly during installation. All connections should be maintained in accordance with manufacturers' recommendations.

13.10 Mechanical Mechanism Exercise. Devices with moving parts require periodic checkups. A molded-case circuit breaker is no exception. It is not unusual for a molded-case circuit breaker to be in service for extended periods and never be called on to perform its overload- or short-circuit-tripping functions. Manual operation of the circuit breaker will help keep the contacts clean, but does not exercise the tripping mechanism. Although manual operations will exercise the breaker mechanism, none of the mechanical linkages in the tripping mechanisms will be moved with this exercise. Some circuit breakers have push-to-trip buttons that should be manually operated in order to exercise the tripping mechanism linkages.

Chapter 14 Ground-Fault Protection

14.1 Introduction. Ground-fault protective devices intended to protect personnel or systems from ground faults are of two distinct types and IT IS EXTREMELY IMPORTANT TO UNDERSTAND THE DIFFERENCE BETWEEN THEM.

14.1.1 Ground-Fault Circuit Interrupter (GFCI). A GFCI is designed to protect a person from electrocution when contact between a live part of the protected circuit and ground causes current to flow through a person's body. A GFCI will disconnect the circuit when a current equal to or higher than the calibration point (4 mA to 6 mA) flows through the protected circuit to ground. It will not eliminate the shock sensation, since normal perception level is approximately 0.5 mA. It will not protect from electrocution on line-to-line contact, since the nature of line-to-line loads cannot be distinguished.

14.1.2 Ground-Fault Protection of Equipment. There are two applications where ground-fault protection of equipment is intended to be used: where there might be excessive ground-fault leakage current from equipment, or when equipment and conductors are to be protected from damage in the event of a higher level ground fault (either solid or arcing). These types of protective equipment are for use only on alternating-current, grounded circuits, and will cause the circuit to be disconnected when a current equal to or higher than its pickup setting or rating flows to ground. They are not designed to protect personnel from electrocution.

14.1.2.1 Equipment ground-fault protective devices are intended to operate upon a condition of excessive ground-fault leakage current from equipment. The ground current pickup level of these devices is from above 6 mA to 50 mA.

14.1.2.2 Circuit breakers with equipment ground-fault protection are combination circuit breaker and equipment ground-fault protective devices designed to serve the dual function of providing overcurrent protection and ground fault protection for equipment. The ground current pickup level of these breakers is typically 30 mA. They are intended to be used in accordance with Articles 426 and 427 of NFPA 70, *National Electrical Code*.

14.1.2.3 Ground-fault sensing and relaying equipment is intended to provide ground-fault protection of equipment at services and feeders. They are rated for ground current pickup levels from 4 amperes to 1200 amperes.

14.2 Definitions. The following list of definitions are in Chapter 3 and are unique to this chapter:

(1) GFCI — Ground-Fault Circuit Interrupter. *(See 3.3.24.)*
(2) GFP — Ground-Fault Protector. *(See 3.3.25.)*

14.3 Ground-Fault Protective Equipment for Excessive Leakage Currents.

14.3.1 Equipment Ground-Fault Protective Devices. These are typically a cord and plug-connected devices. Recommended maintenance will be that specified in Section 18.2 and Section 19.4.

14.3.2 Circuit Breakers with Equipment Ground-Fault Protection. Recommended maintenance is the same as that specified in Chapter 13 for molded-case circuit breakers.

14.3.3 Maintenance.

14.3.3.1 The devices are sealed at the factory, and maintenance should be limited to that recommended as follows or by the manufacturer.

14.3.3.2 In addition to the maintenance specified for the individual types of GFCIs, tripping tests should be performed with the test button on the unit in accordance with the frequency recommended by the manufacturer. Results and dates of tests should be recorded on the test record label or card supplied with each permanently installed GFCI unit.

14.3.3.3 GFCIs are equipped with an integral test means for checking the tripping operation.

14.3.3.4 Separate test instruments are available that can be used for testing and troubleshooting of GFCIs. Such testers should be listed by a nationally recognized testing laboratory to UL 1436, *Outlet Circuit Testers and Similar Indicating Devices.* Separate GFCI test instruments should not be used to test GFCIs protecting 2-wire circuits. Doing so can result in electric shock.

14.3.3.5 When using a separate GFCI test instrument, if the tester indicates "No Trip" and the GFCI integral test button indicates "Trip," the following miswiring scenarios should be investigated:

(1) Line and load wires transposed
(2) Reverse polarity
(3) Open ground

14.3.3.6 Only after ensuring that the GFCI is properly wired should the test result be considered indicative of an improperly functioning GFCI.

14.3.4 GFCI Types. The following are the four types of GFCIs:

(1) Circuit-breaker type
(2) Receptacle type
(3) Portable type
(4) Permanently mounted type

14.3.5 Circuit-Breaker-Type GFCI.

14.3.5.1 A circuit-breaker-type GFCI is designed in the form of a small circuit breaker and is completely self-contained within the unit housing. The circuit-breaker-type GFCI provides overload and short-circuit protection for the circuit conductors in addition to ground-fault protection for personnel. It is intended to be mounted in a panelboard or other enclosure.

14.3.5.2 Recommended maintenance is the same as that specified in Chapter 13 for molded-case circuit breakers.

14.3.6 Receptacle-Type GFCI.

14.3.6.1 A receptacle-type GFCI is designed in the form of a standard receptacle, is completely self-contained within the unit housing, and does not provide overload or short-circuit protection. It is intended for permanent installation in conventional-device outlet boxes or other suitable enclosures.

14.3.6.2 Maintenance required will be the same as that specified in Section 18.3 for standard receptacle outlets.

14.3.7 Portable-Type GFCI.

14.3.7.1 A portable-type GFCI is a unit intended to be easily transported and plugged into a receptacle outlet. Cords, tools, or other devices to be provided with ground-fault protection for personnel are then plugged into receptacles mounted in the unit.

14.3.7.2 Recommended maintenance will be that specified in Section 18.3 for receptacles and in Section 19.4 for connecting cords.

14.3.8 Permanently Mounted-Type GFCI.

14.3.8.1 A permanently mounted-type GFCI is a self-contained, enclosed unit designed to be wall- or pole-mounted and permanently wired into the circuit to be protected.

14.3.8.2 Maintenance beyond tightness of connections and cleanliness should not be attempted. Any repairs needed should be referred to the manufacturer.

14.4 Ground-Fault Protective Equipment to Prevent Damage.

14.4.1 Ground-Fault Sensing and Relaying Equipment. Ground-fault sensing and relaying equipment is used to prevent damage to conductors and equipment. The protective equipment consists of three main components: (1) sensors, (2) relay or control unit, and (3) a tripping means for the disconnect device controlling the protected circuit. Refer to NFPA 70, *National Electrical Code*, for performance testing and record keeping when this equipment is first installed at a site.

14.4.2 Sensing Methods. Detection of ground-fault current is done by either of two basic methods. With one method, ground current flow is detected by sensing current in the grounding conductor. With the other method, all conductor currents are monitored by either a single large sensor or several smaller ones.

14.4.3 Sensors. Sensors are generally a type of current transformer and are installed on the circuit conductors. The relay or control unit can be mounted remote from the sensors or can be integral with the sensor assembly.

14.4.4 Combination Units. Circuit breakers with electronic trip units might have a combination ground-fault sensing and relaying system integral with the circuit breaker. Any maintenance work performed on the electronic circuitry should adhere to manufacturers' instructions. Maintenance on the mechanical operating mechanism components should be done as indicated in Chapter 13.

14.4.5 Maintenance.

14.4.5.1 Maintenance recommendations for the sensors are as specified in 8.9.5.2 for indoor-type instrument transformers. Careful inspection for tight terminal connections and cleanliness should be made.

14.4.5.2 If interconnections between components are disconnected, they should be marked and replaced to maintain the proper phasing and circuitry.

14.4.5.3 A formal program of periodic testing should be established. The manufacturer or NETA *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems,* Section 7.14-1997 should be consulted for test instructions and procedures.

Chapter 15 Fuses

15.1 Fuses Rated 1000 Volts or Less.

15.1.1 Installing and Removing Fuses. Fuseholders should be de-energized before installing or removing fuses. Where it is not feasible or would result in a greater hazard to de-energize fuseholders, installation or removal of fuses should be performed in accordance with appropriate safety-related work practices for the task. (*See 7.3.3.*) *(See NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces.)*

15.1.2 Inspection. Fuse terminals and fuseclips should be examined for discoloration caused by heat from poor contact or corrosion. Early detection of overheating is possible through the use of infrared examination. If evidence of overheating exists, the cause should be determined.

15.1.3 Cleaning and Servicing. The power source to fuseholder should be disconnected before servicing. All fuseholder connections should be tightened. All connections to specifications should be torqued where available. Fuseclips should be checked to be sure that they exert sufficient pressure to maintain good contact. Clips making poor contact should be replaced or clip clamps used. Contact surfaces of fuse terminals and clips that have become corroded or oxidized should be cleaned. Silver-plated surfaces should not be abraded. Contact surfaces should be wiped with a noncorrosive cleaning agent. Fuses showing signs of deterioration, such as discolored or damaged casings or loose terminals, should be replaced.

15.1.4 Replacement. There are many different types of fuses used in power distribution systems and utilization equipment. Fuses differ by performance, characteristics, and physical size. It should be verified that fuses, whether new or replacement, are the proper type and rating. When replacing fuses, fuseholders should never be altered or forced to accept fuses that do not readily fit. An adequate supply of spare fuses with proper ratings, especially those that are uncommon, will minimize replacement problems.

15.1.4.1 Type. The most common fuse classes for 0 ampere through 600 ampere applications on power systems are Class H, K, R, J, T, G, and CC. Class H, K, and R are the same physical size and are interchangeable in standard nonrejection style fuseholders. Special rejection style fuseholders will accept only Class R fuses. Note that Class R fuses are manufactured in two types, Class RK1 and RK5. Class RK1 fuses are more current limiting than Class RK5 fuses and are generally recommended to upgrade older distribution systems. Class L fuses are available in the range of 601 amperes through 6000 amperes. Class J, T, G, CC, and L are size rejection fuses. One type of fuse should never arbitrarily be replaced with a different type simply because it fits into the fuseholder.

15.1.4.2 Ratings. Five characteristics should be considered when replacing fuses: interrupting rating, voltage rating, current rating, degree of time delay, and degree of current limitation.

15.1.4.2.1 Interrupting Rating. Fuses should have an interrupting rating equal to or greater than the maximum fault current available at their point of application. Fuses have interrupting ratings from 10,000 amperes to 300,000 amperes. *(See Section 26.2, and NFPA 70, National Electrical Code.)*

15.1.4.2.2 Voltage. The voltage rating of the fuse should be at least equal to or greater than the system voltage.

15.1.4.2.3 Current. Fuse ampere ratings should be adequate for the applications. Ratings are determined by the service, feeder, and branch-circuit conductors, and the loads served. Consult NFPA 70, *National Electrical Code* and the electrical system single-line diagram for proper fuse sizing. Fuse manufacturers can be contacted for application information.

15.1.4.2.4 Time Delay. Most fuse classes are manufactured in time-delay and non-time-delay versions. Time-delay fuses are especially useful on inductive circuits such as motor and transformer circuits with inrush currents. Time-delay fuses are the most commonly used fuses on power distribution and motor circuits.

15.1.4.2.5 Current Limitation. Fuses are designated as either current-limiting or non-current-limiting based on their speed of response during short-circuit conditions. Non-current-limiting fuses can be replaced with current-limiting fuses, but current-limiting fuses should not be replaced with non-current-limiting fuses unless a review of the specific application is undertaken.

15.1.4.3 Listing. It is important that the fuses bear the listing mark of a nationally recognized testing laboratory. Testing laboratories test fuses for both ac and dc performance characteristics, and the ratings are marked on the fuse label. Be sure to select the proper fuse for the specific application.

15.1.4.4 Special Purpose. Special-purpose fuses are used for supplementary protection of power systems and for utilization equipment such as power rectifiers, variable speed drives, and solid-state controllers. High-speed or semiconductor-type fuses are most commonly used in these applications. These fuses have unique performance characteristics and physical size. They should be matched to the utilization equipment.

15.2 Fuses Rated Over 1000 Volts.

15.2.1 Introduction. Fuses rated over 1000 volts consist of many parts, some current carrying and some non-current carrying, all subject to atmospheric conditions. These fuses can be current limiting or non-current limiting, sand or liquid filled, or vented expulsion type. The frequency of inspection will necessarily be a function of the conditions at a given fuse location and should be determined by the user.

15.2.2 Installing and Removing Fuses. Manufacturers' instructions regarding installing and removing fuses should be followed. If the fuse does not have a loadbreak rating, the system should be de-energized before removing the fuse.

15.2.3 Inspection and Cleaning.

15.2.3.1 The fuse should be disconnected and the mounting de-energized from all power sources before servicing. Insulators should be inspected for breaks, cracks, and burns. The insulators should be cleaned, particularly where abnormal conditions such as salt deposits, cement dust, or acid fumes prevail, to avoid flashover as a result of the accumulation of foreign substances on their surfaces.

15.2.3.2 Contact surfaces should be inspected for pitting, burning, alignment, and pressure. Badly pitted or burned contacts should be replaced.

15.2.3.2.1 The fuse unit or fuse tube and renewable element should be examined for corrosion of the fuse element or connecting conductors, excessive erosion of the inside of the fuse tube, discharge (tracking) and dirt on the outside of the fuse tube, and improper assembly that might prevent proper operation. Fuse tubes or units showing signs of deterioration should be replaced.

15.2.3.3 Bolts, nuts, washers, pins, and terminal connectors should be in place and in good condition. Lock or latch should be checked.

15.2.3.3.1 Fuse tubes made of organic (Class A) material should be refinished as required and specified by the manufacturer.

15.2.3.4 Vented expulsion fuses might be equipped with condensers or mufflers to restrict expulsion of gases during operation. They might have a dropout feature that automatically disengages the fuse when it operates. The lower, or discharge end, of the expulsion fuse might have a sealing disc over the expulsion chamber to prevent entrance of moisture if the fuse is left in an inverted, disconnected position in service. These seals should be inspected to ensure that moisture has not entered the interrupting chamber. If the seals are damaged or show evidence of leakage, the fuses should be replaced.

Chapter 16 Rotating Equipment

16.1 Introduction.

16.1.1 The various classes of rotating equipment have many common features in routine maintenance, both electrical and mechanical. The recommendations that follow are of a general nature and are not intended to cover in detail large or special applications, such as gear pump motors, or those designed for hazardous (classified) locations.

16.1.2 A complete list of the machines in operation, the functions they perform, and the past history of operation form the basis for a schedule of routine maintenance. Frequency of inspection depends on the nature of the service, the hours of operation, and the environment under which the equipment operates. Periodic inspection and appropriate maintenance will assist in making continuous operation of the equipment possible. In some instances, disassembly is necessary for a complete inspection and necessary repairs.

16.2 Safety Precautions. The following safety precautions should be observed:

(1) A machine should be locked out/tagged out before work begins and it should be properly protected against unintentional re-energization.
(2) Personnel protective equipment such as goggles, gloves, aprons, and respirators should be worn when working with solvents.
(3) Great care should be exercised in selecting cleaning agents for any particular task. Be sure to follow all applicable environmental regulations.
(4) Adequate ventilation should be provided to avoid fire, explosion, and health hazards where cleaning agents are used.
(5) A metal nozzle used for spraying flammable cleaning agents should be bonded to the supply drum and to the equipment being sprayed.
(6) Rubber insulating gloves should be used in connecting and operating high-voltage test instruments.
(7) After tests have been made, stored energy should be discharged from windings before test leads are handled.

16.3 Stator and Rotor Windings. The life of a winding depends on keeping it near to its original condition as long as possible. Insulation failure causes immediate outage time. The following points should be carefully examined and corrective action taken during scheduled inspections to prevent operational failures.

16.3.1 Dust and dirt are almost always present in windings that have been in operation under average conditions. Some forms of dust are highly conductive and contribute materially to insulation breakdown as well as by restricting ventilation. (*See 16.6.2 on cleaning.*)

16.3.2 Evidence of moisture, oil, or grease on the winding should be noted and, if necessary, the winding should be cleaned thoroughly with a solvent solution. Generally, after a major cleaning, a drying process is necessary to restore the insulation to a safe level for operation. *(See 16.6.3 on drying.)*

16.3.3 Winding tightness in the slots or on the pole pieces should be checked. One condition that hastens winding failure is movement of the coils due to vibration during operation. The effects of varnishing and oven treatment will serve to fill the air spaces caused by insulation drying and shrinking and will maintain a solid winding.

16.3.4 Insulation surfaces should be checked for cracks, crazing, flaking, powdering, or other evidence of need to renew insulation. Usually, under these conditions, when the winding is still tight in the slots, a coat or two of air-drying varnish can restore the insulation to a safe value.

16.3.5 The winding mechanical supports should be checked for insulation quality and tightness. The ring binding on stator windings and the glass or wire-wound bands on rotating windings should also be checked.

16.3.6 Squirrel-cage rotors should be examined for excessive heating or for discolored or cracked rotor bars, or for cracked end rings that can indicate open circuits or high-resistance points between the end rings and rotor bars. The symptoms of such conditions are slowing down under load and reduced starting torque. Brazing or welding broken bars or replacing bars should be done only by a qualified person or repair shop.

16.4 Brushes, Collector Rings, and Commutators. In general, the machine should be observed while in operation, if possible, and any evidence of maloperation such as sparking, chatter of brushes in the holder, cleanliness, and so on, should be noted as an aid to inspection repairs later.

16.4.1 Brushes. Successful brush operation depends on the proper selection and maintenance of the brush most suitable for the service requirements.

16.4.1.1 Brushes in holders should be checked for fit and free play and those that are worn down almost to the brush rivet should be replaced.

16.4.1.2 Brush studs that might have become loose from the drying and shrinking of insulating washers should be tightened.

16.4.1.3 Brush faces should be examined for chipped toes or heels and for heat cracks. Any that are damaged should be replaced.

16.4.1.4 A check of brush spring pressure should be made using the spring balance method. The spring pressure should be readjusted in accordance with the manufacturers' instructions.

16.4.1.5 The brush shunts should be checked to be sure that they are properly secured to the brushes and holders.

16.4.1.6 In some instances, if changes have occurred in the operation of equipment since installation, it might be necessary to check the following points that would not ordinarily be disturbed:

(1) Brushes should be reset at the correct angle.
(2) Brushes should be reset in the neutral plane.
(3) Brushes should be properly spaced on the commutator.
(4) The brush holders should be correctly staggered.
(5) Brush holders should be properly spaced from the commutator.
(6) A check should be made to ensure that the correct grade of brush as recommended by the manufacturer is being used.

16.4.2 Collector Rings. The surest means of securing satisfactory operation is maintaining the slip-ring surface in a smooth and concentric condition.

16.4.2.1 Insulation resistance should be checked between ring and shaft to detect cracked or defective bushings and collars.

16.4.2.2 A thorough cleaning is usually recommended, using a solvent cleaner and stiff brush.

16.4.2.3 Brush holder end play and staggering should be checked to prevent grooving the rings during operation.

16.4.2.4 When the rings have worn eccentric with the shaft, the ring face should be machined.

16.4.3 Commutators. In general, sources of unsatisfactory commutation are due to either improper assembly of current collecting parts or faulty operating conditions.

16.4.3.1 Commutator concentricity should be checked with a dial gauge if sufficient evidence indicates that the commutator is out of round. A dial indicator reading of 0.001 in. on high-speed machines to several thousandths of an inch on low-speed machines can be considered normal.

16.4.3.2 The commutator surface should be examined for high bars, grooving, evidence of scratches, or roughness. In light cases, the commutator can be hand stoned, but for extreme roughness, turning of the commutator in the lathe is recommended.

16.4.3.3 A check should be made for high or pitted mica, and it should be undercut where deemed advisable.

16.4.3.4 After conditioning a commutator, it should be completely clean, with every trace of copper, carbon, or other dust removed. *(See Westinghouse Electric Corporation reference HB 6001-RS, Electrical Maintenance Hints.)*

16.5 Bearings and Lubrication.

16.5.1 General. The bearings of all electrical equipment should be subjected to careful inspection at scheduled periodic intervals to ensure maximum life. The frequency of inspection is best determined by a study of the particular operating conditions.

16.5.2 Sleeve Bearings.

16.5.2.1 In the older types, the oil should be drained, the bearing flushed, and new oil added at least every year.

16.5.2.2 The new type of sealed sleeve bearings requires very little attention, since oil level is frequently the only check needed for years of service.

16.5.2.3 Waste-packed bearings should be re-oiled every 1000 hours of operation.

16.5.2.4 The air gap should be checked with a feeler gauge to ensure against a worn bearing that might permit the rotor to rub the laminations. On larger machines, a record should be kept of these checks. Four measurements 90 degrees apart should be taken at each bearing location and compared with readings previously recorded to permit early detection of bearing wear.

16.5.2.5 Bearing currents on larger machines are usually eliminated by installing insulation under the pedestals or brackets. Elimination of this circulating current prevents pitting the bearing and shaft. From a maintenance standpoint, a check should be made to be sure that the pedestal insulation is not short-circuited by metal thermostat or thermometer leads or by piping.

16.5.3 Ball Bearings and Roller Bearings.

16.5.3.1 External inspection at the time of greasing will determine whether the bearings are operating quietly and without undue heating.

16.5.3.2 The bearing housings can be opened to check the condition of the bearings and grease. The bearing and housing parts should be thoroughly cleaned and new grease added.

16.5.3.3 Where special instructions regarding the type or quantity of lubricant are recommended by the manufacturer, they should be followed. In all cases, standard greasing practices should be strictly adhered to.

16.5.4 Kingsbury Thrust Bearings. Established lubrication practice for sleeve bearings applies in general for thrust bearings.

16.6 Cleaning and Drying Insulation Structures.

16.6.1 General. Refer to Section 7.6, Equipment Cleaning, for basic recommendations.

16.6.2 Cleaning. The recommended methods for cleaning electrical equipment include the following.

16.6.2.1 Apparatus that has been clogged with mud from dust storms, floods, or other unusual conditions will require a thorough water washing, usually with a hose with pressure not exceeding 1.72 kPa (25 psi). After cleaning, the surface moisture should be removed promptly to keep the amount of water soaked up by the insulation to a minimum.

16.6.2.2 Silicone-treated windings require special treatment, and the manufacturer should be contacted for advice.

16.6.3 Drying. After cleaning, storing, or shipping, apparatus should be dried before being placed in operation if tests indicate that the insulation resistance is below a safe minimum level. Two general methods are commonly used — external or internal heat. External heat is preferred because it is the safer application.

16.6.3.1 Where available, low-pressure steam can be used through radiators or steam pipes placed below the end windings with a temporary built-in enclosure to hold the heat.

16.6.3.2 Forced hot air can be heated electrically, by steam, or by open fire. This method is usually inefficient and costly unless built into the original installation.

16.6.3.3 Electric space heaters or infrared lamps can be used. They should be distributed so as not to overheat the insulation.

16.6.3.4 Coil insulation can be dried by circulating current through the winding. There is some hazard involved with this method because the heat generated in the inner parts is not readily dissipated. This method should be followed only under competent supervision.

16.6.3.5 For synchronous motors, the short-circuit method is sometimes used by shorting the armature windings and driving the rotor, applying sufficient field excitation to give somewhat less than full-load armature current.

16.7 General Overhaul. When indicated by visual inspection or tests, the equipment should be disassembled, and the winding should be cleaned, dried, and re-insulated or dipped and baked, and the bearings checked and relubricated. Rewinding or other repair decisions should be made at this time.

16.8 Methods of Balance. Static imbalance is an imbalance on one side. The solution is either to remove the excess weight or add an equal amount at the opposite side. Small motors can be statically balanced in a test stand with loose bearings or a knife edge. Dynamic balance, also known as two-plane balancing, is typical of cylindrical rotating devices, such as a roller or an electric motor rotor. Dynamic balance requires specialized equipment.

16.9 Records. Sample record forms are shown in Annex F.

16.10 Testing. See Chapter 20 for recommended tests.

Chapter 17 Lighting

17.1 Introduction. A planned maintenance program is an essential part of any initial lighting design and recommendation. The maintenance of lighting systems is aimed at preserving the light-producing capability at the original design level. Dirt and lamp aging are the two major factors that reduce the light output.

17.2 Cleaning.

17.2.1 Lighting equipment — lamps, reflectors, and lenses — should be cleaned periodically. The cleaning interval depends on the amount and type of dirt in the air, although the design of the luminaire will affect the rate at which dust collects. Periodic light meter readings can be taken and cleaning intervals established when the lighting level falls 15 percent to 20 percent, corrected for lamp lumen depreciation (aging).

17.2.1.1 Cleaning can economically be combined with group relamping, although in dirty environments cleaning should also be done between relampings. If spot relamping, the fixtures should be cleaned at relamping, and a separate planned cleaning program should be considered.

17.2.2 Washing is generally better than wiping. The cleaning procedure should be in accordance with the instructions of the luminaire manufacturer. Strong alkaline or abrasive cleaners should be avoided.

17.3 Relamping.

17.3.1 The longer a lamp remains in service, the less light it produces. The different types of lamps — filament, fluorescent, or high-intensity discharge — depreciate at different rates. Since their life expectancy is also different, replacement intervals will vary.

17.3.2 The two general relamping procedures are spot relamping and group relamping. Spot relamping is the replacement of individual lamps as they fail. Group relamping is the replacement of all lamps, at a time typically at 70 to 80 percent of their rated average life, or when the light output falls below the desired level. It is economical to clean the fixtures at the time of replacement. It is also advantageous to inspect the sockets, hangers, reflectors, and lenses at the time of lamp replacement. General replacement recommendations and study results are available from the major lamp manufacturers.

17.3.3 Normally, replacement lamps should be of the same type, color, wattage, and voltage as those being replaced. However, where energy conservation is considered, replacements might warrant appropriate substitutes.

17.3.4 When group relamping, it is appropriate to consider conversion to more energy-efficient lighting. Operating costs can be reduced by a planned conversion to energy-saving lamps or more efficient ballasts. The Energy Policy Act of 1992 eliminated the availability of many full wattage fluorescent and incandescent reflector lamps. The lamp manufacturer should be consulted for compliant energy-efficient replacements.

17.4 Voltage.

17.4.1 Lamps and ballasts are designed to provide rated-average life expectancy and light output at the rated operating voltage.

17.4.2 A filament lamp operating at 5 percent overvoltage will have its life expectancy reduced almost 50 percent, while the light output will be increased by about 18 percent. Five percent undervoltage operation will increase lamp life to about 195 percent, and light output will be reduced to about 84 percent.

17.4.3 Fluorescent lamp ballasts are designed for operation at 115, 120, 200, 208, 230, 240, 277, 460, or 480 volts. The ranges of permissible variations are 110–126, 191–218, 220–252, 254–291, and 440–504 volts. Higher voltage will shorten lamp and ballast life, while lower voltage can shorten lamp life and might cause uncertain starting. Frequent starting will shorten lamp life.

17.4.4 Some high-density discharge lamp ballasts are provided with taps to accommodate variations from rated voltage. Line voltage higher than the rated voltage will shorten ballast and lamp life, while lower voltages will reduce light output and might cause uncertain starting. If a multiple voltage primary winding is used, the connected tap should match the line voltage.

17.5 Lamps and Ballasts.

17.5.1 Fluorescent Lamps. Intermittent lighting of fluorescent lamps will shorten lamp life and can damage a ballast. When blinking occurs, the lamps should be replaced. If this does not solve the problem, the ballast should be replaced.

17.5.1.1 Except for identified exceptions in NFPA 70, *National Electrical Code,* all fluorescent lamp ballast on fixtures installed indoors are required to contain integral thermal protection and be marked "Class P."

17.5.1.2 Inline fuseholders and fuses sized to lighting fixture manufacturers' recommendations will provide supplementary ballast protection and branch-circuit selectivity.

17.5.2 High-Intensity Discharge Lamps. High-intensity discharge (HID) lamps include metal halide, mercury vapor, and high-pressure sodium lamps. These lamps are typically constructed of an outer bulb with an internal arc tube. Metal halide arc tubes operate at higher pressures and temperatures — as high as approximately 1100°C — than other HID lamps. Metal halide arc tubes and outer bulbs can rupture, particularly if the lamp is misapplied. Metal halide lamp types are as follows:

(1) O-type lamps are designed for open fixtures. They contain a shrouded arc tube strong enough to prevent lamp shattering.
(2) E-type lamps are intended for use in enclosed fixtures. Such fixtures include integral containment barriers that enclose the lamp.
(3) S-type lamps can be used in either open or enclosed fixtures. These lamps have no shroud. The design is limited to certain lamps between 350 watts and 1000 watts. The lamps must be operated vertically if used in open fixtures. S-type lamps in open fixtures offer the least protection in the event of a rupture.

17.5.2.1 Fixtures should be listed for the location and purpose. Lamp type and rating should be appropriate for the fixture and should meet the manufacturer's specification.

17.5.2.2 Lamps should be replaced only with lamps of the same type. Fixture covers on enclosed fixtures should be properly reinstalled.

17.5.2.3 In continuously operating metal halide systems (24 hours a day, 7 days a week), lamps should be turned off once per week for a minimum of 15 minutes. Failure to do this increases the risk of rupture.

17.5.2.4 To further reduce risk of rupture, metal halide fixtures should be group re-lamped at 70 percent of rated life.

17.6 Disposal. Certain lamps and ballasts require special disposal considerations. *(See Section 7.7.)*

Chapter 18 Wiring Devices

18.1 Introduction. This section covers the maintenance of attachment plugs, cord connectors, and receptacles rated not more than 200 amperes nor more than 600 volts.

18.1.1 The connection of equipment to supplies of different electrical ratings of current, voltage, phase, or frequency can be hazardous or can cause damage to equipment. Therefore, attachment plugs, cord connectors, and equipment are provided with different ratings and configurations to prevent hazardous interconnection. See Annex G, G.1 and G.2 for configuration chart from NEMA WD 6-1997 *Wiring Devices — Dimensional Requirements* (Revision and Redesignation of ANSI C73-73).

18.1.2 The use of these devices for the connection of equipment provides for rapid removal and replacement and facilitates relocation.

18.1.3 Up to 60 amperes, all devices are tested for the capability of being connected or disconnected under full load. Devices rated above 60 amperes are marked as to whether they are listed for this mode of operation.

18.1.4 Use of these devices to disconnect some equipment under some load conditions such as welders and running or stalled motors can be hazardous. Other load interrupting means intended for this purpose should be used.

18.1.5 If the plug or connector housing or interior is cracked or distorted, or if pieces are missing or damaged, or if the pins or contacts are bent, missing, or discolored, the complete interior should be replaced. For particularly adverse environments, such as highly corrosive environments, high-temperature locations, or hazardous (classified) locations, devices specifically intended for the purpose should be used.

18.1.5.1 If the receptacle or plug insulation is cracked, broken, or discolored, the defective parts should be replaced.

18.1.5.2 Receptacle contacts should retain inserted plugs firmly. Corroded, deformed, or mechanically damaged contacts should be replaced. A check should be made for proper wire connections on receptacles and proper polarity of power connection, including the integrity of the equipment-grounding conductor.

18.1.5.3 If there is abnormal heating of the receptacle, plug, or connector insulation, a check should be made for loose terminations or insufficient pressure between contacts, and they should be corrected or replaced. If there is arc tracking or evidence of burning of the insulation or other damage, it should be replaced.

18.2 Connector and Receptacle.

18.2.1 Plugs should fit firmly when inserted into the mating connector or receptacle. Insufficient mating force can result in contact erosion caused by arcing of the contacts or accidental disengagement. The connector or receptacle should be checked to ensure that adequate contact pressure is present. The complete interior should be replaced if there is discoloration of the housing or severe erosion of the contact.

18.2.1.1 When continuity of service is essential, consideration should be given to the installation of a mechanically held or interlocked assembly.

18.2.2 The equipment-grounding conductor (green insulation) of the cord must be attached to the grounding terminal of the device, thereby ensuring grounding continuity.

18.2.3 The face of the receptacle, plug, or connector should occasionally be thoroughly cleaned.

18.2.4 Cracked, bent, or broken spring doors or covers should be replaced.

18.2.5 All mounting and assembly screws should be present and checked to ensure that they are tight because they can provide grounding, prevent the entrance of adverse environmental products, and provide cable retention.

18.2.6 All gaskets, if used, should be inspected to determine if they are present and maintain the integrity of the enclosure.

18.2.7 To ensure proper selection of replacement parts, the nameplates should be kept clean and legible, and the instructions that were supplied with the product should be maintained on file, together with a list of the manufacturer replacement parts.

18.2.8 Because the grounding circuit path for the equipment can include the external shell, pin, and sleeve devices, these surfaces should not be painted.

18.2.9 Control contacts are occasionally used in conjunction with power pins. These control contacts should be inspected to ensure that they make last and break first.

18.2.10 Devices used in hazardous (classified) locations require some additional inspections. All mechanically and electrically interlocked plugs and receptacles should be inspected for proper operation and for excessively worn or broken parts; they should be replaced as required. All parts and surfaces of these devices should be clean and free of foreign material or corrosion. Flame paths should be inspected to ensure that safe gaps are not exceeded and that no scratches are on the ground joints. All screws holding the receptacle to the body should be installed and tight. Covers and threaded openings should be properly tightened. These devices should be checked to make sure that the plug and receptacle marking agree with the present classification of the area in regard to the class, group, and division.

18.3 Receptacles.

18.3.1 If the receptacle is badly worn, cracked, or broken, or if contacts are exposed, the receptacle should be replaced.

18.3.2 Receptacle contacts should hold and retain inserted plugs firmly. If accidental disengagement of the plug from the receptacle is a recurring problem, the receptacle should be replaced. When continuity of service is essential, consideration should be given to the installation of a locking-type device.

18.3.3 A check should be made to ensure proper wire connections on receptacles and proper polarity of power connections, including the integrity of the equipment ground.

18.3.4 When replacing 15- and 20-ampere non-grounding-type receptacles, refer to Section 406.3(D) of NFPA 70, *National Electrical Code.*

18.3.5 If there is abnormal heating on the receptacle face, a check should be made for loose terminations and if found, they should be corrected or replaced. If there is arc tracking or evidence of burning of the device or other damage, the receptacle should be replaced.

18.4 Adapters. Adapters between locking and nonlocking configurations provide flexibility in obtaining power for maintenance functions. However, adapters should not be used to bypass the equipment ground, nor should adapters with pigtails be used.

18.5 General-Use Snap Switches.

18.5.1 Switches of the ac-dc (T-rated) type should not be used to control inductive loads such as fluorescent lighting or motors where the load exceeds 50 percent of the switch rating. Switches that are rated ac-only are permitted to control up to 100 percent of their rating for inductive loads or 80 percent of their rating for motor loads.

18.5.2 If the switch is broken or the mechanism does not function in a normal manner, the switch should be replaced. Where repeated abuse is incurred, consideration should be given to relocating the switch or replacing it with a switch having a guarded operating means or a switch with a low profile.

18.5.3 The switch should be firmly fastened to the box to ensure electrical and mechanical integrity.

18.5.4 If there is evidence of abnormal heating, the switch should be checked for loose terminals or switch malfunction and corrected or replaced.

18.6 Cover Plates.

18.6.1 All switches and receptacles should be installed with wall plates or covers suitable for the environment and location.

18.6.2 Cracked, bent, or broken wall plates or spring doors or covers should be replaced.

18.7 Boxes. Boxes used for the containment of receptacles and switches should be rigidly secured in place. Locknuts and conduit fittings should be made up tight, and proper box-fill of conductors should be observed. Closures should be placed in unused knockout holes. Where boxes, particularly the surface-mounted type, sustain repeated abuse, consideration should be given to flush mounting or additional guarding means.

18.8 Pin and Sleeve Devices.

18.8.1 Heavy-Duty Industrial-Type Plugs, Cord Connectors, and Receptacles.

18.8.1.1 Introduction. This section covers the maintenance of heavy-duty industrial-type plugs, cord connectors, and receptacles rated not more than 400 amperes nor more than 600 volts.

18.8.1.2 General. Plugs, cord connectors, and receptacles of this type are provided with different ratings and polarizations to prevent hazardous interconnection of different current ratings, voltages, or frequencies.

18.8.1.2.1 Devices connected to circuits having different voltages, frequencies, or types of current on the same premises should not be interchangeable.

18.8.1.2.2 Noninterchangeability is accomplished in these products by at least two methods. The first is the size and location of the contacts. The second is by keying arrangements of the plug sleeve and receptacle housing. By varying these parameters, sufficient variations can be obtained to accomplish noninterchangeability.

18.8.1.2.3 A detailed plan should be prepared specifying the devices, based first on performance requirements and then defining the specific configuration for each voltage, amperage, and frequency of use on the premises.

18.8.1.2.4 The use of these devices for the connection of equipment provides for rapid removal and replacement and facilitates relocation of electrical equipment.

18.8.1.2.5 Most of these assemblies are designed and listed to disconnect the equipment under full-load or locked-rotor currents. If they are not suitable, other load-interrupting means, such as interlocked receptacles, should be used.

18.8.1.3 Plugs. Cord clamps and strain-relief fittings should be checked to ensure that they are tight and that the outer cord jacket is completely within the clamping area.

18.8.1.4 Abnormal heating on the plug surface might be caused by loose terminations, overloading, high ambients, or equipment malfunction. Insulators and contacts should be inspected visually for discoloration of the insulator or pitting of contacts. Inspection of other parts should be initiated if discoloration or pitting is observed. The assembly of individual conductors to terminals should be periodically checked. Individual conductor strands should be properly confined and terminations made tight. Conductor strands should not be soldered when used with binding head screws because this can cause overheating.

18.8.1.5 If the plug or connector housing or interior is cracked or distorted, or if pieces are missing or damaged, or if the pins or contacts are bent, missing, or discolored, the complete interior should be replaced. For particularly adverse environments, such as highly corrosive environments, high-temperature locations, or hazardous (classified) locations, devices specifically intended for the purpose should be used.

18.8.1.5.1 If the receptacle or plug insulation is cracked, broken, or discolored, the defective parts should be replaced.

18.8.1.5.2 Receptacle contacts should retain inserted plugs firmly. Corroded, deformed, or mechanically damaged contacts should be replaced. A check should be made for proper wire connections on receptacles and proper polarity of power connections including the integrity of the equipment-grounding conductor.

18.8.1.5.3 If there is abnormal heating of the receptacle, plug, or connector insulation, a check should be made for loose terminations or insufficient pressure between contacts, and they should be corrected or replaced. If there is arc tracking or evidence of burning of the insulation or other damage, it should be replaced.

18.8.2 Connector and Receptacle.

18.8.2.1 Plugs should fit firmly when inserted into the mating connector or receptacle. Insufficient mating force can result in contact erosion caused by arcing of the contacts or accidental disengagement. The connector or receptacle should be checked to ensure that adequate contact pressure is present. The complete interior should be replaced if there is discoloration of the housing or severe erosion of the contact. When continuity of service is essential, consideration should be given to the installation of a mechanically held or interlocked assembly.

18.8.2.2 The equipment-grounding conductor (green insulation) of the cord must be attached to the grounding terminal of the device, thereby ensuring grounding continuity.

18.8.2.3 Occasionally, the face of the receptacle, plug, or connector should be cleaned thoroughly.

18.8.2.4 Cracked, bent, or broken spring doors or covers should be replaced.

18.8.2.5 All mounting and assembly screws should be present and checked to ensure that they are tight because they can provide grounding, prevent the entrance of adverse environmental products, and provide cable retention.

18.8.2.6 All gaskets, if used, should be inspected to determine if they are present and to maintain the integrity of the enclosure.

18.8.2.7 To ensure proper selection of replacement parts, the nameplates should be kept clean and legible, and the instructions that were supplied with the product should be maintained on file, together with a list of the manufacturer replacement parts.

18.8.2.8 Because the grounding circuit path for the equipment can include the external shell, pin and sleeve devices, these surfaces should not be painted.

18.8.2.9 Control contacts are occasionally used in conjunction with power pins. These control contacts should be inspected to ensure that they make last and break first.

18.8.2.10 Devices used in hazardous (classified) locations require some additional inspections. All mechanically and electrically interlocked plugs and receptacles should be inspected for proper operation and for excessively worn or broken parts; they should be replaced as required. All parts and surfaces of these devices should be clean and free of foreign material or corrosion. Flame paths should be inspected to ensure that safe gaps are not exceeded and that no scratches are on the ground joints. All screws holding the receptacle to the body should be installed and tight. Covers and threaded openings should be properly tightened. These devices should be checked to make sure that the plug and receptacle marking agree with the present classification of the area in regard to the class, group, and division.

Chapter 19 Portable Electrical Tools and Equipment

19.1 Introduction.

19.1.1 Dependable performance and long service life of power tools is becoming more important as the need for mechanization and the use of these tools increases. A plant's entire inventory of portable tools can be kept in top operating condition for maximum production quality and cost efficiency with a planned routine and periodic inspection.

19.1.2 There are many and varied types of portable power tools and many and varied causes of power tool failure. Therefore, the procedures for their maintenance can be general recommendations only. Variations will exist and will depend on the type of tool and the particular conditions of its use. It is strongly recommended that the information on proper use and maintenance given in the tool manufacturer's use and care manual, supplied with each tool, be carefully followed.

19.1.3 Periodic electrical testing will uncover many operating defects, and their immediate correction will ensure safe operation and prevent breakdown and more costly repairs. This testing and the related maintenance should be systematic. A visual inspection is recommended before and after each use when issued and when returned to the tool crib.

19.2 Employee Training.

19.2.1 Employee training in the proper care and use of portable power tools is an important part of preventive maintenance. Employees should be given instructions in selecting the proper tool for the job and the limitations of the tool. Using an underpowered tool for the work load can cause overloading.

19.2.2 Employees should be trained to recognize obvious defects such as cut, frayed, spliced, or broken cords; cracked or broken attachment plugs; and missing or deformed grounding prongs. Such defects should be reported immediately.

19.2.3 Employees should be instructed to report all shocks immediately, no matter how minor, and to cease using the tool. Tools causing shocks should be examined and repaired before further use.

19.3 Maintenance. The following are general recommendations. The best source for maintenance information is the original manufacturer.

19.3.1 Periodic Inspection of Crucial Wear Points. Brushes and commutators should be inspected periodically. This is easily accomplished by removal of brush-holder plugs or inspection plates, depending on the construction of the tool. Brushes worn down to 50 percent of their original size should be replaced. When a brush is replaced, always be sure to use the manufacturer's original equipment.

19.3.2 Excessive Dirt Accumulation. All universal motors are fan ventilated to prevent excessive heat. Even though many tools have filters and deflectors to prevent destructive material from damaging the motor, a small amount of it will pass through. Excessive buildup affects the brush operation and reduces the air volume necessary to cool the motor. When necessary, the tool should be blown out with low-pressure, dry-compressed air when used in a normal environment. More frequent specialized maintenance should be considered if the atmosphere is heavy in abrasives or conducting dusts.

19.3.3 Insufficient or Improper Lubrication. Lubricant inspection is recommended at frequent intervals to ensure sufficient lubricant to prevent wear to mechanical parts. Dirty lubricants should be removed and replaced. Because lubricant varies from tool to tool, it is recommended that proper lubricant be obtained from the manufacturer or the manufacturer's distribution outlet.

19.3.3.1 Manufacturers carefully match lubricants to be compatible with speeds, heat, seals, bearings, and pressure to ensure long gear and mechanism life. Substitutions can damage the tool and invalidate the warranty.

19.3.3.2 The wrong amount of lubricant can cause serious problems. Too little means that surfaces are not adequately covered, and excess wear will result. Too much lubricant can cause excess pressure in the gear case and eventually ruins seals.

19.4 Cord and Attachment Plug Care.

19.4.1 The cord of an electric power tool is the lifeline. It should be kept free of oil, grease, and other material that might ruin the rubber cover. Tangling knots or dragging across sharp surfaces should be avoided. The cord should not be used as a towline to carry or drag the tool.

Table 19.5 Size of Extension Cords for Portable Electric Tools

Extension Cord Length (ft)	Nameplate Ampere Rating 0–2.0 115 V	0–2.0 230 V	2.1–3.4 115 V	2.1–3.4 230 V	3.5–5.0 115 V	3.5–5.0 230 V	5.1–7.0 115 V	5.1–7.0 230 V	7.1–12.0 115 V	7.1–12.0 230 V	12.1–16.0 115 V	12.1–16.0 230 V
25	18	18	18	18	18	18	18	18	16	18	14	16
50	18	18	18	18	18	18	16	18	14	16	12	14
75	18	18	18	18	16	18	14	16	12	14	10	12
100	18	18	16	18	14	16	12	14	10	12	8	10
200	16	18	14	16	12	14	10	12	8	10	6	8
300	14	16	12	14	10	14	8	12	6	10	4	6
400	12	16	10	14	8	12	6	10	4	8	4	6
500	12	14	10	12	8	12	6	10	4	6	2	4
600	10	14	8	12	6	10	4	8	2	6	2	4
800	10	12	8	10	6	8	4	6	2	4	1	2
1000	8	12	6	10	4	8	2	6	1	4	0	2

Notes:
(1) Size is based on current equivalent to 150 percent of full load of tool and a loss in voltage of not over 5 volts.
(2) If voltage is already low at the source (outlet), voltage should be increased to standard, or a larger cord than listed should be used in order to minimize the total voltage drop.

19.4.2 All power tools, unless they are double insulated and so marked, are required to be grounded through an additional grounding conductor in the cord and the grounding prong of the attachment plug. The integrity of this grounding circuit is necessary for the protection of life and should be inspected visually before each use. Experience has shown that the grounding prongs of attachment caps are frequently cut off for use in ungrounded receptacles. This practice should not be permitted.

19.4.3 If a cord is cut, broken, spliced, or frayed; the attachment plug is damaged; or the grounding prong is removed, it should be immediately withdrawn from service until it can be repaired. Cords can be replaced in their entirety, or a damaged cord can be repaired by cutting out the damaged portion and applying a plug and connector to rejoin the two sections. Replacement cords should be of the same type and conductor size and suitable for use.

19.4.4 To avoid accidents, the green insulated conductor is to be used only for connecting the frame of the tool to the equipment-grounding terminal of the attachment plug meeting the conditions of NFPA 70, *National Electrical Code*, Section 400.24. It should not be used for any other purpose.

19.5 Extension Cords. Before placing extension cords in service, the plug and connector should be checked for proper polarity, and the grounding conductor should be tested for continuity and integrity. Extension cords of the proper conductor size should be used to avoid excessive voltage drop that might result in poor operation and possible damage to the tool. *(See Table 19.5 for recommended sizes.)*

19.6 Major Overhauls. Major overhauls and repairs should be performed by the manufacturer; however, large companies that use power tools and who prefer to do their own repairs and overhaul should obtain the necessary parts, schematics, connection diagrams, lubricant charts, and other technical information from the manufacturer.

19.7 Leakage Current Testing. Portable and cord-connected equipment should be tested periodically for the amount of leakage current present to help ensure against shock hazards.

Chapter 20 Testing and Test Methods

20.1 Introduction. This chapter covers the tests ordinarily used in the field to determine the condition of various elements of an electrical power-distribution system. The data obtained in these tests provide information that is used as follows:

(1) To determine whether any corrective maintenance or replacement is necessary or desirable.
(2) To ascertain the ability of the element to continue to perform its design function adequately.
(3) To chart the gradual deterioration of the equipment over its service life.

20.2 Acceptance Tests and Maintenance Tests.

20.2.1 Acceptance Tests. Acceptance tests are tests that are performed on new equipment, usually after installation, prior to energization. These tests are performed to determine whether a piece of equipment is in compliance with the purchase specification and design intent and also to establish test benchmarks that can be used as a reference during future tests. Acceptance tests are also valuable in ensuring that the equipment has not been subjected to damage during shipment or installation. In addition to the tests that are performed, an acceptance program should include a comprehensive visual inspection and an operational check of all circuitry and accessory devices.

20.2.2 Routine Maintenance Tests. Routine maintenance tests are tests that are performed at regular intervals over the service life of equipment. These tests are normally performed concurrently with preventive maintenance on the equipment.

20.2.3 Special Maintenance Tests. Special maintenance tests are tests performed on equipment that is thought or known to be defective or equipment that has been subjected to conditions that could possibly adversely affect its condition or operating characteristics. Examples of special maintenance tests are cable fault-locating tests or tests performed on a circuit breaker that has interrupted a high level of fault current.

20.2.4 Pretest Circuit Analysis. An analysis of the circuit to be tested should be made prior to the testing to assess the potential meaning of the test results.

20.3 As-Found and As-Left Tests.

20.3.1 As-Found Tests. As-found tests are tests performed on equipment on receipt or after it has been taken out of service for maintenance, but before any maintenance work is performed.

20.3.2 As-Left Tests. As-left tests are tests performed on equipment after preventive or corrective maintenance, immediately prior to placing the equipment back in service.

20.3.3 Correlation of As-Found and As-Left Tests. When equipment is taken out of service for maintenance, performing both an as-found and an as-left test is recommended. The as-found tests will show any deterioration or defects in the equipment since the last maintenance period and, in addition, will indicate whether corrective maintenance or special procedures should be taken during the maintenance process. The as-left tests will indicate the degree of improvement in the equipment during the maintenance process and will also serve as a benchmark for comparison with the as-found tests during the next maintenance cycle.

20.4 Frequency of Tests. Most routine testing can best be performed concurrently with routine preventive maintenance, because a single outage will serve to allow both procedures. For this reason, the frequency of testing will generally coincide with the frequency of maintenance. The optimum cycle depends on the use to which the equipment is put and the operating and environmental conditions of the equipment. In general, this cycle can range from six months to three years, depending on the above criteria. The difficulty of obtaining an outage should never be a factor in determining the frequency of testing and maintenance. Equipment for which an outage is difficult to obtain is usually the equipment that is most vital in the operation of the electrical system. Consequently, a failure of this equipment would most likely create the most problems relative to the continued successful operation of the system. In addition to routine testing, tests should be performed any time equipment has been subjected to conditions that could possibly have caused it to be unable to continue to perform its design function properly.

20.5 Special Precautions and Safety.

20.5.1 Many tests on electrical equipment involve the use of high voltages and currents that are dangerous, both from the standpoint of being life hazards to personnel and because they are capable of damaging or destroying the equipment under test. Adequate safety rules should be instituted and practiced to prevent injury to personnel, both personnel who are performing the tests and others who might be exposed to the hazard. Also, the test procedures used should be designed to ensure that no intentional damage to equipment will result from the testing process.

20.5.2 It should be recognized, as the name implies, that over-potential or high-potential testing is intended to stress the insulation structure above that of normal system voltage. The purpose of the test is to establish the integrity of the insulation to withstand voltage transients associated with switching and lightning surges and hence reduce the probability of in-service equipment failures. Direct voltage over-potential testing is generally considered a controlled, nondestructive test in that an experienced operator, utilizing a suitable test set, can often detect marginal insulation from the behavior of measured current. It is therefore possible, in many cases, to detect questionable insulation and plan for replacement without actually breaking it down under test. Unfortunately, some insulations might break down with no warning. Plans for coping with this possibility should be included in the test schedule.

20.5.3 Low-voltage insulation testing can generally be done at the beginning of the planned maintenance shutdown. In the event of an insulation failure under test, maximum time would be available for repair prior to the scheduled plant start-up. Equipment found in wet or dirty condition should be cleaned and dried before high-potential testing is done or a breakdown can damage the equipment.

20.5.4 Low-voltage circuit breakers, which require very high interrupting ratings, are available with integral current-limiting fuses. Although the fuse size is selected to override without damage to the time-current operating characteristic of the series trip device, it is desirable to bypass or remove the fuse prior to applying simulated overload and fault current.

20.6 Qualifications of Test Operators. If a testing program is to provide meaningful information relative to the condition of the equipment under test, then the person evaluating the test data should be assured that the test was conducted in a proper manner and that all of the conditions that could affect the evaluation of the tests were considered and any pertinent factors reported. The test operator, therefore, should be thoroughly familiar with the test equipment used in the type of test to be performed and also should be sufficiently experienced to be able to detect any equipment abnormalities or questionable data during the performance of the tests.

20.7 Test Equipment. It is important in any test program to use the proper equipment to perform the required tests. In general, any test equipment used for the calibration of other equipment should have an accuracy at least twice the accuracy of the equipment under test. The test equipment should be maintained in good condition and should be used only by qualified test operators. All test equipment should be calibrated at regular intervals to ensure the validity of the data obtained. In order to get valid test results, it might be necessary to regulate the power input to the test equipment for proper waveform and frequency and to eliminate voltage surges.

20.8 Forms. If a testing and maintenance program is to provide optimum benefits, all testing data and maintenance actions should be recorded on test circuit diagrams and forms that are complete and comprehensive. It is often useful to record both test data and maintenance information on the same form. A storage and filing system should be set up for these forms that will provide efficient and rapid retrieval of information regarding previous testing and maintenance on a piece of equipment. A well-designed form will also serve as a guide or a checklist of inspection requirements. Samples of typical forms are included in Annex F.

20.9 Insulation Testing.

20.9.1 Introduction.

20.9.1.1 Insulation is the material between points of different potential in an electrical system that prevents the flow of electricity between those points. Insulation materials can be in the gaseous, liquid, or solid form. A vacuum is also a commonly used insulation medium. The failure of the insulation system is the most common cause of problems in electrical equipment. This is true on both high-voltage and low-voltage systems. Insulation tests are tests used to determine the quality or condition of the insulation systems of electrical equipment. Both alternating current and direct current are used in insulation testing.

20.9.1.2 Reasons for Insulation Failure. Liquid and solid insulating materials with organic content are subject to natural deterioration due to aging. This natural deterioration is accelerated by excessive heat and moisture. Heat, moisture, and dirt are the principal causes of all insulation failures. Insulation can also fail due to chemical attack, mechanical damage, sunlight, and excessive voltage stresses.

20.9.2 Direct-Current (dc) Testing — Components of Test Current.

20.9.2.1 When a dc potential is applied across an insulation, the resultant current flow is composed of several components as follows:

(1) Capacitance-charging current
(2) Dielectric-absorption current
(3) Surface leakage current
(4) Partial discharge (corona current)
(5) Volumetric leakage current

20.9.2.2 The capacitance-charging current and the dielectric-absorption current decrease as the time of application of the voltage increases. The test readings of resistance or current should not be taken until these two currents have decreased to a low value and will not significantly affect the reading. The time lapse between the application of voltage and the taking of the reading should be reported as part of the test data. The surface leakage current is caused by conduction on the surface of the insulation between the points where the conductor emerges from the insulation and points of ground potential. This current is not desired in the test results (except for as-found tests) and can be eliminated by carefully cleaning the leakage paths described. Corona current occurs only at high values of test voltage. This current is caused by the overstressing of air at sharp corners or points on the conductor. This current is not desired in the test results and can be eliminated by installing stress-control shielding at such points during the test. Volumetric leakage current is the current that flows through the volume insulation itself. It is the current that is of primary interest in the evaluation of the condition of the insulation.

20.9.2.3 Insulation-Resistance Testing. In an insulation-resistance test, an applied voltage, from 100 volts to 5000 volts, supplied from a source of constant potential, is applied across the insulation. The usual potential source is a megohmmeter, either hand or power operated, that indicates the insulation resistance directly on a scale calibrated in megohms. The quality of the insulation is evaluated based on the level of the insulation resistance.

20.9.2.3.1 The insulation resistance of many types of insulation is variable with temperature, so the data obtained should be corrected to the standard temperature for the class of equipment under test. Published charts are available for this purpose.

20.9.2.3.2 The megohm value of insulation resistance obtained will be inversely proportional to the volume of insulation being tested. For example, a cable 304.8 m (1000 ft) long would be expected to have one-tenth the insulation resistance of a cable 30.48 m (100 ft) long if all other conditions were identical.

20.9.2.3.3 The insulation-resistance test is relatively easy to perform and is a useful test used on all types and classes of electrical equipment. Its main value lies in the charting of data from periodic tests, corrected for temperature, over the life of the equipment so that deteriorative trends might be detected.

20.9.2.4 Dielectric Absorption.

20.9.2.4.1 In a dielectric-absorption test, a voltage supplied from a source of constant potential is applied across the insulation. The range of voltages used is much higher than the insulation-resistance test and can exceed 100,000 volts. The potential source can be either a megohmmeter, as described in 20.9.2.3, or a high-voltage power supply with an ammeter indicating the current being drawn by the specimen under test. The voltage is applied for an extended period of time, from 5 minutes to 15 minutes, and periodic readings are taken of the insulation resistance or leakage current.

20.9.2.4.2 The test data is evaluated on the basis that if an insulation is in good condition, its apparent insulation resistance will increase as the test progresses. Unlike the insulation-resistance test, the dielectric-absorption test results are independent of the volume and the temperature of the insulation under test.

20.9.2.5 Polarization Index. The polarization index is a specialized application of the dielectric-absorption test. The index is the ratio of insulation resistance at two different times after voltage application, usually the insulation resistance at 10 minutes to the insulation resistance at 1 minute. The use of polarization-index testing is usually confined to rotating machines, cables, and transformers. A polarization index less than 1.0 indicates that the equipment needs maintenance before being placed in service. References are available for polarization indexes for various types of equipment.

20.9.2.6 High-Potential Testing.

20.9.2.6.1 General. A high-potential test consists of applying voltage across an insulation at or above the dc equivalent of the 60 Hz operating crest voltage. This test can be applied either as a dielectric-absorption test or a step-voltage test.

20.9.2.6.1.1 Dielectric-Absorption Test. When applied as a dielectric-absorption test, the maximum voltage is applied gradually over a period of from 60 seconds to 90 seconds. The maximum voltage is then held for 5 minutes with leakage-current readings being taken each minute.

20.9.2.6.1.2 Step-Voltage Test. When applied as a step-voltage test, the maximum voltage is applied in a number of equal increments, usually not less than eight, with each voltage step being held for an equal interval of time. The time interval between steps should be long enough to allow the leakage current to reach stability, approximately 1 or 2 minutes. A leakage-current reading is taken at the end of each interval before the voltage is raised to the next level. A linear increase in leakage current is expected, and it should stabilize or decrease from the initial value at each step. A plot of test voltage versus leakage current or insulation resistance is drawn as the test progresses. A nonlinear increase in leakage current can indicate imminent failure, and the test should be discontinued. After the maximum test voltage is reached, a dielectric-absorption test can be performed at that voltage, usually for a 5-minute period.

20.9.2.6.1.3 Proper Discharge. At the end of each test, the test equipment control should be turned to zero voltage and the voltage should be monitored. When the voltage is reduced to 20 percent, or lower, of the maximum test voltage, the metallic components should be grounded in accordance with test procedures or for at least 30 minutes.

20.9.2.6.2 Arrangement Before Testing. Before equipment insulation is tested, it should be cleaned, inspected, and repaired as found necessary to minimize leakage currents. The same action should be taken for cable terminations. Surge arresters should be disconnected.

20.9.2.6.2.1 When testing cables, all transformers, switches, fuse cutouts, switchgear, and so on, should be disconnected wherever practicable. Thus, if significant leakage currents are encountered, it will be known that these currents are in the cable insulation and not in equipment connected thereto. Further, if such disconnection is impractical, it might be necessary to limit the maximum test voltage to the level that such equipment can withstand without damage.

20.9.2.6.2.2 High leakage currents in cables might be due to improper preparation of their ends before the cable terminations were installed, thereby allowing high surface leakage across them.

20.9.2.6.3 Acceptance Test Voltages. The maximum permissible test voltages for acceptance tests performed on cables are listed in the Insulated Power Cable Engineers Association's (IPCEA) standards for rubber, thermoplastic, and varnished cloth insulations, and in the Association of Edison Illuminating Companies (AEIC) standards for solid-type impregnated-paper insulation. Ordinarily, routine maintenance tests are conducted with a maximum test voltage at or below 75 percent of the maximum test voltage permitted for acceptance testing. *(See ANSI/IEEE 400, Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field.)*

20.9.2.6.4 Maintenance Test Voltages.

20.9.2.6.4.1 Care should be taken in choosing the appropriate test voltage for routine maintenance tests on cables that have been in service for longer periods. If the level selected is too low, marginal weak spots might not be revealed; if the level is too high, damage to the insulation might result.

20.9.2.6.4.2 The test voltage should be applied from phase-to-ground on each conductor with the other conductors, the shields, and metallic jackets also connected to ground. The dc to ac (RMS) test voltage ratios ordinarily used are in Table 20.9.2.6.4.2.

20.9.2.6.5 Step-Voltage Testing. When the step-voltage type of test is used, the condition of the cable should be evaluated on the basis of (1) the absolute values of insulation resistance, (2) the slope of the curve of voltage versus insulation resistance, and (3) whether or not a significant downward "knee" appears in the curve at the higher levels of test voltage.

Table 20.9.2.6.4.2 dc to ac (RMS) Test Voltage Ratios

Cable Insulation	Ratio
Rubber or rubberlike, ozone resisting	3.0 to 1
Rubber or rubberlike, other than ozone resisting	2.2 to 1
Impregnated paper, solid type	2.4 to 1
Varnished cloth	2.0 to 1
Polyethylene	3.0 to 1

20.9.3 Alternating-Current (ac) Testing.

20.9.3.1 High-Potential Testing. Alternating-current high-potential tests are made at voltages above the normal system voltage for a short time, such as 1 minute. The test voltages to be used vary depending on whether the device or circuit is low or high voltage, a primary or control circuit, and whether it was tested at the factory or in the field. Manufacturers' instructions and the applicable standards should be consulted for the proper values.

20.9.3.2 Insulation Power-Factor Testing. When power-factor testing is performed the criteria in 20.9.3.2(A) through 20.9.3.2(G) should be utilized.

(A) General. The power factor of an insulation is the cosine of the angle between the charging current vector and the impressed voltage vector when the insulation system is energized with an ac voltage. In other words, it is a measure of the energy component of the charging current. The term *power-factor testing* means any testing performed in order to determine the power factor of an insulation system. For low values of power factor, the dissipation factor can be assumed to be the same as the power factor. Power-factor testing is a useful tool in evaluating the quality of insulation in power, distribution, and instrument transformers; circuit breakers; rotating machines; cables; regulators; and insulating liquids. The equipment to be tested should be isolated from the rest of the system, if practical, and all bushings or terminations should be cleaned and dried. The test should be conducted when the relative humidity is below 70 percent and when the insulation system is at a temperature above 0°C (32°F). Data obtained at relative humidity above 70 percent can be interpreted to recognize the higher humidity.

(B) Test Equipment. The test equipment used should be such that the power factor or dissipation factor can be read directly or such that the charging volt-amperes and the dielectric losses can be read separately so that a ratio might be computed.

(1) The test equipment should also have sufficient electromagnetic interference cancellation devices or shielding to give meaningful test results even when used in an area of strong interference, such as an energized substation.
(2) The test equipment should be able to produce and maintain a sinusoidal wave shape while performing the test at 60 Hz and should be of sufficient capacity and voltage range to perform the test at a minimum voltage of 2500 volts or the operating voltage of the equipment under test, whichever is lower, but in no case less than 500 volts.

(C) Transformer Tests. On transformer tests, the power factor of (1) each winding with respect to ground and (2) each winding with respect to each other winding should be obtained.

(1) In addition, tests should be made of each bushing with a rated voltage above 600 volts, either using the power factor or capacitance tap if the bushing is so equipped or by use of a "hot-collar" test using a test electrode around the outside shell of the bushing.

(D) Circuit Breaker Tests. On circuit breakers, the power factor of (1) each line-side and load-side bushing assembly complete with stationary contacts and interrupters, with the circuit breaker open, and (2) each pole of the circuit breaker with the breaker closed should be obtained.

(1) In addition, tests should be made of each bushing as described above. Air magnetic circuit breakers should be tested both with and without arc chutes.

(E) Rotating Machine Tests. On ac rotating machines, the neutral connection on the stator should be removed and a test of each winding with respect to the other two windings and ground should be obtained.

(F) Cable Tests. For cables, the power factor of each conductor with respect to ground should be obtained, and a hot-collar test should be made of each pothead or termination.

(1) Power-factor testing of insulating oil should be performed in accordance with ASTM D 924, *Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids*.

(G) Data Evaluation. Evaluation of the data obtained should be based on (1) industry standards for the particular type of equipment tested, (2) correlation of data obtained with test data from other similar units tested, and (3) comparison of data with previous test data on the same equipment (if available).

20.9.4 Partial Discharge Testing. A method of partial discharge testing consists of using current transformers to measure the load current that is flowing through an insulated conductor at operating voltage. Analysis of the frequency content of the measured current can provide information as to the occurrence, severity, and location of partial discharges in the insulation system that may lead to failure.

20.10 Protective Device Testing.

20.10.1 Fuses.

20.10.1.1 Fuses can be tested with a continuity tester to verify that the fuse is not open. Resistance readings can be taken using a sensitive four-wire instrument such as a Kelvin bridge or micro-ohmmeter. Fuse resistance values should be compared against values recommended by the manufacturer.

20.10.1.2 Where manufacturers' data are not readily available, resistance deviations of more than 50 percent for identical fuses should be investigated.

20.10.2 Low-Voltage Circuit Breakers — General. Low-voltage circuit breakers can generally be divided into two categories depending on the applicable industry design standards:

(1) *Molded-Case Circuit Breakers.* Designed, tested, and evaluated in accordance with NEMA AB 1, *Molded Case Circuit Breakers and Molded Case Switches,* and UL 489, *Standard for Safety, Molded-Case Circuit Breakers, Molded-Case Switches and Circuit Breaker Enclosures.*

(2) *Low-Voltage Power Circuit Breakers.* Designed, tested, and evaluated in accordance with NEMA SG 6, *Power Switching Equipment*, and ANSI/IEEE C37.13, *Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.*

20.10.2.1 Field Testing in General. The procedures outlined in Sections 2 and 3 of the NEMA publications listed in 20.10.2(1) and 20.10.2(2) are intended for checking the condition and basic electrical operation of circuit breakers, but they should not be considered as calibration tests or comparisons to laboratory tests. Section 3 outlines factors to be considered if laboratory accuracy is to be approached. If checking indicates maloperation, the circuit breaker should be removed and sent to the manufacturer for investigation and test. *It is not advisable to attempt repairs in the field.* If field testing according to NEMA AB 1 or to NEMA SG 3 under Sections 2 or 3 is required, then it is recommended that a competent field service team (either in-house or outside contractor) be employed and that instructions be followed as recommended by the above NEMA AB 1 or SG 3.

20.10.2.2 Assistance. Where needed, manufacturers, electrical contractors, and other competent service organizations will generally provide field-test services; some are equipped to perform field tests on any make of unit. Such service will be found more practicable where accurate tests are required and for all tests on circuit breakers of 600-ampere capacity and above. This is, in part, due to the need for special heavy loading equipment and also due to the difficulty of making suitable testing connections.

20.10.2.3 Field Testing of Circuit Breakers Employing Solid-State Trips. Breakers employing solid-state trip units offer testing opportunities not readily available in other molded-case or low-voltage power breakers. Since solid-state trip units are designed to operate on low-level currents obtained via the secondaries of current transformers mounted on the phase conductors, small, compact test kits can be utilized in performing field tests with a high degree of accuracy. Since these breakers have unique design characteristics, the manufacturers should be consulted for available test kits and testing instructions. *Attempted field repair of the solid-state trip units should be avoided.* Any suspected malfunction should be referred to a competent service group.

20.10.2.4 Molded-Case Circuit-Breaker Testing. When performing molded-case circuit-breaker testing, the criteria listed in 20.10.2.4.1 through 20.10.2.4.6 should be utilized.

20.10.2.4.1 Molded-Case Circuit Breakers — General. Molded-case circuit breakers are available in a wide variety of sizes, shapes, and ratings. Voltage ratings — by standard definitions — are limited to 600 volts, although special applications have been made to 1000 volts. Current ratings are available from 10 amperes through 4000 amperes. Molded-case circuit breakers can be categorized generally by the types of trip units employed as described in Section 13.5.

(A) Electrical testing should be performed in a manner and with the type of equipment required by the type of trip unit employed.

20.10.2.4.2 Testing Thermal-Magnetic Circuit Breakers. The electrical testing of thermal-magnetic circuit breakers can be divided into three steps:

(1) Overload of individual poles at 300 percent of trip rating
(2) Verification of test procedures
(3) Verification of manufacturer's published data

(A) Complete and detailed instructions for testing molded-case circuit breakers in accordance with the above steps are outlined in detail in NEMA AB 2, *Procedures for Verifying Field Inspection and Performance Verification of Molded-Case Circuit Breakers*. Individual manufacturers also publish recommended testing procedures as well as time-current characteristic tripping curves.

20.10.2.4.3 Overload Testing Considerations. When circuit-breaker tripping characteristics are tested, *it is recommended that the overcurrent tests be performed on individual poles at 300 percent of rated current.*

(A) The reaction of the circuit breaker to this overload is indicative of its reaction throughout its entire overcurrent tripping range. This load is chosen as the test point because it is relatively easy to generate the required current in the field, and the wattage per pole from line to load is large enough that the dissipation of heat in the nonactive pole spaces is minor and does not affect the test results appreciably.

20.10.2.4.4 Overcurrent Trip Data. Table 20.10.2.4.4 outlines the current and trip-time values as recommended by NEMA. The minimum/maximum range of values in Table 20.10.2.4.4 was developed to encompass most brands. For more specific values, refer to the manufacturer's data for the circuit breaker being tested.

20.10.2.4.5 Evaluation of Results from Table 20.10.2.4.4.

(A) Minimum Trip Times (columns 3 and 4). Values shown in Table 20.10.2.4.4 should not be considered significant in field testing unless nuisance tripping has been experienced.

(1) The values shown are provided as a guideline only.
(2) If minimum tripping times are lower than those shown in Table 20.10.2.4.4, the breaker should be retested after being de-energized and cooled for the required time.

(B) Maximum Trip Times (column 5). Under normal test conditions, the circuit breaker will trip in less than the maximum values shown in Table 20.10.2.4.4, column 5. Under improper test conditions, the maximum values can exceed those given in Table 20.10.2.4.4.

(C) Maximum Tripping Times for Cable Protection (column 6). If the test value exceeds the maximum tripping time shown in column 5 but falls below the maximum tripping times for cable damage, the circuit breaker is providing an acceptable level of protection.

(1) Coordination with other protective devices should be considered before replacing a circuit breaker that trips beyond the time-current curve.

20.10.2.4.6 Testing Instantaneous-Only Circuit Breakers. The testing of instantaneous-only circuit breakers requires the use of elaborate constant rate-of-rise test equipment coupled with accurate current-monitoring instrumentation — preferably digital readout — for accurate confirmation of manufacturers' test results. Unless this type of equipment is available, it is recommended that these breakers be referred to the manufacturer, electrical contractor, or other competent service organization when calibration is required.

20.10.2.5 Low-Voltage Power Circuit-Breaker Testing. When low-voltage circuit-breaker testing is performed, the criteria listed in 20.10.2.5.1 and 20.10.2.5.2 should be utilized.

20.10.2.5.1 Overcurrent Trip Device. Most low-voltage power circuit breakers are equipped with overcurrent trip devices that sense overload of fault currents and trip the breaker. These devices can be either electromechanical or solid state and will usually have two or more of the following types of elements.

(A) Long Time-Delay Element. This element is designed to operate on overloads between its pickup setting and the pickup of a short time delay or an instantaneous element. The electromechanical long time-delay pickup adjustment is generally within the range of 80 percent to 160 percent of the trip-device rating. Settings higher than an electromechanical trip-device ampere rating do not increase the continuous-current rating of the trip device, and in no event is the rating increased beyond the breaker frame size. The operating time of this element ranges from seconds to minutes.

Table 20.10.2.4.4 Values for Molded-Case Circuit-Breaker Overcurrent Trip Test (at 300 Percent of Rated Continuous Current of Breaker)

		Tripping Time (Seconds)			
		Minimum			
Voltage (Volts)	Range of Rated Continuous Current (Amperes)	Thermal Breakers	Magnetic Breakers	Maximum	Maximum for Cable Protection*
(1)	(2)	(3)	(4)	(5)	(6)
240	15–45	3	—	50	100
240	50–100	5	—	70	200
600	15–45	5	5	80	100
600	50–100	5	5	150	200
240	110–225	10	5	200	300
600	110–225	10	—	200	300
600	250–450	25	—	250	300
600	500–600	25	10	250	350
600	700–1200	25	10	450	600
600	1400–2500	25	10	600	750

*These values are based on heat tests conducted by circuit breaker manufacturers on conductors in conduit.

(B) Short Time-Delay Element. This element has a time delay measured in cycles and is used to protect against moderate fault currents and short circuits. This element usually can be adjusted to pick up within the range of 250 percent to 1000 percent of the trip-device rating.

(C) Instantaneous Element. This element has no intentional time delay and is used to protect against heavy fault currents and short circuits. The pickup settings for this type of element usually range from 500 percent to 1500 percent of the trip-device rating.

(D) Ground-Fault Element. This element is available only on solid-state devices and is used to protect against ground-fault currents at levels below those that would be sensed otherwise.

20.10.2.5.2 Testing. The testing of electromechanical trip devices or solid-state devices by the primary injection method requires the use of a high-current test set capable of producing sufficient current at low voltage to operate each of the elements of the trip device. This test should have means of adjusting the amount of current applied to the trip device and a cycle and second timer to measure the amount of time to trip the breaker at each current setting. At least one test should be made in the range of each element of the trip device. The long time-delay element should ordinarily be tested at approximately 300 percent of its setting. The short time-delay element should be tested at 150 percent to 200 percent of its setting. The instantaneous element should be tested at 90 percent and 110 percent of its setting to ensure that it does not operate at too low a current level, yet will operate at the proper level. For the test of the instantaneous element, the applied current should be symmetrical without an asymmetrical offset, or random errors will be introduced. As-found and as-left tests should always be performed if any need of adjustments is found.

20.10.3 Protective Relays.

20.10.3.1 Introduction. When performing protective relays testing, the following criteria should be utilized.

(A) *(See Caution in 8.9.7.1.)* Protective relays are used in conjunction with medium-voltage circuit breakers (above 600 volts) to sense abnormalities and cause the trouble to be isolated with minimum disturbance to the electrical system and with the least damage to the equipment at fault. They have the accuracy and sophistication demanded by the protective requirements of the primary feeder circuits and larger electrical equipment. Protective relays designed to be responsive to an abnormal excursion in current, voltage, frequency, phase-angle, direction of current or power flow, and so on, and with varying operation characteristics, are commercially available. Each relay application requires custom engineering to satisfy the parameters of its particular intended function in the system.

(B) The more common protective relay is of the electromechanical type. That is, some mechanical element such as an induction disk, an induction cylinder, or a magnetic plunger is caused to move in response to an abnormal change in a parameter of the electrical system. The movement can cause a contact in the control circuit to operate, tripping the related circuit breaker. Protective relays should be acceptance tested prior to being placed in service and should be tested periodically thereafter to ensure reliable performance. In a normal industrial application, periodic testing should be done at least every 2 years.

(C) The various facets involved in testing protective relays can be listed as follows:

(1) The technician should understand the construction, operation, and testing of the particular relay.
(2) The manufacturer's instruction bulletin, as identified on the nameplate of the relay, should be available.
(3) The technician should be given the settings to be applied to each particular relay, and the test points. This data is often furnished on a time-current curve of the coordination study displaying the characteristics of the relay.
(4) A test instrument, suitable to accurately accommodate the various acceptance and periodic maintenance tests described in the manufacturer's instruction manual, should be available.
(5) Most protective relays can be isolated for testing while the electrical system is in normal operation. However, an operation of the breaker is recommended to ascertain that the operation of the relay contacts will trigger the intended reaction, such as to trip the associated circuit breaker.

20.10.3.2 Testing Procedure. When protective relays testing is performed, the procedures listed in 20.10.3.2(A) through 20.10.3.2(J) should be followed:

(A) Inspection. If recommended or desirable, each relay should be removed from its case for a thorough inspection and cleaning. If the circuit is in service, one relay at a time should be removed so as not to totally disable the protection. The areas of inspection are detailed in the manufacturer's instruction manual. These areas generally consist of inspection for loose screws, friction in moving parts, iron filings between the induction disk and permanent magnet, and any evidence of distress with the relay. The fine silver contacts should be cleaned only with a burnishing tool.

(B) Settings. Prescribed settings should be applied, or it should be ascertained that they have been applied to the relay.

(C) Pickup Test. In the case of a time-overcurrent relay, its contacts should eventually creep to a closed position with a magnitude of current introduced in its induction coil equal to the tap setting. The pickup is adjusted by means of the restraining spiral-spring adjusting ring. A pickup test on a voltage relay is made in much the same manner.

(D) Timing Test. In the case of a time-overcurrent relay, one or more timing tests are made at anywhere from two to ten times the tap setting to verify the time-current characteristic of the relay. One timing point should be specified in the prescribed settings. Tests should be made with the relay in its panel and case, and the time test run at the calibration setting.

(E) Time Delay Settings. For example, in the case of one particular overcurrent relay having a 5-ampere tap setting, the timing test could be specified as "25 amperes at 0.4 seconds." It could be seen from the family of curves in the manufacturer's instruction manual for that relay that the test should result in a time-dial setting of approximately 1.6.

(F) Relays to Be Tested. A timing test should be made on most types of relays.

(G) Instantaneous Test. Some protective relays are instantaneous in operation, or might have a separate instantaneous element. In this context, the term *instantaneous* means "having no intentional time delay." If used, the specified pickup on the instantaneous element should be set by test. Again referring to the relay used in the example above, at two times pickup, its instantaneous element should have an operating time of between 0.016 seconds and 0.030 seconds.

(H) Test of Target and Seal-In Unit. Most types of protective relays have a combination target and seal-in unit. The target indicates that the relay has operated. The seal-in unit is adjustable to pickup at either 0.2 amperes or 2.0 amperes. The setting for the seal-in unit should be specified with the relay settings.

(I) Contact Verification. It should be verified by test that the contacts will seal in (hold in closed position) with the minimum specified direct current applied in the seal-in unit.

(J) Test of Tripping Circuit. A test should be made, preferably at the time of testing the relays, to verify that operation of the relay contacts will cause the breaker to trip.

20.11 Transformer Turns-Ratio and Polarity Tests.

20.11.1 The turns-ratio test is used to determine the number of turns in one winding of a transformer in relation to the number of turns in the other windings of the same phase of the transformer. The polarity test determines the vectoral relationships of the various transformer windings. The turns-ratio test is used as both an acceptance and a maintenance test, while the polarity test is primarily an acceptance test.

20.11.2 The tests are applicable to all power, distribution, and instrument transformers. The test equipment used will ordinarily be a turns-ratio test set designed for the purpose, although, if not available, two voltmeters or two ammeters (for current transformers only) can be used. If the two-meter method is used, the instruments should be at least of the 0.25 percent full-scale accuracy type.

20.11.3 When a turns-ratio test is performed, the ratio should be determined for all no-load taps. If the transformer is equipped with a load-tap changer, the ratio should be determined for each LTC position. If the transformer has both an LTC and a no-load-tap changer, then the ratio should be determined for each position of the LTC to one position of the no-load tap changer and vice versa. This test is useful in determining whether a transformer has any shorted turns or improper connections and, on acceptance testing, to verify nameplate information.

20.12 Contact-Resistance Testing. This test is used to test the quality of the contacts on switches and circuit breakers. A test set designed for this purpose is available with direct-scale calibration in microhms, capable of reading contact resistances of 10 microhms or less. An alternate method is to pass a known level of direct current through the contact structure and to measure the dc millivolt drop across the contacts. The data obtained can then be converted to resistance by applying Ohm's law. When millivolt drop data is used directly to describe contact resistance, it is normally stated in terms of the continuous current rating of the device. Millivolt drop data obtained at currents lower than the rated continuous current rating can be converted to the continuous current rating basis by multiplying the actual millivolt readings by the ratio of the continuous rated current to the actual test current. The alternate method requires a source of at least 100 amperes with a millivolt meter of approximately 0 mV to 20 mV range. The contact resistance should be kept as low as possible to reduce power losses at the contacts with the resultant localized heating, which will shorten the life of both the contacts and nearby insulation.

20.13 Impedance Testing of Equipment Grounding Conductor.

20.13.1 This test is used to determine the integrity of the grounding path from the point of test back to the source panel or supply transformer. A low-impedance grounding path is necessary to facilitate operation of the overcurrent device under ground-fault conditions as well as to provide a zero voltage reference for reliable operation of computers and other microprocessor-based electronic equipment.

20.13.2 Instruments are available to measure the impedance of the grounding path. When using these instruments, the user should remember that, although a high-impedance value is an indication of a problem, for example a loose connection or excessive conductor length, a low-impedance readout does not necessarily indicate the adequacy of the grounding path.

20.13.2.1 A grounding path that is found to have a low impedance by the use of relatively low test currents might not have sufficient capacity to handle large ground faults. Visual examinations and actual checking for tightness of connections are still necessary to determine the adequacy of the grounding path.

20.13.3 Impedance tests can be performed reliably on circuits where an equipment-grounding conductor is not connected to other parallel paths. These equipment-grounding conductors can be in nonmetallic sheathed cable, circuits installed in nonmetallic conduits and fittings, flexible cords, and systems using an isolated ground.

20.13.4 Ground loop or grounding conductor impedance cannot be measured reliably in situations where metallic conduits are used or where metallic boxes or equipment are attached to metal building frames or interconnected structures. Such situations create parallel paths for test currents that make it impossible to measure the impedance of the grounding conductor, or even to detect an open or missing grounding conductor. Also, the impedance of a steel raceway varies somewhat unpredictably with the amount of current flowing through it. The relatively low test currents used during testing usually produce a higher impedance than actually encountered by fault currents. However, this higher impedance tends to render the tests conservative, and the impedance values might still be acceptable.

20.14 Grounded Conductor Impedance Testing.

20.14.1 On solidly grounded low-voltage systems (600 volts or less) supplying microprocessor-based electronic equipment with switching power supplies, this test is used to determine the quality of the grounded conductor (neutral) from the point of test back to the source panel or supply transformer. These electronic loads can create harmonic currents in the neutral that can exceed the current in the phase conductors. A low-impedance neutral is necessary to minimize neutral-to-ground potentials and common-mode noise produced by these harmonic currents.

20.14.2 Some instruments used to perform the equipment ground-impedance tests in Section 20.13 can be used to perform grounded conductor (neutral) impedance tests.

20.15 Grounding-Electrode Resistance Testing. Grounding-electrode resistance testing is used to determine the effectiveness and integrity of the grounding system. An adequate grounding system is necessary to (1) provide a discharge path for lightning, (2) prevent induced voltages caused by surges on power lines from damaging equipment connected to the power line, and (3) maintain a reference point of potential for instrumentation safety. Periodic testing is necessary because variations in soil resistivity are caused by changes in soil temperature, soil moisture, conductive salts in the soil, and corrosion of the ground connectors. The test set used will ordinarily be a ground-resistance test set, designed for the purpose, using the principle of the fall of potential of ac-circulated current from a test spot to the ground connection under test. This instrument is direct reading and calibrated in ohms of ground resistance.

20.16 Circuit Breaker Time-Travel Analysis.

20.16.1 This test, used on medium- and high-voltage circuit breakers, provides information as to whether the operating mechanism of the circuit breaker is operating properly. All test instruments should be used in strict compliance with the manufacturer's instructions and recommendations. Failure to follow manufacturer's instructions can result in injury to personnel and can produce meaningless data. It presents in graphical form the position of the breaker contacts versus time. This test can be used to determine the opening and closing speeds of the breaker, the interval time for closing and tripping, and the contact bounce. The test provides information that can be used to detect problems such as weak accelerating springs, defective shock absorbers, dashpots, buffers, and closing mechanisms.

20.16.2 The test is performed by a mechanical device that is attached to the breaker. There are several types of devices available to perform this function. One device, a rotating drum with a chart attached, is temporarily connected to the chassis or tank of the breaker. A movable rod with a marking device attached is installed on the lift rod portion of the breaker. As the breaker is opened or closed, the marking device indicates the amount of contact travel on the chart as the drum rotates at a known speed. With another available device, a transducer is attached to the movable rod, and the breaker operation is recorded on an oscillograph.

20.17 Infrared Inspection.

20.17.1 Introduction. Infrared inspections of electrical systems are beneficial to reduce the number of costly and catastrophic equipment failures and unscheduled plant shutdowns.

20.17.1.1 Infrared inspections should be performed by qualified and trained personnel who have an understanding of infrared technology, electrical equipment maintenance, and the safety issues involved. These inspections have uncovered a multitude of potentially dangerous situations. Proper diagnosis and remedial action of these situations have also helped to prevent numerous major losses.

20.17.1.2 The instruments most suitable for infrared inspections are of the type that use a scanning technique to produce an image of the equipment being inspected. These devices display a picture on which the "hot spots" appear as bright or brighter spots.

20.17.1.3 Infrared surveys can be accomplished by either in-house teams or by the services of a qualified outside contractor. The economics and effectiveness of the two alternatives should be carefully weighed. Many organizations are finding it preferable to obtain these surveys from qualified outside contractors. Because of their more extensive experience, their findings and recommendations are likely to be more accurate, practical, and economical than those of a part-time in-house team.

20.17.1.4 Infrared surveys of electrical systems should not be viewed as a replacement for visual inspections. Visual inspections or checks are still required on lightly loaded circuits or on circuits not energized or not carrying current at the time of the infrared survey (for example, neutral connections).

20.17.2 Advantages of Infrared Inspections. Infrared inspections are advantageous to use in situations where electrical equipment cannot be de-energized and taken out of service or where plant production is affected. They can reduce typical visual examinations and tedious manual inspections and are especially effective in long-range detection situations.

20.17.2.1 Infrared detection can be accurate, reliable, and expedient to use in a variety of electrical installations. More important, it can be relatively inexpensive to use considering the savings often realized by preventing equipment damage and business interruptions.

20.17.2.2 Infrared inspections are considered a useful tool to evaluate previous repair work and proof test new electrical installations and new equipment still under warranty.

20.17.2.3 Regularly scheduled infrared inspections will often require the readjustment of electrical maintenance priorities as well as detect trends in equipment performance that require periodic observation.

20.17.3 Disadvantages. There are some disadvantages to individual ownership of certain types of equipment. Scanning-type thermal imaging devices can be costly to purchase outright. Training is recommended for persons who operate scanning-type thermal imaging instruments.

20.17.3.1 Infrared inspections require special measures and analysis. Equipment enclosed for safety or reliability can be difficult to scan or to detect radiation from within. Special precautions, including the removal of access panels, might be necessary for satisfactory measurements. Weather can be a factor in the conduct of a survey of electrical systems located outdoors, for example, overhead electric open lines and substations. Rain and wind can produce abnormal cooling of defective conductors and components, and the reflection of sun rays from bright surfaces can be misread as hot spots. For this reason, infrared work on outdoor equipment might have to be performed at night. This, in turn, presents a problem because electrical loads are usually lower at night and, consequently, the faulty connections and equipment might not overheat enough to enable detection. Shiny surfaces do not emit radiation energy efficiently and can be hot while appearing cool in the infrared image.

20.17.3.2 The handling of liquid nitrogen, argon, and other liquefied gases with their inherent hazards is a disadvantage of some infrared testing equipment.

20.17.4 Desirable Operational Features. The equipment display should be large and provide good resolution of hot spots. The equipment should provide color or black and white photographs to identify the exact location of the hot spot. The unit should be portable, easy to adjust, and approved for use in the atmosphere in which it is to be used. It should also have a cone of vision that will give enough detail to accurately identify the hot spot.

20.17.4.1 The unit should be designed so that the operator knows the degree of accuracy in the display. There should be easily operated checks to verify the accuracy of the display.

20.17.5 Inspection Frequency and Procedures. Routine infrared inspections of energized electrical systems should be performed annually prior to shutdown. More frequent infrared inspections, for example, quarterly or semiannually, should be performed where warranted by loss experience, installation of new electrical equipment, or changes in environmental, operational, or load conditions.

20.17.5.1 All critical electrical equipment as determined by Section 6.3 should be included in the infrared inspection.

20.17.5.2 Infrared surveys should be performed during periods of maximum possible loading but not less than 40 percent of rated load of the electrical equipment being inspected. The circuit loading characteristics should be included as part of the documentation provided in 20.17.5.4.

20.17.5.3 Equipment enclosures should be opened for a direct view of components whenever possible. When opening the enclosure is impossible, such as in some busway systems, internal temperatures can be higher than the surface temperatures. Plastic and glass covers in electrical enclosures are not transparent to infrared radiation.

20.17.5.4 Infrared surveys should be documented as outlined in 6.5.2 and Section 20.8.

20.17.5.5 The electrical supervisor should be immediately notified of critical, impending faults so that corrective action can be taken before a failure occurs. Priorities should be established to correct other deficiencies.

20.17.5.6 The NETA *Maintenance Testing Specifications for Electric Power Distribution Equipment and Systems* suggest temperature benchmarks similar to the following. Temperature differences as used in this section denote differences from the normal referenced temperature. The normal referenced temperature is determined by the qualified technician.

(1) Temperature differences of 1°C to 3°C indicate possible deficiency and warrant investigation.
(2) Temperature differences of 4°C to 15°C indicate deficiency; repairs should be made as time permits.
(3) Temperature differences of 16°C and above indicate major deficiency; repairs should be made immediately.

20.18 Fault-Gas Analysis. The analysis of the percentage of combustible gases present in the nitrogen cap of sealed, pressurized oil-filled transformers can provide information as to the likelihood of incipient faults in the transformer. When arcing or excessive heating occurs below the top surface of the oil, some oil decomposes. Some of the products of the decomposition are combustible gases that rise to the top of the oil and mix with the nitrogen above the oil.

20.18.1 The test set for this test is designed for the purpose. A small sample of nitrogen is removed from the transformer and analyzed. The set has a direct reading scale calibrated in percent of combustible gas. Ordinarily, the nitrogen cap in a transformer will have less than 0.5 percent combustible content. As a problem develops over a period of time, the combustible content can rise to 10 percent or 15 percent.

20.18.2 A suggested evaluation of the test results is shown in Table 20.18.2.

Table 20.18.2 Fault-Gas Analysis

Percentage of Combustible Gas	Evaluation
0.0 to 1.0	No reason for concern. Make tests at regularly scheduled intervals.
1.0 to 2.0	Indication of contamination or slight incipient fault. Make more frequent readings and watch trend.
2.0 to 5.0	Begin more frequent readings immediately. Prepare to investigate cause by internal inspection.
Over 5.0	Remove transformer from service and make internal inspection.

20.19 Insulating-Liquid Analysis. Regular tests, on a semiannual basis, should be made on insulating oils and askarels. Samples should be taken from the equipment in accordance with ASTM D 923, *Standard Test Method for Sampling Electrical Insulating Liquids.* The maintenance tests most commonly performed on used insulating liquids, together with the appropriate ASTM test methods, are shown in Table 20.19. Also included in this table are suggested limits to be used to determine whether the liquid is in need of reconditioning or reclamation. For comparison, typical test values for new oil are also included in the table.

20.20 Rotating Machine Testing.

20.20.1 Insulation-Resistance Testing.

20.20.1.1 This testing procedure applies to armature and rotating or stationary field windings. A hand crank, rectifier, or battery-operated instrument is suitable for testing equipment rated to 600 volts. For equipment rated over 600 volts, a 1000-volt or 2500-volt motor-driven or rectifier-operated instrument is recommended for optimum test results. Operating machines should be tested immediately following shutdown when the windings are hot and dry. On large machines, the temperature should be recorded and converted to a base temperature in accordance with ANSI/IEEE 43, *Recommended Practice for Testing Insulation Resistance of Rotating Machinery*, to provide continuity for comparative purposes. Voltage sources, lightning arresters, and capacitors or other potential low-insulation sources should always be disconnected before making insulation measurements. Lead-in cables or buses and line side of circuit breakers or starters can be tested as a part of the circuit provided a satisfactory reading is obtained. If the insulation resistance is below the established minimum, the circuit components should be tested separately until the low insulation reading is located. Insulation-resistance history based on tests conducted on new motors or after rewind, cleaning, or from recorded data made under uniform conditions form a very useful basis for interpretation of a machine winding condition. When comparing records of periodic tests, *any persistent downward trend is an indication of insulation trouble* even though the values might be higher than the recommended minimum safe values listed below.

Table 20.19 Summary of Maintenance Tests for Insulating Liquids

Test for:	ASTM Method of Test	Test Limits for Maintenance	Typical New Liquid Value
Acidity, approximate	D 1534-90	Same as neutralization number	Below
Color	D 1500-91 (1968) (petroleum oils) (Also for maintenance testing of askarel)	4.0 max. (oil) 2.0 max. (askarel)	1.0 max. (oil and askarel)
Dielectric breakdown voltage	D 877-87 (disk electrodes) or D 1816-REV A-84 (VDE electrodes)	22 kV min. (oil) 25 kV min. (askarel)	26 kV (oil) 30 kV (askarel)
Examination, visual, field	D 1524-84 (petroleum oils)	Cloudy, dirty, or visible water	Clear
Interfacial tension (oil only)	D 971-91 (1968) (ring method) or D 2285-85 (drop weight)	18 dynes/cm min.	35 dynes/cm min.
Neutralization number	D 974-92 (1968) or D 664-89	0.40 max. (oil) (askarel)*	0.04 max. (oil) 0.014 max. (askarel)
Power factor	D 924-92 (1969)	1.8% max. (oil) 0.5–2.0% (askarel)	0.1% max. (25°C) (oil) 0.2–0.5% max. (25°C) (askarel)

*Replace for any value greater than 0.014.

20.20.1.2 Insulation-resistance readings taken for purposes of correlation should be made at the end of a definite interval following the application of a definite test voltage. For purposes of standardization, 60-second applications are recommended where short-time single readings are to be made on windings and where comparisons with earlier and later data are to be made. Recommended minimum acceptable insulation values without further investigation are as shown in Table 20.20.1.2.

Table 20.20.1.2 Rotating Machine Insulation Testing

Rotating Machinery Voltage	Insulation Resistance (at 40°C)
1000 volts and below	2 megohms
Above 1000 volts	1 megohm per 1000 volts plus 1 megohm

20.20.2 Dielectric-Absorption Testing. A more complete and preferred test applies the voltage for 10 minutes or more to develop the dielectric-absorption characteristic. The curve obtained by plotting insulation resistance against time gives a good indication of moist or dirty windings. A steady rising curve is indicative of a clean, dry winding. A quickly flattening curve is the result of leakage current through or over the surface of the winding and is indicative of a moist or dirty winding. If facilities are not available for a 10-minute test, readings can be taken at 30 seconds and 60 seconds. The ratio of the 60-to-30-second or the 10-to-1-minute ratio will serve as an indication of the winding condition. Table 20.20.2 should serve as a guide in interpreting these ratios.

Table 20.20.2 Dielectric-Absorption Testing

Condition	60:30-Second Ratio	10:1-Minute Ratio
Dangerous	—	Less than 1
Poor	Less than 1.1	Less than 1.5
Questionable	1.1 to 1.25	1.5 to 2
Fair	1.25 to 1.4	2 to 3
Good	1.4 to 1.6	3 to 4
Excellent	Above 1.6	Above 4

20.20.3 Over-Potential Testing.

20.20.3.1 Overvoltage tests are performed during normal maintenance operations or after servicing or repair of important machines. Such tests, made on all or parts of the circuit to ground, ensure that the insulation level is sufficiently high for continued safe operation. Both ac and dc test equipment are available. There is no conclusive evidence that one method is preferred over the other. However, where equipment using several insulating materials is tested, ac stresses the insulation more nearly to actual operating conditions than dc. Also, more comparable data have been accumulated since ac testing has had a head start. However, the use of dc has several advantages and is rapidly gaining favor with increased usage. The test equipment is much smaller, lighter in weight, and lower in price. There is far less possibility of damage to equipment under test, and dc tests give more information than is obtainable with ac testing.

20.20.3.2 The test overvoltages that should be applied will depend on the type of machine involved and the level of reliability required from the machines. However, the overvoltage should be of sufficient magnitude to search out weaknesses in the insulation that might cause failure. Standard overpotential test voltage when new is twice rated voltage plus 1000 volts ac. On older or repaired apparatus, tests are reduced to approximately 50 to 60 percent of the factory (new) test voltage. *(See ANSI/IEEE 4, Standard Techniques for High Voltage Testing.)* For dc tests, the ac test voltage is multiplied by a factor (1.7) to represent the ratio between the direct test voltage and alternating RMS voltage. *(See ANSI/IEEE 95, Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage.)*

20.20.3.3 A high-potential test made to determine the condition of the insulation up to a predetermined voltage level is difficult to interpret. It is common practice to compare known good results against test specimens to determine what is acceptable and what fails the test. For a dc high-potential test, the shape of the leakage current plotted against voltage rise is an additional used criterion.

20.20.3.3.1 As long as the knee of the curve [which indicates impending breakdown (point c in Figure 20.20.3.3.1)] does not occur below the maximum required test voltage, and as long as the shape of the curve is not too steep compared with that of similar equipment or prior test of the same equipment, the results can be considered satisfactory. It should be recognized that if the windings are clean and dry, overvoltage tests will not detect any defects in the end turns or in lead-in wire located away from the stator iron.

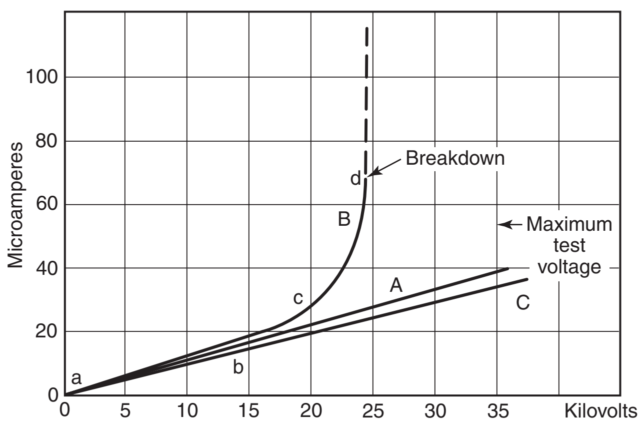


FIGURE 20.20.3.3.1 High-Potential Test.

20.20.4 Surge-Comparison Testing.

20.20.4.1 Surge-comparison testing can detect turn-to-turn, coil-to-coil, group-to-group, and phase-to-phase winding flaws that cannot be detected by insulation-resistance, dielectric-absorption, or over-potential testing. Surge testing should not be undertaken until after the integrity of insulation to ground has been verified.

20.20.4.2 The surge testing principle is based on the premise that the impedances of all 3-phase windings of a 3-phase machine should be identical if there are no winding flaws. Each phase (A/B, B/C, C/A) is tested against the others to determine if there is a discrepancy in winding impedances.

20.20.4.3 The test instrument imposes identical, high-voltage, high-frequency pulses across two phases of the machine. The reflected decay voltages of the two windings are displayed and captured on an oscilloscope screen. If the winding impedances are identical, the reflected decay voltage signatures will coincide and appear on the screen as a single trace. Two dissimilar traces indicate dissimilar impedances and a possible winding flaw. *(See Figure 20.20.4.3.)*

20.20.4.4 The testing and interpretation of results should be conducted by a trained individual.

20.20.5 Other Electrical Tests. There are several other types of tests, depending on the need and desired results listed below. These more complex tests, however, are not employed unless apparatus performance indicates these tests should be made and experienced testers are available with the test equipment.

(1) Turn-to-turn insulation
(2) Slot discharge and corona

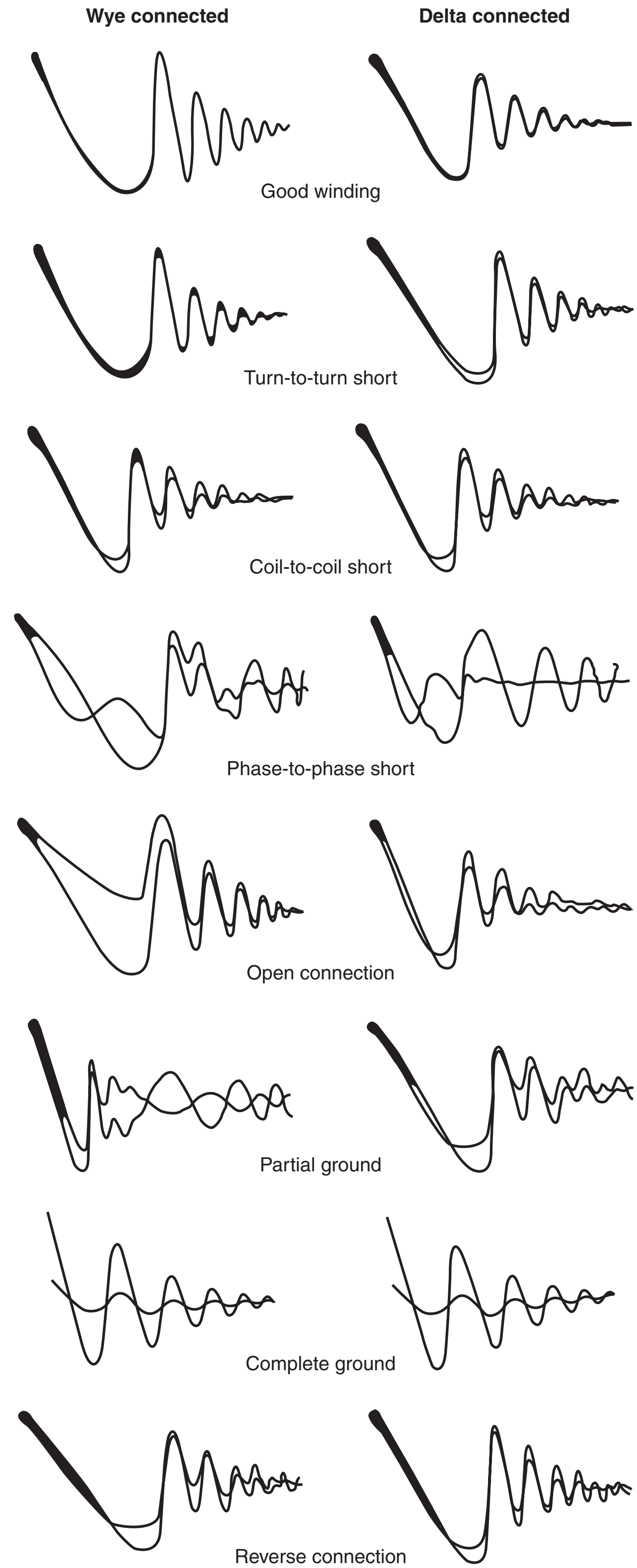


FIGURE 20.20.4.3 Wave Shapes for Winding Faults.

(3) Winding impedance test
(4) Power-factor value
(5) Core loss test

20.20.6 Vibration Testing. Chapter 28 contains information on common methods of measuring vibration.

20.21 Three-Phase Four-Wire Neutral-Current Testing.

20.21.1 Situations exist where it is possible for the neutral current of three-phase systems to exceed the ampacity of the neutral conductor in normal operation. This is usually due to unbalanced phase loading, nonsinusoidal load currents (harmonics), or a combination of the two.

20.21.1.1 There are certain conditions where even perfectly balanced loads result in significant neutral currents. Nonlinear loads, such as rectifiers, computers, variable speed drives, electrical discharge lighting fixtures, and switching mode power supplies, cause phase currents that are not sinusoidal.

20.21.2 Symptoms of a nonsinusoidal condition might be overheating of the neutral conductor, deterioration of conductor insulation, carbonized insulation, and measurable voltage between the neutral and ground conductors (common-mode noise). This condition can cause a fire or malfunction of microprocessor-based equipment.

20.21.3 The neutral current problem can be detected using a true RMS ammeter to measure the current flowing in the neutral conductor. The use of an average responding ammeter calibrated to read the RMS value of a sine wave should not be used, as it will not yield valid results when used on nonsinusoidal waveforms. If the neutral current is found to be excessive, the current in each phase should be measured to determine if an abnormal condition exists. If excessive neutral current exists and the phase currents are not excessive, harmonic content is the most likely cause. A means of analyzing neutral current containing harmonic components is through the use of a wave or spectrum analyzer. Most analyzers on the market today have the ability to provide a direct readout of the harmonic's magnitude.

20.21.4 Verification should be made that the neutral is bonded to the grounding electrode conductor only at the service and at each separately derived source, where used.

20.22 Adjustable Speed Drive Testing. Detailed test procedures should be obtained from the manufacturer. Adjustable speed drives (ASDs) are frequently referred to by other names and acronyms such as variable frequency drives (VFDs) and adjustable frequency drives (AFDs). The following are, at a minimum, routine tests that can be performed on an adjustable speed drive:

(1) Measure currents and voltages, checking for balance and proper levels.
(2) Using an oscilloscope, check firing signals for proper waveform.
(3) Test for proper output of printed circuit board power supplies.
(4) Test manual and automatic reference signals.

CAUTION: If an adjustable speed drive has been de-energized for more than a year, bring the output voltage and frequency up very slowly (typically 10 percent of rated output voltage per 15 minutes) so as to avoid capacitor failure.

Chapter 21 Maintenance of Electrical Equipment Subject to Long Intervals Between Shutdowns

21.1 Introduction.

21.1.1 Due to the more extensive and costly damage possible from electrical failures in continuous-process operations, plus the longer intervals between shutdowns, more thorough and comprehensive maintenance procedures are recommended. The need for and frequency of inspection and maintenance is determined by the effect on safety, plant operation, and severity of service.

21.1.1.1 The primary effects of electrical failure or malfunction are those directly associated with the failure and usually involve the damage to electrical equipment. The secondary effects are those associated with the process or product. Damages resulting from secondary effects can be much more extensive and, in some cases, catastrophic.

21.1.2 In addition to more intensive maintenance procedures, this chapter will cover system design considerations insofar as they relate to safety and maintainability as well as first and future costs.

21.2 General Aspects of Maintaining Medium- and Low-Voltage Distribution Systems.

21.2.1 Unless an electrical distribution system is adequately engineered, designed, and constructed, it will not provide reliable service, no matter how good the maintenance program. Therefore, the following recommendations are much more essential for electrical distribution systems that supply production equipment that can operate for long periods between shutdowns:

(1) Careful planning in the engineering and design stages to permit maintenance work without load interruptions. Alternate electrical equipment and circuits should be provided to permit routine or emergency maintenance on one while the other supplies the load that cannot be shut down. For instance, automatic or manual transfer equipment will permit the load to be switched, with minimal interruption, from a source of circuit that fails to one that is operating.
(2) High-quality equipment that has sufficient capacity and features that permit reasonable inspection of the energized parts while in operation without hazard to an inspector using proper precautions. Viewing windows or expanded metal guards inside hinged doors provide a safe means for inspecting energized components inside enclosures. Complete barriers between adjacent switch and breaker sections, and so on, will permit personnel to work safely inside a de-energized compartment while adjacent ones are energized. Close inspection of the equipment before shipment is the best way to certify compliance with specifications.
(3) Strict adherence to construction specifications complete with detailed drawings and installation procedures.
(4) Close scrutiny during all phases of construction. This is essential to ensure adequate quality workmanship and that cables, insulating materials, and other components are not damaged by poor practices.
(5) Acceptance testing (in accordance with applicable recognized standards), including functional testing and inspection. These tests are valuable to detect equipment that is defective, badly damaged, or installed in an inferior manner. In addition, reinspection and retesting within one or two years after energization might reveal conditions that can lead to in-service failures.

21.2.2 After these prerequisites are satisfied, an adequate EPM program will help to keep the system in good condition and provide the necessary reliability over a long period.

21.2.3 Maintenance, inspection, and test methods for equipment that can operate for long periods are essentially the same as for equipment that might be shut down frequently. However, the recommended work should be performed with more care and diligence to obtain the desired reliability for service to loads that can operate continuously for months or years.

21.2.4 The following should effect an adequate EPM program for reliable long-term operation of an electrical power system:

(1) Good knowledge of the entire power system by all associated personnel. Posted or readily available diagrams, procedures, and precautions are highly beneficial aids in keeping personnel knowledge up to date.
(2) General understanding of the loads served and their electrical quality and continuity of service requirements.
(3) Length of time between scheduled maintenance shutdowns for utilization equipment, process changes, and so on, that will influence the length of intervals between electrical power system maintenance shutdowns.
(4) A complete list of all the electrical system equipment associated with a given process or manufacturing system to ensure that all of it is maintained during one shutdown instead of doing it piecemeal, which would require additional shutdowns.
(5) The amount of time during the utilization equipment shutdown when the electrical power system can be deenergized for EPM.
(6) Knowledge of electrical power system components, including operating and maintenance data. This information is often included in the manufacturers' maintenance instructions.
(7) Knowledge of ambient conditions, such as heat, moisture, and vibration, that can affect the equipment.
(8) Ability to recognize abnormal conditions and early evidence of potential problems, such as overheating and surface tracking on insulating materials, that can cause failure if not corrected in sufficient time.
(9) Standardized maintenance procedures shown in other portions of the text, modified by the above information and knowledge gained through experience.
(10) Knowledge of services available from local, area, and national electrical maintenance contractors that have specialized test equipment and highly qualified personnel who routinely perform this work. Some of the items that fall into this category are relay calibration and testing, circuit-breaker overcurrent trip-device calibration and testing, high-potential testing, power-factor testing, insulating-liquid testing and reconditioning, switchgear maintenance and testing, maintenance and testing of solid-state devices; and infrared inspection.

21.2.4.1 Unless the amount of specialized work is sufficient to keep plant electrical maintenance personnel adept in the performance of such work, the use of specialized electrical maintenance contractors should be considered. However, plant maintenance supervision should have sufficient electrical knowledge to decide with the contractor on the recommended work to be done and to closely follow his or her performance to ensure full compliance. Merely telling a contractor to maintain or test the equipment usually creates a false sense of security that can be shattered by a serious failure caused by inadequate or incorrect maintenance procedures. The result is often the same when plant supervision does not sufficiently instruct plant maintenance personnel.

21.2.5 When a piece of equipment or component fails, merely making repairs or replacement is not sufficient. A complete analysis should be made to determine the cause and to formulate corrective action to prevent recurrence in the same and similar equipment.

21.2.5.1 Following is a list of equipment for which maintenance, inspection, and testing guide tables are located in Annex H. The material contained therein is of a general nature and might have to be revised to conform more closely to the equipment being maintained to ensure the coverage necessary for the required reliability. Experience has indicated that the frequencies of maintenance, and so on, shown in the tables are sufficient for most installations. They might have to be tailored to suit installations where the ambient conditions are more or less severe.

(1) Medium-voltage equipment (over 1000 volts)
    (a) Cables, terminations, and connections
    (b) Liquid-filled transformers
    (c) Dry-type transformers
    (d) Metal-clad switchgear
    (e) Circuit breakers
    (f) Metal-enclosed switches
    (g) Buses and bus ducts
    (h) Protective relays
    (i) Automatic transfer control equipment
    (j) Fuses
    (k) Lightning arresters
(2) Medium- and low-voltage equipment
    (a) Outside overhead electric lines
(3) Low-voltage equipment (below 1000 volts)
    (a) Low-voltage cables and connections
    (b) Dry-type transformers
    (c) Switchgear
    (d) Drawout-type circuit breakers
    (e) Buses and bus ducts
    (f) Panelboards
    (g) Protective relays
    (h) Automatic transfer control equipment
    (i) Circuit-breaker overcurrent trip devices
    (j) Fuses
    (k) Lightning arresters

21.3 Utilization.

21.3.1 General.

21.3.1.1 The utilization of electrical energy in industry is the conversion of electrical energy into useful work such as mechanical operations, lighting, and heating. Of primary concern is the maintenance of the many kinds of utilization equipment used with processes that operate for long intervals between shutdowns. Utilization equipment as covered here is considered to operate at 480 volts and less.

21.3.1.2 Chapters 6 and 7 make reference to the need for planning and developing an EPM program and describe some of the fundamentals. Utilization equipment that serves equipment that operates for long intervals between shutdowns should receive special consideration. The serviceability and safety of the equipment should be thoroughly studied. During the initial design stages, thought should be given to EPM, with ease of maintenance and accessibility being of extreme importance in the design considerations and emphasis on access for adequate visual and infrared inspection of all bus bars and joints.

21.3.1.3 Maintenance personnel who are going to service the equipment should be consulted during the design phases.

21.3.2 Records and Inspection Tours.

21.3.2.1 Keeping records on utilization equipment that operates over long intervals is more important than for short-interval equipment. Wiring changes, parts replacement, and other modifications should all be accurately recorded.

21.3.2.2 Schedules should be laid out for periodic inspection tours of utilization equipment. Records of findings on these inspection tours will help to indicate trends. Another important reason for good record keeping is that personnel often change, and it is necessary for those presently involved to know what has been done prior to their involvement.

21.3.2.3 Power and lighting panel directories should be kept up to date and accurate.

21.3.3 Power-Distribution Panels.

21.3.3.1 Power-distribution panels are either fuse- or circuit-breaker-type. Where critical circuits are involved, power-distribution panels should be appropriately identified by tags, labels, or color coding.

21.3.3.2 Seldom are power panels de-energized, and then only for circuit changes; it is at this time that EPM can be scheduled. Although procedures can be developed for working on them live, it is not recommended because of the safety hazards involved. There is always the possibility of an error or accidental tripping of a main breaker causing an unscheduled shutdown. During operating periods, the panels can only be checked for hot spots or excessive heat. This EPM should be done at a reasonable interval in accordance with the importance of the circuit. A record should be made of areas that have given trouble; memory should not be relied on.

21.3.3.3 During a shutdown and while the panel is dead, all bolted connections should be checked for tightness and visually inspected for discoloration. Should there be discoloration, further investigation should be made and possibly the parts affected replaced. *(For further information, refer to Chapters 13 and 15.)*

21.3.4 Lighting Panels. Lighting panels generally have the same problems as power panels. However, experience indicates an increased probability of circuit overloading and thus protective-device overheating. Since such panels applied in long-term maintenance areas usually feed important circuits, overheating problems should be corrected immediately.

21.3.5 Plug-in-Type Bus Duct. Since plug-in bus duct is seldom used in long-term areas, maintenance of this equipment will not be covered here. *(Refer to Chapters 11, 13, and 15 for related information.)*

21.3.6 Wiring to Utilization Equipment. Maintenance procedures outlined in Chapter 10 are recommended. The visual inspection interval should be based on the importance of the circuits and on previous experience. In addition, more extensive insulation testing might be warranted during shutdown periods to ensure higher reliability.

21.3.7 Rotating Equipment.

21.3.7.1 Proper maintenance of electric motors and rotating equipment is essential to prevent unscheduled downtime. Their most trouble-prone parts are bearings. The quantity of lubricant, the frequency of lubrication, the method of application, and the type of lubricant are of prime concern. Although lubrication of rotating equipment is discussed in Chapter 16, it is important enough with equipment that operates for long periods between shutdowns, and especially motors, that further mention is made here. Suggestions for both oil and grease lubrication systems are listed in 21.3.7.2 through 21.3.7.8.

21.3.7.2 Grease Lubrication Systems. Grease is the most common lubricant used for electric motor bearings. It provides a good seal against the entrance of dirt into the bearing, has good stability, is easy to apply, and is easy to contain without elaborate seals. For extended service intervals, an extremely stable grease is required. Grease should be selected on the basis of the expected temperature range of service. The motor manufacturer can provide advice on exactly which grease to use. A grease that is compatible with the grease already in the bearing should be used.

21.3.7.3 Regreasing. The correct quantity of lubricant in a rolling contact bearing is vital to its proper operation. Either insufficient or excessive lubrication will result in failure. Excessive lubrication can cause motor failure due to migration of grease into the motor winding. Table 21.3.7.3 will serve as a guide in determining regreasing intervals by the type, size, and service of the motor to obtain the most efficient operation and the longest bearing life. Where a variety of motor sizes, speeds, and types of service are involved in a single plant, a uniform relubrication period is sometimes selected. A yearly basis is common, for instance, and such a yearly regreasing might conveniently be carried out on a plantwide basis during a vacation shutdown.

21.3.7.3.1 Motors equipped with grease fittings and relief plugs should be relubricated by a low-pressure grease gun using the following procedure:

(1) The pressure-gun fitting and the regions around the motor grease fittings should be wiped clean.
(2) The relief plug should be removed and the relief hole freed of any hardened grease.
(3) Grease should be added with the motor at standstill until new grease is expelled through the relief hole. In a great majority of cases it is not necessary to stop the motor during relubrication, but regreasing at standstill will minimize the possibility for grease leakage along the shaft seals.
(4) The motor should be run for about 10 minutes with the relief plug removed to expel excess grease.
(5) The relief plug should be cleaned and replaced.

21.3.7.4 Regreasing of Totally Enclosed Fan-Cooled (TEFC) Motors. For totally enclosed, fan-cooled motors, the above instructions apply for greasing the drive-end bearing. The fan-end housing is frequently equipped with a removable grease relief pipe that extends to the outside of the fan casing. First, the pipe should be removed, cleaned, and replaced. Next, during the addition of new grease from a grease gun, the relief pipe should be removed several times until grease is observed in the pipe. After grease is once observed to have been pushed out into this pipe, no more should be added. The pipe, after again being cleaned and replaced, will then act as a sump to catch excess grease when expansion takes place during subsequent operation of the motor.

Table 21.3.7.3 Guide for Maximum Regreasing Periods

Type of Service	Motor Horsepower			
	Up to 7½	10–40	50–150	Over 150
Easy: infrequent operation (1 hr per day), valves, door openers, portable floor sanders	10 yr	7 yr	4 yr	1 yr
Standard: 1- or 2-shift operation, machine tools, air-conditioning apparatus, conveyors, garage compressors, refrigeration apparatus, laundry machinery, textile machinery, wood-working machines, water pumping	7 yr	4 yr	1½ yr	6 mo
Severe: motors, fans, pumps, motor generator sets, running 24 hr per day, 365 days per year; coal and mining machinery; motors subject to severe vibration; steel-mill service	4 yr	1½ yr	9 mo	3 mo
Very severe: dirty, vibrating applications, where end of shaft is hot (pumps and fans), high ambient	9 mo	4 mo	3 mo	2 mo

21.3.7.4.1 In many vertical motors, the ball-bearing housing itself is relatively inaccessible. In such cases, a grease relief pipe is frequently used in a manner similar to that in the totally enclosed, fan-cooled motors. The same regreasing procedures should be used as described above for the TEFC motors.

21.3.7.4.2 Motors with sealed bearings cannot be relubricated.

21.3.7.5 Regreasing of Small Motors. In many small motors, no grease fittings are used. Such motors should be relubricated by removing the end shields, cleaning the grease cavity, and refilling three-quarters of the circumference of the cavity with the proper grade of grease. In the end shields of some small motors, threaded plugs are provided that are replaceable with grease fittings for regreasing without disassembly.

21.3.7.5.1 Because regreasing of motor bearings tends to purge the old grease, a more extensive removal of all the used grease is seldom necessary. Whenever a motor is disassembled for general cleaning, however, the bearings and housing should be cleaned by washing with a grease-dissolving solvent. To minimize the chance of damaging the bearings, they should not normally be removed from their shaft for such a washing. After thorough drying, each bearing and its housing cavity should be filled approximately one-half to three-fourths full with new grease before reassembly. Spinning the bearing with an air hose during cleaning should be avoided. Any bearing that has been removed from the shaft by pulling on the outer ring should not be reused.

21.3.7.6 Oil Lubrication Systems. Oil lubrication is recommended when a motor is equipped with sleeve bearings. It is sometimes used for roller contact bearings under certain conditions.

21.3.7.6.1 Oils for lubricating electrical motors should be high-quality circulating oils with rust and oxidation inhibitors.

21.3.7.6.2 The oil viscosity required for optimum operation of motor bearings is determined by the motor speed and the operating temperature.

21.3.7.6.3 In general, it is recommended that 150 S.U.S. oil be used for motor speeds above 1500 rpm, and 300 S.U.S. oil be used for motor speeds below 1500 rpm. These recommendations might vary with specific application and, in particular, with the ambient temperature to which the motor or generator is exposed. The user should refer to and follow the motor manufacturer's recommendations relative to oil viscosity.

21.3.7.7 Methods and Quantity.

(A) Wick Oiling. Fractional horsepower motors that can be relubricated generally use felt, waste, or yarn packing to feed sleeve bearings. The packing should be saturated at each lubrication interval.

(B) Ring Oiling. Integral horsepower motors can have ring-lubricated sleeve bearings. The rings are located in a slot in the upper half of the bearing and ride loosely on the shaft. There are normally no more than two rings for each bearing. Free turning of the rings should be checked on starting a new motor, at each inspection period, and after maintenance work. The oil level should be such that a 60-degree segment of the oil ring on the inside diameter is immersed while the motor shaft is at rest as shown in Figure 21.3.7.7. A sight glass, constant level oiler, or some other unit should be provided to mark and observe the oil level. Levels should be marked for the at-rest condition and the operating condition.

(C) Bath Oiling. Large, vertical motors frequently have a surrounding oil bath for lubrication of either rolling-element bearings or plate-thrust bearings. Horizontal units equipped with ball and roller bearings might also have an oil bath. The proper oil level is determined by the manufacturer and depends on the bearing system. A sight glass or some other unit should be provided to mark and observe the oil level. This level can change depending on whether the motor is operating or at rest. It should be marked for both situations.

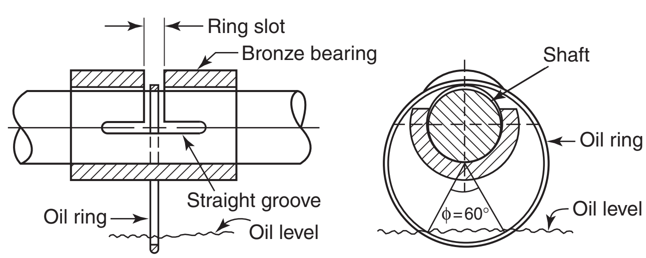


FIGURE 21.3.7.7 Ring Oiling.

(D) Oil-Mist Lubrication. Pressurized oil-mist systems are being increasingly used in refinery applications. These applications normally involve interlocked controls such that the source of mist pressure should be in operation to permit energization of the lubricated motor. Often a single centralized mist source supplies a number of motors. Maintenance should include checking of drain/discharge openings at each bearing to see that pressure can be discharged freely to the atmosphere and that the mist-pressure-regulation equipment is functioning properly.

21.3.7.8 Frequency. In oil-lubricating systems, it is required that the oil level be maintained. This is observed by means of a sight glass, constant level oiler, and so on, and oil should be added as needed. Normally, these systems should be drained and refilled on an annual basis. Wick-oil systems require addition of oil quarterly, and the wick should be saturated.

21.3.7.9 Motor Inspections. Visual inspections should be performed on a periodic basis. These inspections are necessary to detect mechanical or lubrication deficiencies before they become serious. The inspection should include a check for increase in temperature, excessive bearing noise, excessive vibration, and lubricant leakage. If any of these conditions exist, the cause should be located and corrected.

21.3.8 Vibration Tests and Analysis.

21.3.8.1 The life of a ball bearing or roller bearing is defined as the number of revolutions or hours of operation at constant speed that the bearing is capable of running before fatigue develops. If a bearing is properly lubricated, mounted, and handled, all causes of failure are eliminated except one, which is fatigue of the material. These failures initiate with the removal of metal from the races or rolling elements. Vibration-analyzing equipment can be used to predict these failures when it monitors vibration velocity or is able to distinguish vibration displacement as a function of frequency. Such equipment is useful in isolating the source of vibration that might appear to be the result of other malfunctions within a motor. It is also useful for ensuring proper installation of critical production equipment. Anti-friction bearings fail due to a loss of oil film resulting from wear, leakage, and so on. These failures are sudden, and without constant vibration-monitoring equipment, they cannot be predicted.

21.3.8.2 Vibration analyzers are very handy tools to detect trouble and prevent downtime. A formal vibration analysis program can reduce costly machine failures. The program can range from the use of simple hand-held analyzers to sophisticated multi-channel recorders with permanently mounted sensors to provide data for comparison. Such a program makes it possible to keep track of the condition of rotating equipment, particularly high-speed types. Trend charts will assist in establishing maintenance needs. The degree of sophistication depends on the application, but even a hand-held vibrograph is a useful tool in EPM. *(See Chapter 28.)*

21.3.9 Dirt. Where rotating equipment is exposed to dirt, regular inspection is recommended to detect when cleaning is needed. A major cause of burned-out motors is clogged air passages. On motors in dirty atmospheres, filters (where used) frequently become clogged; therefore, filter cleaning or changing should be scheduled. The external surface of motors should be kept cleaned because a pileup of dirt restricts heat dissipation. This is particularly important with T-frame motors. *(Refer to Chapter 16 for cleaning methods.)* In dirty locations and critical applications, more extensive insulation testing might be warranted, as described in Chapter 20. Excessive leakage current might well indicate that a motor failure is imminent.

21.3.10 Control for Rotating Equipment.

21.3.10.1 This involves the motor starters, contactors, and other devices that are directly involved with the control of equipment operating over long periods between shutdowns. The maintenance recommendations of Chapter 11 are pertinent to equipment operating for long periods between shutdowns.

21.3.10.2 While the equipment is in operation, EPM procedures should be modified. Where control panels can be opened while energized, any terminals with a voltage greater than 150 volts to ground should be covered with a transparent protective covering to permit visual inspection. Essentially, EPM will be limited to visual inspection. Maintenance of adequate ventilation should be ensured within enclosures. Gaskets should be kept in good repair where used and where the atmosphere is dirty. Contact wear should be observed where possible.

21.3.11 Redundancy. Although it is expensive, redundant circuits and equipment are often necessary to ensure continuity of operation. During initial design stages, and even at later times, consideration should be given to what is needed to prevent unscheduled shutdowns and high maintenance costs. Frequently, redundancy of critical circuits provides the solution.

21.3.12 Heating Equipment.

21.3.12.1 In general, this equipment cannot be maintained while it is in operation. Perhaps rotating parts are not involved, but certainly there is heat, and the potential for serious burns therefore exists.

21.3.12.2 In most process-heating systems, continuous cycling or on-off operation is carried out. This cycling will cause a certain amount of temperature change. As a result, particular attention should be paid to all connections and joints. The use of Belleville washers has been successful in maintaining tight connections. During the time the equipment is in operation, visually inspect all joints and terminations and look for signs of heating or arcing that would indicate loose joints. The cycling frequently will cause some movement of the wiring; therefore, check the insulation on the wiring where it passes through nipples, access holes, and other openings.

21.3.13 Electrostatic Discharge (ESD) Grounding.

21.3.13.1 The purpose of ESD grounding is to remove the accumulation of static electricity that can build up during machine operation on equipment, on materials being handled or processed, or on operating personnel. On equipment that is in continuous operation, regular inspection and repair procedures should be developed and maintained in order to retain the integrity of the grounding path.

21.3.13.1.1 Since the static charge can build up to several thousand volts, consideration should be given during the initial construction of equipment to reduce the buildup. Equipment is made up of conductors (metal machine frame) and insulators (conveyor belts, plastic parts, and so on). Usually some part of a machine is grounded either electrically or by virtue of construction. Machine parts can be grounded directly or by bonding them to other machine parts that are grounded. Clean, unpainted metal nuts and bolts holding together clean, unpainted metal parts provide adequate continuity. Bonding and grounding can be accomplished by permanently attached jumper wires. When such wires are attached by lugs or placed under bolt heads or nuts, all parts should be clean and unpainted before installation. Any painting of parts used for ESD grounding should be done only after such parts are properly installed and the adequacy of the ground is verified. Slowly rotating parts are normally adequately bonded or grounded through the bearings. However, parts rotating at high RPMs, such as baskets or centrifuges, should be bonded or grounded by wipers, carbon brushes, or other devices. Portable equipment can be temporarily grounded by clamping an ESD ground to the equipment.

21.3.13.2 Adequate ESD Grounding. It might be necessary to obtain the recommendations of experts in a particular ESD grounding problem. However, some guidelines that will provide adequate ESD grounding are listed as follows.

(1) Static electrical charging currents rarely exceed one microampere and often are smaller. Thus, leakage currents of the order of microamperes will provide protection against the accumulation of static electricity to dangerously high potentials.
(2) A leakage resistance between a conductor and ground as high as 10,000 megohms will provide adequate ESD grounding in many cases. However, when charges are generated rapidly, a leakage resistance as low as one megohm might be necessary.
(3) The leakage resistance necessary for adequate ESD grounding will vary among different operations and should be established by a qualified authority. In the absence of any specifications, the leakage resistance from any conductor to ground should not exceed one megohm.
(4) There is no electrical restriction in conductor size for ESD ground wires and jumpers, but larger size conductors might be necessary to limit physical damage. However, where the equipment-grounding conductor for a power circuit is also used for ESD grounding, the conductor should be sized in accordance with Table 250-122 of NFPA 70, *National Electrical Code.* Any equipment-grounding conductor that is adequate for power circuits is more than adequate for static grounding.
(5) An ESD ground wire need not be insulated.

21.3.13.3 Inspection and Maintenance. An inspection and maintenance program is essential in ensuring that the integrity of ESD grounding systems is retained. Inspections should consist of both resistance measurements and a visual check.

21.3.13.3.1 The resistance from all conductive parts to ground should be measured with a suitable megohmmeter (*see 21.3.13.5*). Corrective measures should be made to bring all resistance values within specifications.

21.3.13.3.2 A visual inspection should be made for frayed wires, wires with broken strands, and other physical damage. Such damage should be repaired regardless of measured resistance values.

21.3.13.4 Inspections should be made of all new installations and whenever alterations are made to or parts replaced in an installation. Inspections should be made at regular intervals. The frequency of regular periodic inspections can be determined from experience. Inspections should be most frequent in areas where corrosion is a problem and in areas classified as hazardous.

21.3.13.5 Megohmmeters. A suitably calibrated resistance-measuring device having a nominal open-circuit output voltage of 500 volts dc and a short-circuit current not exceeding 5 mA should be used to check static grounding systems.

21.3.13.6 Hazardous Locations. If the inspections are made in hazardous (classified) locations, the area should be verified nonhazardous if the megohmmeter is not of an intrinsically safe type. The area should be verified as non-hazardous during the testing period when a megohmmeter is used.

21.3.13.7 Record Keeping. Precise records should be made and retained of the results of all inspections and of the corrective actions taken. Precise records will aid in determining the necessary inspection frequency and point out weak spots in the static grounding system that might need modification.

21.3.13.8 Precautions During Inspections. If inspections and corrective measures have to be made when flammable vapors are apt to be present, certain precautions should be taken by the inspector and maintenance personnel, as follows:

(1) Care should be taken that personnel are adequately grounded to prevent a dangerous accumulation of static electricity on their bodies.
(2) Care should be taken that no spark discharge occurs between improperly grounded conductors and personnel, instrumentation, or tools.
(3) Only nonferrous, nonsparking tools should be used in the area.

21.3.13.9 Typical Checkpoints for Inspection. All conductors in a hazardous area should be inspected for adequate static grounding.

21.3.13.9.1 Since machines and operations differ considerably, a checklist should be prepared of all points to be checked.

21.3.13.9.2 The following are typical for many machines and operations:

(1) Permanently installed jumper wires
(2) Static ground wires and clamps used for the temporary grounding of portable and mobile equipment
(3) Metal hose couplings
(4) Metal hose clamps
(5) Metal bolts and nuts used to connect sections of either conductive or nonconductive pipes and ducts
(6) All sections of metal pipes and ducts
(7) Rotating parts and shafts
(8) Rotating baskets of centrifuges
(9) Handles and stems of ball valves and plug valves

21.3.13.9.3 All rotating parts should be checked for the accumulation of electrical charge while in motion.

21.4 Process Instrumentation and Control.

21.4.1 Introduction. The following systems and equipment are covered by this section: power supplies; interlock and logic systems; safety and shutdown systems; sensing, control, and indicating systems; and alarm systems.

21.4.2 Design to Accommodate Maintenance.

21.4.2.1 Section 7.1 of this recommended practice stated that, except for limited visual inspection such as observing operating temperatures, examination for contamination, recording load readings, and so on, the apparatus should be taken out of service to perform an efficient and effective maintenance. Further, unless flexibility is built into the system in the way of duplication or alternate transfer schemes, maintenance of vital electrical apparatus should be scheduled with planned production outage.

21.4.2.2 The importance of identifying and designing for the vital elements of the process control system cannot be overstressed. The elements of the process instrumentation and control system that should be inspected, tested, or maintained while the plant or process remains in operation should be identified in the design stage. The necessary duplication of facilities and provision for test and inspection should be provided.

21.4.2.3 Examples of such provisions are alternate power sources to permit shutdown and inspection of normal power sources, bypass switches for inverters, provisions for on-stream function testing of shutdown circuits, provision of dual sensing components for critical controls, test circuits to permit simulation of alarm conditions, and monitoring devices for important interlock and logic systems. Selection of quality equipment is also mentioned in Section 7.1 as a means of reducing maintenance requirements. Again, the importance of long-run facilities cannot be overemphasized.

21.4.2.4 Whenever possible, control modules should be plug-in type, replaceable with normal precautions and procedures. Test and adjustment of major components should be possible without disconnection or removal from enclosures and with use of standard instruments such as volt-ohm-milliammeter and oscilloscope.

21.4.2.5 Cabinets should be fully compartmented to allow maintenance access to sections not in service without risk to personnel or continuity of service. For instance, the inverter, standby transformer/voltage regulator, and transfer-switch power supply should be in physically separate compartments. Removal or replacement of components in one cabinet section should not require access to other sections.

21.4.3 Power Supplies.

21.4.3.1 Power supplies can be divided into two categories: power supplies normally in service and standby or emergency power supplies.

21.4.3.2 Power supplies that are normally in service should be inspected on a regular basis. This inspection should include the following typical checks and inspections:

(1) Reading of meters to detect changes in or abnormal load or voltage conditions
(2) Check of ground detection equipment for presence of grounds
(3) Integrity of trip and transfer circuits where monitoring lights are provided
(4) State of charge on batteries
(5) Battery charger supply and output load and voltages
(6) Visual inspection of accessible current-carrying parts for signs of overheating
(7) Check on equipment environment for heat, moisture, or dust that exceeds the conditions for which the equipment is designed

21.4.3.3 The inspection interval can be daily, weekly, or monthly, depending on equipment environment and operating conditions. Tasks such as reading of meters and checks on monitoring lights can be incorporated as part of a daily walk-through inspection.

21.4.3.4 Where redundancy in facilities is provided, equipment components should be taken out of service for a thorough inspection and testing and for any recommended maintenance at intervals dictated by service and operating conditions. The initial interval should be in line with manufacturers' recommendations and later shutdowns scheduled in line with the as-found condition of the equipment.

21.4.3.5 Where power supply components are in standby or emergency service, periodic testing should be carried out to ensure that the standby equipment is ready to function and can assume the supply function. This requires periodic startup of emergency generators, operation of auto-transfer switches, etc. Testing should simulate actual operating conditions as closely as possible. For critical facilities, testing intervals such as once a week are suggested.

21.4.3.6 Where it is possible to put critical standby facilities in operation to supply the normal load without disturbing plant operations, the standby facilities should be switched in at regular intervals and operated for a sufficient period to ensure they are functioning properly. An interval of once a month is suggested for operating standby facilities. Where standby facilities are fully rated, they are permitted to share operating time on an equal basis with the normal supply.

21.4.4 Interlock and Logic Systems.

21.4.4.1 Maintenance procedures on interlock and logic systems are limited to visual inspections of components and wiring and checks on monitoring devices unless design features permit onstream functional testing. Also, in some plants, the process operation or equipment arrangement permits periodic function testing.

21.4.4.2 Where functional testing can be done and where the system does not function during normal operations, once-a-week function testing is suggested for systems whose failure can result in hazard to personnel, fire, damage to equipment, or serious degradation or loss of product. Systems of lesser importance should be tested initially on a once-per-month basis with subsequent testing intervals determined by experience and assessment of operating environment.

21.4.5 Sensing, Indicating, and Control Systems.

21.4.5.1 The need for and frequency of inspection and maintenance is determined by the effect on safety, plant operations, and the severity of service. Also, some components can be readily isolated while others can be inspected only during plant or process shutdowns.

21.4.5.2 Visual inspection either by plant operators during normal operations or as part of a scheduled inspection can assist in detection of deficiencies such as loose connections, overheating, and excessive vibration.

21.4.5.3 Sensing, indicating, and control devices can be divided into two categories:

(1) *Primary Elements.* Elements in contact with the process medium directly or indirectly and that might or might not be isolated from the process medium.
(2) *Secondary Elements.* Transmitting, recording, or controlling devices. Some are normally in use and, through this use, are receiving an automatic day-to-day check. Some are remotely located or infrequently used and require a check at regular intervals.

21.4.6 Level Devices.

21.4.6.1 Primary devices installed within process vessels can only be checked with the vessel out of service. Visual inspection should indicate need for maintenance.

21.4.6.2 Where the device can be isolated from the process, visual inspection should be made at least once a year and more frequently if extreme accuracy is needed or if the service is severe or critical.

21.4.7 Temperature Devices.

21.4.7.1 Primary devices are generally installed in wells and can be checked at any time the device appears to be malfunctioning. The well should be visually inspected at each plant shutdown and necessary maintenance carried out.

21.4.7.2 The secondary device or instrument can usually be checked at any time without seriously affecting normal operations.

21.4.8 Pressure Devices.

21.4.8.1 Primary devices usually have block valves to permit isolation from the process and checking at any time malfunction is indicated.

21.4.8.2 Secondary devices can usually be isolated from the primary device and checked at any time.

21.4.8.3 Process impulse connections should be checked during equipment shutdown.

21.4.9 Indicating, Recording, and Controlling Signal Receivers. Checks are limited to day-to-day observation of performance by plant operators. Receiver construction usually permits substitution of spare units for faulty units.

21.4.10 Safety and Shutdown Systems.

21.4.10.1 On-line testing facilities for safety and shutdown systems should be provided in all designs. Where practical, the facilities should include multiple sensors and safe bypass systems around the final control element. This permits testing of the entire shutdown circuit.

21.4.10.2 Safety and shutdown circuits should be tested in the range of once-per-shift to once-per-week unless the circuit functions regularly in normal operation. This might be the case for some shutdown circuits.

21.4.10.3 Because of the frequency of testing, these functional tests might be part of the plant operators' normal duties with maintenance personnel involved only if problems are indicated.

21.4.11 Alarm Systems.

21.4.11.1 Alarm systems are usually equipped with lamp test switches that permit checking lamp and alarm circuit integrity at any time during normal operation. These tests should be made on a once-per-shift to once-per-day basis to detect lamp burnout or circuit defects in alarms that operate infrequently. This can be done as part of the plant operators' normal duties with maintenance personnel involved only if further attention is needed.

21.4.11.2 Alarms for critical conditions that can result in hazard to personnel, fire, equipment damage, or serious degradation or loss of product should be function-tested at regular intervals. A once-per-week to once-per-month interval is suggested depending on the importance and vulnerability of the alarm devices to hostile environments. Function testing requires that either provision be made in the system design for the testing facilities or that it be possible to test by manipulating the process variable or otherwise simulate the alarm conditions.

21.4.12 Wiring Systems. These systems can be visually checked for loose connections, proper grounding and shielding, and signs of deterioration or corrosion. Usually maintenance during plant operation is limited to circuits that malfunction or show evidence of possible malfunction.

Chapter 22 Hazardous (Classified) Location Electrical Equipment

22.1 Types of Equipment. Hazardous location electrical equipment is used in areas that commonly or infrequently contain ignitable vapors or dusts. Designs of hazardous location electrical equipment include explosionproof, dust-ignition-proof, dusttight, purged pressurized, intrinsically safe, nonincendive, oil immersion, hermetically sealed, and other types. Maintenance of each type of equipment requires attention to specific items.

22.2 Maintenance of Electrical Equipment for Use in Hazardous (Classified) Locations.

22.2.1 Electrical equipment designed for use in hazardous (classified) locations should be maintained through periodic inspections, tests, and servicing as recommended by the manufacturer. Electrical preventive maintenance documentation should define the classified area (the class, group, and division specification, and the extent of the classified area) and the equipment maintenance required. Electrical preventive maintenance documentation should identify who is authorized to work on this equipment, where this maintenance is to be performed, and what precautions are necessary. Although repairs to certain equipment should be done by the manufacturer or authorized representatives, inspection and servicing that can be performed in-house should be clearly identified.

22.2.2 Maintenance should be performed only by qualified personnel who are trained in safe maintenance practices and the special considerations necessary to maintain electrical equipment for use in hazardous (classified) locations. These individuals should be familiar with requirements for obtaining safe electrical installations. They should be trained to evaluate and eliminate ignition sources, including high surface temperatures, stored electrical energy, and the buildup of static charges, and to identify the need for special tools, equipment, tests, and protective clothing.

22.2.3 Where possible, repairs and maintenance should be performed outside the hazardous (classified) area. For maintenance involving permanent electrical installations, an acceptable method of compliance can include de-energizing the electrical equipment and removing the hazardous atmosphere for the duration of the maintenance period. All sources of hazardous vapors, gases, and dusts should be removed, and enclosed, trapped atmospheres should be cleared.

22.2.4 Electrical power should be disconnected and all other ignition sources abated before disassembling any electrical equipment in a hazardous (classified) location. Time should be allowed for parts to cool and electrical charges to dissipate, and other electrical maintenance precautions followed.

22.2.5 Electrical equipment designed for use in hazardous (classified) locations should be fully reassembled with original components or approved replacement before the hazardous atmosphere is reintroduced and before restoring power. Special attention should be given to joints and other openings in the enclosure. Cover(s) should not be interchanged unless identified for the purpose. Foreign objects, including burrs, pinched gaskets, pieces of insulation, and wiring, will prevent the proper closure of mating joints designed to prevent the propagation of flame upon explosion.

22.2.6 An approved system of conduit and equipment seals conforming to the requirements of NFPA 70, *National Electrical Code*, and manufacturer's specifications should be maintained. Corrective action should be taken upon maintenance actions that damage or discover damage to a seal. Damage to factory-installed seals within equipment can necessitate replacing the equipment.

22.2.7 Wherever electrical equipment cover bolts or screws require torquing to meet operating specifications, these bolts or screws should be maintained with the proper torque as specified by the manufacturer. Electrical equipment should not be energized when any such bolts or screws are missing. All bolts and screws should be replaced with original components or approved replacements.

22.2.8 Special care should be used in handling electrical devices and components approved for use in hazardous (classified) locations. Rough handling, and the use of tools that pry, impact, or abrade components, can dent, scratch, nick, or otherwise mar close-tolerance, precision-machined joints and make them unsafe.

22.2.8.1 Grease, paint, and dirt should be cleaned from machined joints using a bristle (not wire) brush, an acceptable noncorrosive solvent, or other methods recommended by the manufacturer.

22.2.8.2 Prior to replacing a cover on an enclosure designed to prevent flame propagation upon an explosion, mating surfaces should be cleaned and lubricated in accordance with the manufacturer's instructions.

22.2.9 Field modifications of equipment and parts replacement should be limited to those changes acceptable to the manufacturer and approved by the authority having jurisdiction. Normally, modifications to equipment will void any listing by nationally recognized testing laboratories.

22.2.10 The requirements of NFPA 70, *National Electrical Code*, should be followed.

22.2.10.1 Explosionproof enclosures, dust-ignition-proof enclosures, dusttight enclosures, raceway seals, vents, barriers, and other protective features are required for electrical equipment in certain occupancies. Equipment and facilities should be maintained in a way that will not compromise equipment performance or safety.

22.2.10.2 Intrinsically safe equipment and wiring is permitted in locations for which specific systems are approved. Such wiring should be separate from the wiring of other circuits. NFPA 70, *National Electrical Code, Article 504*, Intrinsically Safe Systems, describes control drawings, grounding, and other features involved in maintenance programs.

22.2.10.3 Purged and pressurized enclosures can be used in hazardous (classified) areas. NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*, provides guidance useful to maintenance personnel.

Chapter 23 De-Energizing and Grounding of Equipment to Provide Protection for Electrical Maintenance Personnel

23.1 Introduction.

23.1.1 Personnel working on, or in close proximity to, de-energized lines or conductors in electrical equipment should be protected against shock hazard and flash burns that could occur if the circuit were to be inadvertently re-energized. Sound judgment should be exercised when deciding on the extent of protection to be provided and determining the type of protective equipment and procedures that should be applied. The extent of protection that should be provided will be dictated by specific circumstances. Optimum protection should be provided. A high level of protection should be provided for any work on high- and medium-voltage circuits; on the other hand, minimal protection might be sufficient for work on minor branch circuits. Balance should be struck between the two extremes of optimum and minimal-but-adequate protection.

23.1.2 Possible conditions and occurrences should be considered in determining the type and extent of protection to be provided as follows:

(1) Induced voltages from adjacent energized conductors; these can be appreciably increased when high fault currents flow in adjacent circuits.
(2) Switching errors causing inadvertent re-energizing of the circuit.
(3) Any unusual condition that might bring an energized conductor into electrical contact with the de-energized circuit.
(4) Extremely high voltages caused by direct or nearby lightning strikes.
(5) Stored charges from capacitors or other equipment.

23.2 Steps for Providing Protection. Providing proper protection should include, but not necessarily be limited to, the following five basic steps:

(1) The proper circuit should be de-energized. Applicable up-to-date drawings, diagrams, and identification tags should be checked to determine all possible sources of supply to the specific equipment. The proper disconnecting device for each source should be opened. In cases where visible blade disconnecting devices are used, it should be visually verified that all blades are fully open. Drawout-type circuit breakers should be withdrawn to the fully disconnected position. Automatic switches or control devices should not be considered to be the disconnecting means for personnel safety.
(2) Precautions should be taken to guard against accidental re-energization. The operating handles of the open disconnecting devices should be locked and HOLD tags with sufficient information should be attached thereto. If fuses have been removed to de-energize the equipment, special precautions should be taken to prevent their unauthorized reinsertion. An established lock and tag policy is an essential part of any electrical maintenance safety program.
(3) The circuit should be tested to confirm that all conductors are de-energized. This test is especially important on circuits that involve switches and fixed-type circuit breakers in which the blades cannot be visually checked. An adequately rated voltage detector should be used to test each de-energized circuit for NO VOLTAGE. BEFORE

and AFTER testing the affected conductors, it should be determined that the voltage detector is operating satisfactorily by proving it on a source that is known to be energized. Some high- and medium-voltage detectors are equipped with a device that will provide the necessary proof voltage.

(4) Until they are grounded, conductors should be considered energized, and personnel should not touch them. If the test indicates there is NO VOLTAGE on the affected conductors, they should then be adequately grounded in accordance with established procedures. The conductors should be grounded to protect personnel in the event that, in spite of all precautions, the equipment does become re-energized. When capacitors are involved, they should be grounded and shorted to drain off any stored charge.

(5) All personnel connected with the work should be involved. Each individual should personally satisfy himself or herself that all necessary steps have been executed in the proper manner.

23.3 Grounding Methods and Procedures. In spite of all precautions, de-energized circuits can be inadvertently re-energized. When this occurs, adequate grounding is the only protection for personnel working on them. For this reason, it is especially important that adequate grounding procedures be established and rigidly enforced.

23.3.1 There are those who still hold to the old mistaken idea that grounding de-energized power conductors with a chain or small-diameter wire and battery clamps provides adequate safety for personnel. Such practices were not safe 50 years ago when power systems were relatively small, and they certainly are not safe on modern systems that are much larger and capable of delivering hundreds of thousands of amperes into a fault. Such currents can easily vaporize a chain or small grounding conductors without blowing fuses or opening a circuit breaker, thereby exposing personnel to dangerous voltages, vaporized conductor metal, and serious power arcs. In the interest of protecting lives, adequate grounding procedures and equipment that ensure positive personnel protection are essential.

23.3.2 A variety of terms is used to identify the grounding of de-energized electrical equipment to permit personnel to safely perform work on it without using special insulated tools. Some of these terms are *safety grounding, temporary grounding,* and *personnel grounding*. Throughout this chapter, the word *grounding* is used to refer to this activity; it does not refer to permanent grounding of system neutrals or non-current-carrying metal parts of electrical equipment.

23.3.3 Grounding equipment consists mainly of special heavy-duty clamps that are connected to cables of adequate capacity for the system fault current. This current may well be in excess of 100,000 amperes that will flow until the circuit overcurrent protective devices operate to de-energize the conductors. The grounding equipment should not be larger than necessary, because bulkiness and weight hinder personnel while connecting them to the conductors, especially while working with hot-line sticks. When selecting grounding equipment, you should consider the following:

(1) Grounding clamps should be of proper size to fit the conductors and have adequate capacity for the fault current. An inadequate clamp can melt or be blown off under fault conditions. Hot-line clamps should not be used for grounding de-energized conductors because they are not designed to carry the high current that would flow if the circuit were to be inadvertently re-energized. They are intended to be used only for connecting tap conductors to energized overhead lines by means of hot-line sticks and are designed to carry only normal load current. If hot-line clamps are used for grounding, high fault current could melt or blow them off without operating the overcurrent protective devices to de-energize the conductors, thereby exposing personnel to lethal voltages and arc burns.

(2) Grounding cables should be of adequate capacity, which, in some instances, might require two or more to be paralleled. Three factors that contribute to adequate capacity are (1) terminal strength, which largely depends on the ferrules installed on the cable ends, (2) size to carry maximum current without melting, and (3) low resistance to keep the voltage drop across the areas in which the personnel are working at a safe level during any period of inadvertent re-energization.

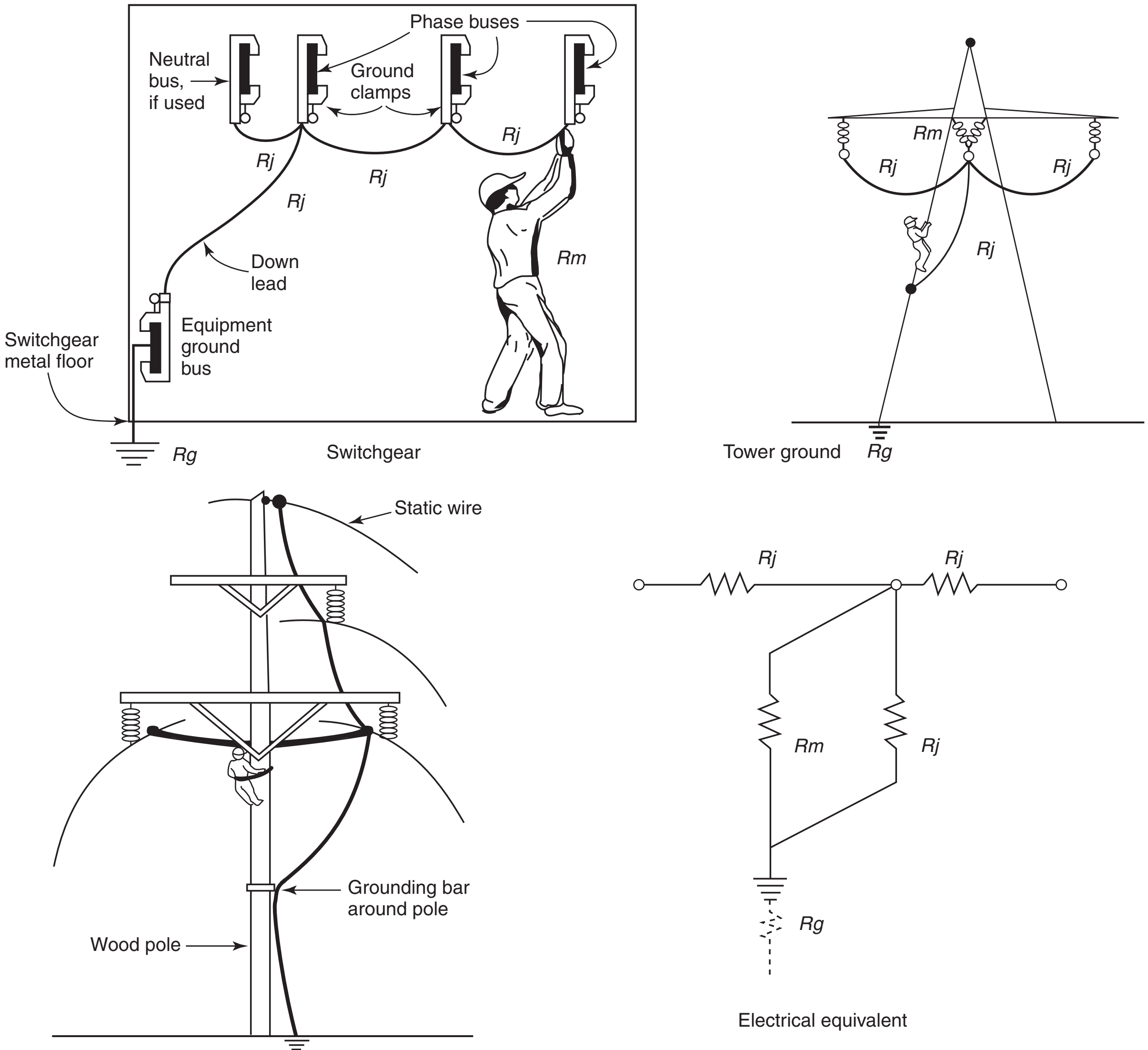
(3) Solid metal-to-metal connections are essential between grounding clamps and the de-energized conductors. Conductors are often corroded and are sometimes covered with paint. Ground clamps should have serrated jaws because it is often impractical to clean the conductors. The clamps should be slightly tightened in place, given a slight rotation on the conductors to provide cleaning action by the serrated jaws, and then securely tightened. Ground clamps that attach to the steel tower, switchgear, or station ground bus are equipped with pointed or cupped set screws that should be tightened to ensure penetration through corrosion and paint, to provide adequate connections.

(4) Grounding cables should be no longer than is necessary to keep resistance as low as possible and to minimize slack in cables to prevent their violent movement under fault conditions. If the circuit should be inadvertently re-energized, the fault current and resultant magnetic forces could cause severe and dangerous movement of slack grounding cables in the area where personnel are working. Proper routing of grounding cables to avoid excessive slack is essential for personnel safety.

(5) Grounding cables should be connected between phases to the grounded structure and to the system neutral (when available) to minimize the voltage drop across the work area if inadvertent re-energization should occur. The preferred arrangement is shown in Figure 23.3.3 with the equivalent electrical diagram.

23.3.4 In Figure 23.3.3 electrical equivalent diagram, it can be presumed that the resistance of the person's body (*Rm*) is 500 ohms. He or she is in parallel with only the resistance of a single cable (*Rj*), which can be on the order of 0.001 ohm. *Rg* is the ground resistance of the switchgear or structure area. If a 1000-ampere current should flow in the circuit grounded in this manner, the person would be subjected to only about 1 volt imposed across the work area; therefore, the current flow through his or her body would be negligible. This should be compared with the nonpreferred grounding arrangement shown in Figure 23.3.4, in which each conductor is connected to a driven ground rod.

23.3.5 In Figure 23.3.4 electrical equivalent diagram, the person's resistance (*Rm*) of 500 ohms is in parallel with the resistance of the jumper cable (*Rj*) and the resistance of the structure area and driven grounds (*Rdg*) in series; these can easily total 1 ohm. The increased resistance in this grounding arrangement can make an appreciable difference in the voltage drop. If a 1000-ampere current should flow in the circuit



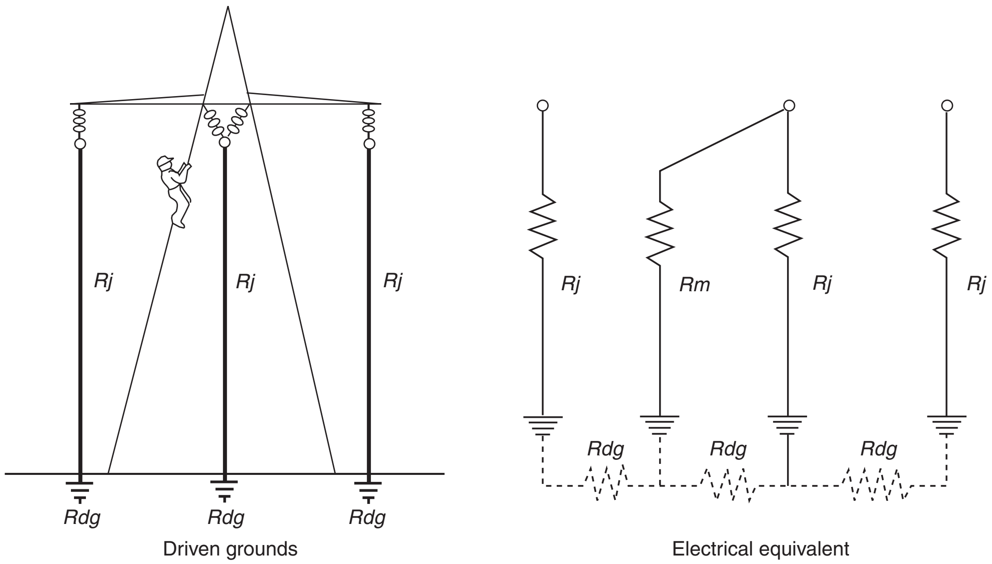
In Figure 23.3.3 electrical equivalent diagram, it can be presumed that the resistance of the person's body *(Rm)* is 500 ohms. He or she is in parallel with only the resistance of a single cable *(Rj)*, which can be on the order of 0.001 ohm. *Rg* is the ground resistance of the switchgear or structure area. If a 1000-ampere current should flow in the circuit grounded in this manner, the person would be subjected to only about 1 volt imposed across the work area; therefore, the current flow through his or her body would be negligible. This should be compared with the nonpreferred grounding arrangement shown in Figure 23.3.4, in which each conductor is connected to a driven ground rod.

FIGURE 23.3.3 Preferred Grounding Arrangement.

grounded in this manner, the person would be subjected to 1000 volts imposed across the work area.

23.3.6 Connecting the phase conductors together with short cables and clamps of adequate capacity, as shown in Figure 23.3.3, minimizes resistance between phases for fast action of the circuit overcurrent protective devices to de-energize the circuit, if it should be inadvertently re-energized. The short down-lead cable between the jumpered phase conductors and the grounded tower or switchgear ground bus reduces resistance to ground and the amount of cable that can move violently in the work area during high current flow. If there is a system neutral conductor at the work location, a cable should also be connected to it for more complete protection and to ensure lowest resistance in the ground return path to the source. Figure 23.3.3 shows buses and a person working inside switchgear; the same conditions would apply to personnel on overhead line towers and outdoor substation steel structures. When someone is working on such properly grounded areas, that person is in parallel with a minimum of resistance so he or she would be exposed to minimum voltage drop in the event of current flow in the system, and the low resistance would cause rapid operation of the fuses or circuit breakers, thus minimizing the time the person is exposed to the voltage drop.

23.3.7 Prior to installing grounding equipment, it should be inspected for broken strands in the conductors, loose connections to the clamp terminals, and defective clamp mechanisms. Defective equipment should not be used.



In Figure 23.3.4 electrical equivalent diagram, the person's resistance *(Rm)* of 500 ohms is in parallel with the resistance of the jumper cable *(Rj)* and the resistance of the structure area and the driven grounds *(Rdg)* in series; these can easily total 1 ohm. The increased resistance in this grounding arrangement can make the appreciable difference in the voltage drop. If a 1000-ampere current should flow in the circuit grounded in this manner, the person would be subjected to 1000 volts imposed across the work area.

FIGURE 23.3.4 Nonpreferred Grounding Arrangement.

23.3.8 Grounding equipment should be installed at each point where work is being performed on de-energized equipment. Often it is advisable to install grounding equipment on each side of a work point or at each end of a de-energized circuit.

23.3.9 One end of the grounding down lead should be connected to the metal structure or ground bus of the switchgear before connecting the other end to a phase conductor of the de-energized equipment. Then, and only then, should the grounding cables be connected between phase conductors.

23.3.10 When removing grounding equipment, the above installation procedure should be reversed by first disconnecting the cables between phases, then disconnecting the down lead from the phase conductor and, finally, disconnecting the down lead from the metal structure or ground bus.

23.3.11 Removal of grounding equipment before the circuit is intentionally re-energized is equally as important as was its initial installation, but for other reasons. If grounding equipment is forgotten or overlooked after the work is completed and the circuit is intentionally re-energized, the supply circuit overcurrent protective devices will immediately open because the conductors are jumpered and grounded. The short-circuit current can damage the contacts of a breaker having adequate interrupting capacity and can cause an inadequate breaker or fuses to explode. If the grounding cables are inadequate, they can melt and initiate damaging power arcs. A procedure should be established to ensure removal of all grounding equipment before the circuit is intentionally re-energized. Recommendations for such a procedure follow:

(1) An identification number should be assigned to each grounding equipment set, and all sets that are available for use by all parties, including contractor personnel, should be rigidly controlled.
   (a) The number and location of each set that is installed should be recorded.
   (b) That number should be crossed off the record when each set is removed.
(2) Before re-energizing the circuit, all sets of grounding equipment should be accounted for by number to ensure that all have been removed.
(3) Doors should not be allowed to be closed nor should covers be allowed to be replaced where a set of grounding equipment has been installed inside switchgear. If it is necessary to do so to conceal grounding equipment, a highly visible sign should be placed on the door or cover to remind personnel that a ground is inside.
(4) Before re-energizing, personnel should inspect interiors of equipment to verify that all grounding sets, including small ones used in testing potential transformers, relays, and so on, have been removed.
(5) Before re-energizing, all conductors should be tested with a megohmmeter to ascertain if any are grounded. If so, the cause should be determined and corrective action taken.

23.3.12 Use of insulated hot-line sticks, rubber gloves, or similar protective equipment by personnel is advisable while installing grounding equipment on ungrounded, de-energized overhead line conductors and also while removing the grounding equipment.

23.3.13 Data available from grounding-equipment manufacturers should be referred to for ampacities of cables and clamps and for detailed application information.

23.3.14 In some instances, specialized grounding equipment might be required, such as traveling grounds on new overhead line conductors being strung adjacent to energized circuits.

23.3.15 Drawout-type grounding and testing devices are available for insertion into some models of switchgear to temporarily replace circuit breakers; they provide a positive and convenient grounding means for switchgear buses or associated circuits by connecting to the switchgear buses or line stabs in the same manner as drawout breakers. One such device has two sets of primary disconnecting stabs; one, designated “BUS,” connects to the switchgear bus stabs, and the other set, designated “LINE,” connects to the switchgear supply line or load circuit stabs. Another type of grounding device has only one set of primary disconnecting stabs that can be positioned to connect to either the switchgear “BUS” stabs or the “LINE” stabs. Grounding cables can be connected from the selected disconnecting stud terminals in one of these devices to the switchgear ground bus. When the device is fully inserted into the switchgear, it grounds the de-energized buses or lines that were previously selected. Utmost care should be exercised when using these devices to prevent the inadvertent grounding of an energized bus or circuit. Such a mistake could expose personnel to flash burns and could seriously damage the switchgear. Before inserting a device with grounding cables connected thereto into switchgear, it is essential that the stabs that are to be grounded are tested for NO VOLTAGE and to verify that only the proper and matching disconnecting stud terminals in the device are grounded.

23.3.16 Figure 23.3.16 is another nonpreferred grounding arrangement. All three grounding cables are connected to a common driven ground. This reduces the resistance (*Rg*) between phases to practically 0 ohm, which would enable the overcurrent protective devices to de-energize the circuit rapidly. However, the driven ground resistance (*Rdg*) is still in parallel with the work area, so the voltage drop across the person would be high.

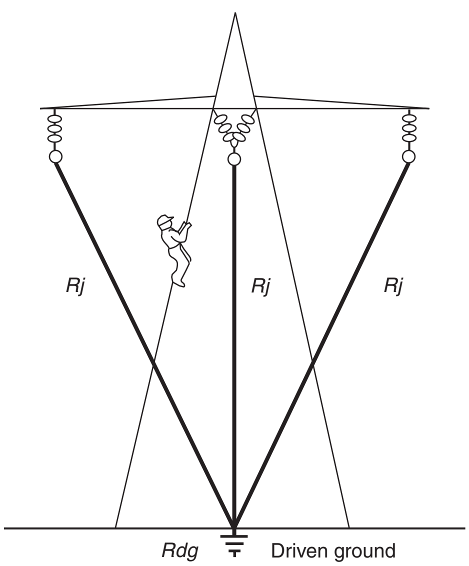


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FIGURE 23.3.16 Second Nonpreferred Grounding Arrangement.

23.3.17 Figure 23.3.17 is electrically the same as Figure 23.3.16, but placing the cables close together for convenience results in slack that can move violently in the work area during periods of high current flow. Therefore, this is not a preferred arrangement.

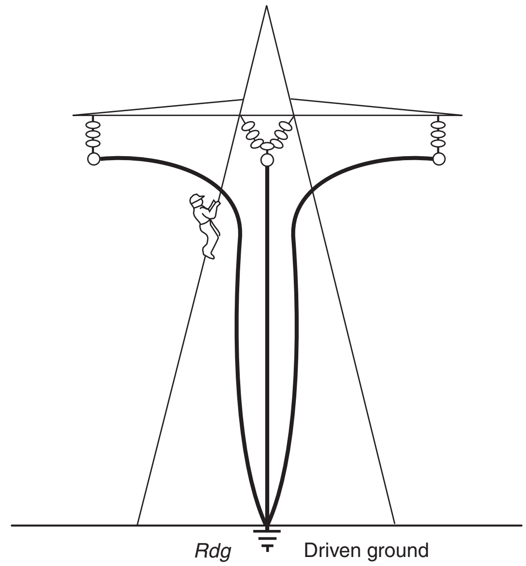


Figure 23.3.17 is electrically the same as Figure 23.3.16, but placing the cables close together for convenience results in slack that can move violently in the work area during periods of high current flow. Therefore, this is not a preferred arrangement.

FIGURE 23.3.17 Third Nonpreferred Grounding Arrangement.

23.3.18 Figure 23.3.18 is also not a preferred arrangement. Even though low resistance between phases would enable the overcurrent protective devices to de-energize the circuit rapidly, and there is only one down lead (*Rj*) to a driven ground (*Rdg*), the ground resistance remains high, so the voltage drop across the person would be too high for personnel safety.

Chapter 24 Cable Tray and Busway

24.1 Introduction.

24.1.1 A cable tray system is a unit or assembly of units or sections and associated fittings made of metal or other noncombustible materials forming a rigid structural system used to support cables. Cable tray systems include ladders, troughs, channels, solid-bottom trays, and other similar structures.

24.1.2 The frequency of maintenance will depend on the environment in which the cable tray is installed. In areas of heavy industrial contamination or coastal areas, frequent inspections might be necessary.

24.2 Cable.

24.2.1 Cable insulation should be visually inspected for damage. Among the factors that might cause insulation damage are sharp corners, protuberances in cable tray, vibration, and thermal expansion and contraction.

24.2.2 Cable insulation should be tested in accordance with Chapter 10.

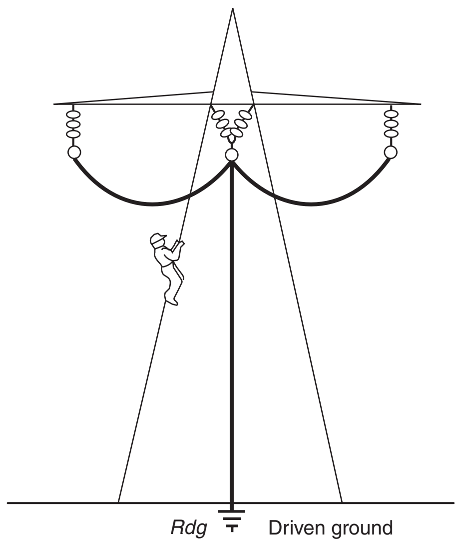


Figure 23.3.18 is not a preferred arrangement. Even though low resistance between phases would enable the overcurrent protection devices to de-energize the circuit rapidly, and there is only one down lead *(Rj)* to a driven ground *(Rdg)*, the ground resistance remains high, so the voltage drop across the person would be too high for personnel safety.

FIGURE 23.3.18 Fourth Nonpreferred Grounding Arrangement.

24.2.3 The number, size, and voltage of cables in the cable tray should not exceed that permitted by NFPA 70, *National Electrical Code*, Article 318. Communication or data-processing circuits are susceptible to interference problems when mixed with power circuits.

24.3 Cable Tray.

24.3.1 The cable tray should be inspected for intrusion of such items as pipe, hangers, or other equipment that could damage cables.

24.3.2 The deposits of dust, industrial process materials, and trash of any description should be checked and evaluated in terms of reduced ventilation and potential fire hazard.

24.3.3 Bolted connections between sections should be visually checked for corrosion and a sample retorquing done in suspect areas.

24.3.4 Certain atmospheric conditions might create fastener failure; therefore, a visual inspection should check for missing or damaged bolts, bolt heads, or nuts. Where necessary, they should be replaced with suitable hardware.

24.3.5 A visual and mechanical check should be made for adequacy of cable tray grounding, and all takeoff raceways should be bonded to the cable tray.

24.3.6 Covers should be inspected to ensure that physical damage does not reduce spacings or damage cables.

24.4 Low-Voltage (600-Volt) Busway.

24.4.1 General. For the purpose of this section, a busway is considered to be a grounded metal enclosure containing factory-mounted, bare, or insulated conductors that are usually copper or aluminum bars, rods, or tubes.

24.4.2 Electrical Joints. A sample check of bolts for tightness should be conducted. Where Belleville spring washers are used and visible, they should be checked for proper torque.

24.4.2.1 Belleville spring washers are designed to help maintain proper tightness at the joints of bus bars and cable connections as the bus material expands and contracts under load. A Belleville spring washer that has been flattened could be a sign that the bolt has been overtorqued or has been heated and lost its temper.

24.4.2.2 Where flattened Belleville washers are observed, bolts should be slightly loosened and retorqued to manufacturer's specifications. Washers showing signs of overheating (discoloration) should be replaced using manufacturer's specifications.

24.4.3 Housing.

24.4.3.1 A visual check should be made to see if all joint covers and plug-in covers are in place and tight. This will prevent accidental contact with energized conductors. Joint covers might also be essential for continuity of ground path between sections.

24.4.3.2 Trash, combustible material, and other debris should be removed from a busway. Ventilation openings should be clear.

24.4.3.3 On an indoor busway, a visual check should be made for evidence of exposure to liquids and the source eliminated or necessary protection provided.

24.4.3.4 On an outdoor busway, a visual check should be made to ascertain if weep hole screws have been removed in accordance with the manufacturer's instructions.

24.4.4 Plugs.

24.4.4.1 Circuit breaker and fusible plugs should be checked for proper operation.

24.4.4.2 Plug hangers should be checked for tightness to ensure proper grounding.

24.4.4.3 If plug installation requires hook sticks for operation, hook-sticks should be checked for availability.

24.4.5 Conduit and Raceways. Cable and raceways should be visibly checked for proper bonding to fittings (plugs, tap boxes).

24.4.6 Testing.

24.4.6.1 Insulation-resistance testing should be performed in accordance with 20.9.2.3.

24.4.6.2 If there is uncertainty concerning the adequacy of the insulation after insulation-resistance testing, a high-potential test should be conducted. *(See 20.9.3.1.)* Normal high-potential voltages are twice rated, voltage plus 1000 volts for 1 minute. Because this might be above the corona starting voltage of some busways, frequent testing is undesirable.

24.4.6.3 Infrared inspection of the busway can reveal abnormal temperatures and possible problem areas and should be performed in accordance with Section 20.17.

24.5 Metal-Enclosed Busway (5 kV to 15 kV).

24.5.1 General. Busway over 600 volts is referred to as metal-enclosed busway. Rated 5 kV and 15 kV, it consists of three types: isolated phase, segregated phase, and nonsegregated phase. Isolated phase and segregated phase are utility-type busways used in power-generation stations; industrial plants use nonsegregated phase for connection of transformers and switchgear and interconnection of switchgear lineups.

24.5.2 Electrical Joints.

24.5.2.1 A sample check of bolts for tightness should be conducted. Where Belleville spring washers are used and visible, they should be checked for proper torque.

24.5.2.1.1 Belleville spring washers are designed to help maintain proper tightness at the joints of bus bars and cable connections as the bus material expands and contracts under load. A Belleville spring washer that has been flattened could be a sign that the bolt has been overtorqued or has been heated and lost its temper.

24.5.2.1.2 Where flattened Belleville washers are observed, bolts should be slightly loosened and retorqued to manufacturer's specifications. Washers showing signs of overheating (discoloration) should be replaced using manufacturer's specifications.

24.5.2.2 Infrared inspection of the busway can reveal abnormal temperatures and potential problem areas and should be performed in accordance with Section 20.17.

24.5.3 Insulators. Bus supports should be visually inspected for dirt or tracking. Dirty insulators should be cleaned; insulators that are cracked or show evidence of tracking should be replaced.

24.5.4 Heaters. A check should be made for proper operation of space heaters. Ammeters in heater supply circuits provide means for quick and frequent observation for proper heater loads to determine if one or more heater units is defective.

24.5.5 Housing.

24.5.5.1 All covers should be in place and properly tightened.

24.5.5.2 A visual check should be made for bonding of bus and equipment to which it is connected.

24.5.6 Testing.

24.5.6.1 Insulation-resistance tests should be performed in accordance with 20.9.2.3.

24.5.6.2 High-potential tests in accordance with IEEE 27, *Standard for Switchgear Assemblies including Metal-Enclosed Bus*, should be conducted at 75 percent of the rated insulation withstand levels shown in Table 24.5.6.2.

Table 24.5.6.2 Metal-Enclosed Bus Dielectric Withstand Test Voltages

Metal-Enclosed Bus Nominal Voltage (kV, RMS)	Insulation Withstand Level (kV, RMS)[a]	High-Potential Field Test (kV, RMS)[b]
4.16	19.0	14
13.8	36.0	27
23.0	60.0	45
34.5	80.0	60

[a] 1 minute
[b] 75 percent of insulation withstand level

Chapter 25 Uninterruptible Power Supply (UPS) Systems

25.1 Introduction. The basic function of uninterruptible power supply (UPS) systems is to preserve power to electrical or electronic equipment. Most UPS systems are intended to provide regulated power to prevent power supply fluctuations or aberrations that can damage or cause malfunction of sensitive electrical/electronic equipment, such as computers and process controllers. A UPS system represents a sizable investment in equipment specifically installed to provide reliable regulated power to equipment. Therefore it is essential that the UPS system be maintained in a manner that the UPS itself will not fail.

25.1.1 The general recommendations in this chapter can be applied to all UPS systems; however, it should be noted that UPS systems are very equipment-specific. As a result, manufacturers' instructions should be followed carefully when performing any maintenance on UPS equipment.

25.1.2 The maintenance program should be planned at the time the UPS system is put into service to provide early attention to ensure the continuing reliability of the system. The development of an EPM program should not be deferred until the end of the warranty period.

25.1.3 Maintenance should be scheduled at times that will least affect operations. Actual maintenance procedures should not be started until the users have been notified.

25.1.4 Only fully trained and qualified persons with proper test equipment should perform UPS maintenance.

25.2 Types of UPS Systems.

25.2.1 There are two basic types of UPS systems: static and rotary. Some systems are hybrid versions incorporating some features of both. A basic rotary system is essentially a motor-generator set that provides isolation between the incoming power supply and the load and buffers out power supply aberrations by flywheel mechanical inertia effect.

25.2.2 A static unit rectifies incoming ac power to dc and then inverts the dc into ac of the proper voltage and frequency as input power to the load. A battery bank connected between the rectifier and inverter sections ensures an uninterrupted supply of dc power to the inverter section.

25.2.3 In the UPS industry, the term *module* refers to a single self-contained enclosure containing the power and control elements needed to achieve uninterrupted operation. These components include transformers, rectifier, inverter, and protective devices.

25.2.4 UPS systems can consist of one or more UPS modules connected in parallel to either increase the capacity of the system power rating or to provide redundancy in the event of a module malfunction or failure. Figure 25.2.4 illustrates a typical single-module static three-phase UPS configuration. Note that in this configuration the solid-state switch (SSS) is internal to the UPS module.

25.2.4.1 Figure 25.2.4.1 illustrates a typical multi-module static three-phase UPS configuration. Note that in this configuration the SSS is located in the stand-alone static transfer switch (STC) control cabinet.

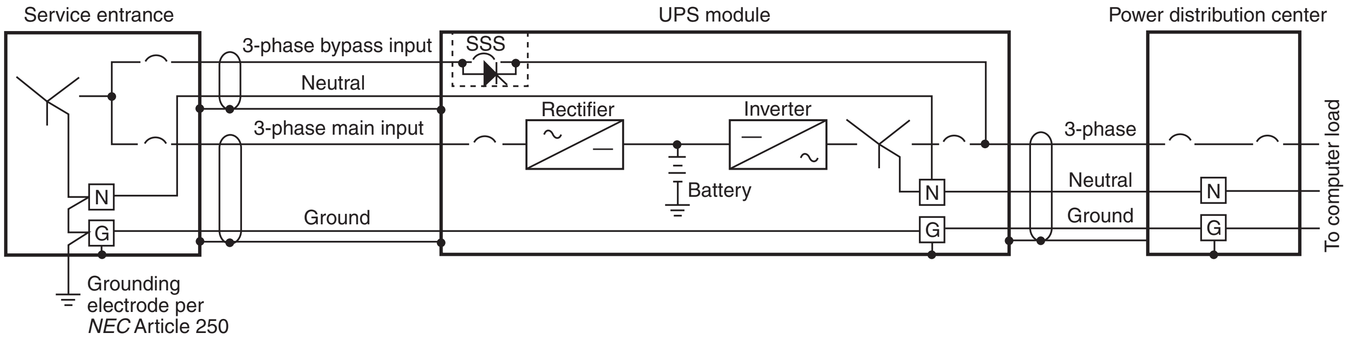


FIGURE 25.2.4 Typical Single-Module Static 3-Phase UPS Configuration.

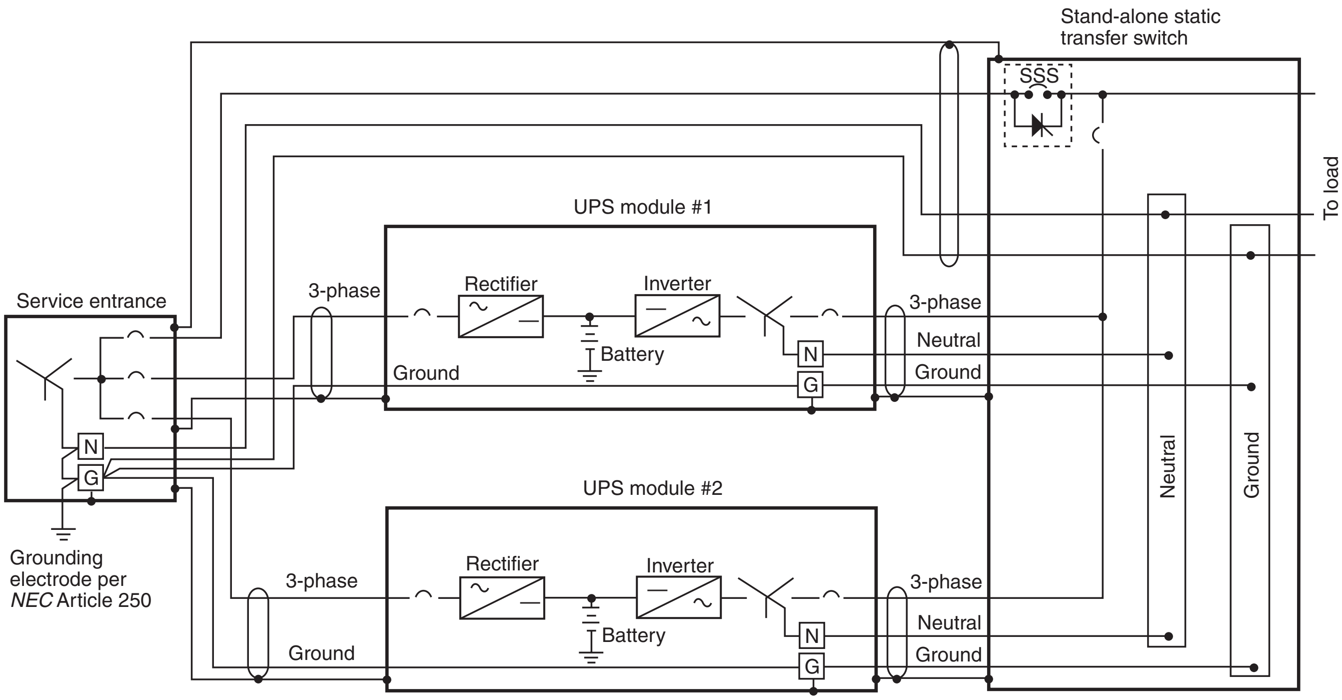


FIGURE 25.2.4.1 Typical Multi-Module Static 3-Phase UPS Configuration.

25.2.5 Components to Be Maintained. Almost all UPS systems comprise these common elements: disconnecting means, bypass and transfer switches, and protective devices and power switchgear, molded-case circuit breakers, and fuses. Depending on the type of UPS (static, rotary, or hybrid), the system might also include transformers, batteries, a battery charger, a rectifier/inverter unit (static system), and a motor-generator set (rotary system). The system might also be supported by a standby generating unit to permit operations to continue during sustained power outages.

25.3 UPS System Maintenance Procedures — General. The routine maintenance procedures for components of UPS systems are covered in the particular equipment sections of this publication (that is, switches, transfer switches, motor controllers, protective devices, batteries and battery chargers, transformers, rotating equipment). However, to aid in an organized preventive maintenance program, the following procedures are recommended.

CAUTION: It is important to avoid interruption of the power output of the UPS system. Extreme caution should be used when servicing the system to prevent unscheduled outages.

25.3.1 Disconnecting Means and Bypass Switches. These elements of the system should be maintained in accordance with the general maintenance procedures prescribed for the particular device in this document or the manufacturer's instructions as applicable.

25.3.2 Transfer Switches. Transfer switches in UPS systems can be of either the manually operated or automatic type. Switching devices should be maintained in accordance with the appropriate sections of this document. If of the static type, they should be maintained in accordance with the general procedures for maintaining electronic equipment in Chapter 12, and specific procedures should be provided by the manufacturer.

25.3.2.1 Transfer switches should also be maintained in accordance with the manufacturer's guidelines.

25.3.3 Circuit Protective Devices. Molded-case circuit breakers should be maintained in accordance with Chapter 13, fuses in accordance with Section 15.1, and other protective devices in accordance with Chapter 8. It is especially important to keep an ample supply of the proper types of spare fuses on hand. UPS systems are generally protected with special fuses. Installing an improper fuse on a UPS can result in severe damage to the UPS and the load equipment.

25.3.4 Batteries and Chargers. Batteries and chargers should be maintained in accordance with manufacturers' instructions. See Chapter 8 for lead–acid batteries and chargers.

25.3.5 UPS Support Standby Generator. If the UPS is supported by a standby generating unit, the generator should be maintained in accordance with the general procedures for maintaining rotating equipment in Chapter 16. It is important that a program be in effect to ensure that the generating unit will be test-run on a regular basis and also be subjected to a full-load test at least monthly for a minimum of 2 hours. In addition, generator startup, transfer, restoration of power, retransfer, and auxiliary generator shutdown operation should be checked at least twice a year.

25.3.6 UPS Ventilation. Ventilation air filters should be inspected on a regular basis. The frequency of cleaning or replacement depends on the amount of dust or dirt in the air at the installation and could range from as little as a week to as much as six months.

25.3.7 UPS Record Keeping. It is strongly recommended that a complete and thorough logbook be maintained for the UPS in a suitable location. The logbook should be used to record all items concerning the UPS, including the following:

(1) System operation — normal settings and adjustments
(2) Meter readings such as voltmeter, ammeter, and frequency meter at input and output, taken on a weekly basis (more frequently as necessary)
(3) Record of abnormal operations, failures, and corrective action taken
(4) Maintenance history

25.3.7.1 This log should be used for comparison to detect changes and degradation of the UPS circuitry, need for adjustment of controls, or other maintenance and testing.

25.3.7.2 Schematics, diagrams, operating procedures, record drawings, spare parts lists, troubleshooting techniques, maintenance procedures, and so on, should be kept in the same suitable location as the logbook.

25.3.8 Routine Maintenance. On a semiannual basis, the inside of cabinets should be vacuumed and the tightness of all electrical connections verified. On an annual basis, tightness of electrical connections should be checked using infrared scanning techniques or testing with a digital low-resistance ohmmeter *(see Section 20.12)*. Possible loose or corroded connections should be identified. These connections should be cleaned and retightened as necessary.

25.3.8.1 All system alarms and indicating lights should be periodically checked for proper operation. On a quarterly basis, a visual inspection should be made for signs of overheating and corrosion. Wherever additional loads are connected to the UPS, the protective-device coordination, calibration, and proper operation of the modified system should be checked.

25.3.8.2 All heating, ventilating, air-conditioning, and humidity-control systems should be checked for proper operation and to ensure that the flow of cooling air is not blocked by obstructions in front of the vents. A check should be made for unusual sounds and odors because these signs might be the first indication of a potential malfunction.

25.3.8.3 The integrity of the grounding system should be maintained as required by Article 250 of NFPA 70, *National Electrical Code*. For separately derived systems, it should be ascertained that the neutral is properly grounded.

25.3.8.4 The neutral output current should be measured during peak loads every 3 months or when new equipment is added to the system. Measurements should be taken using a true RMS-type ammeter to verify that the neutral conductor ampacity is not exceeded. Excessive current readings could indicate the presence of harmonics.

25.3.9 Rectifier and Inverter (Static Systems). This equipment should be maintained in the manner prescribed for electronic equipment in Chapter 12. In many cases, a common enclosure houses the rectifier, inverter, and support battery charger sections of the UPS system.

25.3.9.1 On a semiannual basis, the inverter should be inspected visually for signs of leaking fluid from wave-forming capacitors; the capacitors should be checked for swelling or discoloration. *(See 8.9.3.)*

25.3.9.2 The transformers and the heat sinks should be inspected visually for signs of overheating.

25.3.10 Motor and Generator (Rotary Systems). The motor and generator should be maintained in accordance with the general procedures for maintaining rotating electrical equipment in Chapter 16.

25.3.11 UPS Modifications. It is extremely important that all modifications be reflected in the record drawings and other pertinent documentation *(see 25.3.7)*. Modifications to procedures should be recorded. Component failures and corrective action that impact the documentation, such as a change in components, should be indicated.

25.3.11.1 The manufacturer should be contacted periodically (2-year interval, maximum) for information on equipment upgrades and recommended revisions.

25.4 UPS Testing.

25.4.1 Introduction.

25.4.1.1 UPS systems require periodic testing in order to determine if the system is functioning as designed. Each manufacturer provides, with the equipment, specifications delineating the stated equipment performance (that is, voltage variation, balance, regulation, and harmonic distortion). Batteries can weaken, which will shorten the backup time of the particular manufacturer's specifications. Transfer operations might be generating transients or momentary outages that can create havoc in a computer system. The recommendations in 25.4.2 through 25.5.2 are intended to identify problems and apprise the maintenance personnel of the actual capabilities of the UPS system.

25.4.1.2 Testing should not be attempted unless those performing this work are completely familiar with the manufacturer's recommendations, specifications, tolerances, and safety precautions.

25.4.2 Preliminary Testing.

25.4.2.1 Prior to testing, all operating parameters, such as frequency, voltage, and current, at the bypass switch, UPS input, UPS output, batteries, and at modules should be recorded where applicable.

25.4.2.2 Tests should be performed with the unit under load to ascertain the condition and reserve capability of the batteries. Refer to 8.9.4 for preparation of batteries prior to load testing of the system.

25.4.2.3 An infrared scan of the batteries and UPS equipment should be performed. The scan should look specifically at the battery connections with ac input power disconnected and the battery supplying power to the load. The unit should not be operated under load for long periods of time with covers removed, because cooling might be inhibited, and damage to the unit might result.

25.4.2.4 Any abnormalities that have been detected should be corrected prior to proceeding with further testing.

25.5 System Tests.

25.5.1 Introduction.

25.5.1.1 Certain system tests might be necessary to fully determine the operating condition of a UPS system. These tests should be performed when warranted by special circumstances, such as repeated failure of a system to pass routine maintenance checks. The tests also should be conducted on a 2-year cycle or other periodic basis when the desired degree of reliability justifies the procedure. An independent testing company or the equipment manufacturer might be needed to conduct these tests, because of the complexity and the sophisticated test instruments recommended. The units should be placed under load by using external load banks during such tests.

25.5.1.2 All UPS tests should require that the batteries be fully charged. (Some systems do not utilize battery backup.) Critical loads should be placed on isolation bypass, if available, or connected to another source.

25.5.1.3 It should be verified that all alarm and emergency shutdown functions are operating. It should be ascertained that the load transfers manually and automatically from UPS to bypass. It should be verified that all modules, when applicable, are functioning by load-testing each module individually prior to parallel load testing.

25.5.2 Special Tests. Simultaneous input and output readings of voltage, current, and frequency should be recorded. The external power source should be removed and reapplied to verify output stability.

25.5.2.1 Voltage and frequency recordings of UPS operation during transient response voltage tests should be provided; a high-speed recording device such as an oscillograph should be used to document the following load tests.

25.5.2.2 The load should be stepped from 0 percent to 50 percent to 0 percent; 25 percent to 75 percent to 25 percent; 50 percent to 100 percent to 50 percent; 0 percent to 100 percent to 0 percent of UPS system rating.

25.5.2.3 It should be verified that the voltage regulation and frequency stability are within the manufacturer's specifications. In accordance with the manufacturer's specifications, the load bank should be increased to greater than 100 percent system load to ascertain that the system is within the manufacturer's ratings for input and output current overload rating.

25.5.2.4 Where applicable, UPS ac input power should be removed while the system is supplying 100 percent power to a load bank. The elapsed time until low battery voltage shutdown occurs should be recorded and compared with specifications. Voltage, current, and frequency should be read and recorded during tests. Upon restoration of UPS input power, it should be verified that the battery is recharging properly.

25.5.2.5 Any abnormalities should be corrected, and a check should be made to ensure that the battery is fully recharged prior to returning the system to service.

Chapter 26 System Studies

26.1 Introduction. Electrical studies are an integral part of system design, operations, and maintenance. These engineering studies generally cover the following four areas:

(1) Short-circuit studies
(2) Coordination studies
(3) Load-flow studies
(4) Reliability studies

26.1.1 Copies of single-line diagrams and system study data should be given to the facility maintenance department. It is critical to efficient, safe system operation that the maintenance department keep the single-line diagrams current and discuss significant changes with the facility engineering department or consulting electrical engineer. It should be noted, however, that the data required for system studies is highly specialized, and outside help might be necessary.

26.2 Short-Circuit Studies.

26.2.1 Short circuits or fault currents represent a significant amount of destructive energy that can be released into electrical systems under abnormal conditions. During normal system operation, electrical energy is controlled and does useful work. However, under fault conditions, short-circuit currents can cause serious damage to electrical systems and equipment and create the potential for serious injury to personnel. Short-circuit currents can approach values as large as several hundred thousands of amperes.

26.2.1.1 During short-circuit conditions, thermal energy and magnetic forces are released into the electrical system. The thermal energy can cause insulation and conductor melting as well as explosions contributing to major equipment burndowns. Magnetic forces can bend bus bars and cause violent conductor whipping and distortion. These conditions have grim consequences on electrical systems, equipment, and personnel.

26.2.1.2 Protecting electrical systems against damage during short-circuit faults is required in NFPA 70, *National Electrical Code,* Sections 110-9 and 110-10. Additional information on short-circuit currents can be found in ANSI/IEEE 141, *Recommended Practice for Electric Power Distribution for Industrial Plants* (Red Book), ANSI/IEEE 241, *Recommended Practice for Electric Power Systems in Commercial Buildings* (Gray Book), ANSI/IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis*

(Brown Book), and in ANSI/IEEE 242, *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems* (Buff Book).

26.2.2 Baseline short-circuit studies should be performed when the facility electrical system is designed. They should be updated when a major modification or renovation takes place, but no more frequently than every 5 years. A copy of the most recent study should be kept with other important maintenance documents.

26.2.2.1 The following are some of the conditions that might require an update of the baseline short-circuit study:

(1) A change by the utility
(2) A change in the primary or secondary system configuration within the facility
(3) A change in the transformer size (kVA) or impedance (percent Z)
(4) A change in conductor lengths or sizes
(5) A change in the motors connected to the system

26.2.2.2 A periodic review of the electrical system configuration and equipment ratings should be checked against the permanent records. Specific attention should be paid to the physical changes in equipment including changes in type and quantity. Significant changes should be communicated to the maintenance supervisor, the facility engineering department, or the electrical engineer.

26.2.2.3 A comprehensive treatment of short-circuit currents is beyond the scope of this document. However, there is a simple method to determine the maximum available short-circuit current at the transformer secondary terminals. This value can be calculated by multiplying the transformer full load amperes by 100, and dividing this by the percent impedance of the transformer.

26.2.2.3.1 Figure 26.2.2.3.1 shows an example: 500 kVA transformer, 3-phase, 480 V primary, 208 Y/120 V secondary, 2 percent Z.

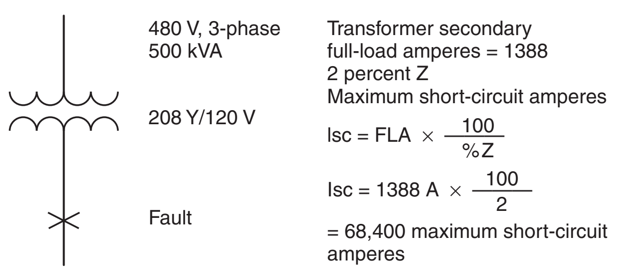


FIGURE 26.2.2.3.1 Example Calculation of Maximum Available Short-Circuit Current at the Transformer Secondary Terminals.

26.2.2.3.2 There are several computer programs commercially available to conduct thorough short-circuit calculation studies.

26.2.2.4 When modifications to the electrical system increase the value of available short-circuit amperes, a review of overcurrent protection device interrupting ratings and equipment withstand ratings should take place. This might require replacing overcurrent protective devices with devices having higher interrupting ratings or installing current-limiting devices such as current-limiting fuses, current-limiting circuit breakers, or current-limiting reactors. For silicon control rectifier (SCR) or diode input devices, change of the source impedance can affect equipment performance. Proper operation of this equipment depends on maintaining the source impedance within the rated range of the device. The solutions to these engineering problems are the responsibility of the maintenance supervisor, the facility engineering department, or the electrical engineer.

26.3 Coordination Studies.

26.3.1 A coordination study, sometimes called a selectivity study, is done to improve power system reliability. *(See 3.3.1 for definition of coordinated system).*

26.3.1.1 Improper coordination can cause unnecessary power outages. For example, branch-circuit faults can open multiple upstream overcurrent devices. This process can escalate and cause major blackouts, resulting in the loss of production. Blackouts also affect personnel safety.

26.3.1.2 NFPA 70, *National Electrical Code,* and various IEEE standards contain the requirements and suggested practices to coordinate electrical systems. The IEEE standards include ANSI/IEEE 141, *Recommended Practice for Electric Power Distribution for Industrial Plants* (Red Book), ANSI/IEEE 242, *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems* (Buff Book), ANSI/IEEE 241, *Recommended Practice for Electric Power Systems in Commercial Buildings* (Gray Book), and ANSI/IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis* (Brown Book).

26.3.2 A baseline coordination study is generally made when the electrical system is designed. A copy of the study should be kept with other important facility maintenance documents.

26.3.3 Changes affecting the coordination of overcurrent devices in the electrical system include the following:

(1) A change in the available short-circuit current
(2) Replacing overcurrent devices with devices having different ratings or operating characteristics
(3) Adjusting the settings on circuit breakers or relays
(4) Changes in the electrical system configuration
(5) Inadequate maintenance, testing, and calibration

26.3.4 The facility electrical system should be periodically reviewed for configuration changes, available short-circuit current changes, changes in fuse class or rating, changes in circuit-breaker type or ratings, and changes in adjustable trip settings on circuit breakers and relays.

26.3.4.1 Any changes noted in the coordinated performance of overcurrent protective devices should be reported to the maintenance supervisor, the facility engineering department, or the consulting electrical engineer.

26.3.4.2 Time-current curves should be kept up to date. Usually this is the responsibility of facility engineering or the consulting electrical engineer. However, it is vitally important for facility maintenance to observe and communicate coordination information to the maintenance supervisor, facility engineering department, or consulting electrical engineer.

26.4 Load-Flow Studies.

26.4.1 Load-flow studies show the direction and amount of power flowing from available sources to every load. By means of such a study, the voltage, current, power, reactive power, and power factor at each point in the system can be determined.

26.4.1.1 This information is necessary before planning changes to the system and will assist in determining the operating configuration. This study also helps determine losses in the system. ANSI/IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis* (Brown Book), provides more detailed information.

26.4.1.2 Load-flow studies should be done during the design phase of an electrical distribution system. This is called the baseline load-flow study. The study should be kept current and revised whenever significant increases or changes to the electrical system are completed.

26.4.1.3 Some of the events that will result in load-flow changes include changing motors, motor horsepower, transformer size, or impedance; operating configurations not planned for in the existing study; adding or removing power-factor correction capacitors; and adding or removing loads.

26.4.2 It is important that the system single-line diagrams and operating configurations (both normal and emergency) be kept current along with the load-flow study.

26.4.3 Some signs that indicate a need to review a load-flow study include unbalanced voltages, voltage levels outside the equipment rating, inability of motors to accelerate to full load, motor starters dropping off line when other loads are energized, or other signs of voltage drop. Additional signs also include poor system power factor, transformer or circuit overloading during normal system operation, and unacceptable overloading when the system is operated in the emergency configuration.

26.4.4 When changes to the electrical system are made, the maintenance department should note the changes on their copy of the single-line diagram. Significant changes, as mentioned above, should be reviewed with the maintenance supervisor, facility engineering department, or the consulting electrical engineer to determine if changes are necessary to the single-line diagram.

26.5 Reliability Studies.

26.5.1 A reliability study is conducted on facility electrical systems to identify equipment and circuit configurations that can lead to unplanned outages.

26.5.1.1 The study methods are based on probability theory. The computed reliability of alternative system designs as well as the selection and maintenance of components can be made to determine the most economical system improvements. A complete study considering all the alternatives to improve system performance will add technical credibility to budgetary requests for capital improvements.

26.5.1.2 An immediate benefit from this investigation is the listing of all system components with their failure modes, frequencies, and consequences. This allows weakness in component selection to be identified prior to calculation of risk indices.

26.5.1.3 ANSI/IEEE 493, *Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems* (Gold Book), and ANSI/IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis* (Brown Book), provide more detailed information. There are also several publications and software packages commercially available that deal with reliability calculations.

26.5.2 A reliability study can be conducted when alternative systems, components, or technologies are being considered to improve reliability. Changes affecting the reliability of an electrical system or component can include one or more of the following:

(1) System design
(2) Reliability of the power source
(3) Equipment selection
(4) Quality of maintenance
(5) Age of equipment
(6) Equipment operating environment
(7) Availability of spare parts

26.5.2.1 Generally, the existing system design cannot be significantly altered; however, it is possible to meet with the utility and discuss methods for increasing the reliability of service. The selection of reliable equipment and the need for additional maintenance can be evaluated from an economic standpoint. The age of equipment and the environment in which it is operated will have an effect on the probability of equipment failure. Spare parts should be monitored and inspected periodically to ensure that they will be available when needed. The study should be kept current and revised whenever a significant change to the electrical system has been made.

26.5.3 A reliability study begins with the system configuration documented by a single-line diagram. Reliability numerics are applied to a system model identifying system outages based on component downtime and system interactions. A failure modes and effect analysis (FMEA) is used to generate a list of events that can lead to system interruption and includes the probability of each event and its consequences. An example FMEA table for a facility's electrical equipment is shown in Table 26.5.3. The frequency of failures per year can be obtained from ANSI/IEEE 493, *Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems* (Gold Book).

Table 26.5.3 Sample FMEA Table

System/ Component	Failure Mode	Frequency per Year	Consequence ($1000)
Breaker B1	Internal fault	0.0036	150
Transformer T1	Winding failure	0.0062	260
Motor M1	Stator damage	0.0762	225

26.5.4 The information in Table 26.5.3 can now be analyzed using event-tree analysis or by computing a system reliability index. The event tree is used to further break down each system or component failure into a series of possible scenarios, each with an assigned probability. The outcome is a range of consequences for each event tree.

26.5.4.1 A system reliability index will assign a number (usually expressed in hours down per year) for each system configuration. The calculations for alternative system configurations can be redone until an acceptable downtime per year is obtained.

Chapter 27 Power Quality

27.1 Introduction.

27.1.1 Special Terms. The following special terms are used in this chapter.

27.1.1.1 Bonding (Bonded). The permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed. The "permanent joining" can be accomplished by the normal devices used to fasten clean, noncorroded parts together. Machine screws, bolts, brackets, or retainers necessary to allow equipment to function properly are items typically employed for this purpose. While welding and brazing can also be utilized, these preclude easy disassembly, and welding can increase rather than decrease resistance across joints. Metallic parts that are permanently joined to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed are bonded.

27.1.1.2 Bonding Jumper. A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected. This conductor can be solid or stranded or braided, and connected by compatible fittings to separate parts to provide this electrically conductive path. The bonding jumper can also be a screw or a bolt. This bonding jumper can be used alone or in conjunction with other electrically conductive paths. It generally is associated with the equipment-grounding path, but might or might not be electrically linked for a lowest impedance path.

27.1.1.3 Central Grounding Point. The location where the interconnected parts of the grounding system are connected in a common enclosure. The central grounding point provides a common connection point for termination of the feeder or branch-circuit equipment-grounding conductors.

27.1.1.4 Common Mode Noise. *(See 3.3.16.1.)*

27.1.1.5 Grounded Conductor. *(See 29.2.17.)*

27.1.1.6 Equipment-Grounding Conductor. *(See 29.2.23.)*

27.1.1.7 Grounding Electrode Conductor. The conductor used to connect the grounding electrode to the equipment-grounding conductor, to the grounded conductor, or to both, of the circuit at the service equipment or at the source of a separately derived system. This conductor must be connected to provide the lowest impedance to earth for surge current due to lightning, switching activities from either or both of the supply and load side, and to reduce touch potentials when equipment insulation failures occur.

27.1.1.8 Harmonics. *(See 3.3.15.)*

27.1.1.9 Interharmonics. Not all frequencies that occur on an electrical power system are integer multiples of the fundamental frequency (usually 60 Hz), as are harmonics. Some loads draw currents that result in voltages that are between harmonic frequencies or less than the fundamental frequency. These frequencies are referred to as interharmonics and can be made of discrete frequencies or as a wide-band spectrum. A special category of these interharmonics is called subharmonics, in which the frequencies involved are less than the fundamental power line frequency.

27.1.1.10 Long Duration Undervoltage. A decrease of the supply voltage to less than 90 percent of the nominal voltage for a time duration greater than 1 minute. *[See ANSI/NEMA C84.1, Electric Power Systems and Equipment, Voltage Ratings (60 Hertz).]*

27.1.1.11 Multipoint Grounding. Multipoint grounding consists of interconnecting primary and secondary neutrals of the transformer. The secondary and primary neutral are common, and they both utilize the same grounding electrode that connects the system to earth.

27.1.1.11.1 These provide corresponding neutral circuit conductors in both the primary and secondary single-phase and wye-connected windings. This provides a low impedance path between each system and allows ground current disturbances to flow freely between them with little or no attenuation. Although there are advantages to these "wye-wye" systems, they can contribute to a common mode noise problem.

27.1.1.11.2 Multipoint grounding can also be found with systems where one or both windings are delta connected.

27.1.1.11.3 The primary and secondary windings are only casually interconnected, and this provides significant impedance to any current flow between them, since there are no corresponding circuit conductors that can be directly connected together. Grounding a circuit conductor at any point up to the service entrance disconnect location of the premises is permitted. Multipoint grounding of separately derived systems is not permitted, and single-phase two-wire, single-phase three-wire (split-phase), or delta-wye multiphase systems are recommended.

27.1.1.12 Sag. A decrease to between 10 percent and 90 percent of the normal voltage at the power frequency for durations of 0.5 cycle to 1 minute. (If the voltage drops below 10 percent of the normal voltage, then this is classified as an interruption.) It is further classified into three categories: (a) instantaneous — 0.5 cycle–30 cycles; (b) momentary — 30 cycles–3 sec; (c) temporary — 3 sec–1 min.

27.1.1.13 Separately Derived System. A premises wiring system whose power is derived from a battery, a solar photovoltaic system, or from a generator, transformer, or converter windings, and that has no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system. Equipment-grounding conductors are not supply conductors and are to be interconnected.

27.1.1.14 Sustained Voltage Interruption. *(See 3.3.22.)*

27.1.1.15 Swell. An increase to between 110 percent and 180 percent in normal voltage at the power frequency durations from 0.5 cycle to 1 minute. It is further classified into three categories: (a) instantaneous — 0.5 cycle–30 cycles; (b) momentary — 30 cycles–3 sec; (c) temporary — 3 sec–1 min.

27.1.1.16 Transients. Transients (formerly referred to as surges, spikes, or impulses) are very short duration, high amplitude excursions outside of the limits of the normal voltage and current waveform. Waveshapes of the excursions are usually unidirectional pulses or decaying amplitude, high frequency oscillations. Durations range from fractions of a microsecond to milliseconds, and the maximum duration is in the order of one half-cycle of the power frequency. Instantaneous amplitudes of voltage transients can reach thousands of volts.

27.1.1.17 Transverse Mode Noise. *(See 3.3.16.2.)*

27.1.1.18 Unbalanced Voltages. *(See 3.3.25.)*

27.1.2 Power quality addresses deviations and interruptions from the pure, ideal power supply. Alternating-current (ac) power used to run equipment often consists of distorted, nonsinusoidal waveforms (nonlinear); waveforms in the three phases of a 3-phase circuit will commonly differ slightly in size and shape; and circuit voltage can change as the load on the circuit changes.

27.1.3 Historically, most equipment was moderately tolerant of typical power quality problems. Some equipment with electronic components is more susceptible to power quality problems. Some equipment conducts current during only part of the power frequency cycle. These are typically called non-linear loads, and are sources of harmonic currents. Rectified input switch-mode power supplies, digital or electronic components, arcing devices including fluorescent lamps, and other nonlinear devices affect waveforms and cause a decrease in power quality.

27.1.4 Power quality problems are frequently caused by equipment or conditions on the customer's premises. Power quality problems are less frequently caused by utility generating, transmission, or distribution equipment. However, off-site equipment belonging to neighbors and line exposures such as from capacitor switching, lightning, vehicles, contaminants, and wildlife can create problems that are carried by the utility to its customers.

27.1.5 Poor power quality can cause electrical faults, jeopardize personal safety, damage or reduce the life of electrical and electronic equipment, cause an increased fire hazard, and reduce equipment performance and productivity. Poor power quality can also affect data and communications.

27.1.6 While power quality problems are often identified by maintenance personnel, diagnosing problems and finding solutions can be difficult. Some solutions require knowledge of electrical engineering, testing, and specialized equipment. A solution might require a custom-engineered approach, not merely equipment repair, upgrade, or replacement.

27.1.7 Power quality disturbances include the following:

(1) Harmonics imposed on the fundamental sine wave
(2) Voltage transients
(3) Voltage sags and swells
(4) Long duration undervoltage and sustained voltage interruptions
(5) Unbalanced voltages and single phasing (partial interruption)
(6) Inadvertent and inadequate grounding
(7) Electrical noise
(8) Interharmonics

27.1.7.1 For common power system disturbances and a waveform sag cleared by the supply line circuit breaker, see Figure 27.1.7.1(a), Figure 27.1.7.1(b), and Figure 27.1.7.1(c).

27.2 Harmonics.

27.2.1 Introduction.

27.2.1.1 The fundamental frequency (usually 60 Hz) is the predominant, intended frequency of a power system. Harmonics are identified by their harmonic number. For example, with a 60 Hz fundamental frequency, 120 Hz is the second harmonic, 180 Hz the third harmonic, and 300 Hz the fifth harmonic.

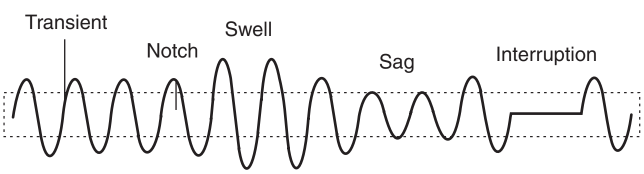


FIGURE 27.1.7.1(a) Common Power System Disturbances.

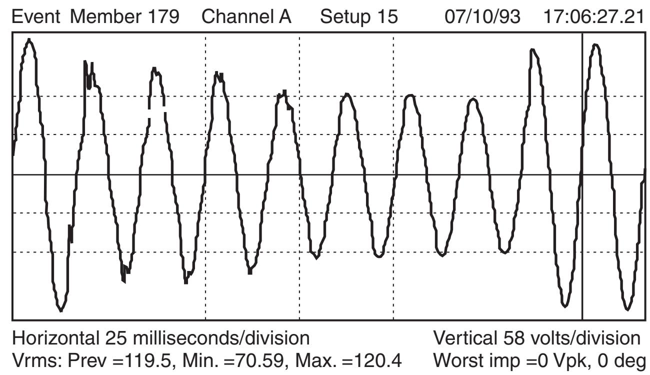


FIGURE 27.1.7.1(b) Waveform of Sag Cleared by Supply Line Breaker Operation.

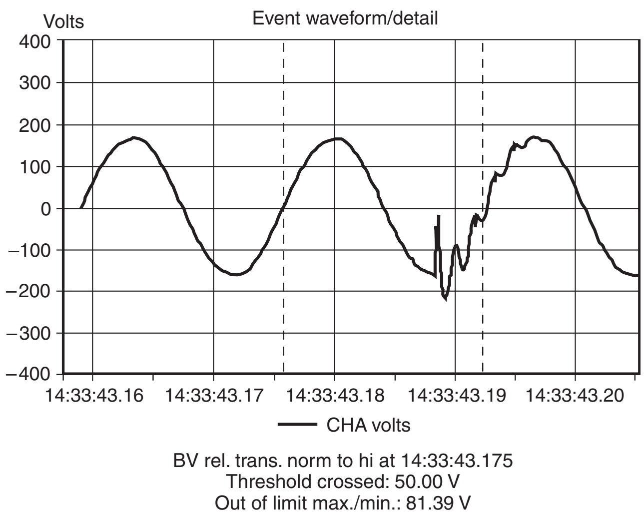


FIGURE 27.1.7.1(c) Waveform with Transient from PF Capacitor Switching.

27.2.1.2 Harmonics distort and change the magnitude of the fundamental. *(See Figure 27.2.1.2.)*

27.2.1.3 Harmonics imposed on the power system are usually expressed as a percentage of the fundamental voltage or current. For example, the total harmonic distortion *(THD)* of a voltage waveform is stated as a percentage and can be defined as 100 times the square root of the ratio (rms) of the sum of the squares of the rms amplitudes of the individual harmonics, divided by the square of the voltage at the fundamental frequency. This value should be considered as related to the maximum load capacity. This is represented by the following formula:

$$THD = \left(\frac{100 \times \sqrt{\sum V_h^2}}{V_f} \right) \%$$

where:
THD = total harmonic distortion (percent)
V_h = rms voltage of the individual harmonic
V_f = rms voltage of the fundamental frequency

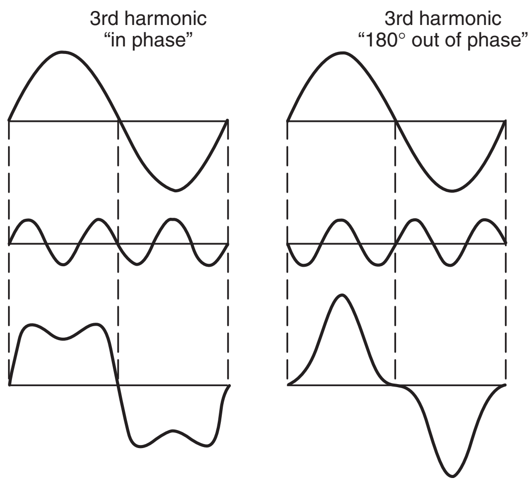


FIGURE 27.2.1.2 Harmonics and the Fundamental Waveform.

27.2.1.4 Line voltage notching is a form of harmonic distortion, as shown in Figure 27.2.1.4. In many cases, line voltage notching caused by phase controlled rectifiers can be more of a problem than current harmonics. Commutation notches can affect the performance of electronic equipment.

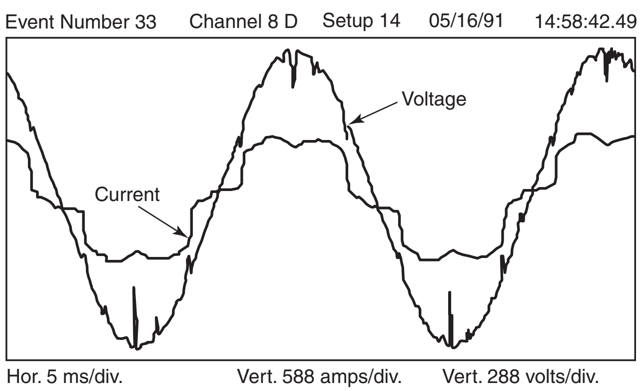


FIGURE 27.2.1.4 Line Voltage Notching Harmonic Distortion.

27.2.2 Harmonic Symptoms and Effects.

27.2.2.1 Harmonics are caused by nonlinear loads in which the current waveform does not conform to the waveform of the impressed voltage. Some of the symptoms and effects of nonlinear loads are comparable to other, more readily recognized symptoms such as overloading and can be difficult to diagnose.

27.2.2.1.1 Problems created by harmonics might include the following:

(1) Excessive neutral current
(2) Overheating of transformers, motors, generators, solenoid coils, and lighting ballasts
(3) Nuisance operation of protective devices
(4) Unexplained blowing of fuses on power-factor correction capacitors
(5) Unusual audible noise in electrical switchgear
(6) Voltage and current waveform distortion that results in misoperation or failure of solid-state electronic equipment
(7) Audible noise interference on telephone circuits
(8) Loss of data on computer systems
(9) False operation of facility distribution power line carrier control systems such as lights, clocks, and load shedding
(10) Failure of UPS systems to properly transfer
(11) Shaft voltages and currents on electric motors causing bearing failure if the bearings are not insulated

27.2.2.1.2 The neutrals of 3-phase, 4-wire systems are especially susceptible to harmonic problems. On such circuits, each phase is displaced by 120 electrical degrees from adjacent phases. If the load is balanced and no harmonics are present, the phase currents cancel vectorially, and the neutral current is zero. However, odd triplen harmonics, such as the third, ninth, and fifteenth, are additive rather than subtractive in the neutral and do not cancel.

27.2.2.1.3 For example, in a 3-phase, 4-wire system, if there are 30 amperes of triplen harmonic current present in a 100-ampere phase current, 90 amperes of triplen harmonic current will flow in the neutral. Neutral current will be higher if the phase currents are unbalanced.

27.2.2.2 Capacitors do not create harmonics, but capacitor failures and blown fuses on power-factor improvement capacitors are often attributable to harmonics. This situation occurs because capacitance can combine with circuit inductance to establish a resonant condition when harmonics are present. Resonance can cause high voltages to appear across elements of the power system and can cause high currents to flow.

27.2.2.2.1 Proper analysis of harmonics involves determining the amount of harmonic current that can be injected by nonlinear loads and then determining the system response to these harmonic currents. The system response will usually be dominated by the interaction of shunt capacitor banks (power-factor correction capacitors) with the system source inductance (step-down transformer). An example of frequency response characteristic is shown in Figure 27.2.2.2.1.

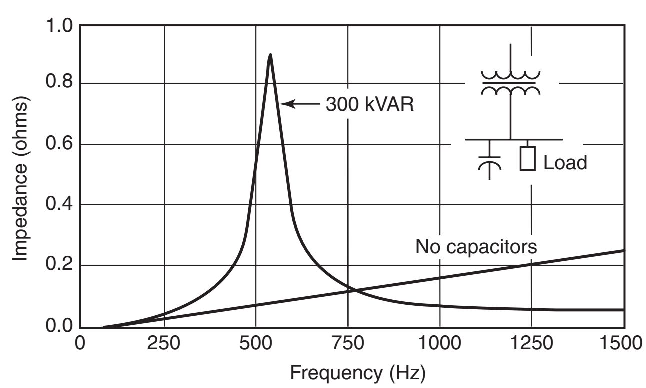


FIGURE 27.2.2.2.1 An Example Frequency Response Characteristic for a 1500 kVA, 13.8/0.48 kV, 6.0 Percent Transformer and a 300 kVAR, 480 V Capacitor Bank.

27.2.2.2.2 The parallel resonance occurs at the frequency where the shunt capacitive reactance is equal to the inductive source reactance and can be expressed in terms of the 60 Hz values as follows:

$$h = \sqrt{\frac{X_c}{X_{sc}}} = \sqrt{\frac{kVA_{sc}}{kVARcap}}$$

where:

h = resonant frequency as a multiple of the fundamental frequency
X_c = shunt capacitive reactance of capacitor
X_{sc} = short-circuit reactance of source
kVA_{sc} = short circuit kVA of source
$kVARcap$ = total capacitor kVAR

27.2.2.2.3 This simple relationship provides an excellent first check to see whether or not harmonics are likely to be a problem. Almost all harmonic distortion problems occur when this parallel resonance moves close to the fifth or seventh harmonic, since these are the largest harmonic current components in most nonlinear loads. However, the eleventh and thirteenth harmonics can also be a problem when nonlinear loads are a large percentage of the total load. If a parallel resonance exists at one of the characteristic harmonics, then the harmonic currents injected by the nonlinear loads are magnified, and high magnitudes of voltage distortion occur.

27.2.2.3 Harmonics can cause overheating, overvoltage, and excessive noise in transformers. Overheating is a compound effect of increased winding I^2R losses due to both excessive current and skin effect and increased eddy current and hysteresis losses in the transformer core.

27.2.2.3.1 On a 3-phase delta-wye-connected transformer, third harmonics generated by the transformer secondary loads are reflected into the primary in the form of circulating currents in the delta-connected primary. It is therefore especially important to use a true rms-reading ammeter when checking a transformer's secondary line, neutral, and, where practical and safe, primary winding current, for possible overload.

27.2.2.3.2 Transformers with relatively high impedance are susceptible to overvoltage and core saturation in the presence of harmonics, causing increased current flow and resultant additional heating. Higher voltages can cause excessive 60 Hz hum, and harmonics can contribute higher-pitched audible noise.

27.2.2.3.3 Motors are also subject to overheating in the presence of harmonics, because of skin effect and increased iron losses. Where fifth harmonics are present, negative-sequence currents will also flow in opposition to the current necessary to develop the torque required for rotation. This counter torque contributes to overheating, and in some extreme cases can result in pulsating torque and excessive vibration.

27.2.2.4 Generators are susceptible to overheating in the presence of harmonics for essentially the same reasons as are motors. Generators equipped with solid-state controls can also operate erratically in the presence of harmonics, especially if the controls incorporate zero-crossing sensing circuits. Generators can cause harmonics due to internal construction. The type of generating winding pitch can determine the magnitude and types of harmonics generated.

27.2.2.4.1 Generators operating in parallel should have the same winding pitch to minimize problems. Where generators operate in parallel with a common neutral, third harmonic currents can circulate between the machines and cause overheating. High resistance grounding of these generators can adequately limit the harmonic current.

27.2.2.5 As is the case with all equipment operating on the principle of electromagnetic induction, ferromagnetic ballasts will also develop excessive heating where harmonics are present. The presence of harmonics can contribute to inaccurate readings (high or low) of induction disc meters.

27.2.2.6 Electrical panels and cables can also exhibit overheating because of excessive neutral current; excessive heating might be detected as discoloration. Harmonics can also cause conductor-insulation failure because of voltage stress and corona discharge.

27.2.2.7 Instrumentation transformers such as current and potential transformers can transfer harmonics from a primary to a secondary, resulting in misoperation of instrumentation, protective relaying, and control circuits.

27.2.2.8 Computers and other computer-type equipment such as programmable logic controllers (PLCs) are very susceptible to harmonic-distorted waveforms, and the possibility of harmonics should be investigated on circuits serving such equipment where neutral-to-ground voltages in excess of 2 volts are measured at the equipment. Harmonic effects on such equipment can range from data errors, process controls operating out of sequence, and erratic operation of production robots or machine tools, through total failure of the electronic equipment.

27.2.2.8.1 In addition to polluting data and control signal transmissions, harmonics can be a source of audible noise on telephone communication circuits. Audible noise can be induced in communication conductors run in proximity to harmonic-bearing conductors. For this reason, voice communication lines should be shielded or rerouted. ANSI/IEEE 519, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems,* contains additional information on the telephone interference factor (TIF).

27.2.3 Causes of Harmonic Distortion. Harmonics from neighboring utility customers can be introduced to the premises by the incoming utility supply. Harmonics originate on the premises in most cases.

27.2.3.1 All equipment operating on the principle of ferromagnetics produces harmonics when operating in the saturation region of the magnetic core. This equipment includes transformers, motors, generators, induction heaters, solenoid coils, lifting magnets, and iron-core arc-discharge lighting ballasts. The extent to which harmonics will be generated will vary with the type of equipment.

27.2.3.2 Arc-producing equipment such as welding machines and arc furnaces also develop harmonics. Arc-discharge lamps also produce harmonics over and above those introduced by the lamp ballast.

27.2.3.3 The most significant contributor to harmonics is often electronic equipment, especially equipment that utilizes a rectified-input switching-mode power supply. The wave-chopping characteristic operation of thyristors, silicon-controlled rectifiers, transistors, and diodes develops current waveforms that do not conform to the applied voltage waveform, and therefore develops harmonics. Included among electronic equipment that is rich in harmonic generation are welders, battery chargers, rectifiers, ac and dc adjustable-speed motor drives, electronic lighting ballasts, computers, printers, reproducing machines, and programmable logic controllers.

27.2.4 Harmonic Surveying and Testing.

27.2.4.1 Where harmonics are suspected as the cause of problems, it is necessary to determine the magnitude of the harmonic frequencies and their contribution to THD. This information will define the extent of the harmonic problem, provide clues as to causes of the harmonics, and provide the data needed to engineer solutions. It will also permit calculation of transformer derating factors in accordance with ANSI/IEEE C57.110, *Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents*.

27.2.4.2 The extent of harmonic surveying and testing will vary widely depending on severity of the problem, available resources, and the facility's particular needs. A very simple test can be performed to confirm or refute the existence of harmonics.

27.2.4.2.1 This test is conducted by taking current readings with an average responding ammeter and a true RMS responding ammeter. If harmonics are present, the average responding instrument generally will yield a lower reading than the rms responding meter.

27.2.4.3 The presence of odd triplen harmonics (third, ninth, fifteenth, and so on) can be readily determined on 4-wire "wye" circuits by measuring neutral current with a true RMS responding ammeter and comparing it with current to be expected on the basis of RMS phase currents. Neutral-to-ground voltages in excess of 2 volts measured at the equipment can also indicate the presence of triplen harmonics. Where such readings determine that triplen harmonics are present, analysis should be undertaken to determine their specific frequencies and magnitudes. Instruments available for harmonic analysis include oscilloscopes, harmonic analyzers, and spectrum analyzers.

27.2.4.4 Oscilloscopes readily permit visual observation of the waveform to determine if it deviates from a sine wave or if line voltage notching exists.

CAUTION: Since one side of the oscilloscope probe might be common to the case, a line isolation device should be used between the probe and the line voltage being measured.

27.2.4.4.1 Harmonic analyzers measure the contribution of harmonic voltage and current at each frequency and calculate THD. Harmonic analyzers are available in a broad range of sophistication, with some also measuring circuit parameters such as kW, kVA, and power factor, and some determining transformer derating factors and telephone interference factors. Spectrum analyzers provide detailed waveform analysis indicating the harmonic frequencies imposed on the fundamental.

27.2.4.5 Total harmonic distortion can vary significantly with load. Therefore, readings should be taken under different load conditions. Measurements should be taken to determine the location and extent of harmonics. Readings should be taken on all phases and neutrals of 3-phase, 4-wire systems, and especially on 3-phase circuits that serve single-phase loads.

27.2.4.6 Voltage measurements on low-voltage circuits can be taken easily by connecting instrumentation directly to the measured point. High voltages, however, will require the use of instrument potential transformers (PTs). The PTs should be dedicated to the test; existing bus potential transformers serving relaying and bus instrumentation should not be used. The measurement instrument should have an input impedance of at least 100 kilohms, and the instrument manufacturer's connection and operating instructions should always be followed.

27.2.4.7 Each facility differs in its tolerance to harmonic distortion. There are some general guidelines that can be followed to determine if harmonics are within acceptable limits. ANSI/IEEE 519, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, is one such standard. Other information sources include the following:

(1) ANSI/IEEE C57.110, *Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents*
(2) Federal Information Processing Standards Publication 94, *Guideline on Electrical Power for ADP Installations*
(3) ANSI/IEEE 1100, *Recommended Practice for Powering and Grounding Sensitive Electronic Equipment,* (Emerald Book)

27.2.5 Recommended Solutions to Harmonic Problems. Solutions to harmonic problems are unique in nature and will depend on the results of the harmonic survey and testing and subsequent analysis. Recommended solutions include any or all of the following:

(1) Derating of existing equipment
(2) Replacement of existing equipment with higher rated equipment
(3) Use of delta-wye- or delta-delta-connected transformers as appropriate
(4) Use of equipment specifically rated for harmonic circuits
(5) Better selection and application of protective and metering devices
(6) Use of rms-sensing protective devices
(7) Balancing of single-phase loads on 3-phase systems
(8) Use of 3-phase rectifiers instead of single-phase rectifiers
(9) Relocating power-factor improvement capacitors
(10) Shielding of conductors and electronic equipment
(11) Isolation of harmonic-sensitive loads
(12) Use of filters to block or shunt off harmonics
(13) Specification of new equipment for low harmonic content
(14) Periodic surveys and power-system adjustments/modifications as might be indicated by survey results
(15) Increased neutral conductor size
(16) Replacement or repair of harmonic producing equipment
(17) Utilization of a motor or generator with an insulated bearing

27.2.5.1 In some cases, solutions can be engineered and implemented with in-house personnel; in other cases, it might be necessary to engage personnel with specialized expertise and equipment.

27.3 Transients (Surges).

27.3.1 Introduction. Transient current is proportional to the transient voltage and the system impedance. System impedance includes source impedance and transient impedance. For rating transient protective devices, transient energy is usually expressed in joules (watt-seconds).

27.3.2 Transient Symptoms and Effects.

27.3.2.1 The effect and severity of the transient depends on magnitude, duration, and frequency. Low-energy transients can cause equipment to malfunction. High-energy transients can cause damage to equipment. When transient-sensitive equipment or transient-producing equipment is installed, problems previously not encountered with existing equipment can occur. In addition, if transient-sensitive equipment and transient-producing equipment are moved electrically closer to each other, problems can result.

27.3.2.2 Within electrical systems without transient voltage protection, transient voltages are limited by flashover of clearances. When the transient reaches breakdown voltage, an arc is established through the air or across the surface of insulation, limiting the maximum transient voltage on the system. Typically, in low-voltage (1000 volts or less) distribution, the maximum transient is limited to about 6 kV for indoor systems, and to about 10 kV to 20 kV for outdoor systems. The transient voltage can be limited to lesser values by surge protective devices.

27.3.2.3 Problems associated with transients include the following:

(1) Unusual equipment damage due to insulation failures or arc-over, even with proven maintenance practices
(2) Damage to electronic equipment components due to their inability to withstand transient voltages
(3) Total failure, lock-up, or misoperation of computer or other microprocessor-based equipment

27.3.3 Causes of Transients.

27.3.3.1 Transient voltages in low-voltage ac power circuits usually originate from lightning effects (direct or indirect) on the power system or from switching operation.

27.3.3.2 Lightning strikes can cause severe transients because of the very high voltages and currents. Lightning can enter the electrical circuit directly, or can be induced by nearby strikes. This might also produce a transient on the grounded and grounding systems.

27.3.3.3 Transients can be caused by the switching of inductive or capacitive loads, such as motors, ballasts, transformers, or capacitor banks. Arcing contacts can also cause transients.

27.3.3.4 Transients can result from abnormal conditions on the power system, such as phase-to-phase or phase-to-ground short circuits.

27.3.4 Transient Monitoring.

27.3.4.1 Monitoring can be used to determine the presence of transients. Storage-type, high-bandwidth oscilloscopes with high-voltage capability can be used, but more information can be obtained from the use of power disturbance analyzers specifically designed for transient and other types of power-quality problems. Monitoring might be required over an extended period of time, due to the characteristics of transients, which vary as loads and system configurations change.

27.3.4.2 Monitoring is often performed at specific locations where a sensitive load is connected, or is to be connected. Other devices on the monitored circuit, such as the power quality monitor itself, can contain surge-protection devices that limit transients and distort the results. If possible, use an alternate power source for powering monitoring equipment.

27.3.4.3 Monitoring can be required phase-to-phase, phase-to-ground, phase-to-neutral, and neutral-to-ground to develop a complete profile of the system.

27.3.5 Recommended Solutions to Transient Problems.

27.3.5.1 The following are devices intended for the suppression of transients: surge arresters, surge capacitors, surge protectors, inductive reactors, and surge suppressors. Proper grounding of all circuits intended to be grounded is required for correct operation of these devices. Manufacturer's instructions should be followed when any of these devices is installed. Engineering evaluation might be required to select the proper type and rating of these devices.

27.3.5.2 Surge arresters are intended to be installed ahead of the service entrance equipment for limiting transient voltage by discharging or bypassing transient currents to ground. They typically provide protection for the effects of lightning.

27.3.5.3 Surge capacitors are placed in a circuit to slow the transient voltage rise time. By spreading out the voltage increase over a longer time span, less electrical stress occurs to equipment subjected to the transient.

27.3.5.4 Surge protectors are gas-tube devices or assemblies composed of one or more gas-tube devices. They are used for low-voltage applications (up to 1000 V rms or 1200 V dc.)

27.3.5.5 A transient voltage surge suppressor (TVSS) is a device intended for installation on the load side of the main overcurrent protection in circuits not exceeding 600 V rms. These devices are composed of any combination of linear or nonlinear circuit elements (that is, varistors, avalanche diodes, and gas tubes), and are intended for limiting transient voltages by diverting or limiting surge current. Filters for electromagnetic interference (EMI) reduction can also be incorporated within TVSS devices.

27.3.5.6 The following are typical locations where transient protection is installed: power circuits at the service entrance, communication circuits entering the building, computer room power, and at susceptible loads.

27.3.5.7 Inductive reactors placed in series with the supply circuit can attenuate off-site transients. Inductive reactors placed in series with noisy equipment can localize transients to the equipment.

27.4 Voltage Sags and Swells.

27.4.1 Sags and swells are the most common types of power quality disturbances. Millions of dollars are lost in productivity each year in the United States due to these disturbances. A simple understanding of their causes will help obtain effective solutions to minimize these disturbances.

27.4.1.1 Different equipment might require a different susceptibility curve. *(See Figure 27.4.1.1(a) and Figure 27.4.1.1(b) for examples of curves.)*

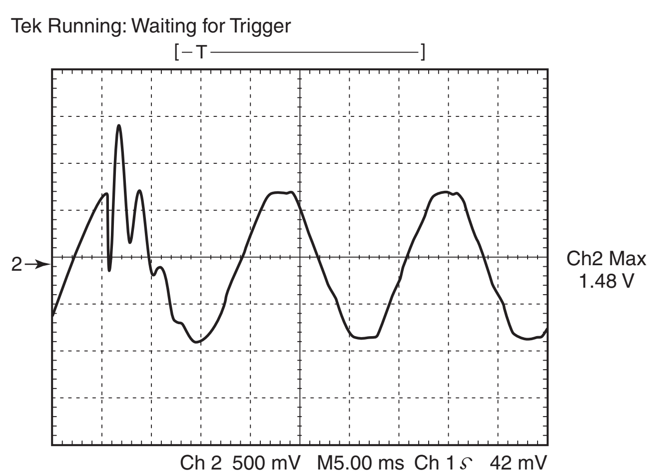


FIGURE 27.4.1.1(a) Typical Low-Frequency Decaying Ringwave. [Courtesy of Information Technology Industry Council (ITI).]

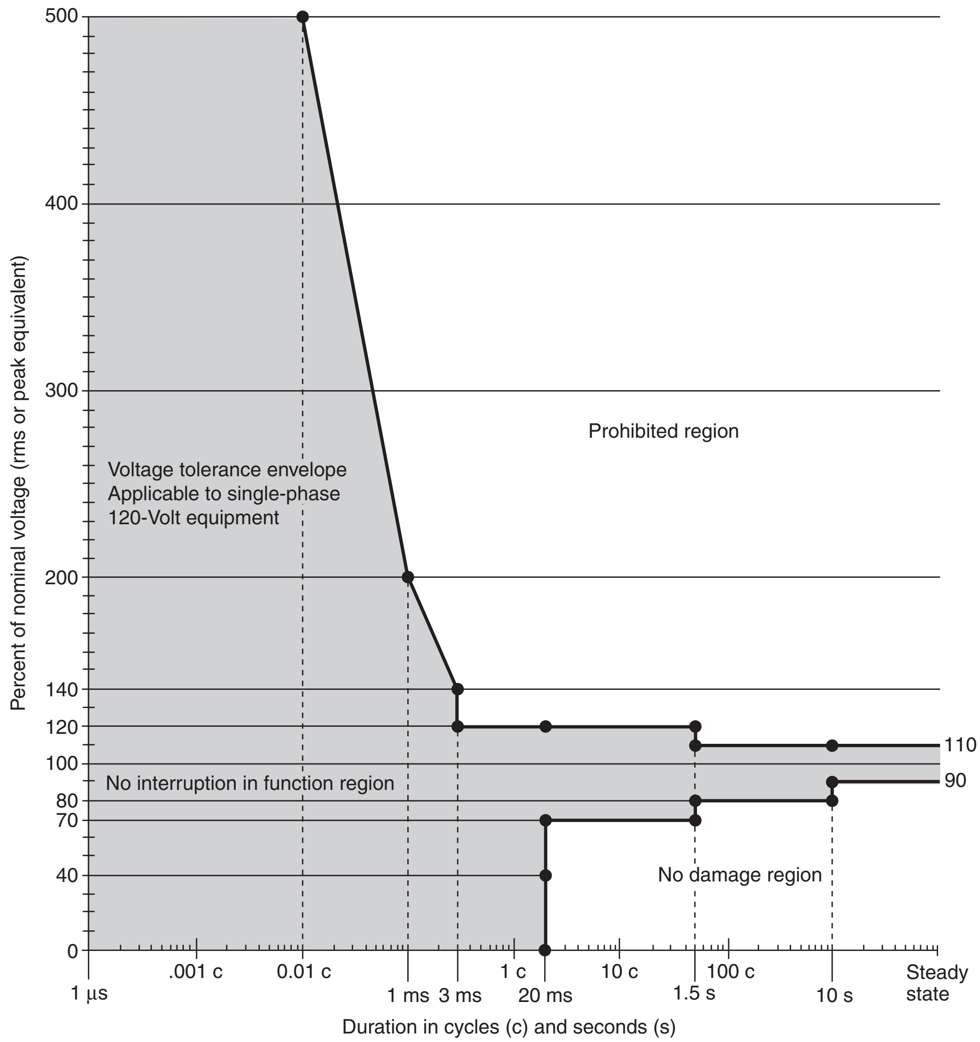


FIGURE 27.4.1.1(b) ITI (CBEMA) Curve. [Courtesy of Information Technology Industry Council (ITI).]

27.4.1.2 Sags are the most common type of voltage disturbances. Typically, sags occur twice as often as swells.

27.4.2 Symptoms of Sags and Swells.

27.4.2.1 Introduction. The effects of a sag are more noticeable than those of a swell. A sag duration longer than three cycles is visible because lighting output is reduced. Sags often are not distinguishable from momentary interruptions, and the effects to the equipment can be the same. Sensitive equipment, such as computers, can experience intermittent lockups or garbled data. Even relays and contactors in motor starters can be sensitive to voltage sags, resulting in shutdown of a process when they drop out.

27.4.2.2 Sophisticated Equipment. Equipment used in industrial plants (for example, process controllers, programmable logic controllers, adjustable speed drives, and robotics) is increasingly sensitive to voltage sags as the equipment becomes more complex. For example, computers are faster, operate at lower logic voltages, and have less power supply ride through, making them much more vulnerable to voltage sags.

27.4.2.3 Loss of Memory. Voltage sags can cause the loss of stored data in programmable electronic systems.

27.4.2.4 Equipment Shutdowns. Motor contactors and electromechanical relays can drop out with a sag to 70 percent of rated voltage lasting 1 cycle or longer. High-intensity discharge lamps generally require restriking for sags below 80 percent. The ride-through of some adjustable-speed drives varies from 0.05 second to 0.5 second. Remote I/O units of some programmable logic controllers trip on a reduction to 90 percent of rated voltage for just a few cycles.

27.4.2.5 Component Breakdown. The effects of a swell can be more physically destructive to the equipment than those of a sag. The overvoltage can cause breakdown of components in the power supplies of the equipment. This can be a gradual, cumulative effect.

27.4.3 Causes of Voltage Sags and Swells. Sags and swells occur in utility transmission and distribution systems, and facility power distribution systems. A common, underlying cause in all three areas is a sudden change of current flow.

27.4.3.1 Sag Causes — Transmission Systems.

27.4.3.1.1 Outside Sources. Severe weather, construction accidents, transportation accidents, or animals can cause faults that result in sags. Lightning is a common cause of faults on overhead transmission and distribution lines. A fault can occur by lightning directly striking a phase conductor or striking a nearby grounded object, such as a transmission shield wire or tower.

27.4.3.1.2 Transmission system voltage sags are normally shorter in duration than utility distribution sags. The fault-clearing mechanisms (the relay/breaker schemes) are designed to react faster for transmission faults. Sags to 75 percent in a facility have been caused from transmission faults 300 miles away.

27.4.3.2 Sag Causes — Utility Distribution Systems.

27.4.3.2.1 Outside Causes. In addition to the transmission system causes, contact with tree limbs and motor vehicle accidents can result in voltage sags. Such faults can be 3-phase, line-to-line or line-to-ground. The 3-phase faults are the most severe, but are relatively uncommon. Single line-to-ground faults on the utility system are a common cause of voltage sags in an industrial plant. A fault on a single feeder can result in an interruption to loads on that feeder, as well as a sag on the other feeders.

27.4.3.2.2 Sag Duration. Typically, distribution system sags are 6 cycles to 20 cycles. Repeated sags can occur when reclosing on the same fault. Depending on the number of reclosures, feeders can experience several voltage sags in succession.

27.4.3.3 Sag Causes — Facility Power Systems.

27.4.3.3.1 Sudden increases in the current demand within a facility can cause sags until the large current demand decreases. The sudden increases can be the result of fault conditions within the building, or the startup of large inductive loads, such as motors. In one large-scale study *(see Section 27.10)*, 50 percent or more of the sags and swells recorded were caused by load equipment in the same building.

27.4.3.3.2 A voltage sag can last for 30 cycles for large, high current demand motors.

27.4.3.3.3 A utility fault usually creates a more severe sag than a motor start sag. The sag will last until the fault is cleared or removed.

27.4.3.4 Swell Causes.

27.4.3.4.1 Swells are less common than voltage sags, and are usually associated with system fault conditions. A swell can occur due to a single line-to-ground fault on the system, which can result in a temporary voltage rise on the unfaulted phases.

27.4.3.4.2 Swells can also be generated by sudden load decreases. The abrupt interruption of current can generate a large voltage, proportional to the inductance and the rate of change of the current. Switching on a large capacitor bank can also cause a swell, though it more often causes a high frequency transient.

27.4.4 Monitoring and Testing for Sags and Swells.

27.4.4.1 Different types of monitoring equipment are available to monitor sags and swells. These range from event indicators that visually indicate that a sag or swell has occurred, to graphical monitors that provide a cycle-by-cycle picture of the disturbance and record the minimum/maximum values, duration, and time of occurrence.

27.4.4.2 Finding the Source. Data on the timing and magnitude of the sag or swell can often identify the source of the initiating condition. If the phase current levels of the load did not change prior to the voltage sag, the source is more likely to be upstream. When the magnitude of the sag is severe, it is likely that the source was close by. A power-factor correction capacitor being switched on can result in an oscillatory transient followed by a swell.

27.4.4.3 Unless there is significant information pointing to the source of the disturbance, it is common practice to begin monitoring at the point where the utility service connects to the facility equipment.

27.4.4.4 If the source of the disturbance is determined to be internal to the facility, then placing multiple monitors on the various circuits within the facility would most likely identify the source of the problem quickly.

27.4.4.5 Monitoring Instrument Sensitivity. Power monitoring instruments are quite sensitive, and outside factors can influence their accuracy. Long measurement leads are susceptible to RFI/EMI pickup, which can distort the results.

27.4.5 Solutions for Sags and Swells.

27.4.5.1 A transformer tap change can be used to raise or lower the nominal voltage level and make the system less susceptible to sags or swells. Automatic solid-state tap-changing transformers that are controlled by electronic sensing circuits can react relatively quickly (1 cycle to 3 cycles).

27.4.5.2 Different transformer configurations can be used to minimize the effects of events that cause sags and swells. For example, a delta-delta configuration tends to hold voltage levels higher than a delta-wye or a wye-delta configuration.

27.4.5.3 Fault current limiters, zero voltage independent pole closing capacitor switches, and high-energy surge arresters can be added to the electric system.

27.4.5.4 Ferroresonant transformers, also called constant-voltage transformers, can handle most short-duration voltage sags. They provide excellent regulation but have limited overload capacity and poor efficiency at low loads.

27.4.5.5 Magnetic controlled voltage regulators use transformers, inductors, and capacitors to synthesize 3-phase voltage outputs. Enough energy is stored in the capacitors to ride through one cycle. The overall response time is relatively slow (3 cycles to 10 cycles).

27.4.5.6 A UPS can provide isolation from power line disturbances, in addition to providing ride-through during a sag. *(See Chapter 25.)*

27.4.5.7 A static transfer switch is capable of transferring the supply voltage from one voltage source to another within a quarter-cycle.

27.5 Long Duration Undervoltages and Sustained Voltage Interruptions.

27.5.1 Normal Supply Voltage Variations. Variations in the normal supply voltage are to be expected because loads on the supply system and plant distribution system are not constant. Electric utilities, equipment manufacturers, and end users have established standards for steady-state operating voltage limits that accommodate these variations. Facility utilization equipment can be designed and rated to operate within the range of supply system voltage while allowing for voltage drop in the plant system. *[See ANSI /NEMA C84.1, Electric Power Systems and Equipment, Voltage Ratings (60 Hertz).]*

27.5.1.1 Electric Utilities. Electric utilities can be required by their regulatory commissions to maintain service voltages within prescribed limits for the various types of service. Plant electrical people should be aware of any required service voltage limits for their type of service. The utility generally works with the customer to ensure that the service voltage remains within the required limitations or within their standard design limits where there are no required limitations.

27.5.1.2 As the system load varies, the utility automatic voltage-regulating equipment maintains the service voltage within the required range. When the serving utility's electrical system is severely stressed, the utility can implement a load reduction strategy by reducing the voltage on its distribution lines, typically up to 5 percent. During these periods, the service voltage can be near the lower limit of the required range. As a result, a long-term undervoltage condition can exist at plant utilization equipment. It is strongly recommended that plant distribution system voltage drops be kept to a reasonable level.

27.5.2 Symptoms of Long Duration Undervoltage. Undervoltage might not be readily apparent. Depending on the length and magnitude of the undervoltage, there can be a detrimental effect on electrical and electronic equipment. Equipment such as induction motors might run hotter. Electronic equipment such as computers or microprocessor-based devices can function erratically.

27.5.3 Causes of Long Duration Undervoltage. A long duration undervoltage can originate on the electric utility system or on the plant electrical system. The utility system can be stressed due to line or equipment failure or system load conditions exceeding the supply capability. The plant electrical system or connected loads can result in unacceptable voltage drops even though the voltage is normal at the service point.

27.5.4 Monitoring and Testing of Long Duration Undervoltages. Because the occurrence of a long duration undervoltage might not be obvious, and damage to equipment and systems can result, an appropriate monitoring system is recommended where reliability is vital.

27.5.4.1 The monitoring system can consist of a sophisticated warning scheme with visual and audible alarms at appropriate locations. Alternatively, it can simply be a voltage sensing relay located at the facility service entrance or at sensitive equipment with alarms placed in appropriate locations.

27.5.5 Solutions for Long Duration Undervoltages. When a long duration undervoltage occurs, costly and/or sensitive equipment should be disconnected to prevent possible damage. If it is necessary to keep the equipment or system in operation, then an alternative power supply should be provided.

27.5.6 Symptoms of a Sustained Voltage Interruption. A sustained voltage interruption is obvious because electric power is unavailable for an extended period of time except for equipment served by an alternate power source.

27.5.7 Causes of Sustained Voltage Interruption. Sustained voltage interruptions are caused by power system disruptions such as power lines going down in a storm, the utility's distribution transformer failing, a fault condition causing a circuit protective device to open, or plant wiring problems.

27.5.8 Solutions for Sustained Voltage Interruptions. Solutions include generator sets, multiple power sources, and battery banks.

27.6 Unbalanced Voltages and Single Phasing. *(See 3.3.26 for definition of unbalanced voltages.)*

27.6.1 Percentage Limitations. On 3-phase circuits, unbalanced voltages can cause serious problems, particularly to motors, transformers, and other inductive devices.

27.6.1.1 Single phasing, which is the complete loss of a phase, is the worst-case voltage unbalance condition for a 3-phase circuit.

27.6.1.2 The National Electrical Manufacturers Association (NEMA) in its *Motors and Generators Standards* (MG1) part 14.35, defines voltage unbalance as follows: percent unbalance = 100 ×(maximum voltage deviation from the average voltage) divided by the average voltage.

27.6.1.3 NEMA states that polyphase motors shall operate successfully under running conditions at rated load when the voltage unbalance at the motor terminals does not exceed 1 percent. Also, operation of a motor with more than 5 percent unbalance condition is not recommended, and will probably result in damage to the motor.

27.6.1.4 Example: With line-to-line voltages of 460, 467, and 450, the average is 459, the maximum deviation from average is 9, and the percent unbalance equals 100 × (9/459) = 1.96 percent, which exceeds the 1 percent limit.

27.6.2 Causes of Unbalanced Voltages.

27.6.2.1 Unbalanced voltages usually occur because of variations in the load. When phases are unequally loaded, unbalanced voltages will result because of different impedances.

27.6.2.2 Symptoms and causes of unbalanced voltages include the following:

(1) Unequal impedance in conductors of power supply wiring
(2) Unbalanced distribution of single-phase loads such as lighting
(3) Heavy reactive single-phase loads such as welders
(4) Unbalanced incoming utility supply
(5) Unequal transformer tap settings
(6) Large single-phase load on the system
(7) Open phase on the primary of a 3-phase transformer
(8) Open delta-connected transformer banks
(9) A blown fuse on a 3-phase bank of power factor correction capacitors

27.6.3 Symptoms.

27.6.3.1 The most common symptoms of unbalanced voltages are improper operation of, or damage to, electric motors, power supply wiring, transformers, and generators.

27.6.3.2 Unbalanced voltages at motor terminals can cause phase current unbalance to range from 6 to 10 times the voltage unbalance for a fully loaded motor. As an example, if a voltage unbalance is 2 percent, then current unbalance could be anywhere from 12 percent to 20 percent. This causes motor overcurrent, resulting in excessive heat that shortens motor life.

27.6.3.2.1 The unbalance at the motor terminals will cause speed and torque to be reduced. If the voltage unbalance is great enough, the reduced torque capability might not be adequate for the application. Noise and vibration levels can also increase as a result of voltage unbalance.

27.6.3.3 Motor Heating and Losses. Insulation life is approximately halved for every 18°F (10°C) increase in winding temperature. Table 27.6.3.3 illustrates the typical percentage increases in motor losses and heating for various levels of voltage unbalance.

Table 27.6.3.3 Voltage Unbalance vs. Temperature Rise at Average Voltage of 230

Percent Unbalanced Voltage	Percent Unbalanced Current	Increased Temperature Rise °C
0.3	0.4	0
2.3	17.7	30
5.4	40	40

27.6.3.3.1 The motor often continues to operate with unbalanced voltages; however, its efficiency is reduced. This reduction of efficiency is caused by both increased current (I) and increased resistance (R) due to heating. Essentially, this means that as the resulting losses increase, the heating intensifies rapidly. This can lead to a condition of uncontrollable heat rise, called *thermal runaway*, which results in a rapid deterioration of the winding insulation, ending in winding failure.

27.6.3.4 Motor Operation Under Single-Phase Condition. Single-phase operation of a 3-phase motor will cause overheating due to excessive current and decreased output capability. If the motor is at or near full load when single-phasing occurs, it will not develop enough torque and therefore will stall. This results in high currents, causing an extremely rapid temperature rise. If motor protection is not adequate, the stator winding will fail, and the rotor may be damaged or destroyed.

27.6.3.4.1 Standard (thermal, bimetallic, eutectic alloy) overload relays are normally relied upon to provide protection against single phasing where properly selected and applied. Protective relays or other devices can provide supplemental single-phasing protection.

27.6.4 Monitoring and Testing.

27.6.4.1 The first step in testing for unbalanced voltages should be to measure line-to-line voltages at the machine terminals. If the motor starter is close by, the tests can be made at load or "T" terminals in the starter. The current in each supply phase should be measured to check for current unbalance.

27.6.4.2 Detecting Single Phasing.

27.6.4.2.1 Single phasing should be suspected when a motor fails to start. The voltage should be checked for balanced line-to-line voltages.

27.6.4.2.2 If the motor is running, the voltage and the current in each phase of the circuit should be measured. One phase will carry zero current when a single-phasing condition exists.

27.6.5 Solutions for Unbalanced Voltages.

27.6.5.1 Unbalanced voltages should be corrected; unbalance caused by excessively unequal load distribution among phases can be corrected by balancing the loads. Also, checking for a blown fuse on a 3-phase bank of power factor correction capacitors is recommended.

27.6.5.2 When voltage unbalance exceeds 1 percent, the motor should be derated as indicated by the curve in Figure 2 of NEMA MG 1 *Motors and Generators Standards*.

27.6.5.3 Automatic Voltage Regulator (AVR). AVRs can be used on a per phase basis to correct under- and overvoltage, as well as voltage unbalance. The AVR can compensate for voltage unbalance, provided that the input voltage to the AVR is within its range of magnitude.

27.6.5.4 Relays. Negative sequence voltage relays can detect single phasing, phase-voltage unbalance, and reversal of supply phase rotation. Reverse phase or phase sequence relays provide limited single-phasing protection by preventing the starting of a motor with one phase of the system open.

27.6.5.5 Transformer tap settings should be checked; unequal power transformer tap settings can be a cause of voltage unbalance. This condition should be checked prior to taking other steps.

27.6.5.6 An unsymmetrical transformer bank should be replaced. For example, an open delta bank can be replaced with a three-transformer bank.

27.7 Symptoms — Grounding.

27.7.1 If the equipment ground conductor and the service neutral are not electrically connected to the central grounding point, noise voltages can develop between them and appear as common mode noise.

27.7.1.1 Wiring without an equipment ground conductor and without electrically continuous conduit can produce common mode noise.

27.7.1.2 Ground loops are undesirable because they create a path for noise currents to flow.

27.7.2 Monitoring and Testing — Grounding. The electrical connection to earth can be measured using the three-point system referred to in ANSI/IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems* (Green Book). Minimizing the impedance between the equipment grounded conductor and the grounding conductor is recommended, as follows:

(1) A visual inspection should be made to verify the integrity of the grounding and bonding conductors and associated connections.
(2) An impedance test should be performed on the equipment-grounding conductor.
(3) Voltage should be measured between the equipment-grounding conductor and the grounded conductor.
(4) A check should be made for abnormal currents on the equipment-grounding conductor.

27.7.3 Solutions — Grounding.

27.7.3.1 The grounded conductor should be connected to the equipment-grounding conductor only as permitted by NFPA 70, *National Electrical Code*.

27.7.3.2 Isolated Equipment Ground. One solution is to install an "isolated ground" receptacle (identified by orange color or an orange triangle) in which the equipment-grounding terminal is insulated from the mounting strap. An insulated equipment-grounding conductor is then connected from the grounding terminal of the receptacle in accordance with Article 250 of NFPA 70, *National Electrical Code*. The insulated equipment-grounding conductor is connected to the applicable derived system or service grounding terminal only at the power source.

27.7.3.3 Isolation Transformer. An isolation transformer has separate primary and secondary windings with an interwinding shield that has its own grounding connection. The bonding jumper between the equipment-grounding conductor and the secondary grounded conductor provides protection from common mode electrical noise.

27.7.3.4 Signal Circuit Isolation. Breaking the ground loop current path will minimize ground currents on signal circuits. This can be accomplished by one or more of the following:

(1) Grounding at a single point per system *[See ANSI/IEEE 142, Recommended Practice for Grounding of Industrial and Commercial Power Systems (Green Book)]*
(2) Fiber optic transmission over completely nonconducting path
(3) Optical isolators
(4) Signal circuit isolation transformers in signal circuit or power circuits

27.8 Noise in Electrical and Electronic Systems.

27.8.1 Introduction. Noise is undesirable electrical signals in an electrical or electronic circuit. It can be random or continuous in nature. Noise can occur at any frequency and amplitude. Noise can be introduced into a circuit from a multitude of sources and can manifest itself in equipment malfunction or data corruption.

27.8.1.1 Common Mode Noise. In a 3-phase system, common mode noise is seen equally and in phase between any phase conductor or neutral and the grounding conductor. Neutral-to-ground voltage or ground current can be a result of common mode noise. *(See 3.3.16.1 for a definition of common mode noise.)*

27.8.1.2 Transverse Mode Noise. In a 3-phase system, transverse mode noise occurs in phase on all 3-phase conductors and neutral. *(See 3.3.25 for a definition of transverse mode noise.)*

27.8.1.3 Interference. Interference that is electromagnetically coupled into a wiring system is called electromagnetic interference (EMI). Interference that is capacitively coupled into a wiring system is called radio frequency interference (RFI). Interference can appear as transverse or common mode noise.

27.8.2 Symptoms.

27.8.2.1 Electrical noise is present in all circuits to a certain degree. It might or might not present a problem. Unlike sags or swells, electrical noise does not normally destroy equipment. It does not cause circuit breakers to trip, unless the noise affects shunt trip or undervoltage release controls.

27.8.2.2 Electrical noise usually manifests itself in the form of data corruption and/or unexplained equipment malfunction. For example, electrical noise can create "hum" in a telephone system or "snow" on a video image, or can cause a computer to lock up.

27.8.3 Causes. Electrical noise is a by-product of the normal operation of electrical equipment. The type and sources of noise are as diverse and numerous as the number of facilities that contain power systems and include the following:

(1) Transformers generate magnetic fields that can influence adjacent pieces of equipment.
(2) Long cable runs between interconnected pieces of computer equipment can act as an antenna to a local radio station.
(3) Any piece of electronic equipment that contains a switch mode power supply will introduce electrical noise to some degree into both the building wiring system, as well as the air.
(4) Poor electrical wiring connections can create electrical noise. A loose connection can vibrate, creating an arc at the connection, resulting in noise.

27.8.4 Monitoring and Testing. Locating the sources, frequency, and amplitude of noise can be a difficult and time-consuming task. Troubleshooting becomes increasingly difficult as multiple sources of noise might be present. Determining the amplitude and frequency of the noise signal is essential in identifying the source. Typically, several different types of test equipment can be required to isolate the nature of the noise. These include the following:

(1) Spectrum analyzer — capable of measuring a wide range of frequencies
(2) Conducted RFI/EMI recorder — capable of measuring noise levels superimposed on the voltage waveform
(3) Radiated RFI/EMI recorder — capable of measuring electrical noise levels present in the air
(4) Digital storage oscilloscope with line decoupler
(5) Power quality monitor

27.8.5 Solutions.

27.8.5.1 Elimination. Once the nature of noise disturbance is determined, the best solution is to isolate and eliminate the source. Unfortunately, the source of the noise cannot always be located, or the offending piece of equipment removed. In these cases, the noise should be attenuated or filtered out of the system. Some methods of attenuating or filtering out noise are listed below.

27.8.5.2 Signal Reference Grid. This is a special type of grounding system designed for data processing installations. It provides the lowest possible ground impedance across the widest spectrum of frequencies when properly installed. The grid places the entire data processing ground system at a common potential.

27.8.5.3 Isolation Transformers. Transformers equipped with multiple electrostatic shields can significantly attenuate transverse and common mode noise.

27.8.5.4 Filters. Filtering can be low pass, high pass, band pass, or notch types. Once the frequency and amplitude of the noise signal is determined, a filter can be tuned to "trap" the unwanted noise signal.

27.8.5.5 Signal Cable. The use of twisted pair and shields in low power, signal cables can effectively reduce noise.

27.8.5.6 Shielding. Plane shielding mounted on walls, floors, and/or ceilings can reduce radiated noise if properly grounded.

27.9 Interharmonics.

27.9.1 Symptoms.

27.9.1.1 The flickering of lights is often a result of subharmonics that occur below 24 Hz, which is observable. Around 9 Hz, as little as a 0.25 percent variation in the rms voltage can be detected in some types of lighting.

27.9.1.2 The misoperation of equipment that occurs because of harmonics, such as the overheating of transformers and the misoperation of control devices, can also occur with interharmonics. In addition, CRT flicker, overload of conventional series tuned filters, overload of outlet strip filters, communications interference, and CT saturation can result from interharmonics. *(See 27.2.2 for additional information.)*

27.9.2 Causes. Operation of loads that draw current or have mechanical processes that are not synchronized to the power line frequency can result in interharmonic voltages and currents. Examples are cycloconverters, static frequency converters, subsynchronous converter cascades, induction motors, arc furnaces, and arc welders. Arc furnaces, which draw very large arcing currents during the melting stage, can generate interharmonics over a wide range of frequencies.

27.9.3 Monitoring and Testing. Harmonic analyzers that use conventional fast Fourier transform (FFT)–based harmonic analysis might not be fully effective in determining the presence of interharmonics. The energy of the interharmonic will often be split between two adjacent harmonic values. Spectrum analyzers or harmonic analyzers with interharmonic capabilities are recommended.

27.9.3.1 A flickermeter is a special type of meter for measuring the presence of voltage fluctuations that can result in light flicker.

27.9.4 Solutions. The solutions for minimizing the effects of interharmonics are often similar to those used with harmonics *(see 27.2.5)*. These solutions include filtering, impedance reduction, derating of transformers and motors, and isolation of sensitive equipment.

27.10 Voltage Fluctuations and Flicker.

27.10.1 Explanation of Voltage Fluctuations and Flicker.

27.10.1.1 Voltage fluctuations are variations in the RMS voltage that are less than those that would be considered a “sag.” They generally do not cause equipment to malfunction, but often result in light flicker.

27.10.1.2 Flicker is the change in light output from a lamp, caused by the fluctuation of the supply voltage in the frequency range of 0.5 Hz to 30 Hz, where as little as a quarter of a percent voltage fluctuation at 9 times per second can be perceived. Figure 27.10.1.2 contains an example of a flicker sine wave.

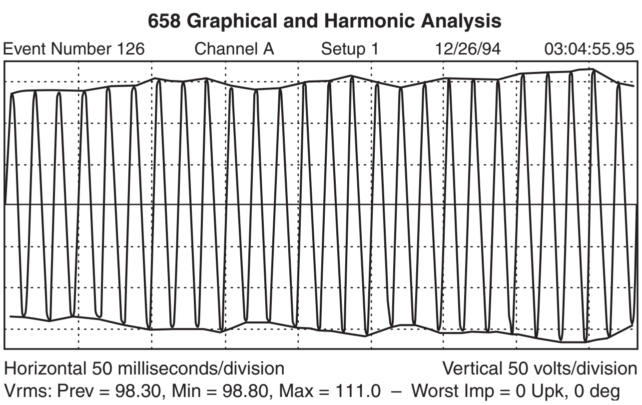


FIGURE 27.10.1.2 Example of a Flicker Sine Wave. (Courtesy of Dranetz Technologies, Inc.)

27.10.2 Symptoms.

27.10.2.1 The effects of the voltage fluctuations are normally perceived as an annoyance and distraction when the lights flicker. They can induce discomfort in the form of nausea or headaches. They usually are not severe enough to disrupt most manufacturing processes, though they can cause variations in the processes.

27.10.2.2 Factors affecting severity include the following:

(1) Frequency of voltage fluctuations (how often it occurs)
(2) Magnitude of voltage fluctuations (how much of a change)
(3) Type of lighting (incandescent, fluorescent, HID)
(4) Ambient light level
(5) Amount of the surface illuminated
(6) Type of activity and the eye-brain characteristics of the individual person

27.10.3 Causes.

27.10.3.1 The voltage fluctuations or modulations of the RMS envelope follows the same basic rules as the RMS variations that result in sags (dips) or swells. They are usually the result of a change in load current, which causes a change in the voltage drop across the source impedance, which then results in a change in the voltage supply.

27.10.3.2 The frequency of the voltage fluctuation can be the direct result of the frequency of the current draw by the load as the result of folding back of higher frequencies modulating with 50/60 Hz fundamental or their harmonics, which produces sidebands around the fundamental or harmonic frequency.

27.10.3.3 Common sources of voltage fluctuations include the following:

(1) Lamp dimmers
(2) Resistance welding machines
(3) Rolling mills
(4) Large electric motors with variable loads
(5) Arc furnaces and arc welders
(6) Switching on and off of PF correction capacitors
(7) Medical imaging machines (X-ray, MRI, CAT scan)
(8) Large-capacity copy machines
(9) Electric motor starts
(10) Household appliances

27.10.4 Monitoring and Testing.

27.10.4.1 The perception of the light flickering is measured using a flicker meter, which measures two parameters: Pst is the short-term perception index, and Plt is the long-term perception index.

27.10.4.1.1 A value of 1 should be assigned to the lower bound of the observable flicker perception curve for 60 W incandescent light bulbs.

27.10.4.1.2 The larger the number, the more perceptible is the flicker.

27.10.4.2 Monitoring for voltage fluctuations generally begins at the point of common coupling. The change in current versus the change in voltage helps to determine whether the monitoring point is upstream or downstream from the source. Some flicker meters and some power quality analyzers have the capability to capture the waveforms and other calculations that help determine the source.

27.10.5 Solutions. Three solutions to minimizing the effects of the voltage fluctuation on lighting are reducing the magnitude and/or changing the frequency of the load current; reducing the source impedance; and changing the type of lighting, such as changing from an incandescent lamp to a fluorescent lamp.

27.11 Power Quality References. See Annex K for these references.

Chapter 28 Vibration

28.1 Introduction. Many rotating machinery failures occur for mechanical reasons, such as poor alignment, bearing failure, imbalance, or improper mounting.

28.2 Machine Vibration. All equipment vibrates when it is running. Excessive vibration indicates a problem. It might be in the mechanical integrity of the machine, for example, as imbalance, misalignment, loose parts, or faulty bearings. It might be in the electrical integrity of the machine, for example, an open rotor bar or cracked endring in a squirrel cage motor, or a faulty power supply to a direct-current motor.

28.2.1 There are three common methods of measuring vibration. When measured as displacement, the units are mils peak-to-peak or microns peak-to-peak. Velocity measurements are in inches per second or millimeters per second. Acceleration measurements are expressed in m/sec^2 (ft/sec^2). Vibration is usually measured at the bearing housing.

28.2.2 Displacement is generally used as an indicator of vibration severity for both low-speed equipment and low-frequency vibration. Examples include rotational imbalance, belt vibration, and shaft seal rub. The acceptable value of displacement for machine vibration decreases with increasing speed.

28.2.3 For example, a machine rotating at 900 rpm might have an acceptable vibration displacement limit of 2.5 mil. Running at 3600 rpm, the acceptable vibration displacement limit might be 1 mil.

28.2.4 For higher-frequency problems, either vibrational velocity or acceleration measurements are generally used. Velocity is independent of machine speed and therefore a better general indicator of overall vibration severity. *(See Table 28.2.4.)* Acceleration, measured in grams peak, is used to evaluate high-frequency problems such as those related to bearings and gears.

Table 28.2.4 Vibration Severity Chart

Velocity RMS					
mm/sec	**in./sec**	**Class 1**	**Class 2**	**Class 3**	**Class 4**
0.71	0.028	A	A	A	A
1.12	0.044	B	A	A	A
1.8	0.071	B	B	A	A
2.8	0.110	C	B	B	A
4.5	0.177	C	C	B	B
7.1	0.279	D	C	C	B
11.2	0.440	D	D	C	C
18.0	0.708	D	D	D	C
28.0	1.10	D	D	D	D

Notes: Class 1: Up to 20 hp on fabricated steel foundation
Class 2: a. 25 hp–100 hp on fabricated steel foundation
b. 100 hp–400 hp on heavy solid foundation
Class 3: Above 400 hp on heavy solid foundation
Class 4: Above 100 hp on fabricated steel foundation
Grade A: Good
Grade B: Useable
Grade C: Just acceptable
Grade D: Not acceptable

Table 28.2.5 Unfiltered Vibration Limits

Speed (rpm)	Rotation Frequency (Hz)	Peak Velocity	
		mm/s	**in./sec**
3600	60	3.8	0.15
1800	30	3.8	0.15
1200	20	3.8	0.15
900	15	3.0	0.12
720	12	2.3	0.09
600	10	2.0	0.08

Note: These levels pertain to bearing housing monitoring in the vertical, horizontal, and axial directions. Test conditions are uncoupled and without load.

28.2.5 Unfiltered Vibration Limits. Suggested vibration limits for larger machines are specified in Table 28.2.5.

28.3 Types of Instruments. Analog and digital instruments are available to measure displacement, velocity, and acceleration. In addition, there are computerized data collecting analyzers that store vibration spectrums, using fast Fourier transform (FFT) methodology.

28.4 Resonance. All machines have certain natural frequencies of vibration. When vibration occurs at a frequency equal to one of the machine's natural frequencies (critical frequencies), the machine or component will exhibit a large amplitude of vibration.

28.4.1 When this happens, the machine is said to have a resonant vibration. It is suggested that machine speed be at least 15 percent removed from any critical frequency. Where a machine should pass through one or more critical frequencies in coming up to running speed, it should pass through these quickly.

28.5 Methods of Balance. Static imbalance is an imbalance on one side. The solution is either to remove the excess weight or add an equal amount at the opposite side. Small motors can be statically balanced in a test stand with loose bearings or a knife edge. Dynamic balance, also known as two-plane balancing, is typical of cylindrical rotating devices, such as a roller or an electric motor rotor. Dynamic balance requires specialized equipment.

28.6 Assembly and Installation Guidelines.

28.6.1 Installation of Accessories. Where possible, bearings, gears, and couplings should be uniformly preheated before installation to minimize damage. All rotating bodies should be dynamically balanced to within standard tolerance, established by the manufacturer. Equipment with accessories should be balanced without these extra items. Accessories should then be installed individually and the equipment rebalanced.

28.6.2 Alignment. All rotating equipment should be properly aligned when installed. The "eyeball" and straight edge, feeler gauges, and bubble gauges do not provide the precision required. Rim and face and reverse dial methodology, or both, should be used. For high-speed equipment and precision work, laser-alignment technology is available. Laser alignment can provide the advantages of accuracy, speed, and minimum chance for operator error. If the operating temperature of equipment changes significantly, thermal expansion should be considered.

28.7 Baseline Data. Together with other tests, it is strongly recommended to keep data on vibration levels. With time, vibration tends to increase. Scheduled maintenance can reduce such problems, usually at a fraction of the cost of a breakdown caused by insufficient maintenance. These readings should be made at three- to six-month intervals or more often as required. Causes of a substantial change in vibration should be investigated promptly.

28.8 Noise. All machines produce some sound when running. Changes in the sound level might indicate problems and should be investigated. Manufacturers can often supply equipment with low noise levels when necessary. Excess noise can be caused by many factors, such as using rigid conduit connections instead of flexible connections, locating a machine in the corner of a room with hard-sound reflecting side walls, and designing an installation with inadequate vibration isolators.

28.8.1 Variable frequency inverters, which operate ac motors at varying speeds, sometimes have low switching frequencies that will show up as noise in the load motor. To correct this problem, a higher-frequency switched inverter, isolation transformer, line choke, or motor with a skewed rotor design can be used.

Chapter 29 Grounding

29.1 Introduction.

29.1.1 *Grounding* is a term that has many different facets, depending on the application. For example, certain current-carrying electrical system conductors (or common of a three-phase wye electrical system) are intentionally grounded. This intentional connection stabilizes the voltage under normal operating conditions and maintains the voltage at one level relative to earth or something that serves in place of the earth.

29.1.2 Electrically conductive surfaces are also normally grounded for safety purposes. Grounding is necessary to keep the metal enclosures, metal housings, or non-current-carrying parts of the electrical equipment at earth potential and to avoid hazardous voltages between the equipment and earth.

29.1.3 During maintenance or construction, de-energized, ungrounded conductors are also temporarily grounded for personnel protection against the energizing of circuit conductors. Therefore, grounding is also a temporary protective measure involving connecting the de-energized lines and equipment to earth through conductors.

29.1.4 Common reasons for grounding both electrical systems and equipment are to limit the voltage imposed by lightning, line surges (transients) or unintentional contact with higher voltages; to stabilize the voltage to earth under normal operation; and to establish an effective path for fault current. This fault current path should be capable of safely carrying the maximum fault likely to be imposed on it, and should have sufficiently low impedance to facilitate the operation of overcurrent devices under fault conditions. This path should also be designed and installed to limit touch and step potentials to safe values.

29.1.5 Grounding is one of the most important and essential aspects of an electrical system. However, it is often misunderstood because of its many different interpretations and misuse of definitions.

29.2 Special Terms. The following special terms are used in this chapter.

29.2.1 Bonding (Bonded). *(See 27.1.1.1.)*

29.2.2 Bonding Jumper. *(See 27.1.1.2.)*

29.2.3 Equipment Bonding Jumper. The connection between two or more portions of the equipment-grounding conductor.

29.2.4 Case (Enclosure) Ground. See 29.2.24, Grounding Terminal.

29.2.5 Central Grounding Point. *(See 27.1.1.3.)*

29.2.6 Counterpoise. A conductor or system of conductors arranged beneath the transmission/distribution supply line; located on, above, or most frequently below the surface of the earth; and connected to the grounding system of the towers or poles supporting the line. (This conductor(s) might or might not be the continuous length of the supply path. It is often used to provide a lower surge impedance path to earth for lightning protection when there is a transition from overhead supply conductors to underground insulated cable.) Counterpoise is also used in communication systems, where it is a system of conductors, physically elevated above and insulated from the ground, forming a lower system of conductors of an antenna. Note that the purpose of a counterpoise is to provide a relatively high capacitance and thus a relatively low impedance path to earth. The counterpoise is sometimes used in medium- and low- frequency applications where it would be more difficult to provide an effective ground connection. Sometimes counterpoise is confused with equipotential plane. See 29.2.14, Equipotential Plane.

29.2.7 Down Conductor. A conductor from a lightning protection system to earth ground designed to provide a low impedance path for the current from a lightning strike and/or dissipate the charge buildup that precedes a lightning strike. This conductor typically goes from the air terminals to earth. Due to the very high currents at very high frequencies, the impedance of the entire system is very critical. Normal wiring conductors are not suitable for the down conductor. Typically, they are braided conductors. There might be certain instances where additional investigation about the interconnection between the lightning and the grounding electrode system is warranted.

29.2.8 Earth Grounding. The intentional connection to earth through a grounding electrode of sufficiently low impedance to minimize damage to electrical components and prevent an electric shock that can occur from a superimposed voltage from lightning and voltage transients. In addition, earth grounding helps prevent the buildup of static charges on equipment and material. It also establishes a common voltage reference point to enable the proper performance of sensitive electronic and communications equipment.

29.2.9 Earthing. See 3.3.7, Ground. This is an IEC term for ground.

29.2.10 Effective Grounding Path. The path to ground from circuits, equipment and metal enclosures for conductors shall (1) be permanent and electrically continuous, (2) have capacity to conduct safely any fault current likely to be imposed on it, and (3) have sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protection devices. The earth should not be used as the sole equipment-grounding conductor.

29.2.11 Equipment Ground. An ambiguous term that can mean either case ground, equipment-grounding conductor or equipment bonding jumper; hence, use of this term should be avoided.

29.2.12 Electrostatic Discharge (ESD) Grounding. The conductive path created to reduce or dissipate the electrostatic charge where it builds up as a result of equipment operation or induced from an electrostatically charged person or material coming in contact with the equipment. Also referred to as *static grounding*.

29.2.13 Equipotential Bonding. Electrical connection putting various exposed conductive parts and extraneous conductive parts at a substantially equal potential.

29.2.14 Equipotential Plane. (1) (as applied to livestock) An area accessible to livestock where a wire mesh or other conductive elements are embedded in concrete, are bonded to all metal structures and fixed nonelectrical metal equipment that may become energized, and are connected to the electrical grounding system to prevent a difference in voltage from developing within the plane. (2) (as applied to equipment) A mass or masses of conducting material that, when bonded together, provide a uniformly low impedance to current flow over a large range of frequencies. Sometimes the equipotential plane is confused with counterpoise.

29.2.15 Ground. *(See 3.3.7.)*

29.2.16 Grounded. *(See 3.3.12.)*

29.2.17 Grounded Conductor. A system or circuit conductor that is intentionally grounded. This intentional grounding to earth or some conducting body that serves in place of earth takes place at the premises service location or at a separately derived source. Control circuit transformers are permitted to have a secondary conductor bonded to a metallic surface that is in turn bonded to the supply equipment-grounding conductor. Examples of grounded system conductors would be a grounded system neutral conductor (three phase or split phase) or a grounded phase conductor of a three-phase, three-wire, delta system.

29.2.18 Effectively Grounded (as applied to equipment or structures). Intentionally connected to earth (or some conducting body in place of earth) through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages that might result in undue hazards to connected equipment or to persons.

29.2.19 Effectively Grounded (as applied to systems). This is defined by ratios of impedance values that must be within prescribed limits.

29.2.20 High-Impedance Grounded. High-impedance grounded means that the grounded conductor is grounded by inserting a resistance or reactance device that limits the ground-fault current to a low value.

29.2.21 Solid Grounded. Solidly grounded means that the grounded conductor is grounded without inserting any resistor or impedance device.

29.2.22 Grounding Conductor. A conductor used to connect equipment or the grounded circuit conductor of a wiring system to a grounding electrode or electrodes. This ensures the electrical continuity of equipment bonding and grounding into the system, and provides for an equipotential bonding to minimize voltage differences between individual units, and between these units and the grounding electrode conductor.

29.2.23 Equipment-Grounding Conductor. The conductor used to connect the noncurrent-carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor, the grounding electrode conductor, or both, at the service equipment or at the source of a separately derived system.

29.2.24 Grounding Terminal. A terminal, lug, or other provision provided on some equipment cases (enclosures) to connect the conductive portion of the enclosure to the equipment-grounding conductor.

29.2.25 Ground Resistance/Impedance Measurement. *(See 3.3.8.)*

29.2.26 Ground Fault. Unintentional contact between an ungrounded conductor and earth or conductive body that serves in place of earth. Within a facility, this is typically a fault between a current-carrying conductor and the equipment-grounding path that results in the operation of the overcurrent protection.

29.2.27 Ground Leakage Current. Current that is introduced into the grounding conductor by normal equipment operation, such as capacitive coupling. Many RFI/EMI filters in electronic equipment have capacitors from current-carrying conductors to the equipment-grounding conductor to shunt noise emitted from or injected into their power supplies. While there are relatively low current level limits imposed by regulatory agencies (e.g., UL specifies maximum 3.5 mA, hospital equipment 0.5 mA), not all equipment is listed. Even with listed equipment, the sum of the current from a large quantity of such equipment in a facility can result in significant ground currents.

29.2.28 Ground Loop. Multiple intentional or unintentional connections from a conductive path to ground or the conductive body that serves in place of earth. Current will flow in the ground loop if there is voltage difference between the connection nodes. Re-grounding of the grounded circuit conductor (neutral) beyond the service point will result in ground loops. This might or might not be harmful depending on the application.

29.2.29 Ground Well. See 3.3.13, Grounding Electrode System.

29.2.30 Grounding-Type Receptacle. *(See 3.3.14.)*

29.2.31 Grounding Electrode. A conductive body deliberately inserted into earth to make electrical connection to earth. Typical grounding electrodes include the following:

(1) The nearest effectively grounded metal member of the building structure
(2) The nearest effectively grounded metal water pipe, but only if the connection to the grounding electrode conductor is within 5 ft of the point of entrance of the water pipe to the building
(3) Any metal underground structure that is effectively grounded
(4) Concrete encased electrode in the foundation or footing (e.g., Ufer ground)
(5) Ground ring completely encircling the building or structure
(6) Made electrodes (e.g., ground rods or ground wells)
(7) Conductive grid or mat used in substations

29.2.32 Grounding Electrode System. *(See 3.3.13.)*

29.2.33 Isolated Equipment-Grounding Conductor. An insulated equipment-grounding conductor that has one intentional connection to the equipment-grounding system. The isolated equipment-grounding conductor is typically connected to an equipment-grounding terminal either in the facility's service enclosure or in the first applicable enclosure of a separately derived system. The isolated equipment-grounding conductor should be connected to the equipment-grounding system within the circuits' derived system.

29.2.34 Insulated Ground. See 29.2.33, Isolated Equipment-Grounding Conductor.

29.2.35 Lightning Ground. See 3.3.13, Grounding Electrode System.

29.2.36 Noise(less) Ground. *(See 3.3.7.2.)*

29.2.37 Multipoint Grounding. *(See 27.1.1.11.)*

29.2.38 Personnel Ground. *(See 3.3.7.3.)*

29.2.39 Protective Bonding Circuit. See 29.2.13, Equipotential Bonding.

29.2.40 Protective Conductor. See 29.2.23, Equipment-Grounding Conductor.

29.2.41 Protective Ground. See 29.2.13, Equipotential Bonding.

29.2.42 RFI/EMI Grounding. See 29.2.27, Ground Leakage Current.

29.2.43 Separately Derived System. *(See 27.1.1.13.)*

29.2.44 Single-Point Grounding. *(See 3.3.20.)*

29.2.45 Safety Ground. See 3.3.7.3, Personnel Protective Ground.

29.2.46 Shield Ground. Intentional grounding of one or both ends of the shield of a cable.

29.2.46.1 Data Communications Cables. The shield of data communication cables can be connected to the equipment-grounding conductor at either one end of the cable (single end) or at both ends (double ended). When both ends of a shield are grounded, another shield should be provided inside the outer shield and that one single end grounded.

29.2.46.1.1 There are advantages and disadvantages to both types, single- or double-ended. Single-ended grounding minimizes the ground loop potential, but can result in the shield voltage at the ungrounded end rising above safe levels for equipment or personnel. Single-end grounded shields can have the ungrounded end grounded through a high frequency drain, such as a surge device, to help control this.

29.2.46.1.2 Double-ended grounding can minimize the potential voltage rise, but can result in a ground loop that exceeds the current-carrying capacity of the outer shield.

29.2.46.2 Shield Ground, Power Cables. The shield of power cables can be connected to the equipment-grounding conductor at either one end of the cable (single end) or at both ends (double ended). Shielding will ensure uniform dielectric stress along the length of the cable. When grounded at both ends, cable derating might be necessary because of heat due to ground loop current.

29.2.47 Substation Ground. Grounding electrode system (grid) in a substation. See 3.3.13, Grounding Electrode System.

29.2.48 System Grounding. *(See 3.3.23.)*

29.3 Symptoms and Causes of Inadequate Grounding.

29.3.1 Common mode noise voltages can develop when the equipment-grounding conductor and the grounded conductor are not effectively bonded.

29.3.2 Common mode noise can be produced in wiring without an equipment-grounding conductor and without electrically continuous raceway.

29.3.3 Ground loops can be undesirable because they create a path for noise currents to flow.

29.3.4 Undesirable touch potentials can result when contacting metallic surfaces that are improperly grounded.

29.3.5 Equipment misoperation due to unequal ground potentials results in improper data communication or improper readings of transducers.

29.3.6 Shutdown or damage of electronic equipment can be due to electrostatic discharge (ESD).

29.3.7 Non-operation or malfunction of protective circuit devices or voltage sag can be due to high impedance ground fault paths.

29.3.8 Damage, non-operation, or misoperation of electronic components can be caused by poor connections in the grounding path.

29.3.9 Damage or destruction of the neutral conductor or cable shields can result from improper sizing of a high impedance neutral grounding device.

29.3.10 Voltage can be present on de-energized circuits during testing of these conductors.

29.3.11 Destruction of equipment and surge protection devices can follow a voltage transient, such as a lightning strike.

29.4 Grounding System Inspection, Testing, and Monitoring.

29.4.1 A visual and physical inspection should be made to verify the integrity of the grounding and bonding conductors and associated connections.

29.4.2 Check the integrity of the grounding electrode system and substation grids on a periodic basis. The electrical connection to earth can be measured using one of several available methods and technologies. *(See Section 20.15.)* Also refer to ANSI/IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems* (Green Book).

29.4.3 A ground loop impedance test should be performed on the equipment-grounding path with a four-lead, low-resistance ohmmeter such as a wheatstone bridge, a kelvin bridge, or a digital low-resistance ohmmeter. Impedances should be appropriate for the type, length, and size of the path.

29.4.4 Measure the voltage between the equipment-grounding conductor and the grounded conductor at multiple locations throughout the system, as applicable.

(A) At the bonding jumper, the voltage should normally be less than 0.1 V ac.

(B) It is normal to find voltage downstream from the main bonding jumper in energized circuits, due to current flow in the grounded conductor. Readings in excess of 3 V ac or less than 0.5 V ac at locations remote from the bonding jumper should be further investigated to determine if this represents a problem for this system.

29.4.5 Measure the current on the equipment-grounding conductor for objectionable levels, which will depend on the location and type of the facility. Determine and correct the source of currents on equipment-grounding conductors. Use of true RMS ammeter is recommended.

29.4.6 Measure the voltage from the chassis of equipment and an external ground point. Differences should be less than 2 V.

29.4.7 Continuous monitoring of ground and neutral currents in information technology areas is recommended.

29.4.8 In the absence of any specifications, when examining electrostatic discharge (ESD) systems, the leakage resistance should not exceed 1 megohm from any conductor to ground. *(See 21.3.13.2.)*

29.4.9 Testing of the ground integrity of data communication cable shields may require special instrumentation and expertise.

29.4.10 If a result of testing indicates that changes to a substation grounding system are necessary or required, refer to ANSI/IEEE 80, *Guide for Safety in AC Substation Grounding*, for appropriate design requirements.

29.5 Solutions to Inadequate Grounding.

29.5.1 In order to minimize the resistance between the grounding electrode system and the earth, the following should be done:

(1) Clean and tighten and test connections as needed, using appropriate safety precautions.
(2) Replace or repair damaged or corroded components.
(3) Size the grounding electrode conductor in accordance with NFPA 70, *National Electrical Code*.
(4) Use soil enhancement material as necessary.

29.5.2 Connect the grounded conductor to the equipment grounding conductor only as permitted by NFPA 70, *National Electrical Code*. Size the grounded conductor and the equipment grounding conductor in accordance with NFPA 70.

29.5.3 Many of the grounding electrode corrosion problems are caused by galvanic action. Minimize this problem by using a system of cathodic protection (active or passive). Avoid the use of dissimilar metals.

29.5.4 Isolation Transformer.

29.5.4.1 An isolation transformer has separate primary and secondary windings. The bonding jumper between the equipment-grounding conductor and the secondary grounded conductor provides protection from common mode electrical noise.

29.5.4.2 It is recommended that a shielded isolation transformer be used. It contains an electrostatic shield between the primary and secondary windings that is connected to the equipment-grounding terminal.

29.5.5 Signal Circuit Isolation. Breaking the ground loop current path will minimize ground currents on signal circuits. This can be accomplished by one or more of the following:

(1) Fiber optic cable
(2) Grounding at a single point per system *[See ANSI/IEEE 1100, Recommended Practice for Power and Grounding Electronic Equipment (Emerald Book).]*
(3) Optical isolators
(4) Signal circuit isolation transformers in signal circuit or power circuits

29.5.6 Isolated Ground Receptacles. One solution is to install an isolated ground receptacle (identified by orange color and/or orange triangle) in which the equipment-grounding terminal is insulated from the mounting strap. An insulated equipment-grounding conductor is then connected from the grounding terminal of the receptacle in accordance with Article 250 of NFPA 70, *National Electrical Code*. The insulated equipment-grounding conductor is connected to the applicable derived system or service grounding terminal.

Annex A Explanatory Material

Annex A is not a part of the recommendations of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.3.2.1 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction (AHJ). The phrase "authority having jurisdiction," or its acronym AHJ, is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.3.2.3 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.4.2.8 Table A.4.2.8 represents the results of a study performed by only one of the major insurance groups (Factory Mutual) that specializes in industrial fire and machinery insurance. The table indicates that in a 2-year period, one-half of the losses associated with electrical equipment failures might have been prevented by an effective EPM program.

Table A.4.2.8 1987–1991 Losses Associated with Electrical Failures Including Electrical and Fire Damage[1] by Number of Losses and Gross Amounts[2]

Class of Equipment	Number of Losses, All Causes Including Unknown	Gross 1992[1] Dollar Loss, All Causes Including Unknown in Thousands	Number, Cause Unknown	Gross 1992[1] Dollar Loss, Cause Unknown in Thousands	Number of Losses of Known Causes Due to Inadequate Maintenance	Gross 1992[2] Dollar Loss of Known Causes Due to Inadequate Maintenance in Thousands
Transformers	529	$185,874	229	$ 27,949	71	$ 47,973
Generators	110	110,951	31	39,156	14	40,491
Cables	230	99,213	68	59,881	23	7,756
Motors	390	57,004	199	17,027	34	15,343
Circuit breakers	104	24,058	32	6,874	10	5,054
Controllers, switches, switchgear, and switchboards	108	17,786	36	5,537	17	2,308
Total	1,471	$494,886	595	$156,424	169	$118,925

[1] Statistics compiled by only one of the major insurance groups (Factory Mutual) that specialize in industrial fire and machinery insurance.
[2] Gross amounts are in thousands of dollars indexed to 1992 values.

Annex B Suggestions for Inclusion in a Walk-Through Inspection Checklist

This annex is not a part of the recommendations of this NFPA document but is included for informational purposes only.

B.1 General. These suggested items are directed toward minimizing the day-to-day electrical hazards. The list is not complete, nor do the items necessarily appear in order of importance. It is presented as a guide for the preparation of a checklist that should be developed for each plant. Because of the similarity to the plant fire prevention inspection, both inspections can be carried out by the same personnel.

B.1.1 Flexible Cords (including those on appliances). Heater-type cords are recommended for portable heating appliances, such as toasters, grills, and coffee makers. An inspection for badly worn or frayed spots, splices (not permitted), improper type, or current-carrying capacity that is too small should be made.

B.1.2 Plugs and Connectors. A check should be made for stray strands and loose terminals. They should be grounding type where required for specific appliances. The green conductor should be connected to the grounding terminal.

B.1.3 Extension Cords. Are extension cords used in place of permanent wiring, and are they of excessive length and of proper type? They should not pass through walls, partitions, or doors.

B.1.4 Multiple Current Taps. Are multiple current taps used because of too few receptacles? In particular, are they used in areas such as canteens, lunchrooms, and offices?

B.1.5 Appliances. Grills, toasters, and similar equipment should be permanently spaced from combustible material.

B.1.6 Heating Appliances. Where used with combustible material, such appliances generally require a signal light to indicate when "on."

B.1.7 Hot-Water Heaters. A check should be made for proper electrical protection. The combination temperature- and pressure-relief valve should be manually operated to be sure it is free and the drain line is clear. The setting should be visually checked.

B.1.8 Office Equipment. Condition of flexible cords, plugs, and connectors should be checked, looking for excessive use of extension cords and multiple current taps.

B.1.9 Receptacle Outlets. Grounding-type receptacles are generally required. Each receptacle should be checked for continuity of grounding connection, using a suitable test instrument. Are special receptacle configurations used for those supplying unusual voltages, frequencies, and so on? Are they well marked or identified? In particular, missing faceplates, receptacles showing signs of severe arcing, loose mounting, and so on, should be noted.

B.1.10 Portable Equipment (Tools, Extension Lamps, and Extension Cords). In the shop or tool room after each use, a check should be made for isolation between live parts and frame. The condition of cord and plug should be noted. Is continuity maintained between frame and grounding pin of plug? The green conductor should connect only to the plug grounding pin. On lamps, the condition of guards, shields, and so on, should be checked. See NFPA 70, *National Electrical Code,* for portable hand lamps; metal-shell, paper-lined lampholders for hand lamps are not permitted.

B.1.11 Lighting Fixtures. All lighting fixtures should be labeled and grounded. See NFPA 70, *National Electrical Code,* for connection of electric-discharge lighting fixtures. These are permitted to be connected by suitable, three-conductor flexible cord where visible for its entire length and terminated at outer end in a grounding-type attachment plug or busway plug. No fixtures should be located close to highly combustible material. The location of fixtures having burned out bulbs or tubes; where fixtures are heavily coated with dust, dirt, or other material; and where the reflectors are in need of cleaning should be noted.

B.1.12 Equipment Grounding. Where machinery or wiring enclosures are grounded through the conduit system, look for broken or loose connections at boxes and fittings, flexible connections, and exposed ground straps should be identified. Multiple bonding of conduit and other metallic enclosures to interior water piping systems, including sprinkler systems, is sometimes used as a precaution where building vibration is severe, even though a separate equipment-grounding conductor is run with the circuit conductors inside of the conduit.

B.1.13 Yard Transformer Stations. The condition of transformers, fence, gates, and locks should be noted. Yard and equipment should be free of storage of combustible material, weeds, grass, vines, birds' nests, and so on. Indication of localized overheating indicated by conductor discoloration, should be watched for. Indication of excessive transformer temperature, pressure, or oil leakage should be noted.

B.1.14 Services. The condition of weatherheads and weatherhoods should be visually checked to determine that they remain in good condition. Eliminate birds' nests and rats' nests, and so on. At the same time, the apparent condition of lightning arresters, surge capacitors, grounding conductors, and grounds should be determined. Are switches safely and readily accessible?

B.1.15 Switch Rooms and Motor Control Centers. Switch rooms and motor control centers should be clean and should be used for no other purpose. They should be free of storage of any kind, especially combustible material. Ventilation equipment should be in working condition and unobstructed. Any unusual noises or odors should be noticed and reported promptly. Metering equipment should be checked for high or low voltage and current and any indication of accidental grounding (ungrounded systems). Are switches and motor controllers properly identified as to function; are fire extinguishers in place, of suitable type, and charged?

B.1.16 Grouped Electrical Control Equipment (such as might be mounted on walls). Is grouped electrical control equipment protected from physical damage and readily accessible? Are any equipment enclosures damaged, or do any have missing or open covers? Are any live parts exposed? Any condition that prevents quick or ready access should be reported.

B.1.17 Enclosures of Electrical Parts (motor control equipment, junction boxes, switches, and so on). Are covers secured in place? The location of broken or loose conduit, wiring gutters, and so on, should be reported. Missing dust caps should be replaced.

B.1.18 Hazardous (Classified) Location Equipment. All cover bolts should be in place and tight. Permanent markings should not be obstructed by paint. Joints between cover and case should be examined for signs of having been pried open in removing cover. This might have damaged the mating surfaces of the joints. Excessive accumulations of dust and dirt should be noted for removal from all enclosures, including motors, that also should be examined for obstructed ventilation. The use of nonexplosionproof electric equipment, including lighting that might have been installed in the hazardous (classified) location area, should be noted and reported.

B.1.19 Emergency Equipment. Exit lights should all be functioning properly.

Emergency lights should all be in working condition. Periodic tests are recommended to ensure that emergency lights function when normal lighting is lost.

Emergency power supplies, such as batteries, engine-driven generators, and so on, normally receive scheduled tests. Records or periodic tests should be checked. Are fuel and cooling supplies for engine drives adequate? Are fire extinguishers in place, of proper type, and charged?

B.1.20 Emergency lights should all be in working condition. Periodic tests are recommended to ensure that emergency lights function when normal lighting is lost.

B.1.21 Emergency power supplies, such as batteries, engine-driven generators, and so on, normally receive scheduled tests. Records or periodic tests should be checked. Are fuel and cooling supplies for engine drives adequate?

B.1.22 Alarm systems, such as for fire, intrusion, smoke detection, sprinkler water flow, and fire pumps, also receive periodic tests. Records of these tests should be checked to ensure that all signals are properly transmitted and that equipment is in good working condition.

Annex C How to Instruct

This annex is not a part of the recommendations of this NFPA document but is included for informational purposes only.

C.1 Introduction. Training is basically a process for changing behavior. These behavioral changes are the product of new knowledge, reshaped attitudes, replaced skills, and newly acquired skills that express themselves, or become observable, as improved work techniques of the learner.

The trainer's function is to structure the instruction process in a manner that will make learning take place more effectively and in the shortest period of time.

C.2 Shortcomings of Learning by Trial and Error. Trial-and-error learning is learning at random. It is slow; it is costly in terms of time and mistakes. It also is costly because it involves so much "unlearning" of incorrect practices and "relearning" after the mistakes have been made.

Trial and error is the instructional process that continues to dominate industry. Its inefficiency can be illustrated by examining the case of the newly hired maintenance electrician assigned to instrument circuit repair work until "he gets the feel of the plant and 'learns' his way around."

For example, assume that the assignment is to disconnect an instrument from the power source so that an instrument technician can change out a defective chart drive motor.

Consistent with apparent good safety practice, and without consulting anyone, the electrician opened the switch that fed power to the entire instrument panel.

Loss of control of the process resulted in major product spoilage.

This example illustrates what can happen any time people are put on jobs, simple or complex, without first being given organized instruction, either personally on the job or in groups off the job.

An even clearer illustration of the inefficiency of trial-and-error learning is the example of an *inexperienced* maintenance electrician who is charged with responsibility for motor trip-out troubleshooting but who receives no formal instruction on this subject.

His first attempts will include many blind alleys, such as going to the job location without the proper tools; a random inspection of the motor starter, the motor, and the driven load; or a random replacement of heater elements. As the number of his attempts to correct motor trip-outs increases, he might learn to avoid many of the blind alleys, and eventually he might come up with a logical (to him) sequence of steps that will shorten his job time.

If, on the other hand, he had been properly trained, the job could have been performed correctly in the minimum amount of time because the maintenance electrician would have had full knowledge of the task and confidence in his own abilities to perform it. The further benefit of such training would have been less downtime, less material waste, and less chance of injury to himself and to other employees.

The justification for planned on- and off-the-job training, therefore, is to get better results in the form of greater job knowledge, greater skills, and better job attitudes toward such factors as quality, cost, and productivity and in the shortest amount of time.

The job of the instructor, therefore, is to direct learning activities of trainees to avoid the blind alleys and mislearning that are inevitable with trial and error. This requires organized presentation.

C.3 Philosophy of Training. In organizing a training program for a new learning situation, the following major tasks are involved:

(1) Selection of the experiences that will help the trainee learn what needs to be done
(2) Guiding of the trainee's efforts toward the proper learning objectives
(3) Applying the trainee's past experience
(4) Avoiding failures, frustrations, and loss of interest because the trainee does not perceive the relationships between what is presently being taught and future activity

In discussing how the instructor can organize the presentation of subject material, assume for the time being that motivation has been provided and that the trainee recognizes the need for the training and has a desire to learn.

Whenever a skill is being taught, the instructor is not only presenting facts but is also forming attitudes. For example, in learning how to make a relay adjustment, new information is being acquired. In addition, the trainee is forming attitudes and mind-sets concerning the information presented as well as performance, precision standards, quality, safety, and equipment design. It is these attitudes and mind-sets that will determine how the employee will approach or handle the job.

C.4 The Four-Step Method of Instruction. A proven method of instruction is the "Four-Step Method." These four steps are as follows:

(1) Step One: Preparation
(2) Step Two: Presentation
(3) Step Three: Application
(4) Step Four: Observation

C.4.1 Step One: Preparation.

C.4.1.1 Preparation of Subject Matter. A carefully laid out plan of action is a necessary operation for the presentation of new information and skills. Any mistakes made in presenting new material early in the teaching process will permanently confuse the trainee. To avoid teaching mistakes, the instructor should use a clearly worked out subject content outline and a step-by-step breakdown of the operations to be covered during instruction.

C.4.1.2 Subject Content Outline. A carefully worked out subject content outline is important to both the beginning instructor and the expert. The new instructor might not deal fully with all the steps of the explanation. The expert might overlook steps that seem to be obvious. Therefore, both the new instructor and the expert should plan their presentations from the viewpoint of the trainee in order to instruct effectively.

C.4.1.3 Breakdown of the Subject Matter. Instruction proceeds from the known to the unknown. It begins with the simple and proceeds to the complex.

Use of a step-by-step breakdown will ensure that the instruction will move progressively through a job, presenting it as it should be done from start to completion.

Instruction is accomplished by making certain that each new step is thoroughly explained and demonstrated in proper order and by making sure that the trainee understands what has been covered after each step.

The process of instruction is a natural process, with each step falling logically into place.

The problems encountered in instruction are generally due to the instructor's failure to take the time beforehand to carefully develop each explanation so that the entire topic makes sense.

When the presentation has been carefully broken down so that each unit being taught is clear and logical, the major obstacle to successful training has been overcome.

C.4.1.4 Preparation of Trainee. The following four steps should be followed:

(1) *Put the Trainee at Ease.* The trainee should be receptive. Tensions should be minimized. This can be achieved by creating an atmosphere of personnel security. Trainees should be introduced, a friendly manner demonstrated, and the business at hand promptly introduced. The situation should be relieved by anticipating the questions that normally are raised by the trainees, by clearly describing the objectives, by making the trainees aware of the advantages, and by letting them know how the program will affect them personally.
(2) *Develop Favorable Attitudes.* Attitude is a by-product of everything that occurs. The instructor will influence the shaping of the trainee's attitudes. Because attitude is a by-product, the development of a favorable attitude or outlook toward this program cannot be obtained by the simple process of talking about attitude directly. Instead, the instructor's responsibility is to do a good job of presenting the course, pointing out what is going to be covered, and explaining how the program serves both the trainee's and the company's interest.
(3) *Find Out What the Trainees Already Know.* Individual interest and receptivity of trainees to the subject material can be determined by briefly reviewing the backgrounds of members of the training group. This will avoid duplication and provide the instructor with information that will reveal the gap between what members of the group already know and the material to be presented.
(4) *Preview Material to Be Covered.* Having determined background knowledge already known to the group, the instructor should brief the trainees on the ground to be covered. This briefing need not necessarily come in the same order as outlined here. The important consideration is that at some point before getting into the body of the lesson the instructor should tell the trainee what is going to be covered during the period.

Preliminary groundwork is frequently looked upon as a waste of time. But in training, it should be remembered that part of getting the job done is dealing first with the intangible assignment of psychologically preparing the trainee. Step One failure is the most common among new instructors. No lesson should be considered ready for presentation until specific measures to prepare the trainees have been developed.

C.4.2 Step Two: Presentation. The main points in a successful presentation follow.

C.4.2.1 Show How to Do the Job. The instructor should demonstrate the operation carefully and accurately. If the operation is difficult, two or three demonstrations of the operation should be made. The instructor should not lose sight of the fact that *showing is very important in teaching.* The instructor should demonstrate, or show how, before the trainee tries to do the job.

C.4.2.2 Tell and Explain the Operation. After the class has seen the job demonstrated, the instructor should tell how the job is performed. It is important that the instructor let the class learn by doing *only after they have had the necessary instruction. The individual or class should never be put in the position of having to learn only by trial and error or by simple observation.* In other words, the trainee should be *shown* and *told* exactly *what is expected and how to do it.* The details he should remember should be pointed out to him.

C.4.2.3 Present Any Related Theory. An electrical maintenance worker might actually carry out the sequence of actions required to do a job without knowing the basic principles that underlie the action. He might not understand why he does what he does; however, he will be a better technician if he does know why. This makes the difference between mechanical, machinelike, unmotivated performance and purposeful, participating workmanship.

C.4.2.4 Direct Attention of the Learner. Showing and telling require that the instructor direct the attention of the trainees to the job. Describing an operation, showing a picture, or demonstrating an action is not enough. The important details should be pointed out and emphasized by directing the attention of the trainees to them. Attention can be directed in a number of ways.

One method of directing attention is to point out the item. Such emphasis will usually be coupled with telling, with a question, or with a demonstration. Attention might also be directed by the use of graphic devices, sketches, diagrams or board drawings, mobiles, and by the use of colors in printed material and on charts.

Board work can be emphasized by use of colored chalks. Changing the voice, slowing down the rate of talking, pausing, and the hundreds of devices of showmanship that dramatize a point are all effective means for directing the learner's attention.

C.4.3 Step Three: Application (Try-Out Performance). Application provides a checkpoint on what has been learned. It is accomplished by having the class members carry out or show back how the job or operation is done. There are four major reasons for Step Three, as follows:

(1) To repeat instructions
(2) To show the trainees that the job can be done by following the instructions as given
(3) To point out and to learn at which points the trainee might be experiencing difficulty
(4) To indicate to the instructor whether or not the instructions given in Steps One and Two have been effective

Performing the physical steps to actually do a job will not test all the learning that should have been acquired. The instructor should check the trainees by additional means such as questioning, having them identify parts, asking them to summarize the steps verbally, and having them state reasons for functions.

C.4.3.1 Have the Trainee Explain and Perform Each Step. To keep mistakes at a minimum, the instructor should have the trainee do the following:

(1) Tell *what* he is going to do
(2) Tell *how* he is going to do it
(3) *Do* the job. Telling "what" and "how" should come *in advance of doing it.* Have him carry out the necessary physical movements *after*, not before, the instructor is satisfied that the trainee knows how to do it.

The instructor should have the trainee show how to do the job by the same method the instructor used in performing the operations. Because Step Three is the trainee's first opportunity to actually apply what has been taught, it is important to avoid incorrect practices from the start.

C.4.3.2 Have the Trainee Do Simpler Parts of the Operation First. At this point, encouragement and success are important conditioners. Early successes are beneficial to learning, to remembering, and to building interest in future learning.

The trainee should be into the job with as few errors as possible. As the most expert member of the group, it might be necessary for the instructor to assist the trainee by handling the more difficult parts the first time through.

C.4.3.3 Question the Trainee on Key Points. One of the training hazards encountered in Step Three is the instructor's tendency to overlook slight omissions and details of the job that require explanation. *The instructor should never assume that the trainee understands what has been taught but should verify it by asking questions.* If there are omissions of details in the trainee's demonstration and explanations, the instructor should raise questions to cover the details and have complete discussion of the points involved.

C.4.3.4 Make Corrections in a Positive and Impersonal Manner. It should be remembered that the trainee is in the psychological position of trying to do what the instructor wants. The instructor should not lose sight of this and should not attempt to rush the learning or become impatient. In particular, the instructor should carefully consider each corrective step taken and should praise the good work, even if it is very minor. Then the instructor should tell how some operations might have been performed more effectively. During the trainee's demonstration, it will sometimes be better to permit minor mistakes to pass until the trainee has completed the explanation. Questions raised after the demonstration cause less interference and can be effectively used to get across the correct knowledge, methods, and points of view. When trainee mistakes are too frequent, the instructor will usually find the cause by going back to the instruction provided in Steps One and Two. *In other words, rather than attempt to explain mistakes made in Step Three presentations by trainees as being due to their failure to learn, the instructor's own handling of the trainees up to Step Three should be re-examined.* Usually, when the frequency of errors in the presentation step is high, or when the same errors are being made by several trainees in the group, the cause can be traced to ineffective Step One or Step Two instruction.

In summary, the instructor should observe the following basic rules to obtain better results and build more favorable work-related attitudes:

(1) Make corrections in a *positive* manner.
(2) Make corrections in an *impersonal* manner.
(3) Focus attention on the *causes* of mistakes.
(4) Help the trainees to *detect their own* mistakes and make their own critiques.
(5) Correct with leading *questions*.
(6) Get every trainee into the act; provide as much practice under direct observation as possible in the time allotted.

After members of the training group have shown they understand and can perform the operation, and after the instructor has been satisfied that a solid foundation of basic learning has been acquired, the group is ready to move to the final phase of instruction.

C.4.4 Step Four: Observation (Follow-Up and Performance Testing). Before considering the final step in the cycle of instruction, let us briefly summarize the instruction process thus far in Table C.4.4.

Table C.4.4 Instruction Process Summary

Step	Purpose
One: Preparation	Organize
Two: Presentation	Motivate, show, and tell
Three: Application	Trainee demonstration

The purpose of Step Four is to prove that the trainees have learned by putting them in a work situation as nearly typical of the normal maintenance environment operations as possible.

Step Four provides an opportunity for the trainees to practice and gain experience in phases of the job that the instructor has covered. Job knowledge is reinforced and job skills are acquired only by doing. Without practice, skills cannot be developed.

The following guidance factors are critical in Step Four.

C.4.4.1 Provide Close Follow-Up on the Job. When training is being provided simultaneously to a group, it becomes practically impossible for the instructor to do an adequate job of follow-up on each trainee. Despite this, *prompt follow-up is the most important aspect of Step Four.* Unless the trainees put the techniques they have been taught into practice, instruction has no purpose.

It takes application to learn techniques. It takes correct application to learn correct techniques. Trainees, if left on their own, will often develop incorrect ways of doing their job. Follow-up is the only means to prevent this. Responsibility for providing follow-up should definitely be assigned. Although it is common practice for the instructor to provide Step Four follow-up, there are definite advantages in sharing follow-up responsibilities with the supervisors of employees in training.

The training of maintenance electricians finds greater acceptance when there has been active line-supervision involvement. One way that this can be achieved is by using engineering and maintenance supervision as a pilot group before the program is presented to the trainees. Another common practice is to use engineers or maintenance supervisors as instructors. Their use provides a variety of benefits, the most important being the bond built between the classroom and on-the-job performance. Also, inadequacies in training show up quickly, and on-the-job follow-up is efficiently implemented.

C.4.4.2 Provide Immediate Follow-Up on the Job. Heavy emphasis has been placed on follow-up. The timing of follow-up is crucial.

Unfortunately, the trainee sometimes views training as ending when the presentation phase is completed.

Follow-up is an easy function to put off. Its benefits are intangible, while daily maintenance demands are not. It is something the supervisor is not accustomed to, and other demands on his or her time get priority. Meanwhile, "wrong learning" multiplies. *Learning is learning, right or wrong.* Each error repeated is just that much more firmly instilled in the memory. This fact makes timing important. On-the-job follow-up should be phased out as performance demonstrates that correct methods and procedures have been learned and are being applied.

C.4.4.3 Maintain Performance Standards. Performance expectations should be high. There is no room for exceptions. If a quality standard is right, it should be observed when appraising trainee performance. If the standard is not right, it should be changed, not ignored.

Fault-free performance should be the training standard. Uniform results depend on uniform methods. High standards of equipment performance depend equally on high standards of equipment installation, operation, and maintenance.

Performance observation is the final filter in this developmental process. If the mesh is coarse, the product will be irregular. Trainees should not be graduated until they demonstrate capability using prescribed methods to obtain prescribed quality standards.

There might be times when many in a training group exhibit inadequate understanding of maintenance practices or quality requirements. Reinstruction of the entire group might be the most economical means for bringing about the improvement desired in these instances. Two items of correction technique have immense bearing on the success of retraining.

First, emphasis should be placed on what to do instead of concentrating on what was done incorrectly. Each correct detail should be commended. The step that is right should be emphasized. The operation should be commenced at that point and the next right step supplied. Then, each phase of the operation should be repeated as it should be done. This is positive reinforcement.

Second, questions should be asked instead of making statements. Correct information should be drawn out instead of being supplied again. The purpose should be to establish a learning situation in which the trainee is an active participant. Trainees should be encouraged to analyze their own performance. The goal is maximum trainee involvement.

C.5 Summary: The Instruction Process in Brief.

C.5.1 Instruction is the process of teaching employees the knowledge, skills, and attitudes they need to do their jobs.

C.5.2 Instruction involves a variety of methods and techniques. The acquisition of knowledge, skills, and attitudes is the objective. How effectively instruction is organized and carried out determines the amount, rate, and permanence of new learning.

The industrial instructor's challenge is to develop ways to involve the trainee, and to discard the passive, lecture-based, nonparticipative methods inherited from the old-line techniques of academic institutions. Involvement is recommended if the trainee is to acquire new information and practical skills more effectively in the least amount of time. Equally important is the interest and desire to apply the new learning in the work situation.

C.5.3 Organized instruction is only effective when it is based on training methods that motivate the trainee.

C.5.3.1 Instruction should be presented so that it has practical meaning. The instructor should practice the following:

(1) Present practical applications.
(2) Use familiar experiences and words.
(3) Get the trainee to participate in the instruction.
(4) Use problem-solving discussions.
(5) Relate class work to on-the-job situations.

C.5.3.2 Instruction should be purposeful; it should have a goal. To give purpose to training, the instructor should do the following:

(1) Make certain the reasons for the training are clear.
(2) Emphasize the benefits to the individual.
(3) Point out the practical applications of what is being taught.
(4) Let the trainees know how they are doing.

C.5.4 Instructions should be organized in a way that generates active trainee participation. Participation can be increased by methods such as the following:

(1) Using models, mockups, graphs, charts, exhibits, and inspection tours of actual operations
(2) Using discussion and questions, having trainees prepare class materials, and encouraging trainee solutions of problems brought up in class
(3) Making specific assignments to trainees, providing individual practice, and having trainees research information

C.5.5 The instruction process can be broken into four steps.

C.5.5.1 Step One: Prepare the Trainee.

(1) The instructor should develop motivation, reasons, advantages, and objectives.
(2) The instructor should get the student interested in the training project.
(3) The instructor should become familiar with what trainees already know about the operation.
(4) The instructor should state the job to be done, covering the whole job briefly.

C.5.5.2 Step Two: Presentation (Present the Operation).

(1) The instructor should tell, explain, show, and illustrate one step at a time, going from simple to complex.
(2) The instructor should stress each key point.
(3) The instructor should instruct clearly, completely, and patiently.

C.5.5.3 Step Three: Application (Try-Out Performance).

(1) The instructor should have trainees perform operations step by step.
(2) The instructor should make certain that errors are corrected.
(3) The instructor should have each trainee perform the operation again while explaining each key point.

C.5.5.4 Step Four: Observation (Follow-Up).

(1) The instructor should put trainees on their own.
(2) The instructor should designate to whom they should go for help.
(3) The instructor should establish definite arrangements for frequent checks.
(4) The instructor should encourage discussions and questions.
(5) The instructor should taper off follow-up.

Annex D Symbols

This annex is not a part of the recommendations of this NFPA document but is included for informational purposes only.

D.1 Figure D.1 contains some typical electrical symbols that are used on electrical power and control schematic drawings.

D.2 Figure D.2 contains some typical electrical symbols that are used on electrical control schematic drawings.

D.3 Figure D.3 contains some typical miscellaneous electrical symbols and tables that are used on electrical control schematics.

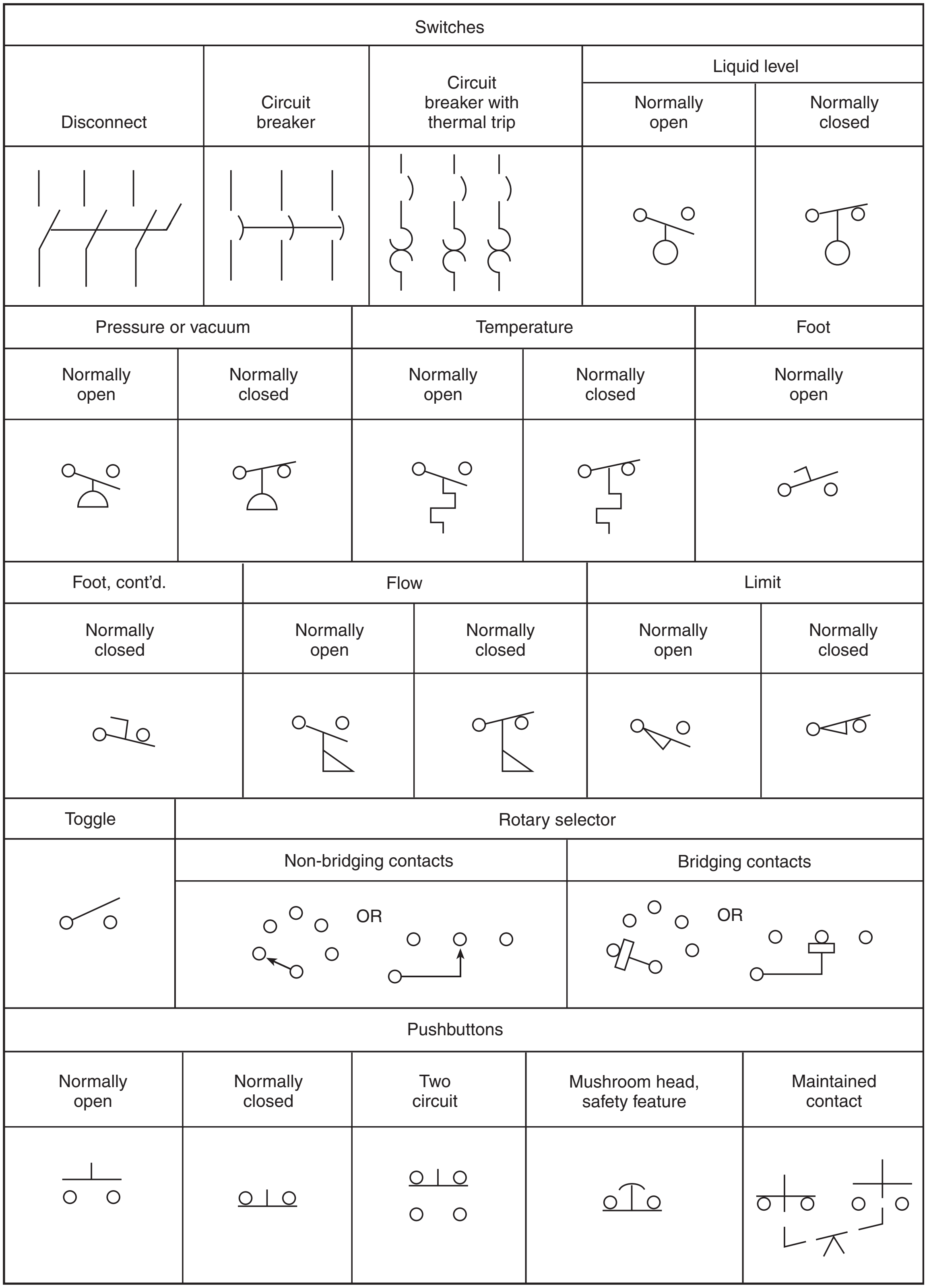


FIGURE D.1 Some Typical Electrical Symbols for Power and Control Schematics.
(Courtesy of ANSI/IEEE 315.)

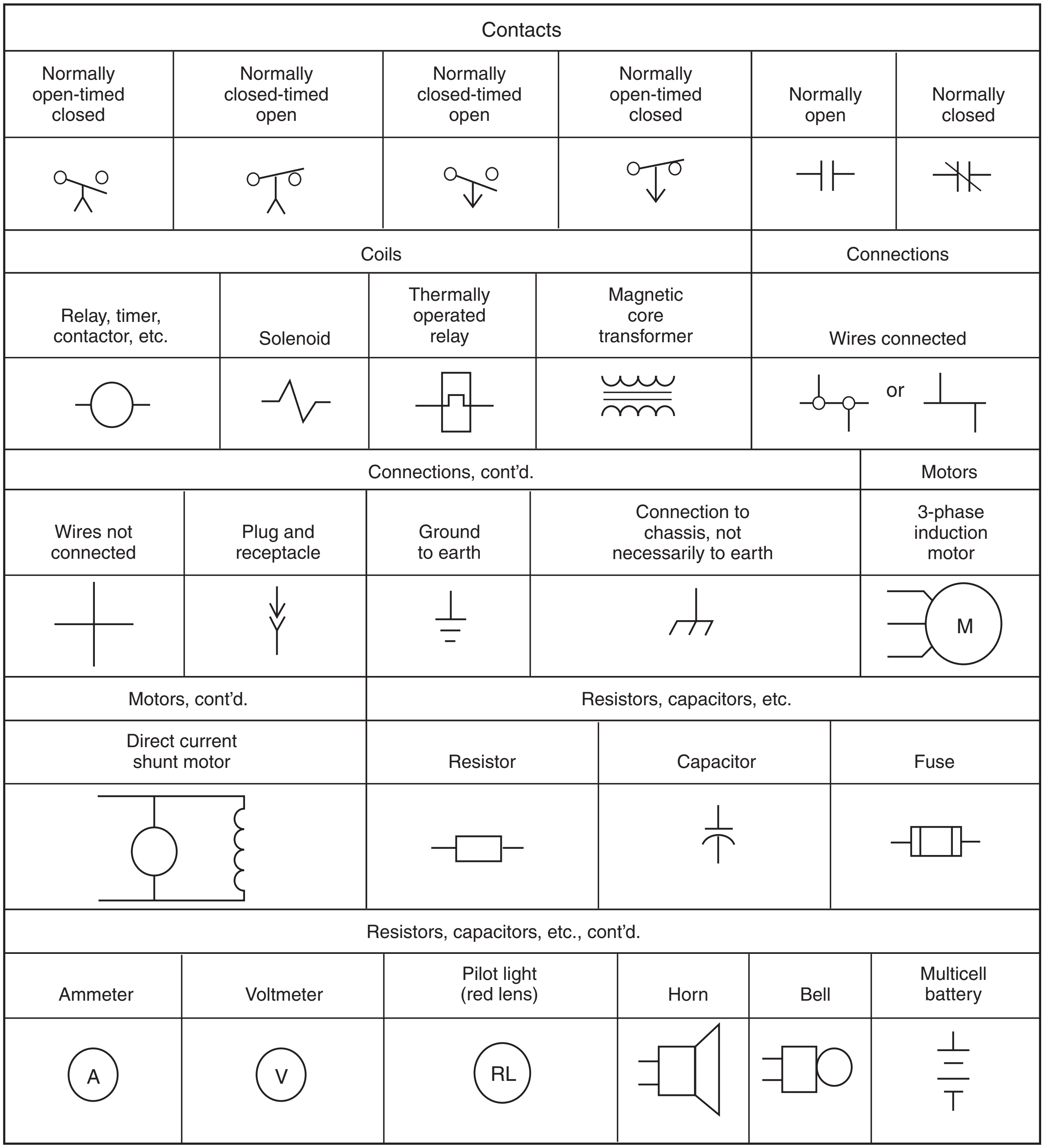
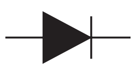
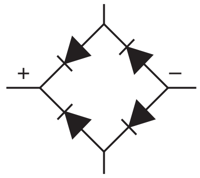
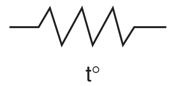
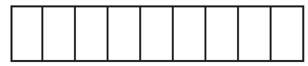


FIGURE D.2 Some Typical Electrical Symbols for Electrical Control Schematic Drawings.

Semiconductors			Miscellaneous
Rectifier diode	Rectifier bridge	Thermistor	Terminal block
			

Miscellaneous, cont'd.

Table of contact operation for control switch

Detached contacts shown elsewhere on diagram

Contact	Position		
	1	2	3
A	X		
B		X	
C			X

X-Indicates contact closed

Miscellaneous, cont'd.

Table of contact operation for drum switch (sliding contact type)

Detached contacts shown elsewhere on diagram

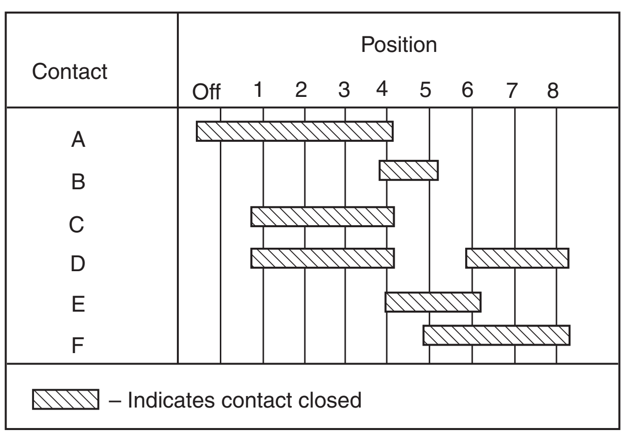


FIGURE D.3 Some Typical Miscellaneous Electrical Symbols.

Annex E Diagrams

This annex is not a part of the recommendations of this NFPA document but is included for informational purposes only.

E.1 Note that Annex E is presented to show use of symbols and should not be construed to indicate recommendations. Figure E.1 shows the use of some typical symbols in a single-line power distribution program.

E.2 Figure E.2 shows a diagram wiring for a reversing starter with control transformer.

E.3 Figure E.3 shows a power and control schematic for reversing starter with low-voltage remote pushbuttons. Forward, reverse, and stop connections are shown.

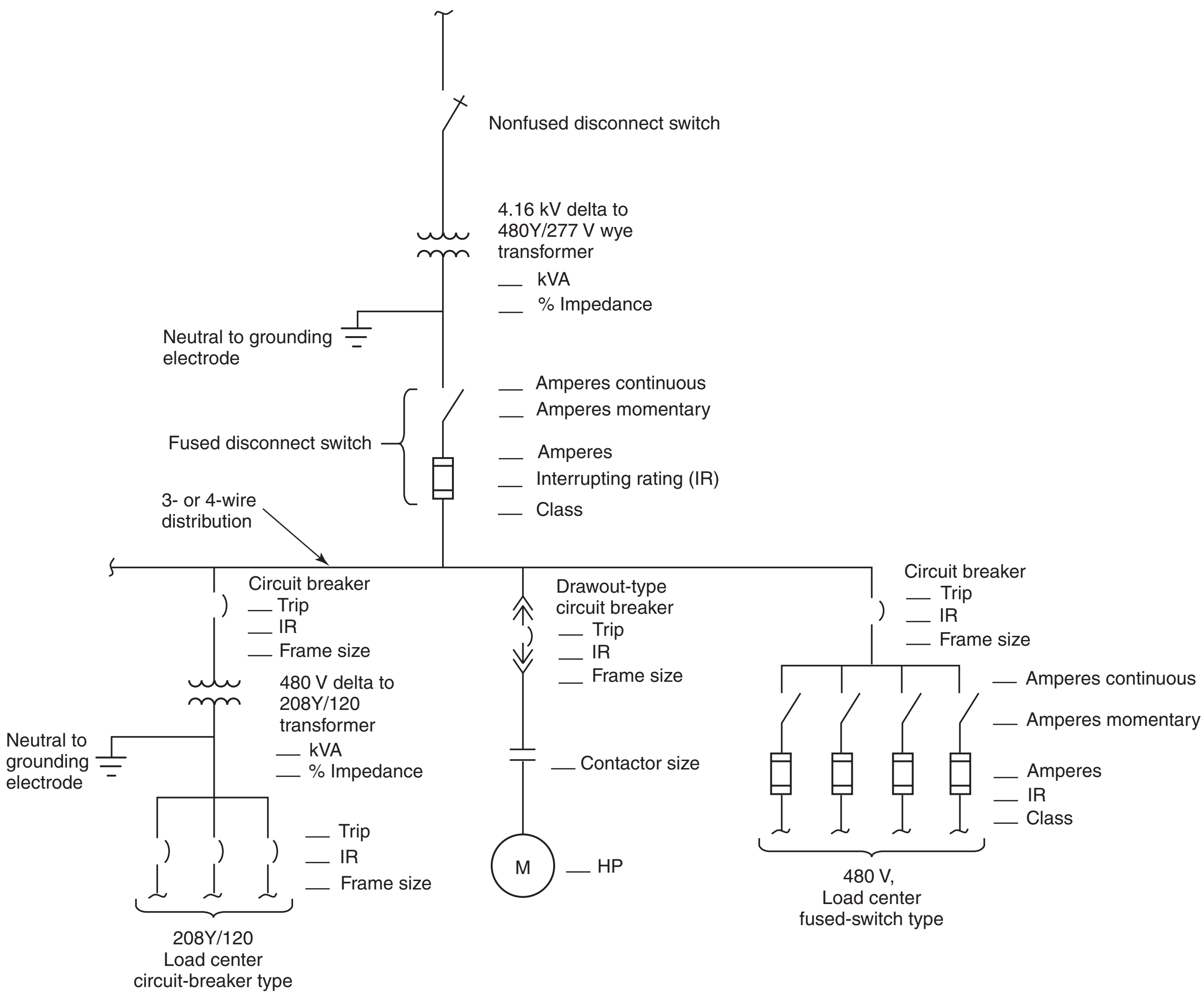


FIGURE E.1 Typical Use of Symbols in a Single-Line Power Distribution Program.

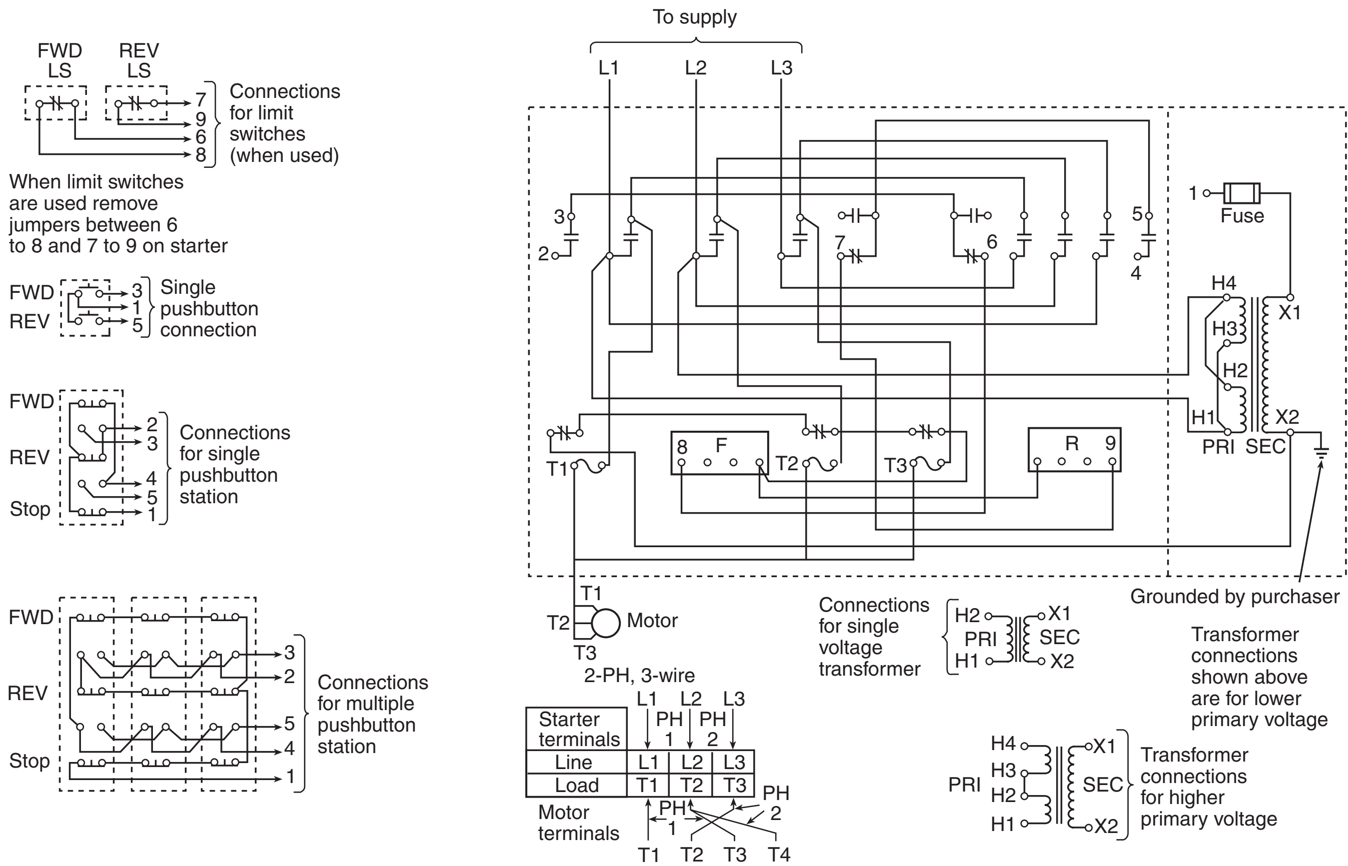
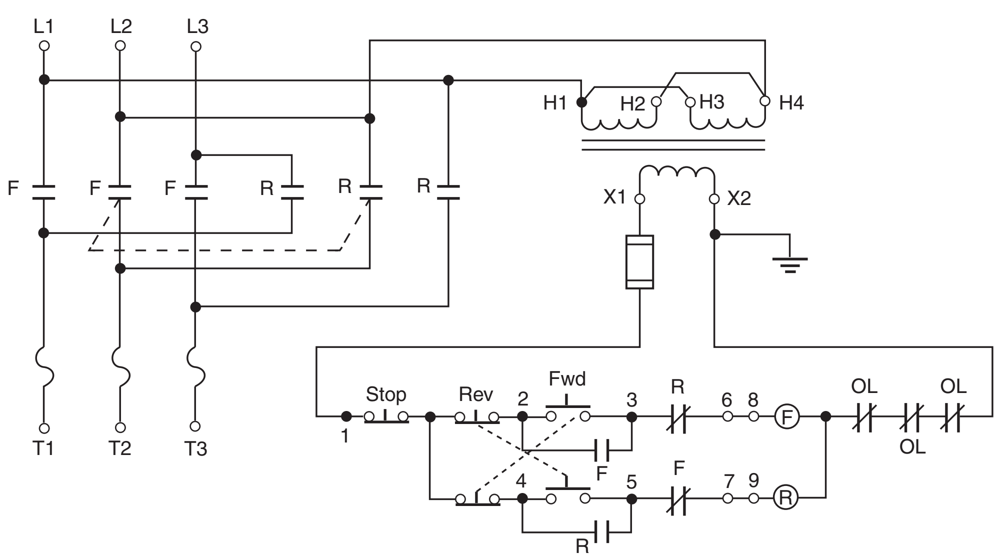


FIGURE E.2 Typical Wiring Diagrams.



Power and control schematic for reversing starter with low-voltage remote pushbuttons.
Forward, reverse, stop connections are shown.

FIGURE E.3 Typical Schematic Diagram.

Annex F Forms

This annex is not a part of the recommendations of this NFPA document but is included for informational purposes only.

F.1 Figure F.1 shows a typical work order request form.

Work Order Request

Work Order No. **Craft**

| | | | | — | |

Plant Department

Directions to Requester: Complete Section I ONLY. Submit four copies to the Plant Department. Maintain last copy for your files. Prepare a separate request for each job. This request will be returned to you and becomes a work order only when approved and assigned a work order number by the Plant Department. Allow sufficient time for completion. Please TYPE your request.

I. To be completed by requester: Date ______ / ______ / ______

Summary of work request ______

Location of work: Room(s) ______ Building ______

Details of work request ______

Typical work order request form consists of five parts — includes copies for plant department (or plant engineer), data processing, receiving stores, requester, and requester's department. Work to be done is spelled out in detail.

Special time requirement: Date needed ______ / ______ / ______ Indicate reason ______

Department ______ Tel. ext. ______ ❑ Plan attached ❑ Info. attached

Authorized signature ______ Title ______ Approval if required ______

II. For plant department use only: Date Received ______ / ______ / ______

A. Your request has been ❑ Approved ❑ Disapproved ❑ Forwarded to ______ for action. Use the assigned work order number when referring to this request.

B. Instructions: ______

Job Estimates	Craft	Total Hours	Total Labor	Material	Grand Total
	Hours		$	$	$

Assigned to ______ Craft ______ ❑ Day ❑ Night

Foreman —

C. Completed per plant instructions? ❑ Yes ❑ No

Can recurrence be prevented? ❑ Yes ❑ No

If yes, indicate ______

Actual hours used	Tot. reg.	Tot. O/T	Tot. equiv. hrs.

Requester —

Completed per your request? ❑ Yes ❑ No

Plant and requester note variations ______

Date ______ Foreman's signature ______ Requester's Signature ______

III. For data processing use only:

Dept.	Bldg.	Class	Category	Cause	Pay	O/T $

Total Labor $	+	Total Material $	=	Total $

Work description (Alphabetic) ______

Plant Department

Work Order No. — **Craft**

FIGURE F.1 Typical Work Order Request Form.

F.2 Figure F.2 shows a typical air circuit breaker — inspection record.

Plant ______________________ Date ______________________
Location ______________________ Serial No. ______________________
Mfr. ______________________ Type or Model ______________________
Drawout ❑ Non-drawout ❑ Switchboard ❑ Metalclad ❑
Rating: Volts __________ Amperes __________ Interrupting Amperes ______________
Operation: Manual ❑ Electrical ❑ Remote Control ❑
Volts close __________ ac ❑ dc ❑ Volts trip __________ ac ❑ dc ❑
Protective Devices: Induction Relays ❑ Direct Trips ❑ Direct Trips ❑
CL Fuses ❑ TD Setting __________ Inst. Setting __________

Annual Inspection

Date										
Inspector's Initials	Aux.	Main	Aux.	Main	Aux.	Main	Aux.	Main	Aux.	Main
Contact Condition										
Good — Surface Smooth										
Fair — Minor Burns										
Poor — Burned and Pitted										
Contact Check										
Pressure (Good, Weak, Bad)										
Drawout Contacts										
Pressure (Good, Weak, Bad)										
Alignment (Good, Bad)										
Lubricate (Must Do — Use a No-Oxide Lubricant by Mfr.)										
Arcing Assemblies										
Clean and Check the Arc-Splitting Plates Surface Conditions										
Bushings										
Clean and Check Surface Condition										

Date					
Inspector's Initials					
Operating Mechanisms					
Checks					
Positive Close and Trip					
Bushing and Pin Wear					
Set Screws and Keepers					
Protective Devices					
Lubricate Wear Points					
Clean Pots and Replace Oil with Equipment Mfrs. Recommended Oil					
Insulation Condition					
Loose Connections					
Discolored Areas					
Corona Tracking					
Clean Surfaces					
Insulation Tests					
Phase to Phase (Megohm)					
Phase to Ground (Megohm)					
Test Operation					
Close and Trip					
Counter Reading (No. of Ops.)					
Electrical Load					
Peak Indicated Amperes					

Remarks: (Record action taken when indicated by inspection or tests)

____

____

Other repairs recommended:

____

____

FIGURE F.2 Air Circuit Breaker — Inspection Record.

F.3 Figure F.3 shows a typical air circuit breaker test and inspection report.

Customer ______________ Date ______________ Work Order No. ______________
Address ______________ Air Temp. ______________ Rel. Humidity ______________
Breaker Owner/User ______________ Date Last Inspection ______________
Address ______________ Last Inspection Report No. ______________
Equipment Location ______________
Owner Identification ______________

Breaker Data:

Manufacturer ______________ Voltage ______________ Type ______________ Amperes ______________ Int. Rating ______________
Serial No. ______________ Type Oper. Mech. ______________ Age ______________ Other N.P. Data ______________

Test Data:	**Tank 1**	**Tank 2**	**Tank 3**
Ins. Res. _____ kV, Megohms			
Contact Resistance, Microhms			
Closing Speed/Opening Speed			
Reference, P.F. Test Sheet No.			
Adjustments:	**Mfr's. Rec.**	**As Found**	**As Left**
Arcing Contact Wipe			
Main Contact Gap			
Main Contact Wipe			
Latch Wipe			
Latch Clearance			
Contact Travel			
Prop Clearance			
Stop Clearance			

Inspection and Maintenance:	**Insp.**	**Dirty**	**Cleaned/ Lubed**	**See Remarks**
Overall Cleanliness				
Insulating Members				
Mech. Connections				
Structural Members				
Cubicle				
Pri. Contact Fingers				
Shutter Mech.				
Relays				
Auxiliary Devices				
Racking Device				
Arc Chutes				
Blow Out Coil				
Puffers				
Liner				
Arc Runners				
Main Contacts				
Cubicle Wiring				
Breaker Wiring				
Heaters				
Panel Lights				
Bearings				
Contact Sequence				
Ground Connection				
Counter Reading				

Remarks ______________

Inspections and Test by: ______________ Equipment Used: ______________ Sheet No. ______________

FIGURE F.3 Air Circuit Breaker Test and Inspection Report.

F.4 Figure F.4 shows a typical low-voltage circuit breaker 5-year tests form.

Plant ______________________ Date ______________________

Substation ______________ Feeder ______________ Load Reading ______________

Breaker Data

Mfr. ______________ Type ______________ Serial No. ______________

Trip Coil Rating ________ Amperes Characteristic ____________ Mfr's. Time Curve ____________

Trip Devices: Long Time Delay ❑ Short Time Delay ❑ Instantaneous Trip ❑

Time Delay Type: Oil Sucker Dashpot ❑ Air Bellows ❑ Air Orifice ❑ Oil Orifice ❑ Other ❑

Settings:

LT Delay — Amperes __________ Adjustable Range __________ Time Adjustable? Yes ❑ No ❑

ST Delay — Amperes __________ Adjustable Range __________ Time Adjustable? Yes ❑ No ❑

Instantaneous Trip — Amperes ____________________ Adjustable? Yes ❑ No ❑

Test Data

		Left Pole	Center Pole	Right Pole	Time Range From Curve
Date of Test					
Inspector's Initials					
As Found Test (Trip Time in Seconds) % Pickup ______ Amperes ______					
Time Delay	(As Found — Amperes)				
Minimum Pickup (Nullify Time Delay)	(Adjusted — Amperes)				
Time Delay Tests (Trip Time in Seconds) % Pickup Amperes					
Long Time ______ ______					
______ ______					
Short Time ______ ______					
______ ______					
Resettable Delay	(Satisfactory)				
(____ % for ____ sec)	(Tripped)				
Instantaneous Trip	(As Found — Amperes)				
	(Adjusted — Amperes)				

Remarks (Record unusual conditions, corrections, needed repairs, etc. Use separate form to record annual breaker inspection details.)

____

____

FIGURE F.4 Low-Voltage Circuit Breaker 5-Year Tests Form.

F.5 Figure F.5 shows a typical electrical switchgear–associated equipment inspection record.

Plant ____________________ Date ____________________

Location ____________________ Serial No. ____________________

Mfr. ____________________ Year Installed ____________________

Rating: Volts ____________________ Bus Capacity Amperes ____________________

Type: Switchboard ❑ Indoor Metalclad ❑ Outdoor Metalclad ❑

Annual Inspection (Disregard items that do not apply.)

Date						Date					
Inspector's Initials						Inspector's Initials					
Switchboards						Disconnect Switches					
Clean						Check Contact Surfaces					
Check Wiring						Check Insulation Condition					
Inspect Panel Insulation						Lubricate per Mfr's. Instructions					
Exposed Bus and Connections						Test Operate					
Clean and Check Porcelain						Fuses and Holders					
Insulators for Cracks or Chips						Check Contact Surfaces					
Check and Tighten Connections						Lubricate per Mfr's. Instructions					
Inspect Potheads for Leaks						Meters and Instruments					
Check for Environmental Hazards						Check Operation					
Test Insulation (Megohms)						Test Meters per Eng. Std.					
Metalclad Enclosures						Test Relays per Mfr's. Instructions					
Clean						Interlocks and Safety					
Check for Openings that Permit Dirt, Moisture and Rodent Entrance — Repair						Check for Proper Operations					
Check Hardware for Rust or Corrosion						Check Lightning Arresters					
Paint Condition						Check Ground Detectors					
Check Heaters and Ventilators						Check Equipment Grounds					
Metalclad Bus and Connections						Station Battery					
Clean Insulators and Supports						Periodic Routine					
Check and Tighten Connections						Maintenance is performed					
Check for Corona Tracking											
Inspect Potheads for Leaks											
Test Insulation (Megohms)											

Remarks: (Record action taken when indicated by inspection or tests)

____

____

Recommendations:

____

____

____

FIGURE F.5 Typical Electrical Switchgear–Associated Equipment Inspection Record.

F.6 Figure F.6 shows a typical transformer — dry type — inspection record.

Plant ____________ Date ____________
Location ____________ Serial No. ____________
Year Purchased ____________ Year Installed ____________ Mfr. ____________
kVA ____________ Voltage ____________ Impedance ____________
Phase ____________ Taps ____________
Cooling System: Room Vent Fan ❑ Trans. Fan ❑ Gravity ❑

Annual Inspection

Date							Date					
Inspector's Initials							Inspector's Initials					
Electrical Load							Bushings					
							Cracks or Chips					
							Cleanliness					
Secondary Voltage							Equipment Ground					
No Load Volts							Check Connections					
Full Load Volts							Measured V					
Dust on Windings							Resistance					
Minor Collection							Temperature Alarms and Indicators					
Major Collection							Operation					
Cleaned							Accuracy					
Connections							Case Exterior					
Checked							Covers Intact					
Tightened							Paint Condition					
Cooling Systems							Lighting Arresters					
Fan Operation							Check Connections					
Filter Cleanliness							Check Bushings					
System Adequate												

Complete Internal Inspection

Report of Conditions Found:
Cooling System ____________
Coil Insulation ____________
Other ____________

Description of Work Performed:
____
____

Other Repairs Recommended: ____________
____
____

Shop or Contractor: ____________ Cost: ____________

FIGURE F.6 Transformer — Dry Type — Inspection Record.

F.7 Figure F.7 shows a typical transformer — liquid filled — inspection record.

Plant ____________ Date ____________
Location ____________ Serial No. ____________
Year Purchased ________ Year Installed ________ Mfr. ________
kVA ________ Voltage ________ Taps ________
Check type: Free Breathing ❑ Conservator ❑ Sealed ❑ Fan Cooled ❑
Phase ________ Weight ________ Impedance ________
Insulating Fluid: Type ________ Gallons ________

Annual Inspection

Date							Date					
Inspector's Initials							Inspector's Initials					
Tank — Liquid Level							Exposed Bushings					
Normal							Cracks or Chips					
Below							Cleanliness					
Added Fluid							Equipment Ground Connection					
Entrance Compartment Liquid Level							Good					
Normal							Questionable					
Below							Tested					
Added Fluid							Temp Indicator					
Electrical Load							Highest Reading					
Peak Amperes							Reset Pointer					
Secondary Voltage							Pressure–Vacuum Indicator					
Full Load							Pressure					
No Load							Vacuum					
Gaskets and Case Exterior							Ventilators, Dryers, Gauges, Filters and Other Auxiliaries					
Liquid Leaks							Operation OK					
Paint Condition							Maint. Req'd.					

Remarks: (Record action when inspection data or test are out of limits, etc.)

____

____

Reports of Conditions Found: ____________

____

Description of Work Performed: ____________

____

Other Repairs Recommended: ____________

____

Shop or Contractor: ____________ Cost: ________

FIGURE F.7 Transformer — Liquid Filled — Inspection Record.

F.8 Figure F.8 shows a typical transformer fluid test — oil. Readings that plot in the shaded zone should be reported immediately to the Engineering Division, Electrical Section.

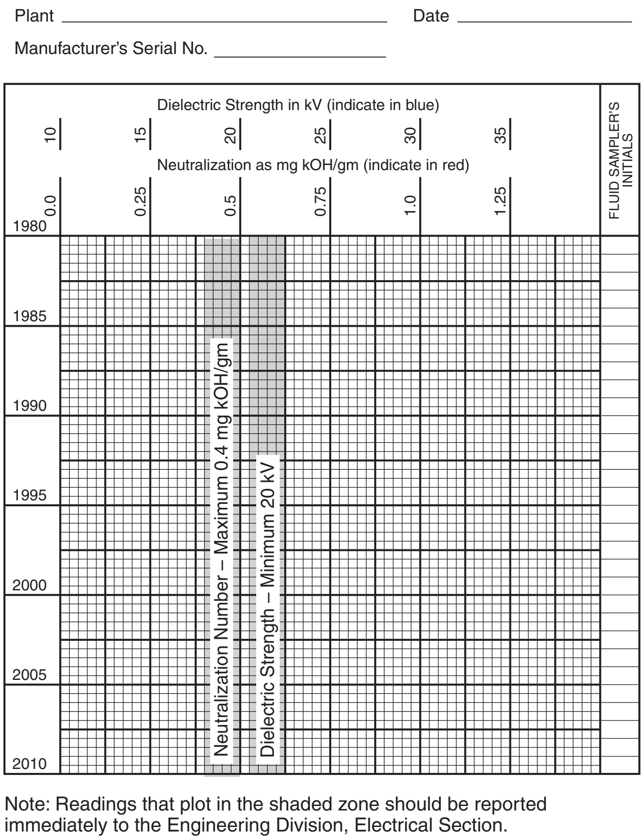


FIGURE F.8 Transformer Fluid Test — Oil.

F.9 Figure F.9 shows a typical transformer fluid test — askarel. Readings that plot in the shaded zone should be reported immediately to the Engineering Division, Electrical Section.

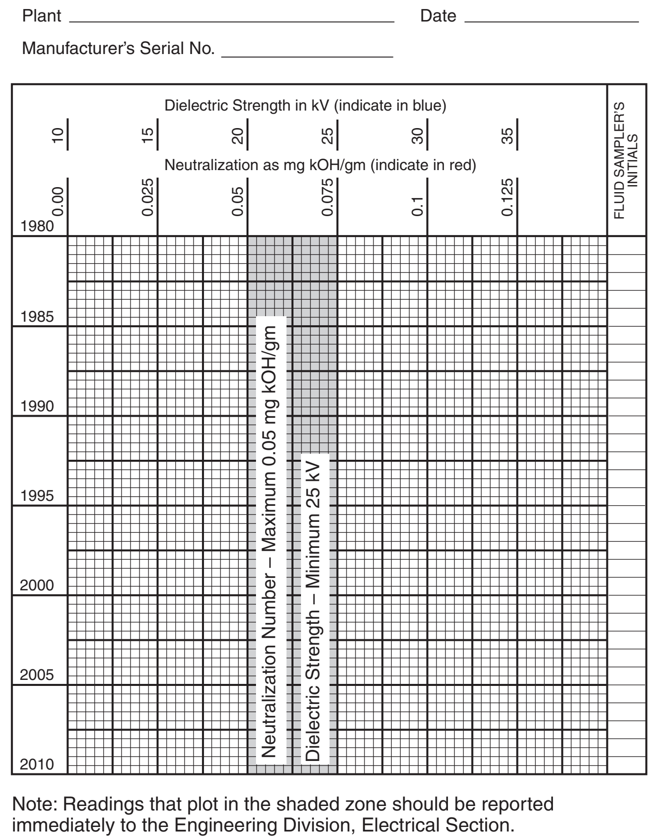


FIGURE F.9 Transformer Fluid Test — Askarel.

F.10 Figure F.10 shows a typical transformer insulation resistance record.

Plant ______________________ Date ______________

Scope: Power transformers of 150 kVA and greater capacity with primary voltage of 2300 volts or higher. Direct reading — recorded and plotted.

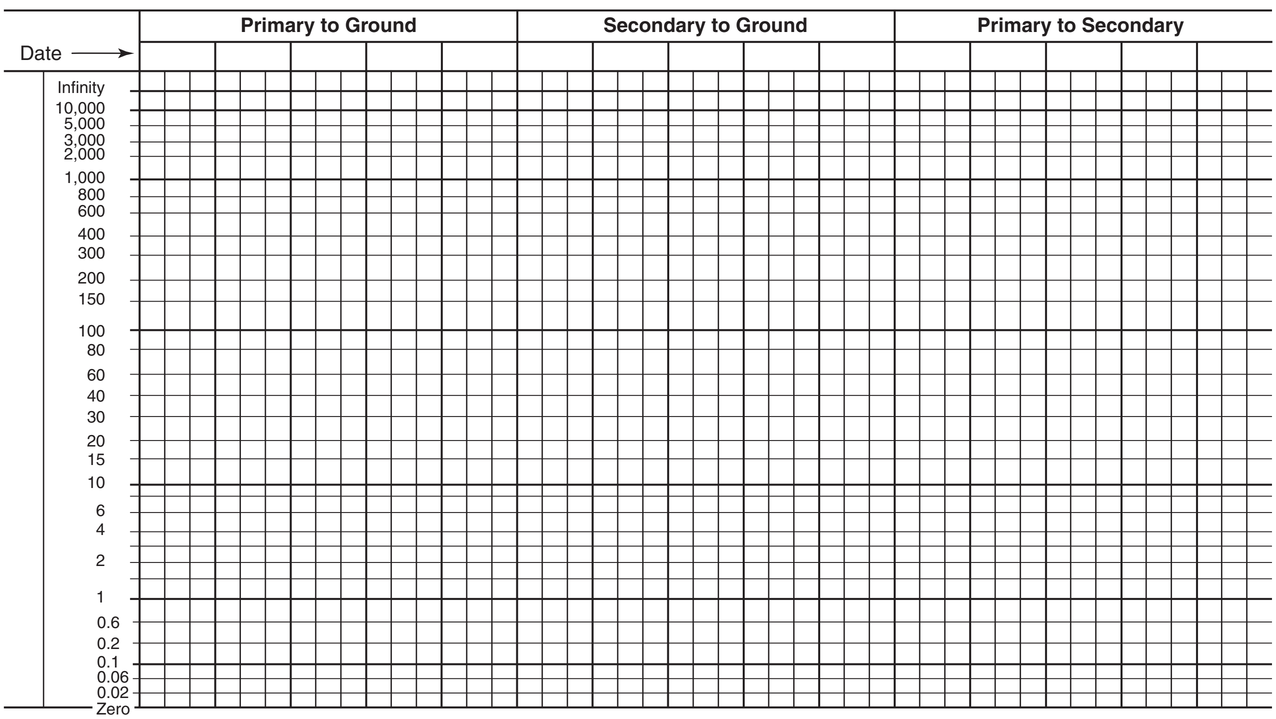
Transformer Serial No. ______________ Phase ______________

Location ______________ Instrument Used ______________

Equipment Included in Test ______________________

I I*	Date	Pri. to Grd.	Sec. to Grd.	Pri. to Sec.	Internal Temp.	Ambient Temp.

*Inspector's Initials



Remarks:

FIGURE F.10 Transformer Insulation Resistance Record.

F.11 Figure F.11 shows a typical battery record.

No. Cells ____________ Type ____________ Services ____________ Bldg. ____________

Note: Correct specific gravity readings for temperature.

Weekly Pilot Cell Readings: Cell No. ______

Date	Pilot Cell Sp. Gr.	Pilot Cell Temp.	Bus Volts	Water Clean	Check Charger

Remarks: ____

Quarterly Cell Readings: Date ______

Cell	Specific Gravity	Volts	Cell	Specific Gravity	Volts
1			31		
2			32		
3			33		
4			34		
5			35		
6			36		
7			37		
8			38		
9			39		
10			40		
11			41		
12			42		
13			43		
14			44		
15			45		
16			46		
17			47		
18			48		
19			49		
20			50		
21			51		
22			52		
23			53		
24			54		
25			55		
26			56		
27			57		
28			58		
29			59		
30			60		

Bus Volts ____________ Current ____________

Battery Room Condition ____________________

Cell Temps: 1 ________ 15 ________

30 ________ 45 ________ 60 ________

FIGURE F.11 Battery Record.

F.12 Figure F.12 shows a typical insulation resistance — dielectric absorption test sheet power cable.

Test No. ____________

____________ Company Date ____________

____________ Location Time ____________

Circuit		Circuit Length		Aerial Duct Burned	
Number of Conductors	Conductor Size	AWG MCM (kcmil)		Belted Shielded	
Insulating Material		Insulating Thickness		Voltage Rating	Age
Pothead or Terminal Type				Location Indoors Outdoors	
Number and Type of Joints					
Recent Operating History					
				Mfr.	
State if Potheads or Terminals Were Guarded During Test					
List Associated Equipment Included in Test					
Misc. Information					

Test Data — Megohms

Part Tested					Test Made	Hours Days / After Shutdown
Grounding Time					Dry-Bulb Temp.	°F
Test Voltage					Wet-Bulb Temp.	°F
Test Connections	To Line	To Line	To Line	To Line	Dew Point	°F
	To Earth	To Earth	To Earth	To Earth	Relative Humidity	%
	To Guard	To Guard	To Guard	To Guard	Absolute Humidity	Gr./#
¼ minute					Equipment Temp.	°F (°C)
½ minute					How Obtained	
¾ minute						
1 minute						
2 minutes					"Megger" Inst.:	
3 minutes					Serial No.	
4 minutes					Range	
5 minutes					Voltage	
6 minutes						
7 minutes						
8 minutes						
9 minutes						
10 minutes						
10:1 min. Ratio						

Remarks ____________

Tested By:

FIGURE F.12 Insulation Resistance — Dielectric Absorption Test Sheet Power Cable.

F.13 Figure F.13 shows a typical cable test sheet.

Company ______________________ Date __________ Job No. __________

Test Location ______________ Circuit __________ Air Temp. ______ °C % Hum. __________

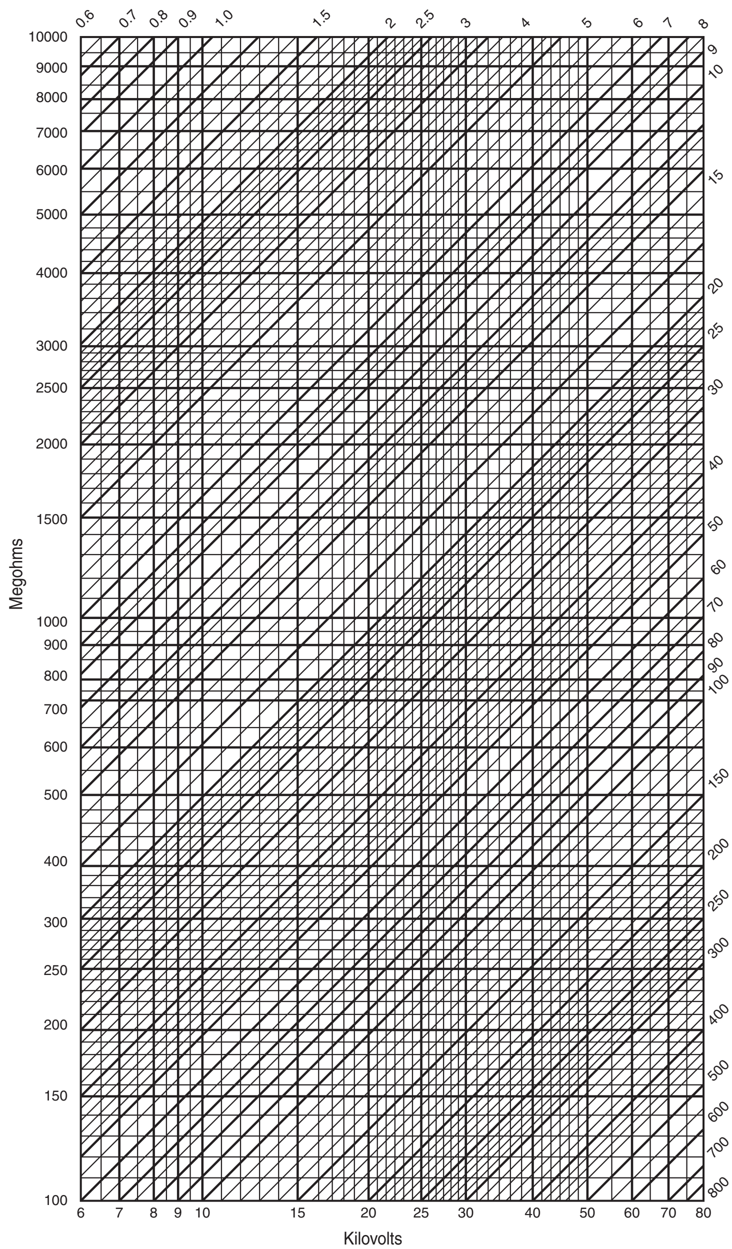
Test Type: Acceptance ❑ Periodic ❑ Special ❑ Date Last __________ Sheet No. ______ Weather __________

Cable Mfr.				
Rated kV	(Gnd., Ungnd.)			
Oper. kV	(Gnd., Ungnd.)			
Length				
Age				
No. Cond.				
No. Size				
Insul. Material				
Insul. Thickness				
Insul. Type				
Covering				
Installed In				
Factory Test kV				
% Factory Test kV				
Max. Test kV				
Voltmeter kV				
Time Min.	Volts kV	Leakage Current-Microamps		
		ϕ1 – ⊙	ϕ2 – △	ϕ3 – ⊡
Insulation Resistance Test One Minute @ 2.5 kV — 1000 Megohms				
ϕ TO GND.				
ϕ 1 TO ϕ	—			
ϕ 2 TO ϕ	—	—		

Authorization of Max.
Test kV and Verifying Voltmeter kV

____
Signature

Remarks: ______________________________



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____

____

Test Set No. __________ Tested By ______________ Sheet No. __________

FIGURE F.13 Cable Test Sheet.

F.14 Figure F.14 shows a typical insulation resistance test record.

Date ____________________

Scope: Dielectric Absorption without Temperature Correction

Apparatus ____________________ Equipment Temp. __________ Ambient Temp. __________

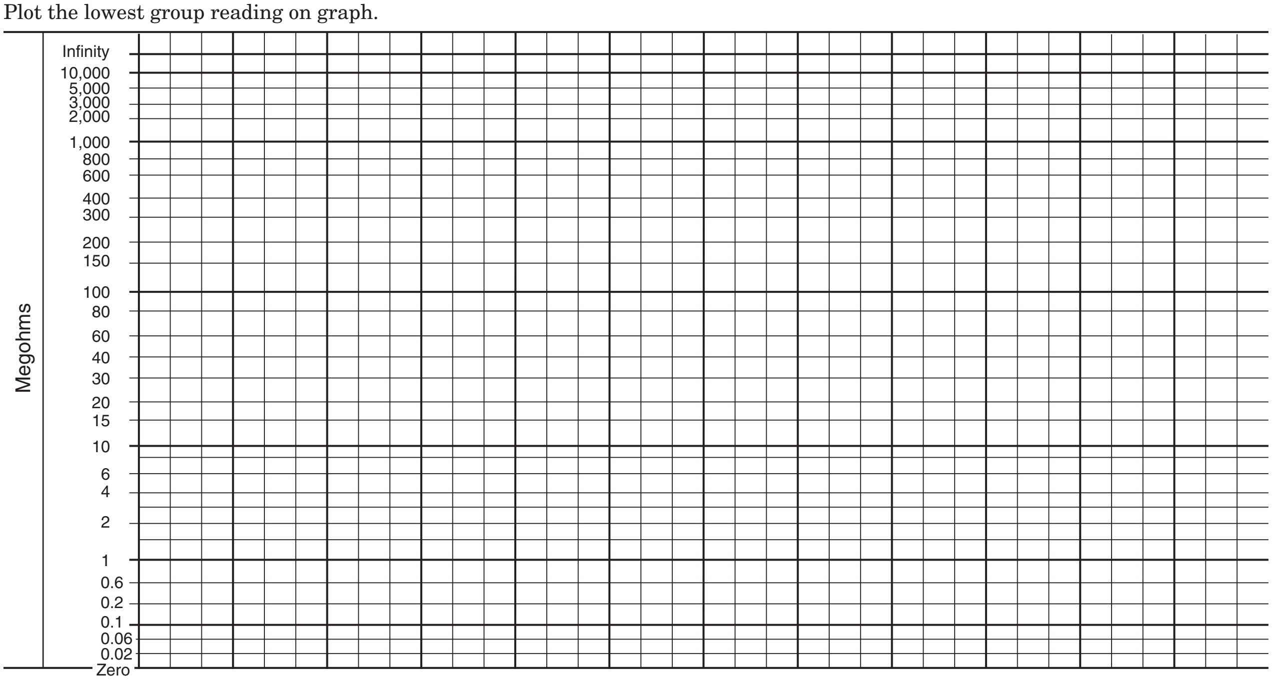
Instrument Used ____________________ Polarization Index No. ____________________

Condition 10:1 Min. Ratio

Dangerous	Less than 1	Fair	2 to 3
Poor	Less than 1.5	Good	3 to 4
Questionable	1.5 to 2	Excellent	Above 4

Time in Minutes		0.25	0.5	1	2	3	4	5	6	7	8	9	10
To Ground	Phase 1												
	Phase 2												
	Phase 3												
Between Phases	Phase 1–2												
	Phase 2–3												
	Phase 3–4												

Plot the lowest group reading on graph.



Tested by ____________________

FIGURE F.14 Insulation Resistance Test Record.

F.15 Figure F.15 shows a typical insulation resistance test record rotating machinery.

Reference

IEEE Publication No. 43

Scope

Dielectric Absorption — Temperature Corrected

ac machines 1000 kVA or more
dc machines 100 kW or more

Date ____________________

Apparatus ____________________ Voltage __________ Rating __________

Test Conditions:

List Associated Test Equipment
Included in Test ____________________

Winding Grounding Time __________ Test Made __________ Hours After Shutdown

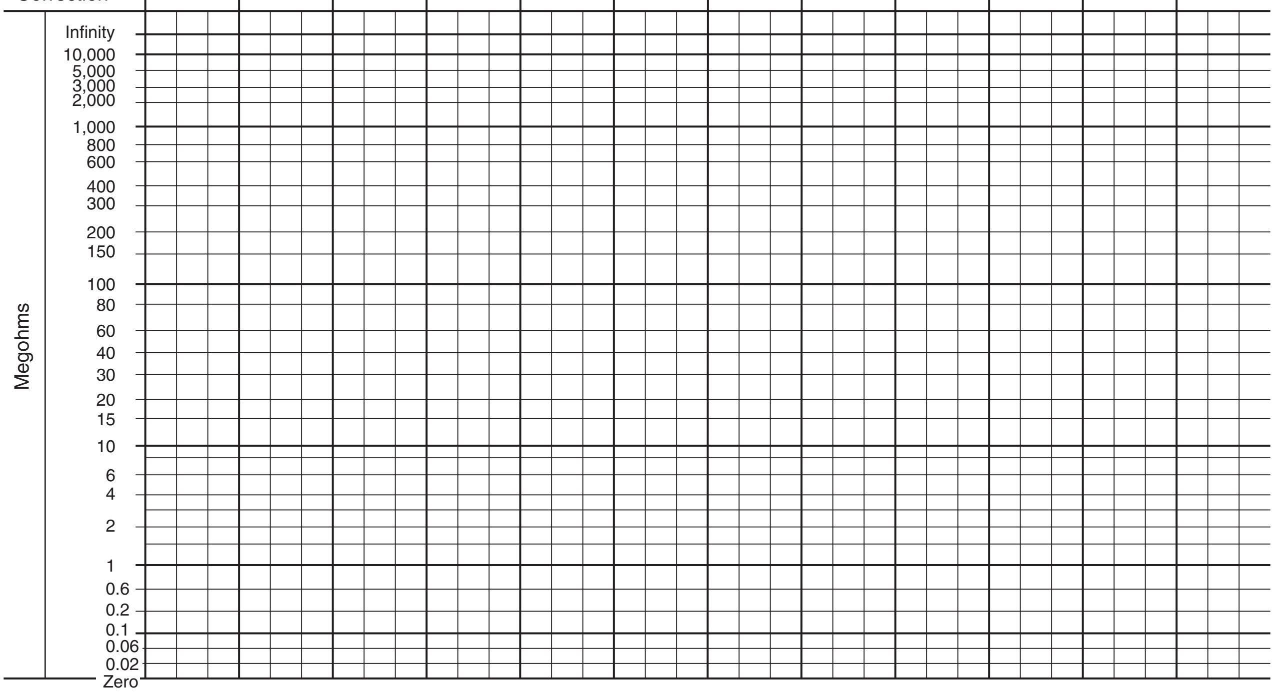
Ambient Temperature __________ °F Relative Humidity __________ % Weather __________

Equipment Temperature __________ How Obtained __________

Instrument __________ Range __________ Voltage __________

Test Data:

Minutes	0.25	0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Reading												
Correction												



Polarization No. (10:1 min. ratio) __________ Tested by __________

Remarks:

FIGURE F.15 Insulation Resistance Test Record Rotating Machinery.

Annex G NEMA Configurations

This annex is not a part of the recommendations of this NFPA document but is included for informational purposes only.

G.1 Figure G.1 shows the typical NEMA configurations for general-purpose nonlocking plugs and receptacles.

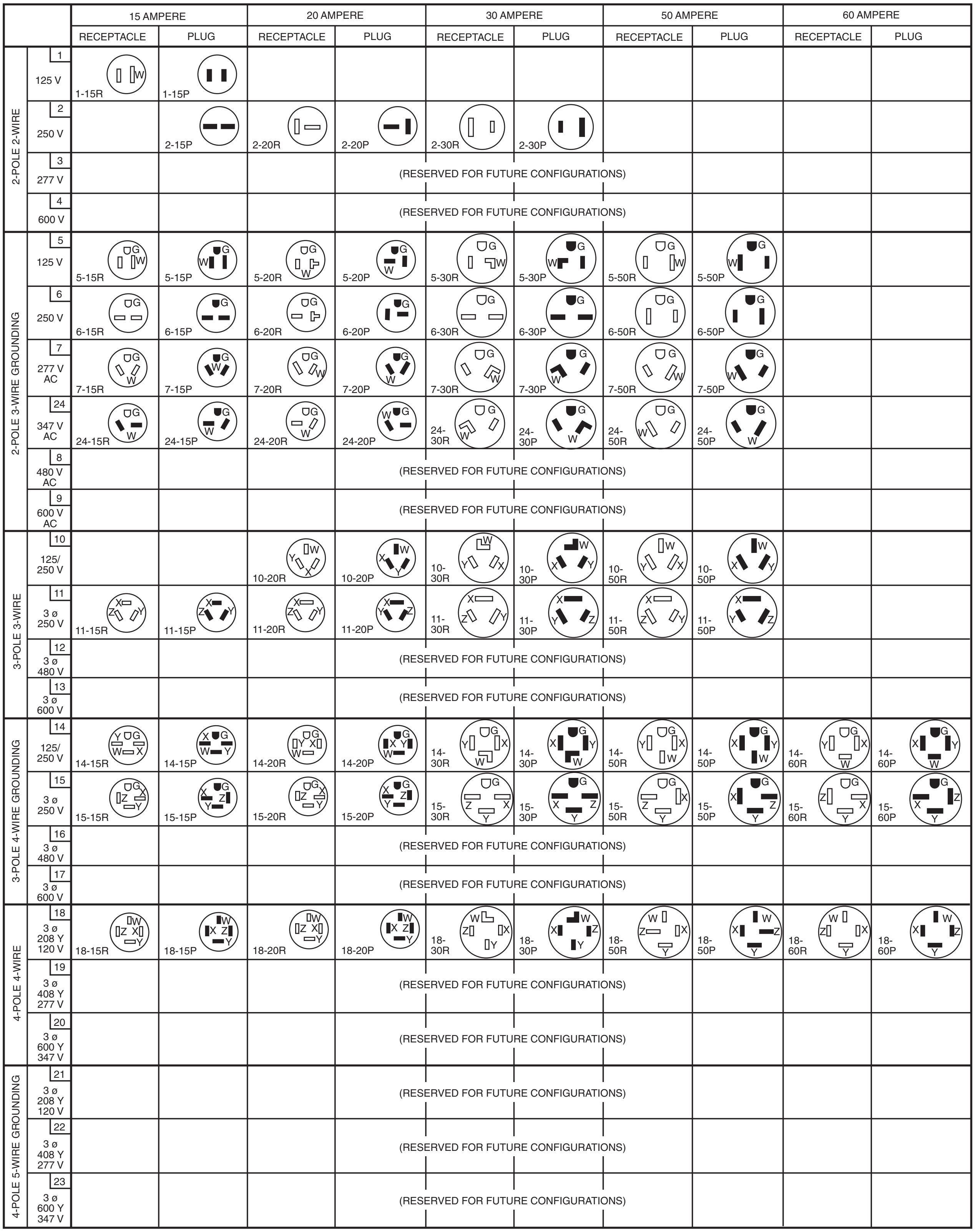


FIGURE G.1 NEMA Configurations for General-Purpose Nonlocking Plugs and Receptacles.

G.2 Figure G.2 shows the typical NEMA configurations for locking plugs and receptacles.

			15 AMPERE		20 AMPERE		30 AMPERE	
			RECEPTACLE	PLUG	RECEPTACLE	PLUG	RECEPTACLE	PLUG
2-POLE 2-WIRE	125 V	L1	L1-15R	L1-15P				
	250 V	L2			L2-20R	L2-20P		
	277 V ac	L3	F	U	T	U	R	E
	600 V	L4	F	U	T	U	R	E
2-POLE 3-WIRE GROUNDING	125 V	L5	L5-15R	L5-15P	L5-20R	L5-20P	L5-30R	L5-30P
	250 V	L6	L6-15R	L6-15P	L6-20R	L6-20P	L6-30R	L6-30P
	277 V ac	L7	L7-15R	L7-15P	L7-20R	L7-20P	L7-30R	L7-30P
	480 V ac	L8			L8-20R	L8-20P	L8-30R	L8-30P
	600 V ac	L9			L9-20R	L9-20P	L9-30R	L9-30P
3-POLE 3-WIRE	125/250 V	L10			L10-20R	L10-20P	L10-30R	L10-30P
	3ø 250 V	L11	L11-15R	L11-15P	L11-20R	L11-20P	L11-30R	L11-30P
	3ø 480 V	L12			L12-20R	L12-20P	L12-30R	L12-30P
	3ø 600 V	L13					L13-30R	L13-30P
3-POLE 4-WIRE GROUNDING	125/250 V	L14			L14-20R	L14-20P	L14-30R	L14-30P
	3ø 250 V	L15			L15-20R	L15-20P	L15-30R	L15-30P
	3ø 480 V	L16			L16-20R	L16-20P	L16-30R	L16-30P
	3ø 600 V	L17					L17-30R	L17-30P
4-POLE 4-WIRE	3ø 208Y/ 120 V	L18			L18-20R	L18-20P	L18-30R	L18-30P
	3ø 480Y/ 277 V	L19			L19-20R	L19-20P	L19-30R	L19-30P
	3ø 600Y/ 347 V	L20			L20-20R	L20-20P	L20-30R	L20-30P
4-POLE 5-WIRE GROUNDING	3ø 208Y/ 120 V	L21			L21-20R	L21-20P	L21-30R	L21-30P
	3ø 480Y/ 277 V	L22			L22-20R	L22-20P	L22-30R	L22-30P
	3ø 600Y/ 347 V	L23			L23-20R	L23-20P	L23-30R	L23-30P

FIGURE G.2 NEMA Configurations for Locking Plugs and Receptacles.

Annex H Long-Term Maintenance Guidelines

This annex is not a part of the recommendations of this NFPA document but is included for informational purposes only.

H.1 Introduction. This annex deals specifically with the maintenance of equipment that, by nature of its application, necessitates long intervals between shutdowns. It should be stressed that environmental or operating conditions of a specific installation should be considered and might dictate a different frequency of maintenance than suggested in this annex.

Maintenance guidelines are presented in the tabular form for the following equipment.

H.2 Medium-Voltage Equipment. Table H.2(a) through Table H.2(k) address equipment that should be considered items for long-term maintenance intervals. This includes the following equipment and techniques:

(1) Cables, terminations, and connections
(2) Liquid-filled transformers
(3) Dry-type transformers
(4) Metal-clad switchgear
(5) Circuit breakers
(6) Metal-enclosed switches
(7) Buses and bus ducts
(8) Protective relays
(9) Automatic transfer control equipment
(10) Circuit breaker overcurrent trip devices
(11) Fuses
(12) Lightning arresters

Table H.2(a) Medium-Voltage Equipment, Cables, Terminations, and Connections; Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
Solid Dielectric (Chapter 10)	**Inspections (while energized) of** (10.2.1):	One year.
	Conduit entrances (10.4).	Observe for deformation due to pressure and for bends with radius less than minimum allowed.
	Poles and supports.	Same as above.
	Binder tape terminations (aerial cables) (10.3).	Same as above.
	Ends of trays (10.4).	Same as above.
	Splices (10.2.3).	Same as above.
	Terminations (stress cones and potheads) (10.2.3) (10.2.5).	Same as above plus dirt, tracking, water streaks, chipped porcelain, shield ground connections (where visible) and adequate clearances from grounded metal parts.
	Fireproofing (where required) (10.2.3).	Observe for continuity.
	Loading.	Make certain loads are within cable ampacity rating.
Varnished Cambric Lead Covered and Paper Insulated Lead Covered	**Inspections (while energized) of** (10.2.1):	
	Same as above.	Same as above.
	Lead sheath (10.2.3).	Observe for cracks or cold wipe joints — often indicated by leakage of cable oil or compound.
All Types	**Major Maintenance and Testing (de-energized)** (7.3) (10.2.1):	Three to six years.
	Complete inspection same as above.	Same as above.
	Clean and inspect porcelain portions of potheads (10.2.5) (8.1.2.1):	For cracks and chips.
	Clean and inspect stress cones and leakage sections (10.2.3) (8.2.13).	For soundness of stress cones. X-ray or disassemble, if soft spots are detected. For surface tracking.
	Check plastic jackets for longitudinal shrinkage from splices and terminations.	Jacket shrinkage might have damaged shielding tapes or stress cones.
	Check integrity of shield grounding (10.2.3).	Observe ground connections for stress cones. Suggest checking electrical continuity of shielding tape.
	Check general condition of cable (10.2.3).	Does insulating material appear to have been damaged by overheating?

Table H.2(a) ***Continued***

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
All Types *(cont.)*	Observe connectors for overheating (10.2.5) (8.1.3) (8.2.14).	Discoloration and/or oxidation indicate possible problem. Check bolts for tightness, if accessible. If connectors are insulated with tape, deterioration or charring of tape is indicative of overheated connector, caused by loose bolts, etc. Infrared survey while conductors are energized and loaded to at least 40 percent of ampacity might be beneficial to detect overheated connections. Use good quality infrared scanning equipment.
	Test cable insulation with high potential dc (10.5) (20.9.1).	Disconnect cables from equipment and provide corona protection on ends. Ground other conductors not being tested. Record leakage current in microamperes at each test voltage level. Record temperature and relative humidity.
	Determine condition of cable insulation (20.9.2.6).	Interpret test results, considering length of cable, number of taps, shape of megohm or leakage current curve, temperature and relative humidity.
	Reconnect cables to equipment.	Tighten connectors adequately.
	Aluminum conductors.	Make certain that connectors of the proper type are correctly installed. Use Belleville washers when bolting aluminum cable lugs to equipment. Advisable to determine conductivity of connection using microhmmeter or determine voltage drop under test load conditions (20.12).

Table H.2(b) Medium-Voltage Equipment, Liquid-Filled Transformers; Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
(Oil and Askarel) Sealed Tank, Conservator and Gas Sealed Systems (Chapter 9)	**Inspections (while energized) of:**	
	Top liquid temperature (9.2.4).	Weekly to monthly. Record findings. Present temperature and highest indicated. Reset drag needle. 80°C (176°F) nominal max. permitted.
	Head space pressure (sealed tank type) (9.2.5.2).	Should vary under changes in loading and ambient temperature. If gauge remains at zero, gauge is broken or leak exists in tank head space, which permits transformer to breathe and allows entrance of moisture.
	Nitrogen pressure (pressurized tank type).	Check nitrogen bottle pressure and pressure in transformer head space.
	Liquid level in tanks (9.2.5.1).	Should be between min. and max. marks on gauge.

Table H.2(b) *Continued*

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
(Oil and Askarel) Sealed Tank, Conservator and Gas Sealed Systems (Chapter 9) *(cont.)*	Liquid levels in oil-filled bushings (if so equipped).	Should be between min. and max. marks on gauge.
	Evidence of oil leaks (9.2.7.4).	From tanks, fittings, cooling tubes, and bushings.
	Automatic load tap changer mechanism.	General condition; note and record number of operations.
	Tests (while energized) of:	
	Oil — draw sample and test in laboratory for (9.2.8).	Annually for normal service transformers. Biannually for rectifier and arc furnace transformers. Dielectric strength, acidity, and color. If dielectric is low, determine water content.
	Askarel — draw sample and test in laboratory for (9.2.8). (Observe EPA regulations for handling and disposal.)	Same frequency as for oil. Dielectric strength, acidity, color, and general condition. If dielectric is low determine water content.
	Comprehensive liquid tests.	Frequency three to six years. In addition to above, tests include interfacial tension, water content, refractive index power factor at 25°C (77°F) and 100°C (212°F) (20.9.3.2) corrosive sulfur (askarel), and inclusion of cellulose material.
	Dissolved gas content in liquid of transformers in critical service or in questionable condition as might be indicated by above liquid tests (20.16).	Frequency six years or as conditions indicate. Draw sample in special container furnished by test laboratory. Spectrophotometer test will detect gases in oil caused by certain abnormal conditions in transformer. A series of tests on samples drawn over period of time might be necessary to determine if abnormal condition exists and to determine problem. Devices are available for installation on transformers to collect gases to be tested for combustibility to determine if internal transformer problem exists.
	Major Maintenance and Tests (de-energized) (7.3) (9.2.7.2):	Three to six years or more often if above tests indicate.
	Make above tests well in advance of scheduled shutdown.	Determine possible problems that require attention.
	Inspect pressure relief diaphragm for cracks or holes or mechanical pressure relief device for proper operation (9.2.7.3).	Replace if defective. Possible cause of pressure in sealed type transformers remaining at zero.
	Pressure test with dry nitrogen the head space areas of sealed-type transformers if pressure gauge remains at zero and pressure relief device is satisfactory.	Apply liquid along seams, etc., to locate leaks. Make necessary repairs.
	Clean bushings and inspect surfaces (9.2.7.3).	Consider application of silicone grease in badly contaminated areas. Should be removed and reapplied at maximum two-year intervals, preferably one year.

Table H.2(b) *Continued*

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
(Oil and Askarel) Sealed Tank, Conservator and Gas Sealed Systems (Chapter 9) *(cont.)*	Inspect load tap changer mechanism and contact.	Follow manufacturer's instructions on maintenance and number of operations between contact replacements.
	Paint tank as required.	Wire-brush rust spots and prime paint. Finish paint.
	Check ground system connections (9.2.7.5).	In each tap position. As an acceptance test and after major repairs.
	Perform turns ratio test (20.11).	
	Perform power factor tests (disconnect from equipment) (20.9.3.2).	Windings, bushings, and insulating liquid.
	Consider making winding/tap changer resistance tests.	Use microhmmeter in each tap position to detect abnormally high contact resistance.
	Make undercover inspection through manholes (provide positive protection to prevent entrance of moisture) (9.2.7.6). This inspection might not be necessary at 6-year intervals unless tests indicate problems.	Six-year frequency should definitely be considered for rectifier and arc furnace transformers. Inspect for moisture or rust under cover, water on horizontal surfaces under oil, tap changer contacts (insofar as possible), trash, oil sludge deposits, loose bracing and loose connections.
	Consider high-potential dc tests (9.2.9.4) (20.5 through 20.8).	dc in excess of 34 kV can polarize liquid and thereby increase leakage currents.
	If above inspections and/or tests indicate possible internal problems, it might be necessary to transport transformer to shop to untank the core and coil assembly for cleaning, inspecting, testing and making repairs as found necessary.	
	Filtering insulating liquid (de-energize transformer and ground windings).	Frequency as required. Remove moisture by heating and pumping liquid through cellulose filters, a centrifuge or a vacuum dehydrator. Thoroughly clean hose and filtering equipment before switching from oil to askarel or vice versa (9.2.1.2). Observe ANSI C107.1 1974 for handling and disposal of askarel.
	Re-refining insulating oil (de-energize transformer and ground windings).	Frequency as required. Filter through fuller's earth to remove polar compounds and acids. Add dibutylparacresol to replace oxidation inhibitors.
	Refilling transformer with insulating liquid (9.2.7.7, 9.2.7.8).	Refill under partial vacuum if transformer tank is so designed. Follow manufacturer's instructions. Always test insulating liquid for dielectric strength (min. 26 kV for oil) prior to pumping into transformer and pump through filter (min. 30 kV Askarel).
	Special Testing (de-energized):	To test phase-to-phase and turn-to-turn insulation. (200 Hz to 300 Hz for 7200-volt cycles).
	Induced potential test (9.2.9.2).	Proof test.
	AC high potential test (20.9.3.1)	Proof test.

Table H.2(c) Medium-Voltage Equipment, Dry-Type Transformers; Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
Ventilated (Indoors) (9.1, 9.3)	**Inspections (while energized) of:**	Weekly to monthly. Record findings.
	Operating temperature (9.3.4).	Present temperature and highest indicated. Reset drag needle. 150°C (302°F) is max. operating temperature for transformers rated 80°C (176°F) rise. 220°C (428°F) is max. operating temperature for transformers rated 150°C (302°F) rise.
	Cleanliness of screens located over or behind ventilation louvers in enclosure (9.3.6).	Clogged screens restrict ventilation and thereby increase operating temperature of core and coil assembly. Vacuum screens without de-energizing transformer if dust and lint are on outside of screens. If same is on inside, transformer should always be de-energized and enclosure sides removed to clean screens.
	Ventilating fan operation (if so equipped).	Check operation of fans with control switch in “Manual” position. Do not operate fans continuously with switch in “Manual”; leave in “Automatic” so temperature detectors will operate fans at temperatures above specified levels. Also check alarm contacts for proper operation at excessive temperature levels.
	Room ventilation (9.3.6)	Adequate ventilation system to admit and exhaust air. Air streams should not be directed toward upper vent louvers in transformer enclosure because it will restrict ventilation inside transformer and cause overheating.
	Evidence of condensation and water leaks in room (9.3.6).	Inspect top of transformer. Make necessary corrections.
	Major Maintenance (de-energized) (9.3.7) (7.3):	Three to six years. More often if required.
	Remove enclosure covers and clean vent louvers and screens (9.3.7.2).	
	Clean insulators, core, and windings (9.3.7.2, 9.3.7.3).	Use bottle of dry nitrogen with pressure regulator, hose and small nozzle to blow off dust. Restrict pressure to 207 kPa (30 psi max). Clean with soft bristle brush as required.
	Inspect following components:	
	Interphase barriers (9.3.7.2).	Should not touch windings.
	Wedges and clamping rings (9.3.7.2).	For proper clamping of windings. Tighten as required.
	Primary and secondary buses and conductors (9.3.7.2) (8.1.3).	For tightness of connections.
	Porcelain insulators (8.1.2).	For chips, cracks, and water streaks.
	Insulating materials (9.3.7.2) (8.2.10 through 8.2.14).	For surface tracking.
	Windings (9.3.7.2) (8.2.14) (9.3.7.3).	For damage to insulation, including overheating.

Table H.2(c) ***Continued***

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
Ventilated (Indoors) (9.1, 9.3) *(cont.)*	Tap connections (9.3.7.2).	For tightness and correctness to provide proper voltage.
	Core assembly.	For loose and/or dislocated laminations, localized or general overheating, and for integrity of ground strap, which is *only* place where core assembly is permitted to be grounded.
	Ventilating channels between core and windings and between windings (9.3.7.3).	For clogging with lint, dust, or tape used to hold spacers, etc., in place during assembly. Clean as required to allow proper air flow.
	Space heaters for proper operation.	Used to keep windings dry when transformer is de-energized.
	Temperature detectors.	For proper location and proper support of leads.
	Temperature indicators.	For accuracy and operation of fan and alarm contacts at proper temperatures.
	Cooling fans.	For free turning and proper operation.
	Testing (de-energized) (20.1) (20.4 through 20.8):	Three to six years. More often if required.
	Turns-ratio test (20.11).	In each tap position as an acceptance test and after major repairs.
	Polarization index test (9.2.9.1) (9.2.9.2, 9.2.9.3) (20.9).	Use 1000-volt insulation resistance tester. Low P.I. results often indicate moisture in winding. If so, investigate cause and satisfactorily dry transformer before making high potential dc test and returning transformer to service.
	High-potential dc test (9.2.9.4) (20.9.2.6).	Record leakage currents in microamperes, temperature, and relative humidity.
	Special Testing (de-energized):	
	Induced potential test (9.2.9.2).	To test phase-to-phase and turn-to-turn insulation. (200 Hz to 300 Hz for 7200-volt cycles.) Proof test.
	ac high-potential test (20.9.3.1).	Proof test.

Table H.2(d) Medium-Voltage Equipment, Metal-Clad Switchgear; Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
Indoor (Chapter 8)	**Inspections (while energized):**	Three to six months.
	Open external doors and inspect components:	
	Fronts of circuit breakers.	Record number of operations.
	Protective and control relays (8.8.7).	Wiring and connections — not internals.
	Auxiliary devices, wiring and terminal blocks (8.4.6).	Proper indicating lights should light.
	Space heaters (8.2.7).	Operate continuously to overcome possible malfunction of thermostats. Consider installation of ammeters in heater supply circuits to monitor full load current of heaters on each circuit to assure that all are operating.

Table H.2(d) *Continued*

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
Indoor (Chapter 8) *(cont.)*	Ventilation (8.2.8).	Ventilation louvers should be open.
	Insulators and insulating materials (8.2.10 through 8.2.14).	
	Cable terminations (10.1 through 10.4).	Observe stress cones and leakage sections annually for cleanliness and tracking.
	Batteries (8.9.4).	
	Also inspect for following conditions:	
	Loading.	Record loads.
	Cleanliness (8.2.9).	Moderate amount of dry nonconductive dust not harmful.
	Dryness (8.2.5, 8.2.6).	Evidence of condensation or water leaks.
	Rodents and reptiles (8.2.4).	
	Overheating of parts (8.2.14).	Discoloration and/or oxidation indicate possible problem.
	Tracking on insulating surfaces (8.2.13).	Take necessary corrective action.
	Major Maintenance or Overhaul:	Three to six years, depending on ambient conditions.
	De-energize (7.3). **Verify that no parts of the power or control circuitry are energized by "back feed" from alternate power or control sources.** Completely clean, inspect, tighten, and adjust all components (8.4.1):	Follow manufacturer's maintenance instructions.
	Structure and enclosure (8.2.3, 8.2.4).	Wire-brush and prime paint rust spots. Finish paint.
	Ventilating louvers and air filters (8.2.8).	Clean or replace filters as required.
	Buses, splices, and bolts (8.1.3) (8.2.14).	Check bolts for manufacturer's recommended torque. If inaccessible, check insulating tape, boot, or compound box over bus splices for heat deterioration due to loose bolts, etc.
	Insulators and insulating materials (8.2.10 through 8.2.14) (8.1.2).	Clean and inspect for surface tracking.
	Circuit breakers (8.4 through 8.6).	Refer to oil and air circuit breaker sections.
	Breaker disconnect studs and finger clusters (8.4.3.7).	Lubricate, unless manufacturer's instructions specify that they should not be lubricated.
	Drawout breaker racking mechanisms (8.1.7).	Alignment and ease of operation.
	Cable terminations and connections (10.1 through 10.4).	Clean and inspect for surface tracking. Check connections for tightness.
	Meters (8.8.7).	Test for accuracy.
	Controls, interlocks and closing power rectifiers (8.8.8).	Make functional tests. Check voltages.
	CTs, PTs, and control power transformers (8.8.5).	
	Fuseclips and fuses (15.2).	Check clips for adequate spring pressure.
	Grounding (8.1.5) (8.8.9).	Proper fusing.
	Components and conditions in above block.	Make necessary repairs.
	Testing (Chapter 20) (7.3):	Three to six years, depending on ambient conditions.
	Test buses, breakers, PTs, CTs, and cables with high-potential dc.	Record leakage currents in microamperes (20.9.2.6) (10.5).

Table H.2(d) *Continued*

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
Indoor (Chapter 8) *(cont.)*	Calibrate and test protective relays (20.10.3).	Refer to protective relays section.
	Functionally trip breakers with relays (20.10.3.2).	Preferably, inject test current into CT and relay circuits.
	Test conductivity of aluminum cable connections (20.12) (8.1.3).	Use microhmmeter or determine voltage drop under test load conditions.
	Test wiring for controls, meters and protective relays for insulation resistance (20.9.2.3).	1000 volt dc for control wiring+. 500 volt dc for meters and relays.
Outdoor	**Inspections (while energized):**	One to three months.
	Same as for indoor gear except:	
	Special emphasis on evidence of condensation and water leaks (8.2.3) (8.2.5) (8.2.6).	Rust spots on underside of metal roof indicative of condensate.
	Special emphasis on space heater operation (8.2.7).	
	Ventilating louvers and air filters and cleanliness (8.2.8).	Clean or replace air filters as required.
	Major Maintenance or Overhaul:	Three years. More often if conditions require.
	De-energize (7.3). **Verify that no parts of the power or control circuitry are energized by "back feed" from alternate power or control sources.** Same as for indoor gear.	Follow manufacturer's maintenance instructions.
	Testing. (Chapter 20) (7.3):	
	Same as for indoor gear.	Three years. More often if conditions require.

Table H.2(e) Medium-Voltage Equipment, Circuit Breakers; Maintenance of Equipment Subject to Long Intervals Between Shutdowns — Electrical Distribution

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
Air-break, Drawout Type (8.4)	**Inspection and Maintenance (withdrawn from switchgear and de-energized)** (7.3):	Max. of three years or at manufacturer's maximum number of operations since previous maintenance, whichever occurs first.
		Immediately after breaker opens to interrupt a serious fault.
		Follow manufacturer's maintenance instructions.
		If breaker is stored energy closing type, follow manufacturer's safety precautions, determine that closing springs are discharged, or mechanism is blocked to prevent personal injury. Keep hands away from contacts and mechanism while test operating breaker (8.4.1.1).
	Remove arc chutes. Inspect, adjust and clean where necessary:	
	Main contacts (8.4.3).	For pitting, spring pressure, overheating, alignment, overtravel, or wipe.
		Adjust or replace accordingly.
	Arcing contacts (8.4.3.2).	For alignment, overtravel, or wipe and for arc erosion.
		Adjust or replace accordingly.

Table H.2(e) *Continued*

Type	Inspections, Maintenance, and Tests	Typical Frequency and Remarks
Air-break, Drawout Type (8.4) *(cont.)*	Moving parts and linkages (8.4.5.1 through 8.4.5.3).	For freedom of movement.
	Closing mechanism (8.4.5).	For quick and positive closing action.
	Tripping mechanism (8.4.5).	For freedom of movement and reliability to open breaker contacts.
	Interlocks and safety devices (8.8.8) (8.4.6.2).	Functionally test to prove proper operation.
	Primary disconnect finger clusters (8.4.3.7).	For proper adjustment and spring pressure. Lubricate, unless manufacturer's instructions specify that they should not be lubricated.
	Secondary disconnect contacts (8.4.3.7).	For alignment and spring pressure. Lubricate.
	Closing and trip coils (8.4.6.1).	General condition and evidence of overheating.
	Spring charging motor and mechanism (stored energy type) (8.4.6.1).	Proper operation. Oil leaks from gear motor.
	Shunt trip device (8.4.6.1).	For freedom of movement. Functionally test.
	Undervoltage trip device.	For freedom of movement. Functionally test.
	Auxiliary contacts.	For proper operation with closing and opening of breaker.
	Closing (x and y) relays (electrically operated breakers).	Contact erosion. Dress or replace as required.
	Current transformers (8.8.7.2) (8.2.10).	General condition. Check nameplate ratio.
	Connection bolts (11.3.1 through 11.3.3).	Check for tightness.
	Structure or frame.	For proper alignment and loose or broken parts.
	Fuses and mountings (15.1, 15.2).	General condition and tightness.
	Frame-grounding device.	Connect before and disconnect after primary fingers.
	Position indicators (8.4.6.2) (8.8.6.2).	For proper operation.
	Auxiliary wiring.	General condition and tightness of terminal screws.
	Arc chutes (8.4.4).	For broken parts, missing arc splitters, and amount of metal spatter and burning on interior surfaces. Snuffer screens should be clean. Repair or replace as necessary.
	Operation counter.	For proper operation. Record number of operations.
	Insulators and insulating materials (8.2.10, 8.2.12, 8.2.13) (8.4.2).	For cracks, breaks, corona, tracking, and overheating.
	Breaker auxiliary devices (8.4.6).	Make necessary repairs.
	Testing (withdrawn from switchgear and de-energized) (7.3) (20.5; 20.6; 20.7, 20.8): Insulation (20.9.1) (20.9.2.3) (20.9.2.4) (20.9.2.6).	Max. of three years, etc., same as above block. High-potential test each main contact with breaker open and all other main contacts and frame grounded. Record results. Use 1000-volt megohmmeter on auxiliary devices, controls and associated wiring.
	Contact conductivity or resistance (20.12).	Use microhmmeter or determine voltage drop under test load conditions.