IEC 61557-1

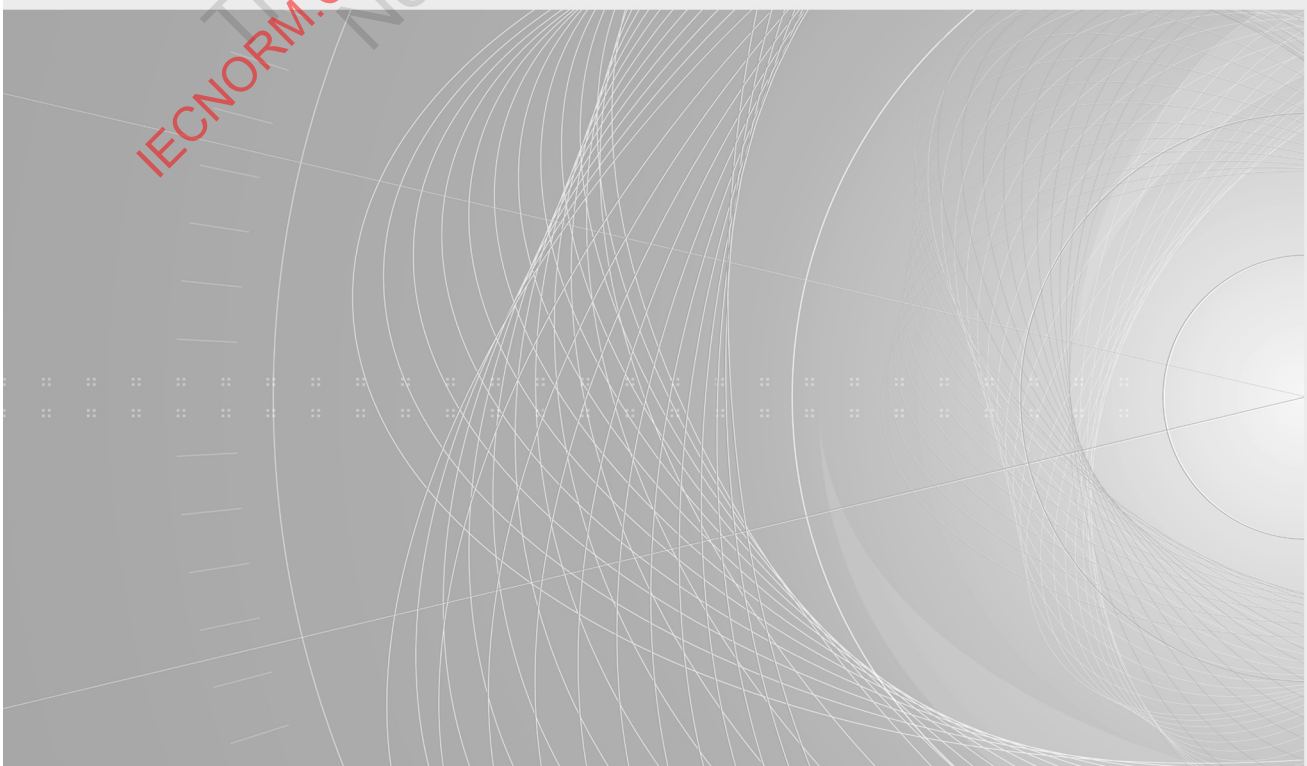
Edition 3.0 2019-07

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures
Part 1: General requirements

Sécurité électrique dans les réseaux de distribution basse tension au plus égale à 1 000 V c.a. et 1 500 V c.c. – Dispositifs de contrôle, de mesure ou de surveillance de mesures de protection
Partie 1: Exigences générales



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRICAL SAFETY IN LOW VOLTAGE DISTRIBUTION SYSTEMS UP TO 1 000 V AC AND 1 500 V DC – EQUIPMENT FOR TESTING, MEASURING OR MONITORING OF PROTECTIVE MEASURES

Part 1: General requirements

FOREWORD

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International Standard IEC 61557-1 has been prepared by technical committee 85: Measuring equipment for electrical and electromagnetic quantities.

This third edition cancels and replaces the second edition published in 2007. This edition constitutes a technical revision.

This third edition includes the following significant technical changes with respect to the previous edition:

a) terms aligned with IEC 60050;
b) measurement of uncertainty revised according to the equations in 4.2 of ISO/IEC Guide 98-3:2008 (GUM);
c) updated references for safety and EMC requirements;

d) updated references for marking and operating instructions;

e) updated references for testing safety and EMC;

f) Annex A contains an explanation of GUM;

g) Annex B addresses environmental aspects.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
85/689/FDIS	85/692/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61557 series, published under the general title *Electrical safety in low voltage distribution systems up to 1 000 V AC and 1 500 V DC – Equipment for testing, measuring or monitoring of protective measures*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

IEC 60364-6 stipulates standardized conditions for the initial test of power installations in TN, TT or IT systems for continuous monitoring and for testing these installations after modifications. In addition to general references for the performance of the tests, IEC 60364-6 contains requirements that have to be verified by measurements. Only in a few instances, for example when measuring the insulation resistance, does IEC 60364-6 contain details of the characteristics of the measuring device to be used. Circuits which are given as examples in IEC 60364-6, and referred to within the text of that document, are generally not suitable for practical use.

The tests are carried out in installations where hazardous voltages can occur and where careless use or a defect in the equipment can easily cause an accident. Therefore, the technician has to rely on measuring devices which ensure safe test methods, in addition to simplifying the measurements.

The application of the general safety regulations for electrical and electronic measuring devices (IEC 61010-1) for testing the protective measures is not sufficient in itself. The performance of measurements in the installation can cause hazards not only to the technician, but also to third persons, depending on the measuring method used.

Likewise, reliable and comparable results of measurement with measuring devices from different manufacturers are an important precondition in order to obtain an objective assessment about the installation, for example when the installation is handed over for periodic tests, for continuous insulation monitoring or in the case of performance warranty.

The IEC 61557 series has been established with the aim of stipulating common principles for measuring and monitoring equipment for testing electrical safety and measuring performances in systems with nominal voltages up to 1 000 V AC and 1 500 V DC which correspond to the above-mentioned characteristics.

For that reason, the following common requirements have been stipulated in IEC 61557-1 (other parts of IEC 61557 can specify additional requirements or deviations):

– protection against extraneous voltages;
– class II protection (except insulation monitoring devices and insulation fault location systems);
– requirements and safety precautions against hazardous touch voltages at the measuring device;
– requirements for the assessment of connection configurations with respect to wiring errors in the tested equipment;
– special mechanical requirements;
– measuring methods;
– measured quantity;
– specification of the maximum operating uncertainty;
– requirements for testing the influencing quantity and the calculation of the operating uncertainty;
– uncertainties of the measuring device at the thresholds specified in the respective standards;
– specification of the nature of type and routine tests and the required conditions for testing.

Contrary to the usual convention, terms and definitions that occur more than once in another part of the series are listed in IEC 61557-1:2019, Clause 3. Only terms and definitions specific to the respective part of IEC 61557 are listed in Clause 3 of that part.

ELECTRICAL SAFETY IN LOW VOLTAGE DISTRIBUTION SYSTEMS UP TO 1 000 V AC AND 1 500 V DC – EQUIPMENT FOR TESTING, MEASURING OR MONITORING OF PROTECTIVE MEASURES

Part 1: General requirements

1 Scope

This part of IEC 61557 specifies the general requirements applicable to measuring and monitoring equipment for testing the electrical safety in low-voltage distribution systems with nominal voltages up to 1 000 V AC and 1 500 V DC.

When measuring equipment or measuring installations involve measurement tasks of various measuring equipment covered by this series of standards, then the part of this series relevant to each of the measurement tasks is applicable.

NOTE The term "measuring equipment" will hereafter be used to designate "testing, measuring and monitoring equipment".

Other parts of IEC 61557 can specify additional requirements or deviations.

This document does not cover functional safety or cybersecurity.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60038:2009, *IEC standard voltages*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP code)*
IEC 60529:1989/AMD1:1999
IEC 60529:1989/AMD2:2013[1]

IEC 61010-1:2010, *Safety requirements for electrical equipment for measurement, control and laboratory use – Part 1: General requirements*
IEC 61010-1:2010/AMD1:2016[2]

IEC 61010-031, *Safety requirements for electrical equipment for measurement, control and laboratory use – Part 031: Safety requirements for hand-held and hand-manipulated assemblies for electrical test and measurement*

[1] A consolidated version of this publication exists, comprising IEC 60529:1989, IEC 60529:1989/AMD1:1999 and IEC 60529:1989/AMD2:2013.

[2] A consolidated version of this publication exists, comprising IEC 61010-1:2010 and IEC 61010-1:2010/AMD 1:2016.

IEC 61010-2-030:2017, *Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 2-030: Particular requirements for equipment having testing or measuring circuits*

IEC 61010-2-032, *Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 2-032: Particular requirements for hand-held and hand-manipulated current sensors for electrical test and measurement*

IEC 61010-2-034:2017, *Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 2-034: Particular requirements for measurement equipment for insulation resistance and test equipment for electric strength*

IEC 61326-1:2012, *Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 1: General requirements*

IEC 61557-8:2014, *Electrical safety in low voltage distribution systems up to 1 000 V AC and 1 500 V DC – Equipment for testing, measuring or monitoring of protective measures – Part 8: Insulation monitoring devices for IT systems*

IEC 61557-9:2014, *Electrical safety in low voltage distribution systems up to 1 000 V AC and 1 500 V DC – Equipment for testing, measuring or monitoring of protective measures – Part 9: Equipment for insulation fault location in IT systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
nominal system voltage
U_n
value of the voltage by which the distribution system is designated and to which certain characteristics are assigned

3.2
voltage against earth
U_o
<in distribution systems with an earthed neutral point> voltage between a phase conductor and the earthed neutral point

3.3
voltage against earth
U_o
<in all other distribution systems> voltage present between the remaining phase conductors and earth when one of the phase conductors is short-circuited to earth

3.4
fault voltage
U_f
voltage between a given point of fault and reference earth resulting from an insulation fault

[SOURCE: IEC 60050-826:2004, 826-11-02, modified – The symbol has been added.]

3.5
effective touch voltage
U_t
voltage between conductive parts when touched simultaneously by a person or an animal

Note 1 to entry: The value of the effective touch voltage may be appreciably influenced by the impedance of the person or the animal in electric contact with these conductive parts.

[SOURCE: IEC 60050-195:1998, 195-05-11, modified – The symbol has been added.]

3.6
conventional touch voltage limit
U_L
maximum value of the touch voltage which is permitted to be maintained indefinitely in specified conditions of external influences and is usually equal to 50 V AC, RMS or 120 V ripple free DC

[SOURCE: IEC 60050-826:2004, 826-11-04, modified – "prospective" has been omitted from the term and from the definition and values for the limit have been added to the definition; the symbol has been added.]

3.7
supply voltage
voltage that is used to power the measurement equipment

Note 1 to entry: If a supply voltage is specified, for instance in the supply contract, then it is called "declared supply voltage".

3.8
rated supply voltage
U_S
value of the supply voltage at a point where the measuring equipment does or can accept electric energy as a supply

3.9
output voltage
U_a
voltage across the measuring equipment terminals where this equipment does or can output electric energy

3.10
open-circuit voltage
U_q
voltage present across unloaded terminals on the measuring equipment

3.11
rated voltage
U_N
voltage value assigned by a manufacturer or other entity for a specified operating condition of the measuring equipment

Note 1 to entry: The value for the rated voltage of low-voltage equipment is generally assigned from the list of nominal voltages in IEC 60038:2009, Tables 1 and 6.

Note 2 to entry: Equipment may have more than one rated voltage value or may have a rated voltage range.

[SOURCE: IEC 60050-614:2016, 614-03-09, modified – The domain <of equipment> and Note 1 have been omitted; the symbol has been added; the term specifically adapted for measuring equipment.]

3.12
extraneous voltage
external voltage to which the measuring equipment can be subjected during measurement

3.13
rated current
I_N
current assigned by the manufacturer for the specified operating condition of the measuring equipment

Note 1 to entry: The specified operating condition is a value (or values) within the rated operating conditions that are designated by the manufacturer.

[SOURCE: IEC 60050-442:1998, 442-01-02, modified – "for accessories" has been deleted from the term and Note 1 has been added; the definition has been adapted for application to measuring equipment.]

3.14
short-circuit current
over-current resulting from a short circuit due to a fault on the terminals or within the measuring equipment

3.15
rated frequency
f_N
frequency for which the measuring equipment is intended to be used and for which it has been designed

3.16
uncertainty of measurement
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

Note 1 to entry: This term is used in the "uncertainty" approach.

Note 2 to entry: The parameter can be, for example, a standard deviation (or a given multiple of it), or a half-width of an interval having a stated level of confidence. Various ways of obtaining uncertainty are defined in the GUM.

Note 3 to entry: Uncertainty of measurement comprises, in general, many components. Some of these components can be evaluated from the statistical distribution of the results of a series of measurements and can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated from the assumed probability distributions based on experience or other information.

[SOURCE: IEC 60050-311:2001, 311-01-02]

3.17
operating uncertainty
calculated uncertainty taking into account the intrinsic uncertainty and defined influence quantities to mirror the worst case situation

3.18
fiducial uncertainty
uncertainty of measuring equipment expressed as a percentage of the fiducial value

3.19
fiducial value
clearly specified value to which reference is made in order to define the fiducial uncertainty

Note 1 to entry: This value can be, for example, the upper limit of the measuring range, the scale length or any other value which is clearly stated.

[SOURCE: IEC 60050-311:2001, 311-01-16, modified – "error" has been replaced by "uncertainty"; Note 1 has been omitted.]

3.20
percentage operating uncertainty
operating uncertainty of measuring equipment expressed as a percentage of the fiducial value

3.21
intrinsic uncertainty
uncertainty of a measuring instrument or supply instrument when used under reference conditions

Note 1 to entry: The uncertainty caused by friction is part of the intrinsic uncertainty.

[SOURCE: IEC 60050-311:2001, 311-03-09, modified – "or supply instrument" has been added to the definition; the Note has been deleted and Note 1 has been added.]

3.22
performance
characteristics defining the ability of a measuring instrument to achieve the intended functions

[SOURCE: IEC 60050-311:2001, 311-06-11]

3.23
influence quantity
quantity which is not the subject of the measurement and whose change affects the result of the measurement

Note 1 to entry: This term is used in the "uncertainty" approach.

Note 2 to entry: Influence quantities can originate from the measured system, the measuring equipment or the environment.

Note 3 to entry: As the calibration diagram depends on the influence quantities, in order to assign the result of a measurement it is necessary to know whether the relevant influence quantities lie within the specified range.

Note 4 to entry: An influence quantity may be external or internal with reference to the equipment. When the value of one of the influence quantities changes within its measuring range, it may affect the uncertainty due to another quantity. The measured quantity, or a parameter of it, may itself act as an influence quantity. For example, for a voltmeter, the value of the measured voltage may produce an additional uncertainty due to non-linearity or its frequency may also cause an additional uncertainty.

[SOURCE: IEC 60050-311:2001, 311-06-01, modified – "the relationship between the indication and" has been deleted from the definition; Note 4 has been added.]

3.24
variation
<due to an influence quantity> difference between the indicated values for the same value of the measurand of an indicating measuring instrument, or the values of a material measure, when an influence quantity assumes, successively, two different values

[SOURCE: IEC 60050-311:2001, 311-07-03]

3.25
reference conditions
set of specified values and/or ranges of values of influence quantities under which the uncertainties, or limits of error, admissible for a measuring instrument are specified

[SOURCE: IEC 60050-311:2001, 311-06-02, modified – "are the smallest" has been replaced with "are specified".]

3.26
operating condition
characteristic which may affect performance of a component, device or equipment

Note 1 to entry: Examples of operating conditions are ambient conditions, characteristics of the power supply, duty cycle or duty type.

[SOURCE: IEC 60050-151:2001, 151-16-01]

3.27
rated operating conditions
specified set of conditions which may affect the performance of a measuring device and under which the operating uncertainty is maintained

3.28
measuring voltage
U_m
voltage present at the measuring terminals during the measurement

3.29
uncertainty of measuring equipment
uncertainty of the result of a direct measurement of a measurand having negligible intrinsic uncertainty

Note 1 to entry: Unless explicitly stated otherwise, the measuring equipment uncertainty is expressed as an interval with coverage factor 2.

Note 2 to entry: In single-reading direct measurements of measurands having low intrinsic uncertainty with respect to the measuring equipment uncertainty, the uncertainty of the measurement coincides, by definition, with the measuring equipment uncertainty. Otherwise the measuring equipment uncertainty is to be treated as a component of category B in evaluating the uncertainty of the measurement on the basis of the model connecting the several direct measurements involved.

Note 3 to entry: The measuring equipment uncertainty automatically includes, by definition, the effects due to the quantization of the reading values (minimum evaluable fraction of the scale interval in analogic outputs, unit of the last stable digit in digital outputs).

Note 4 to entry: For material measures, the measuring equipment uncertainty is the uncertainty that should be associated to the value of the quantity reproduced by the material measure in order to ensure the compatibility of the results of its measurements.

4 Requirements

4.1 General requirements

Measuring equipment, when used for a designated purpose, shall not endanger persons, livestock or property. Furthermore, measuring equipment with additional functions not forming part of the application of the IEC 61557 series shall also not endanger persons, livestock or property.

4.2 Influence quantities – Operating uncertainty (B), percentage operating uncertainty (B [%])

The operating uncertainty shall be calculated by means of Equation 1:

$$B = \pm\sqrt{A^2 + \tfrac{4}{3}\Sigma_i E_i^2} \quad B = \pm\sqrt{A^2 + \frac{4}{3}\sum_i E_i^2} \tag{1}$$

where

A is the intrinsic uncertainty;

E_i is the variation;

i is the consecutive number of the variations.

The percentage operating uncertainty shall be calculated by means of Equation 2:

$$B[\%] = \pm\frac{B}{F} \times 100\,\% \tag{2}$$

where

F is the fiducial value.

The influencing variations used for calculating the operating uncertainty are denoted as follows:

- variation due to changing the position E_1
- variation due to changing the supply voltage E_2
- variation due to changing the temperature E_3
- variation due to interference voltages E_4
- variation due to earth electrode resistance E_5
- variation due to changing the phase angle of impedance of circuit under test E_6
  - variation due to system phase angle 0° to 18° (use as applicable) $E_{6.1}$
  - variation due to system phase angle 0° to 30° (use as applicable) $E_{6.2}$
- variation due to changing the system frequency E_7
- variation due to changing the system voltage E_8
- variation due to system harmonics E_9
- variation due to system DC quantities E_{10}
- variation due to external low-frequency magnetic fields E_{11}
- variation due to load current E_{12}
- variation due to touch current caused by common mode voltage E_{13}
- variation due to frequency E_{14}
- variation due to repeatability E_{15}

The permissible percentage operating uncertainties are stated in other parts of IEC 61557.

Only one of the influence quantities is varied when calculating the operating uncertainty, whilst the remaining influence quantities are kept under reference conditions. The larger of the respective values of the variation (positive and negative variation) is inserted into the equation for the calculation of the operating uncertainty.

4.3 Rated operating conditions

The following rated operating conditions shall apply, except for insulation monitoring devices (IMD) in accordance with IEC 61557-8 and for insulation fault location systems (IFLS) in accordance with IEC 61557-9:

– temperature range from 0 °C to 35 °C;

– a position of ±90° from the reference position for portable measuring equipment;

– 85 % to 110 % of the nominal supply voltage for supply from the distribution systems (if applicable). The values in IEC 60038 shall be applied for a supply from the distribution system;

– the charge condition in accordance with 4.4 shall apply to the battery or batteries/ accumulators for measuring equipment with a supply from batteries/accumulators;

– the range of revolutions per minute stated by the manufacturer for measuring equipment with a supply from a hand-driven generator;

– frequency of the supply voltage ±5 % (if applicable).

NOTE Additional rated operating conditions are stated in other parts of the IEC 61557 series.

4.4 Battery test facility

Measuring equipment with power supplied from dry or rechargeable battery cells shall test and indicate that the state of charge of these batteries will permit measurement within the specification. This may be done automatically as part of the measurement cycle or as a separate function. Where the battery test is a separate function, the test load shall be of the same level as the one appearing during a measurement.

4.5 Safety

Measuring and monitoring equipment shall be in accordance with IEC 61010-1, IEC 61010-2-030, IEC 61010-031, IEC 61010-2-034 and, if applicable, IEC 61010-2-032, and with the following additional requirements.

Overvoltage categories and/or measurement categories are specified in the relevant parts of IEC 61557.

Handheld measuring equipment shall fulfil the requirements for double or reinforced insulation.

The conductive parts of the terminals shall not be accessible and hazardous in connected, partially connected or unconnected conditions.

The protective conductor if used for measuring purposes shall be treated as a live part, except where a different requirement is specified in other parts of IEC 61557.

The terminals shall be designed so that the probe assembly can be connected to the measuring equipment reliably.

4.6 Electromagnetic compatibility

4.6.1 Immunity

For immunity requirements, IEC 61326-1:2012, Table 2 shall apply. For testing, see 6.5.

4.6.2 Emission

For emissions, either class A or class B limits in accordance with IEC 61326-1:2012, 7.2 shall apply.

4.7 Mechanical strength against vibration

In addition to the mechanical resistance tests in accordance with IEC 61010-1, measuring equipment shall successfully pass the following vibration conditions (type test):

– direction: three mutually perpendicular axes;
– amplitude: 1 mm;
– frequency: 25 Hz;
– duration: 20 min.

5 Marking and operating instructions

5.1 General

Marking and operating instructions shall comply with IEC 61010-1, IEC 61010-2-032, IEC 61010-2-030 and, in addition, these instructions shall comply with the requirements specified in the relevant parts of IEC 61557.

5.2 Marking

The measuring equipment shall carry the following marking:

– type of equipment;
– type and current rating of the fuse in the case of exchangeable fuses;
– type of battery/accumulator and polarity of connection in the battery compartment;
– nominal system voltage and, if applicable, the symbol for double insulation in accordance with IEC 61010-1:2010, Table 1, symbol 11;
– manufacturer's name or registered trade mark;
– model number, name or other means to identify the equipment (inside or outside);
– reference to the operating instructions in accordance with IEC 61010-1:2010, Table 1, symbol 14.

Units of the measured quantities and ranges of measurement shall be stated on the enclosure or on the display.

5.3 Operating instructions

5.3.1 Performance requirements

The operating uncertainty, the intrinsic uncertainty and the variations E_1 to E_{15} shall be provided in the operating instructions (with the exception of measuring devices covered by IEC 61557-8 and IEC 61557-9).

5.3.2 Other information

The operating instructions shall contain the following details:

– connection diagrams;
– instructions for measurements;
– brief description of the principle of measurement;
– diagrams or tables showing the maximum permissible indicated values taking into consideration the tolerances stated by the manufacturer (if necessary);
– type of battery/rechargeable cells;
– information on the charging current, charging voltage and duration of charging for rechargeable cells;

– operational lifetime/runtime of the battery/rechargeable cells or the possible number of measurements;
– type of IP protection according to IEC 60529;
– any necessary special guidance notes.

6 Tests

6.1 General

Measuring equipment shall be tested in accordance with the safety standards IEC 61010-1, IEC 61010-2-030, IEC 61010-031, IEC 61010-2-034 and, if applicable, IEC 61010-2-032, and the EMC standards of IEC 61326 (all relevant parts).

All tests shall be carried out under reference conditions unless otherwise specified. The reference conditions are stated in the relevant parts of IEC 61557.

Tolerances are added in the relevant parts of IEC 61557.

6.2 Operating uncertainty

6.2.1 General

The operating uncertainty shall be determined according to 6.2.2 to 6.2.4.

6.2.2 Influence of changing position

The variation E_1 due to changing the position in accordance with 4.2 and 4.3, if applicable, shall be determined for positions +90° or –90° from the reference position stated by the manufacturer (routine test).

6.2.3 Influence of temperature

The variation E_3 shall be determined from the reference temperature at 0 °C and 35 °C after the device has reached a state of equilibrium (type test).

6.2.4 Influence of the supply voltage

The variation E_2 due to changing the supply voltage shall be determined under the following rated operating conditions (routine test):

– limits in accordance with 4.3 for measuring equipment supplied from distribution systems;
– limits in accordance with 4.4 and 6.3 for measuring equipment supplied from a battery/accumulator;
– limits in accordance with 4.3 for measuring equipment supplied by a hand-driven generator.

6.3 Battery test facility

The lower and upper limits for the battery voltage to which the battery test facility in accordance with 4.4 is set, shall be determined by means of an external voltage source. These values shall be used during the test in accordance with 6.2.4 as limits for variation E_2 by changing the supply voltage (routine test).

6.4 Safety tests

Compliance with 4.5 shall be tested (type test).

6.5 EMC tests

For the electromagnetic radio frequency field (RF) and conducted RF the following requirements apply:

– the auxiliary circuits of the measuring equipment shall be energised with the rated voltage;
– the measuring equipment shall be tested in its operating conditions.

6.6 Mechanical requirements

The test shall be performed in accordance with 4.7 (type test).

The tests are deemed to have been passed successfully when no parts have become loose or bent and the connecting leads are not damaged. After the process, the measuring equipment shall comply with the requirements for intrinsic uncertainty of the equipment (type test), if applicable.

6.7 Marking and operating instructions

The marking and the operating instructions shall be confirmed by visual inspection (type test).

The marking shall be inspected during type test and routine test.

6.8 Records

Compliance with the tests in Clause 6 shall be recorded.

Annex A
(informative)

Explanation of the application of GUM in series IEC 61557

A.1 Overview

The operating uncertainty is a predictive parameter characterizing the expanded uncertainty of the results generated by the measuring device under defined operational conditions.

The operating uncertainty forms an upper limit of the expanded uncertainty which can be expected if the device is operated within the defined operational conditions.

The operating uncertainty might be used to characterize results generated by the device if the device is used within defined operational conditions.

When possible and convenient, the uncertainty may be expressed in the relative form or in the fiducial form. The relative uncertainty is the ratio U/V of the absolute uncertainty U to the measure value V, and the fiducial uncertainty is the ratio U/V_{f} of the absolute uncertainty U to a conventionally chosen value V_{f}.

The principles of the GUM (ISO/IEC Guide 98-3:2008) are used to calculate the operating uncertainty.

A.2 Basic model of evaluation of results under operational conditions

A.2.1 General

The basic model for the evaluation of the results under operational conditions is:

$$Y_{\mathrm{oper}} = Y_{\mathrm{ref}} + \sum_i \delta E_i$$

The result under reference conditions Y_{ref} is the result which could be generated under reference (calibration) conditions. The uncertainty $u(Y_{\mathrm{ref}})$ is evaluated during calibration.

The deviations δE_i are derived from the operational conditions. Usually the expectation value of the δE_i is zero and some limits are known.

A.2.2 Standard uncertainty of a result

The standard uncertainty of a result under operational conditions $u(Y_{\mathrm{oper}})$ can be calculated using uncertainty propagation. The sensitivity of all input quantities is equal to 1.

$$u\left(Y_{\mathrm{oper}}\right) = \sqrt{u\left(Y_{\mathrm{ref}}\right)^2 + \sum_i u\left(\delta E_i\right)^2}$$

The standard uncertainty under reference conditions is equal to the expanded uncertainty evaluated during calibration divided by the coverage factor:

$$u\left(Y_{\mathrm{ref}}\right) = \frac{U_{\mathrm{cal}}\left(Y\right)}{k_{\mathrm{cal}}}$$

A.2.3 Expanded uncertainty

The expanded uncertainty of the calibration $U_{cal}(Y)$ and the coverage factor k_{cal} (usually equal to 2) are stated in the calibration certificate.

For the deviations δE_i, usually only some limits symmetric to zero are known. According to GUM, limits can be converted to a standard uncertainty with the use of a rectangular distribution:

$$u(\delta E_i) = \frac{e_i}{\sqrt{3}}$$

The e_i is the half width of the limits characterizing the deviation δE_i.

The operating uncertainty is equal to the standard uncertainty under operational conditions multiplied by the operating coverage factor:

$$U(Y_{oper}) = k_{oper} \times u(Y_{oper})$$

The operating coverage factor k_{oper} is fixed to 2,0.

This is equivalent to the half width of coverage interval with a coverage probability of 95,45 % under the assumption that the results are distributed normally.

A.2.4 Relative operating uncertainty

The relative operating uncertainty as a percentage can be calculated using a fiducial value Y_f.

$$W(Y_{oper}) = \frac{U(Y_{oper})}{Y_f} \times 100\,\%$$

The operating uncertainty and the relative operating uncertainty as a percentage can be written as symmetric interval limits using plus and minus signs.

A.2.5 Calibration uncertainty

For practical calculations, the calibration uncertainty $U_{cal}(Y)$ may be replaced by A, and e_i, by E_i. The resulting equation is:

$$U(Y_{oper}) = \sqrt{A^2 + \frac{4}{3}\sum_i E_i^2} \le |A| + 1{,}5 \times \sqrt{\sum_i E_i^2}$$

under the assumption that the coverage factor k_{cal} stated in the calibration certificate is equal to the operating coverage factor k_{oper} = 2,0.

Therefore the following equation may be used as an upper bound for the operating coverage interval:

$$B = \pm\left[\left|A\right| + 1{,}15 \times \sqrt{\sum_i E_i^{\,2}}\right]$$

A.3 Operating uncertainty calculations as basis for 4.1

A.3.1 Standard uncertainty

The basis for this model is the addition of faults.

Uncertainty in respect to GUM (ISO/IEC Guide 98-1:2009, measuring method B) for any statistical distribution:

$$u = \sqrt{a^2 + \sum_i e_i^{\,2}}$$

where

a is the expected intrinsic operating uncertainty for example by calibration certificates;

e_i e_i = is the expected operating uncertainty by influencing factors for example through temperature;

u is the standard uncertainty of the result of a measurement expressed as a standard deviation.

A.3.2 Operating uncertainty in accordance with 4.1

The basis for this model of calculation is the expanded uncertainty according to GUM (ISO/IEC Guide 98-3:2008, 6.2).

Determination of the operating uncertainty for the IEC 61557 series with stipulation of the defined statistical distributions based on empirical values:

– $B = \pm\, k \times u$ with $k = 2$ for coverage probability of 95,45 %;

– $a = \frac{A}{2}\; a = \frac{A}{2}$ standard distribution for the intrinsic uncertainty;

– $e_i = \frac{E_i}{\sqrt{3}}\; e_i = \frac{E_i}{\sqrt{3}}$ rectangular distribution for the operating uncertainty through influence factors in the operation;

– $B = \pm\sqrt{A^2 + \frac{4}{3}\sum_i E_i^2}$ uncertainty for coverage probability of 95,45 % according to GUM, (ISO/IEC Guide 98-3:2008, 7.22).