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INTERNATIONAL
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AEROSPACE RECOMMENDED PRACTICE

SAE ARP5015

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GROUND EQUIPMENT - 400 HERTZ GROUND POWER PERFORMANCE REQUIREMENTS

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1. SCOPE:

1.1 This SAE Aerospace Recommended Practice (ARP) covers the requirements for ground power equipment that supplies 115/200 V, 3-phase, 400 Hz output capable of powering aircraft type loads requiring MIL-STD-704E/DFS-400 quality power. All forms of ground power including mobile and fixed systems are addressed by this document. High voltage (270 V DC) systems are not included in this specification.

1.2 The intent of this document is to combine the numerous specifications for engine generators, motor generators, and solid-state converters into one unified specification tailored for performance with modern aircraft, applicable to all unless otherwise noted. Modern aircraft are requiring more power at a higher quality without interruption which places new constraints such as No-Break-Power-Transfer (NBPT) operation on the ground power units (GPUs). The protective trip limits are designed to allow a two tier protection utilizing both the aircraft's electrical power generating system (EPGS) and the GPUs protection. Some of these specifications will place some new design constraints on the manufacturers of GPUs but will help promote compatibility with both old and new aircraft with all types of ground power equipment.

1.3 While GPUs are designed to provide the same quality of power as the aircraft's EPGS, there are differences in rated capacity. Engines utilized in GPUs must be sized for the peak kW specified which is why a 125% overload is specified for GPUs. Increasing the size of the engine to match the aircraft's EPGS typical 150 to 200% overload rating would not be practical. The 150 to 200% overload rating is designed for abnormal conditions (such as fault clearing) and the use of a GPU to clear aircraft on-board faults is not recommended. GPUs that utilize engine generators are also self-excited which implies that they are not capable of providing output under excessive fault current since their output voltage is utilized to excite the generator. Most aircraft EPGS have a permanent magnet pilot machine that provides the excitation supply to allow for fault clearing current. GPUs are typically rated for a 0.8 power factor which differs from aircraft EPGS which are rated at 0.75 PF. An engine generator will have to have a slightly larger engine to accommodate a 0.8 PF when compared to a 0.75 PF which infers that 0.8 is actually a conservative rating for GPUs.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP1247A General Requirements for Aerospace Powered Mobile Ground
J1175 Bystander Sound Level Measurement Procedure

2.2 ANSI Publications:

Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 1540 Aerospace - Characteristics for Aircraft Electrical Systems
ISO 6858 Ground Support Electrical Supplies - General Requirements

2.3 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-G-21480A Generators and Regulators, Air-cooled, AC, Equipment
MIL-STD-461 Electromagnetic Interface Characteristic Requirements for Equipment
MIL-STD-704E Electric Power, Aircraft, Characteristics and Utilization of

2.4 UL Publications:

Available from Underwriter Laboratories Publications, 333 Pfingsten Road, Northbrook, IL 60062.

UL 1446-1980 Systems of Insulating Materials - General Revised 3/86

2.5 NEMA Publications:

Available from National Electrical Manufacturers Association, 2101 L. St. NW, Washington, DC 20037.

NEMA MG-1 NEMA Standards Publication - Motor and Generators (N/A to Solid-State)
NEMA PE-1 Uninterruptable Power Systems

2.6 IEC Publications

Available from International Electrotechnical Commission, 3. rue de Varembe. CH-1211 Geneve 20 Switzerland

IEEE-519 Guide for Harmonic Control and Reactive Compensation of Static Converters

2.7 ATA Publications:

Available from Air Transport Association, 1709 New York Avenue NW, Washington, DC 20006

ATA-Spec 101 Specification for Ground Power Equipment Technical Data

2.8 Other Publications:

AN-3114, AN-3440	Army/Navy 6-Pole Socket/Plug Reqmts. (MS90362/MS25486 Cable:MS90328)
BSI 2G-219	General Requirements for Ground Support Electrical Supplies for Aircraft
DFS-400	Eurostandard 400 Hertz Systems

2.9 Definitions and Abbreviations:

This glossary of terms is included as part of this document for use in its interpretation.

ALTERNATOR SPEED: The nominal speed at which the alternator operates to produce 400 Hz.

ALTITUDE: The maximum height in feet above sea level at which the unit must operate and maintain characteristics within recommended limits.

AMBIENT TEMPERATURE: The temperature range in degrees in which the unit must operate and maintain characteristics within recommended limits.

BREAK TRANSFER: The mode of transferring the aircraft load from aircraft power source to ground power source or vice versa whereby power to the aircraft is momentarily interrupted.

CREST FACTOR: The ratio of the peak voltage to the rms voltage. This ratio with a true sine wave is 1.414.

DEAD FRONT: Constructed so that there are no exposed live parts on the front of the assembly.

DIELECTRIC TESTS: The high voltages impressed between a component and the chassis of the unit. This test is used to check insulation characteristics.

FREQUENCY CHARACTERISTIC OF VOLTAGE MODULATION: The component frequencies which make up the modulation envelope waveform.

FREQUENCY DRIFT: The slow and random variation in frequency within the steady state limits.

FREQUENCY DRIFT RATE: The rate of change of frequency due to frequency drift when plotted against time.

FREQUENCY MODULATION: The cyclic variation of instantaneous frequency about a mean frequency during any steady state load. Frequency modulation in percent is calculated by taking maximum frequency minus minimum frequency times 100 and dividing this value by maximum frequency plus minimum frequency.

FREQUENCY MODULATION RATE: The rate of change of frequency due to frequency modulation when plotted against time.

FREQUENCY REGULATION: The band that the output frequency stays within except during transients.

2.9 (Continued):

FREQUENCY TRANSIENT RECOVERY: The time required for the output frequency to recover to and remain within the prescribed limits after load application or removal.

FREQUENCY TRANSIENTS: The maximum instantaneous deviation of the output frequency from the frequency regulation band.

HIGHEST PHASE VOLTAGE LIMITING: A means of limiting the highest phase voltage of the unit output during any unbalanced load condition.

INDIVIDUAL HARMONIC: The rms value of any individual harmonic voltage when measured with a harmonic analyzer. This value is expressed as a percentage of the fundamental.

LINE DROP COMPENSATION: A system of increasing the unit output voltage in proportion to the current and power factor in the output cable(s) such that the voltage is held constant at the aircraft receptacle.

NO BREAK POWER TRANSFER (NBPT): The mode of transferring the aircraft load from aircraft power source to ground power source or vice versa whereby the aircraft and ground power sources are simultaneously connected to the aircraft load and in parallel with each other, possibly out of synchronization. NBPT can also occur between on-board aircraft sources as well.

NOMINAL VOLTAGE RATING: The root-mean-square line-to-neutral and line-to-line voltage at which the unit output is rated. The unit is normally set such that output voltage is maintained at this value. Adjustable voltage range is the range in adjustment of the line-to-line voltage as controlled by the regulator adjustment to enable checking over and under voltage protection devices.

OUTPUT TERMINALS: The terminals on the ground power unit side of the output power feeders. This is considered to be the point of regulation for the ground power unit.

OVERLOAD RATING: The normal overload value expressed in kVA at 0.8 power factor for specified time.

PHASE VOLTAGE BALANCE WITH BALANCED LOAD: The maximum deviation of any of the three phase voltages from the average of the three phase voltages with a balanced three-phase load. The percent unbalance is calculated by taking maximum deviation of any one line-to-neutral voltage from the average of the three phase voltages times 100 divided by the average of the three phase voltages.

PHASE VOLTAGE BALANCE WITH UNBALANCED LOAD: The maximum deviation of any of the three phase voltages from the average of the three phase voltages with a prescribed unbalanced load. Percent unbalance is calculated in the same method as under balanced load conditions.

2.9 (Continued):

PHASE VOLTAGE DISPLACEMENT WITH BALANCED LOAD: The maximum deviation in degrees from 120 degrees between phases of the alternator voltages during balanced load conditions.

PHASE VOLTAGE DISPLACEMENT WITH UNBALANCED LOAD: The maximum deviation in degrees from 120 degrees between phases of the alternator voltages during a prescribed unbalanced load.

PRIME MOVER: The source of power for driving the alternator.

REGULATOR SENSING: The means by which the voltage is sensed and fed to the voltage regulator.

REMOTE SENSING: A means of providing constant voltage at the aircraft receptacle(s) by sensing the voltage at the receptacle with three separate leads in the output cable.

SHORT-CIRCUIT CURRENT: Aircraft onboard power systems typically provide current limit between 2.2 and 3.0 per unit operator. The voltage is folded back to accomplish this current limit mode. The purpose is to allow shorts to clear and assure operation of the protective current trips on the aircraft power bus. GPUs typically do not provide this mode since it is undesirable to have a GPU feeder fault arc for 5 s prior to tripping. Also, voltage foldback during NBPT is undesirable due to GPU and aircraft power control interactions.

TEMPERATURE RISE: The rise in degrees above ambient for components of the unit.

TOTAL HARMONIC CONTENT: The total RMS voltage remaining when the fundamental component is removed. This value is determined by calculating the square root of the sum of the squares of the individual harmonics and expressing this value as a percentage of the fundamental.

TOTAL LIFE: Defined to be the hours of use from time of delivery of the equipment to the using activity until its identity is destroyed by classifying it as salvage and/or subject to cannibalization.

TRIP: Occurs when the output is turned off or the output contactor is opened.

TYPE OF MOUNTING: The means of mounting the unit and controls.

UNIT: Refers to the complete power package such as the prime mover, alternator, and all associated equipment and systems.

UNIT RATING: The full load value (rated continuous) expressed in kVA at 0.8 power factor. The unit shall be capable of operating at any power factor from 0.8 lagging to 1.0 (unity) with reduced output power at higher power factors.

2.9 (Continued):

VOLTAGE MODULATION: The cyclic variation about an average of the AC peak voltage during any steady state load. The modulation envelope is formed by a continuous curve connecting each sine wave peak. Voltage modulation in percent is calculated by taking maximum voltage minus minimum voltage times 100 and then dividing this value by maximum voltage plus minimum voltage.

VOLTAGE REGULATION: The band that the output voltage stays within except during transients.

VOLTAGE REGULATION STEADY STATE: The band that the output voltage stays within with a fixed load.

VOLTAGE TRANSIENTS: The maximum momentary deviation of the output voltage from the steady state voltage as a result step load changes.

VOLTAGE TRANSIENT RECOVERY: The time required for the output voltage to recover to and remain within the prescribed limits after load application or removal.

3. TECHNICAL REQUIREMENTS:

3.1 Equipment Specifications:

All specifications are referenced to the unit's output terminals unless otherwise stated.

3.1.1 Prime Mover: The prime mover for driving the alternator shall be an engine or electric motor of sufficient horsepower to produce the rated kVA at 0.8 power factor and specified overload at the altitude and temperature range in which the equipment will be operated. The unit shall be capable of operating at any power factor from 0.8 lagging to 1.0 (units) with reduced output power at higher power factors. Not applicable to Solid-State.

3.1.2 Alternator Speed: Shall be based on the continuous operating speed of the prime mover. Not applicable to Solid-State.

3.1.3 Temperature Rise: Components of an alternator shall have insulating properties meeting NEMA MG-1 Standards. Solid-State converters shall utilize UL Class 180 transformer insulation systems in any magnetics greater than 1000 VA.

3.1.4 Dielectric Tests: The components of the alternator shall meet the dielectric strength tests of MIL-G-21480A. Not applicable to Solid-State.

3.1.5 Continuous Rating: The continuous kVA rating shall be at 0.8 power factor. Reference 3.6.4 for details involving environmental conditions and deratings.

3.1.6 Overload Rating: The normal overload rating shall be 125% of rated kVA at 0.8 power factor for 5 min. Reference 3.6.4 for details involving environmental conditions and deratings.

3.1.7 Nominal Voltage Rating: The AC system shall be a 3-phase, 4-wire "Y" system with grounded neutral having a nominal voltage of 115/200 V. The grounded neutral shall be solidly tied to the unit chassis ground with sufficient capacity in the tie to handle maximum ground fault current for a period of 5 s.

3.1.8 Adjustable Voltage Range: The adjustable voltage range shall be ±15% of the nominal voltage rating line-to-line in unloaded condition for checking overvoltage and undervoltage protective devices. Any equipment with this dynamic voltage range shall be equipped with such protective devices.

3.1.9 Regulator Sensing: Regulator sensing shall be three-phase averaging.

3.1.10 Highest Phase Voltage Limiting: A highest phase voltage limiting system shall be optional in the voltage regulator to limit the highest phase voltage of the alternator to 124 V during unbalanced load conditions.

3.1.11 Line Drop Compensation: A system of automatic line drop compensation shall be incorporated in the voltage regulator to provide constant voltage at the aircraft receptacle regardless of current. Minimum compensation capability shall be 5% at rated load for a single output. This corresponds to a 5.75 V rise for a 115 V rms system.

3.1.12 Voltage Regulation Steady State: The voltage at the unit output terminals shall stay within the steady state limits shown in Figure 1 for any rated load condition.

3.1.13 Voltage Transients: Shall be limited to the operating area shown in Figure 1 with step load changes equivalent to the full continuous load rating shown in 3.1.5.

3.1.14 Short-Circuit Current: The unit shall trip off line if current exceeds the overload capacity of the GPU. No current limit voltage foldback mode shall be used.

3.1.15 Voltage Modulation: The modulation of phase voltage (including the effects of frequency modulation) shall not exceed 3.5 V when measured as the peak-to-valley difference between the maximum and minimum peak voltages reached on the modulation envelope over a period of at least 1 s.

3.1.16 Frequency of Voltage Modulation: The frequency components of the voltage modulation envelope waveform shall not exceed 100 Hz.

3.1.17 Phase Voltage Balance with Balanced Load: The maximum deviation of any of the three-phase voltages from the average of the three-phase voltages shall not exceed 1% with a balanced three-phase load. The voltages shall be measured at the unit output terminals.

3.1.18 Phase Voltage Displacement with Balanced Load: The phase voltage displacement with a balanced three-phase load shall be within the limits of 120 degrees ± 1.5 degrees.

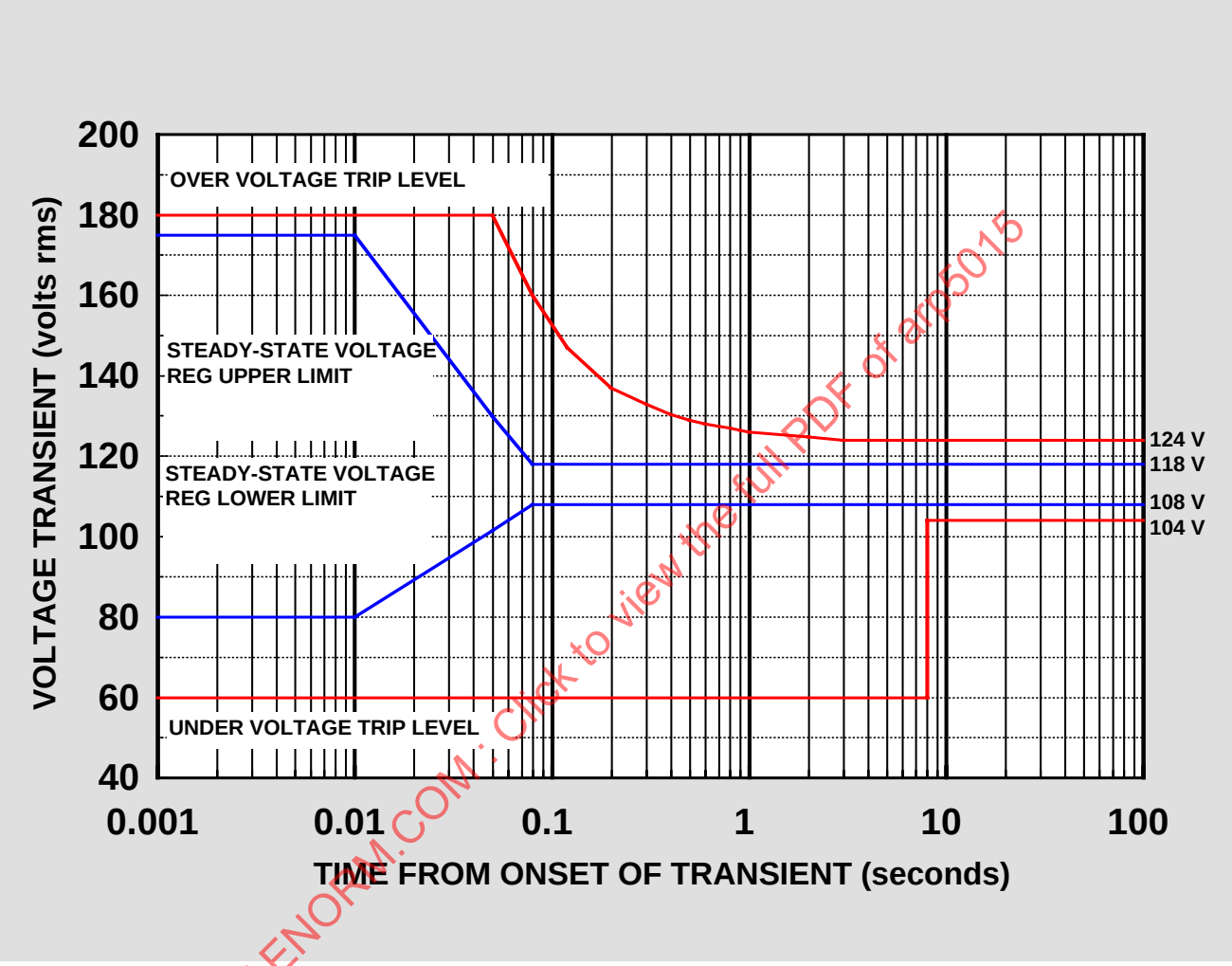

FIGURE 1 - Voltage Compliance and Protection

3.1.19 Phase Voltage Balance with Unbalanced Load: The maximum deviation of any of the phase voltages from the average of the three-phase voltages shall not exceed 4% with 1/3 rated current at 0.8 power factor lagging on any one phase and no load on the other two phases when measured at the output terminals. If measurement of phase voltage balance with unbalanced load is to be taken at other than the output terminals, maximum deviation, output cable size, and output cable length must be specified by the purchaser.

3.1.20 Phase Voltage Displacement with Unbalanced Load: The phase voltage displacement with a 1/3 rated current unbalanced load shall be within the limits of 120 degrees ± 4 degrees between any phase (line to neutral) voltages.

3.1.21 Individual Harmonic: The rms value of any individual voltage harmonic shall not exceed 2% of the fundamental (rms) when measured from line-to-line and line-to-neutral at no load and rated kVA (linear load) at 0.8 power factor with a harmonic analyzer.

3.1.22 Total Harmonic Content: The total harmonic content of the output voltage shall not exceed 3% of the fundamental (rms) when measured from line-to-line and line-to-neutral at no load and rated kVA (linear load) at 0.8 power factor with a distortion meter, or calculated from the individual harmonics as measured with a harmonic analyzer. The total harmonic content of the output voltage shall not exceed 4% of the fundamental (rms) when measured from line-to-line and line-to-neutral for a 1/3 rated current unbalanced load.

3.1.23 Crest Factor: The crest factor of the alternator shall be 1.414 ± 0.07.

3.1.24 Frequency Regulation: The output frequency shall stay within 400 Hz ± 5 Hz at all steady state loads up through full rated load.

3.1.25 Frequency Transients: The instantaneous frequency shall not be greater than 415 Hz or less than 385 Hz during full load application or removal as shown in Figure 2.

3.1.26 Frequency Transient Recovery: Output frequency shall recover to and stay within 400 Hz ± 5 Hz in 2 s as shown in Figure 2.

3.1.27 Frequency Modulation: The output frequency modulation shall not exceed 0.25% of the steady state frequency for all loads up to and including full rated load.

3.1.28 Frequency Modulation Rate: The rate of frequency modulation shall not exceed 13 Hz per second.

3.1.29 No Break Power Transfer (NBPT): The unit must be able to operate in an uninterrupted fashion during NBPT and maintain voltage and frequency within specified limits with onboard and ground power sources out of synchronization by as much as ±30°, ±2 Hz frequency, ±10 V for maximum time duration of 100 ms. If the NBPT conditions are more severe, the unit's protection device(s) may be activated. Thirty degrees corresponds to a circulating current equivalent to 125% overload at 90 kVA.

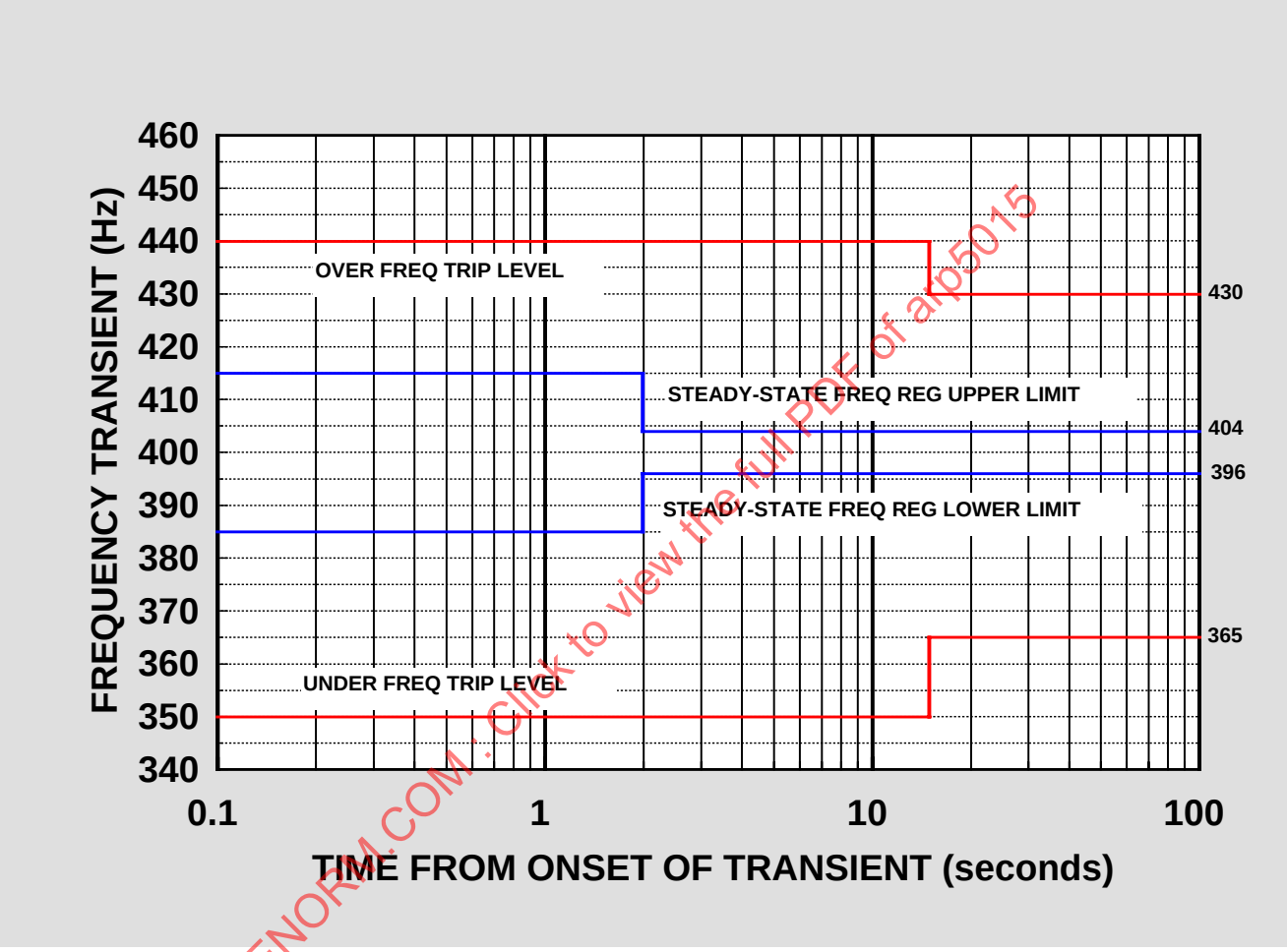

FIGURE 2 - Frequency Compliance and Protection

3.1.30 Phase Rotation: Phase rotation shall be A-B-C.

3.2 Personnel Safety:

3.2.1 Each unit shall offer safety to personnel operating or in vicinity of an operating unit. Control panel doors should be provided with locks to prevent entrance by others than authorized personnel when practical. Only authorized personnel shall be capable of operating unit with control panel doors open. Inside the control panel, any voltage over 250 V shall be specially shielded or suitably interlocked to prevent accidental contact. Suitable warning labels or covers shall be provided if internal voltages decay slowly after shutdown.

3.2.2 All rotating or moving parts shall be shielded to prevent accidental contact while unit is in normal operating mode. Label per codes - See NEMA PE-1-1992, pg. 47,48.

3.3 Equipment Protection:

3.3.1 The GPU over-voltage protective system shall automatically remove the power from the output terminals when the AC line-to-neutral exceeds curve of Figure 1 at output terminals.

3.3.2 The GPU under-voltage protective system shall automatically remove the power from the output terminals when the average AC line-to-neutral voltage drops below curve of Figure 1 at output terminals.

3.3.3 The GPU under-frequency protective system shall automatically remove the power from the output terminals when the frequency drops below the limits shown in Figure 2.

3.3.4 The over-frequency protective systems shall automatically remove the power from the output terminals when the frequency exceeds the limits shown in Figure 2.

3.3.5 The overload protective system shall automatically remove the power from the output terminals when the output exceeds the overload rating of the GPU. Overload protection should have an inverse time characteristic and should operate to protect the unit if a short-circuit occurs within the GPU or its distribution system.

3.3.6 The protective system shall include fault indication.

3.3.7 E/F Interlock Circuit: The E/F interlock circuit shall electrically isolate the output in the absence of 28 V DC interlock signal with the aircraft. This prevents a plug from being powered while it is not connected to the aircraft for personnel safety. A maintenance mode is provided to allow servicing and testing the GPU. Use of this 28 V DC interlock source should be limited to 1/2 A per cable. An easily accessible switch or control shall allow selection of either of the following two modes:

a. Normal: For aircraft loads.

b. Maintenance: For dummy loads or no load.

In maintenance position, the E/F circuit shall in be inhibited. If the cable is plugged into the aircraft the unit should automatically return to normal mode when practical (i.e., in new designs).