BS EN 62631-1:2011

BSI Standards Publication

Dielectric and resistive properties of solid insulating materials

Part 1: General

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National foreword

This British Standard is the UK implementation of EN 62631-1:2011. It is identical to IEC 62631-1:2011.

Together with other parts of BS EN 62631 (when published) it will supersede BS 6233:1982 and may affect other standards that use measurement of dielectric and resistive properties of solid electric insulating materials in procedures and test methods. The planned structure of this series and information on standards that may be affected in the future can be found in the IEC introduction.

The UK participation in its preparation was entrusted to Technical Committee GEL/112, Evaluation and qualification of electrical insulating materials and systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Compliance with a British Standard cannot confer immunity from legal obligations.

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EN 62631-1

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Supersedes HD 429 S1:1983 (partially), HD 438 S1:1984 (partially), HD 568 S1:1990 (partially)

English version

Dielectric and resistive properties of solid insulating materials - Part 1: General
(IEC 62631-1:2011)

Propriétés diélectriques et résistives des matériaux isolants solides -
Partie 1: Généralités
(CEI 62631-1:2011)

Dielektrische und resistive Eigenschaften fester Elektroisolierstoffe -
Teil 1: Grundlagen
(IEC 62631-1:2011)

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Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

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CENELEC
European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of document 112/169/FDIS, future edition 1 of IEC 62631-1, prepared by IEC TC 112, Evaluation and qualification of electrical insulating materials and systems, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 62631-1 on 2011-06-02.

This European Standard partially supersedes HD 429 S1:1983, HD 438 S1:1984 and HD 568 S1:1990.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2012-03-02
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2014-06-02

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 62631-1:2011 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60216-1	NOTE	Harmonized as EN 60216-1.
IEC 60247	NOTE	Harmonized as EN 60247.
IEC 60505	NOTE	Harmonized as EN 60505.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application 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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-212	-	International Electrotechnical Vocabulary (IEV) - Chapter 212: Insulating solids, liquids and gases	-	-
IEC 60093	1980	Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials	HD 429 S1	1983
IEC 60167	1964	Methods of test for the determination of the insulation resistance of solid insulating materials	HD 568 S1	1990
IEC 60250	1969	Recommended methods for the determination of the permittivity and dielectric dissipation factor of electrical insulating materials at power, audio and radio frequencies including metre wavelengths	-	-
IEC 60345	1971	Method of test for electrical resistance and resistivity of insulating materials at elevated temperatures	HD 438 S1	1984
IEC 60377-1	1973	Methods for the determination of the dielectric properties of insulating materials at frequencies above 300 MHz - Part 1: General	-	-
IEC 60377-2	1977	Methods for the determination of the dielectric properties of insulating materials at frequencies above 300 MHz - Part 2: Resonance methods	-	-
ISO 291	-	Plastics - Standard atmospheres for conditioning and testing	EN ISO 291	-
ISO 558	-	Conditioning and testing - Standard atmospheres - Definitions	-	-

CONTENTS

INTRODUCTION

The IEC 62631 series is divided into four main parts, which are further subdivided into component parts. The present Part 1 of IEC 62631 considers, general aspects related to the measurement of dielectric and resistive properties of solid electric insulating materials. Parts 2 and 3 outline basic procedures for the measurement of dielectric and resistive properties by means of AC and DC methods. These parts will gradually replace hitherto existing International Standards. Part 4 will cover special methods of measurement and computational methods.

Table 1 shows the planned future structure of IEC 62631, together with the standards it will replace.

Table 1 – Planned structure of IEC 62631

Main title	DIELECTRIC AND RESISTIVE PROPERTIES OF SOLID INSULATING MATERIALS	
Part number	**Part title**	**Remarks**
IEC 62631-1	**– General**	Amends and replaces IEC 60093, IEC 60167, IEC 60250, IEC 60345
IEC 62631-2	**– Permittivity and dielectric dissipation factors (AC methods)**	New
IEC 62631-2-1	– Technical frequencies (1 Hz to 100 MHz)	Replaces IEC 60250
IEC 62631-2-2	– High frequencies (1 MHz to 300 MHz)	Replaces IEC 60250
IEC 62631-2-3	– Very high frequencies (above 300 MHz)	Replaces IEC 60377-1 and IEC 60377-2
IEC 62631-2-4	– Low frequencies (1 MHz to 1 kHz)	New
IEC 62631-3	**– Resistive properties (DC methods)**	New
IEC 62631-3-1	– Volume resistance and volume resistivity	Replaces IEC 60093
IEC 62631-3-2	– Surface resistance and surface resistivity	Replaces IEC 60093
IEC 62631-3-3	– Insulation resistance	Replaces IEC 60167
IEC 62631-3-4	– Special requirements for the determination of resistive material properties at elevated temperatures	Replaces IEC 60345
IEC 62631-4	**– Special methods**	New
IEC 62631-4-1	– Computational methods for the evaluation of data gained by the use of broadband dielectric spectrometers	New
IEC 62631-4-2	– Thermal analysis by means of observation of dielectric properties	New

Measured values of dielectric and resistive properties of solid insulating materials are dependent upon different factors such as the magnitude and time of voltage application, frequency, the nature and geometry of the electrodes, the surface condition, contamination, temperature and humidity of the ambient atmosphere and of the specimens during conditioning and measurement and, in certain cases, on electric field strength also.

Therefore, the electrical and dielectric properties covered by the IEC 62631 series may only be comparable as far as the circumstances of the measurement's parameters are stipulated. The test specimen's shape and dimensions, as well as the measurement parameters, may be defined in product standards or the relevant parts of this series of standards dealing with test procedures, depending on the requirements to be considered for a certain demand of measurement. Care should be taken when using measured values from the IEC 62631 series for the purposes of designing an electric product.

NOTE It is not possible to give a comprehensive overview covering the dielectric and resistive properties of solid electrical insulating materials within a framework of an International Standard. Therefore, the user is encouraged to read up on the literature such as that recommended in the bibliography.

DIELECTRIC AND RESISTIVE PROPERTIES OF SOLID INSULATING MATERIALS –

Part 1: General

1 Scope

This part of IEC 62631 gives general guidelines for the determination of dielectric and resistive properties of solid electrical insulating materials.

2 Normative references

The following referenced documents are indispensable for the application 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 60050-212, *International Electrotechnical Vocabulary – Part 212: Electrical insulating solids, liquids and gases*

NOTE For IEC 60050, free online access is provided by www.electropedia.org.

IEC 60093:1980, *Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials*

IEC 60167:1964, *Methods of test for the determination of the insulation resistance of solid insulating materials*

IEC 60250:1969, *Recommended methods for the determination of the permittivity and dielectric dissipation factor of electrical insulating materials at power, audio and radio frequencies including metre wavelengths*

IEC 60345:1971, *Method of test for electrical resistance and resistivity of insulating materials at elevated temperatures*

IEC 60377-1:1973, *Recommended methods for the determination of the dielectric properties of insulating materials at frequencies above 300 MHz – Part 1: General*

IEC 60377-2:1977, *Recommended methods for the determination of the dielectric properties of insulating materials at frequencies above 300 MHz – Part 2: Resonance methods*

ISO 291, *Plastics – Standard atmospheres for conditioning and testing*

ISO 558, *Conditioning and testing – Standard atmospheres – Definitions*

3 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those given in IEC 60050-212, apply.

3.1 General definitions

3.1.1
electrical insulating material
solid material with negligibly low electric conductivity, used to separate conducting parts at different electrical potentials

NOTE In English, the term "electrical insulating material" is sometimes used in a broader sense to also designate insulating liquids and gases. Insulating liquids are covered by IEC 60247.

3.2 Definitions for resistive properties

The resistive properties of an insulating material are those comprehensive materials whose behaviour can be measured with a DC in a time domain. Five examples are given below.

3.2.1
insulation resistance
resistance under specified conditions between two conductive bodies separated by the insulating material

NOTE Insulation resistance includes parts of volume resistivity and surface resistivity with respect to a given geometric shape of the test specimen.

3.2.2
volume resistance
quotient of a direct voltage applied between two electrodes in contact with an insulating medium and the current through it at a given duration of voltage application

NOTE Within this definition, current along the surface is excluded and possible polarization phenomena at the electrodes are neglected.

3.2.3
volume resistivity
quotient of a DC electric field strength and the current density within an insulating medium at a given time of voltage application

NOTE 1 According to IEC 60050-212, "conductivity" is defined as "the scalar or matrix quantity whose product by the electric field strength is the conduction current density" and "resistivity" as "the reciprocal of the conductivity". The volume resistivity is an average of this quantity over possible heterogeneities in the volume incorporated in the measurement, and includes the effect of possible polarization phenomena at the electrodes.

NOTE 2 Usually, volume resistivity in practice is taken as the volume resistance reduced to a cubical unit volume.

3.2.4
surface resistance
that part of the insulation resistance which is due to conduction along the surface

NOTE The surface current generally depends strongly on the time of voltage application and often varies in an erratic manner.

3.2.5
surface resistivity
surface resistance reduced to a square area

NOTE The numerical value of the surface resistivity is independent of the size of the square.

3.3 Definitions for dielectric properties

The dielectric properties of an insulating material are those comprehensive materials whose behaviour can be measured with an AC in a given frequency domain. Four examples are given below.

3.3.1
absolute permittivity
electric flux density divided by the electric field strength

NOTE The measured permittivity (formerly known as dielectric constant) ε of an insulating material is the product of its relative permittivity ε_r and the permittivity of a vacuum ε_0:

$$\varepsilon = \varepsilon_0 \times \varepsilon_r \tag{1}$$

The permittivity is expressed in farad per meter (F/m); the permittivity of vacuum ε_0 has the following value:

$$\varepsilon_0 = 8{,}854 \times 10^{-12}\ F/m \tag{2}$$

3.3.2
relative permittivity
ratio of the absolute permittivity to the permittivity of a vacuum, ε_0

NOTE 1 In the case of constant fields and alternating fields of sufficiently low frequency the relative permittivity of an isotropic or quasi-isotropic dielectric is equal to the ratio of the capacitance of a capacitor, in which the space between and around the electrodes is entirely and exclusively filled with the dielectric, to the capacitance of the same configuration of electrodes in a vacuum.

NOTE 2 In practical engineering, it is usual to employ the term 'permittivity' when referring to relative permittivity.

NOTE 3 The relative permittivity ε_r of an insulating material is the quotient of capacitance C_x of a capacitive test specimen (capacitor), in which the space between the two electrodes is entirely and exclusively filled with the insulating material in question, and the capacitance C_0 of the same configuration of electrodes in vacuum:

$$\varepsilon_r = \frac{C_x}{C_0} \tag{3}$$

The relative permittivity ε_r of dry air free from carbon dioxide, at normal atmospheric pressure, is equal to 1,000 53, so that in practice, the capacitances C_a of the configuration of electrodes in air can normally be used instead of C_0 to determine the relative permittivity ε_r with sufficient accuracy.

3.3.3
relative complex permittivity
permittivity in a complex number representation, under steady sinusoidal field conditions expressed as

$$\underline{\varepsilon}_r = \varepsilon'_r - j\varepsilon''_r = \varepsilon_r \times e^{-j\delta} \tag{4}$$

where ε'_r and ε''_r have positive values.

NOTE 1 The complex permittivity $\underline{\varepsilon}_r$ is customarily quoted either in terms of ε'_r and ε''_r , or in terms of ε_r and tan δ. If $\varepsilon'_r > \varepsilon''_r$ then $\varepsilon_r \approx \varepsilon'_r$ which are both called relative permittivity.

NOTE 2 ε''_r is termed loss index.

3.3.4
dielectric dissipation factor tan δ (loss tangent)
numerical value of the ratio of the imaginary to the real part of the complex permittivity

$$\tan\delta = \frac{\varepsilon''_r}{\varepsilon'_r} \tag{5}$$

NOTE 1 Thus, the dielectric dissipation factor tan δ of an insulating material is the tangent of the angle δ by which the phase difference φ between applied voltage and resulting current deviates from $\pi/2$ rad when the solid insulating material is exclusively used as dielectric in a capacitive test specimen (capacitor) (compare Figure 1).

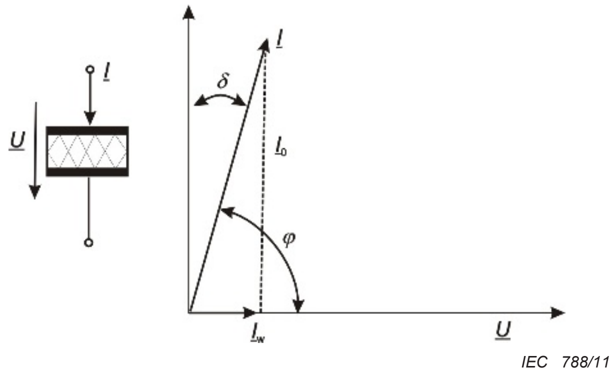

Figure 1 – Dielectric dissipation factor

The dielectric dissipation factor can also be expressed by an equivalent circuit diagram using an ideal capacitor with a resistor in series or parallel connection (see Figure 2).

$$\tan\delta = \omega C_S \times R_S = \frac{1}{\omega C_P \times R_P} \tag{6}$$

with

$$\frac{C_P}{C_S} = \frac{1}{1 + \tan^2 \delta} \tag{7}$$

and

$$\frac{R_P}{R_S} = 1 + \frac{1}{\tan^2 \delta} \tag{8}$$

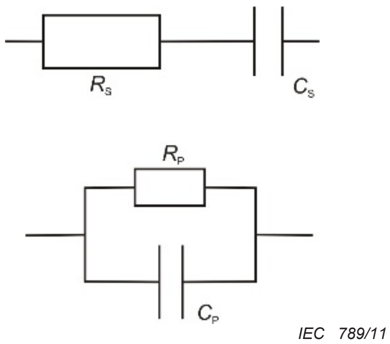

Figure 2 – Equivalent circuit diagrams

NOTE 2 R_S and R_P respectively are not directly related with but affected by the volume and the surface resistance of an insulating material. Therefore also the dielectric dissipation factor may be affected by these resistive materials properties.

3.4
capacitance
C
property of an arrangement of conductors and dielectrics which permits the storage of electrical charge when a potential difference exists between the conductors

NOTE *C* is the ratio of a quantity *q* of charge to a potential difference *U*. A capacitance value is always positive. The unit is farad when the charge is expressed in coulomb and the potential in volts.

$$C = \frac{q}{U} \tag{9}$$

3.5
voltage application
application of a voltage between electrodes

NOTE Voltage application is sometimes referred as electrification.

3.6
current after voltage application
current between two electrodes in contact with an insulating medium when direct voltage is applied between them

NOTE The current after voltage application is a function of time. Usually this current is determined 1 min after voltage application (1 min value).

3.7
conduction current
steady-state component of the current after voltage application

3.8
charging current
transient component of the current after voltage application which flows during the charging of the test specimen

3.9
electric field strength
vector field quantity *E* which exerts on any charged particle at rest a force *F* equal to the product of *E* and the electric charge *Q* of the particle:

$$F = Q \times E \quad (10)$$

3.10
electric flux density
vector quantity obtained at a given point by adding the electric polarization *P* to the product of the electric field strength *E* and the permittivity of vacuum ε_o:

$$D = \varepsilon_o E + P \quad (11)$$

3.11
polarization
P
phenomenon of material that describes the direction of the transverse electric field. Electric polarization at a given point within a domain of quasi-infinitesimal volume, V, vector quantity equal to the electric dipole moment, *p,* of the substance contained within the domain divided by the volume V:

$$P = \frac{p}{\mathrm{V}} \quad (12)$$

NOTE 1 The polarization *P* satisfies Equation (11).

NOTE 2 Polarization may occur as a displacement of charged particles or as orientation of dipoles. It may also occur at boundaries, such as electrodes, as well as inner boundaries in the electrical insulating material. All polarization effects are strongly dependent on time and frequency respectively and on temperature as well. The effect of polarization therefore strongly affects the dielectric and resistive properties. Because of this, the time-dependent process of becoming polarized, which an electrical insulating material undergoes by the procedure of voltage application, is commonly understood as polarization when the resistive properties of an electrical insulating material are to be determined.

3.12
depolarization
process of removing electrical polarization from an electrical insulating material until the depolarization current is negligible

NOTE Depolarization is generally recommended before measuring the resistive properties of an electrical insulating material.

3.13
polarization current
transient component of the current after voltage application, depleted by a possible contribution of the charging current

NOTE The polarization current is usually measured after previously short-circuiting the electrodes for sufficient time that the short-circuit current is negligible.

3.14
depolarization current
current through a short-circuit established between two electrodes in contact with an insulating medium after direct voltage application for some time

NOTE The depolarization current is usually measured after voltage application for sufficient time that the polarization current is negligible.

3.15
measuring electrodes
conductors applied to, or embedded in, a material to make contact with it to measure its dielectric or resistive properties

NOTE The design depends on the specimens and the purpose of test.

4 Factors influencing properties of electrical insulating materials

4.1 General

Electrical insulating materials shall provide acceptable values for resistive and dielectric properties, depending on the demands of the specific application, consistent with acceptable mechanical, chemical, thermal and other necessary properties.

NOTE Dielectric and resistive materials properties should be measured with the service conditions in mind.

Insulation resistance consists of two parts: surface resistance and volume resistance. Both are affected by many parameters, e.g. humidity, temperature, electric field strength, shape of the test specimen, surface condition and the electrodes. The change of resistance with temperature, chemical and gaseous environment, humidity and electric field strength may be great and must be known when designing for operating conditions.

The permittivity and dielectric loss are also affected by many parameters, but to a lesser extent than the insulation resistance. With the exception of the influence of temperature, they are strongly affected by the frequency.

4.2 Factors influencing resistive and dielectric properties

4.2.1 General

The following parameters may be of influence to the dielectric and resistive properties of electrical insulating materials and shall be stated in any test report:

- time;
- frequency;

- temperature;
- moisture;
- electric field strength;
- voltage;
- conditioning;
- electrode material.

These parameters are treated separately as outlined below.

4.2.2 Time

As outlined in 3.11, polarization effects are time dependent. For each kind of polarization, a relaxation time, τ, can be assigned. With this relaxation time, values obtained by time domain measurements (i.e. resistive properties) depend on the time of voltage application.

For some materials the relaxation times can be considerably long (up to at least several months). To get proper results, it would be necessary to carry out the measurement for a very long time. However, for practical reasons, the measurement of resistive properties is carried out 1 min after voltage application, accepting a deviation between this 1 min value to the real behaviour of the electrical insulating material.

NOTE The resistive properties may, however, be apparently affected by charging currents which are time dependent due to the internal resistance of the voltage source.

4.2.3 Frequency

As the permittivity and dissipation factors are not constant over a large frequency range, it is necessary to measure them at those frequencies at which the dielectric material will be used.

Figure 3 shows, in a simplified way, that at a certain frequency, the loss index ε_r'' shows a maximum value within the relaxation transition. During this relaxation transition, the permittivity ε_r' changes from a higher level ε_{rs} (static case) to a lower level (the frequency is infinite) $\varepsilon_{r\infty}$. The reason for this behaviour is the time dependence of polarization (see 3.6), which is described by the relaxation time τ:

$$\omega_m' = \frac{1}{\tau} \qquad (13)$$

However, due to the relationship to polarization, in reality more than one relaxation transition will occur.

The dielectric dissipation factor *tan* δ is also frequency dependent. As a consequence of the definitions given in 3.3.4, and the lowering of ε_r' with increasing frequency, in comparison with the loss index, the maximum of *tan* δ is shifted to higher frequencies by the following relationship:

$$\omega_m = \sqrt{\frac{\varepsilon_{rs}}{\varepsilon_{r\infty}}} \times \omega_m \qquad (14)$$

NOTE Time and frequency dependence is related to each other, which is described by the theory of Debye. The bibliography gives further reference material concerning to these questions.

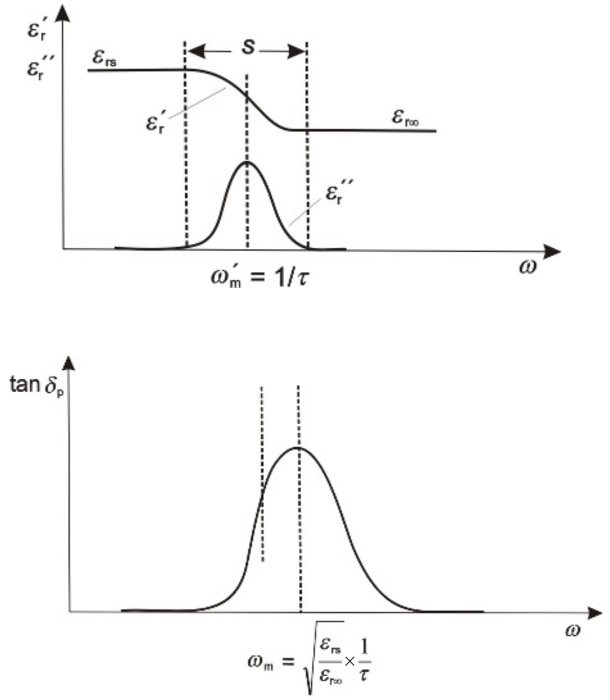

Figure 3 – Influence of frequency ω = 2π*f* on permittivity and dielectric dissipation factor tan *δ*

4.2.4 Temperature

With elevating temperatures, the dielectric dissipation factor may show one or more maxima (see Figure 4), as the temperature affects polarization (see 3.6) and the relaxation times are reduced. Consequently, the permittivity increases stepwise with the temperature.

In addition, at higher temperatures, charges such as ions or electrons are able to move more freely and contribute to an elevated conductivity.

For the same reasons, the values of insulating resistance, surface or volume resistivity may also strongly depend on the temperature.

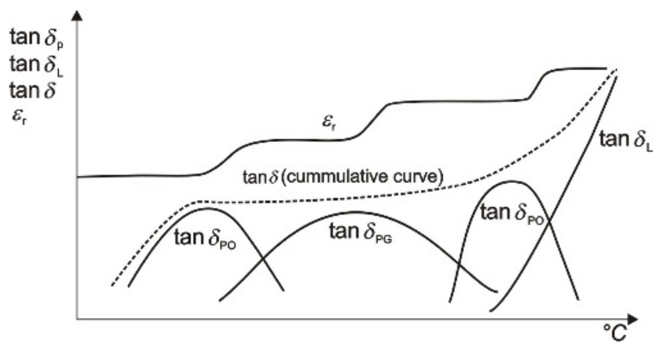

Figure 4 – Example of the influence of temperature on the permittivity and dielectric dissipation factors

NOTE 1 Thermal ageing effects may also affect the dielectric dissipation factor and resistive properties of the material in question. For a qualification of the thermal endurance of electrical insulating materials and systems according to IEC 60216-1 and IEC 60505 respectively, measurements of the dielectric or resistive behaviour may be useful.

NOTE 2 At elevated temperatures in particular, the conduction current caused by the resistive properties of the materials may contribute considerably to an increase of the dielectric dissipation factor (see Equation (7)).

4.2.5 Moisture

All dielectric and resistive properties, such as permittivity, dissipation factor, volume and surface resistivity, are influenced by moisture. Conditioning of the test specimens is therefore of utmost importance, as is the control of the moisture content, both before and during testing.

4.2.6 Electric field strength

All kinds of dielectric polarization effects, except for interfacial polarization, behave in an almost linear fashion with regard to the applied electric field strength, provided no electron emission or related effects dominate. When interfacial polarization exists, the number of free ions increases with the electric field strength, and the magnitude and the position of the dielectric dissipation factor maximum are altered. The dissipation and permittivity factors generally show only a weak dependency on electric field strength, provided no ionization effects occur.

4.2.7 Voltage

Non-linear effects may occur with increasing measurement voltages or electric field strengths, respectively. Time-dependent charging currents are also voltage dependent.

4.2.8 Conditioning

Resistive and dielectric properties of most solid insulating materials are influenced by different parameters as already indicated. It is therefore necessary to specify the type and duration of conditioning procedures of a test specimen both before and during testing as stipulated in ISO 291 and ISO 558.

A preferred climate for conditioning before and during testing is 23 °C ± 2 K and 50 % ± 5 % relative humidity.

The behaviour of the material will be influenced by the surface condition. Cleaning can influence the test results. However, in certain cases, if necessary the surface of the test specimen might need to be cleaned before conditioning.

4.2.9 Test specimen

The shape and dimensions of the test specimen may influence the measured values. The preferred dimensions of test specimens shall be those used in the test procedures of future IEC 62631-2 and future IEC 62631-3[1]. However, because shape and dimensions are strongly dependent on the type of insulation material and its application, there may be cases where the shape has to be defined by appropriate product standards.

4.2.10 Electrode material

The choice of the electrode material is fundamental to the achievement of reliable measurement results. The issue of electrodes is therefore treated in a separate clause.

5 Electrode systems

The electrodes for insulating materials shall be of a material that is readily applied to the specimen surface, allowing intimate contact and introducing no appreciable error because of electrode resistance or contamination of the specimen. The electrode material shall be corrosion-resistant under the conditions of the test.

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[1] As mentioned in the Foreword, until these future standards are published, the dimensions cited in IEC 60093, IEC 60167, IEC 60250, IEC 60345, IEC 60377-1 and IEC 60377-2 remain valid.

NOTE For alternating current measurements, a system of non-contacting electrodes may sometimes be used with specimens of sufficiently low surface conductivity.

The shape of the electrodes as well as the thickness of the test specimen shall be determined carefully in order to avoid severe errors, when deriving the dielectric and resistive properties from measured values. Detailed information regarding electrode systems appropriate for certain kinds of measurement are given in the parts of this series dealing with test procedures (see Table 1).

6 Test procedures

Test procedures are described in further parts of IEC 62631 (see Table 1).

Any reliable test device or instrument available may be used to determine the above-mentioned properties according to a given test method. However, the precision of the test instrument shall always be stated so as to comply with the requirements of the material being tested.

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