IEC 60034-27-3

Edition 1.0 2015-12

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Rotating electrical machines –
Part 27-3: Dielectric dissipation factor measurement on stator winding insulation of rotating electrical machines

Machines électriques tournantes –
Partie 27-3: Mesure du facteur de dissipation diélectrique sur le système d'isolation des enroulements statoriques des machines électriques tournantes

IEC 60034-27-3:2015-12(en-fr)

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ROTATING ELECTRICAL MACHINES –

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FOREWORD

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International Standard IEC 60034-27-3 has been prepared by IEC technical committee 2: Rotating machinery.

This first edition cancels and replaces the first edition of IEC TR 60894 published in 1987. This edition constitutes a technical revision.

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

a) digital measurement of dissipation factor and capacitance included;
b) limits for dissipation factor values given;
c) detailed description of measuring techniques;
d) extension of scope to complete windings.

The text of this standard is based on the following documents:

FDIS	Report on voting
2/1803/FDIS	2/1804/RVD

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

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

A list of all parts in the IEC 60034 series, published under the general title *Rotating electrical machines*, can be found on the IEC website.

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

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- withdrawn,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

INTRODUCTION

This International Standard provides guidelines for dielectric dissipation factor measurements on form-wound stator bars or coils as well as for complete windings.

The dielectric dissipation factor is a measure of the dielectric losses in the stator winding insulation. Measurement of dielectric dissipation factor is an appropriate means of assessing the quality of new and also aged stator winding insulation of rotating electrical machines. Especially, the method is useful for assessing the uniform quality of manufacturing and the dielectric behaviour of the insulation as a whole. For aged stator windings, the dielectric dissipation factor provides information about insulation condition.

The dielectric dissipation factor measurements give no indication of the distribution of loss within the insulation and – in contrast to off-line partial discharge measurements – do not permit localization of weak points of the insulation system.

The main principle is to measure the dielectric dissipation factor over a range of voltages and to derive different characteristic dielectric loss parameters as basis for the evaluation.

Empirical limits verified in practice can be used as a basis for evaluating the quality of stator winding insulation systems in manufacturing. Furthermore, trend evaluation, e.g. diagnostic tests as part of the functional evaluation of insulation systems or in connection with servicing and overhaul of rotating machines, can also provide information on ageing processes, necessary further measures and intervals between overhauls. However, such trend evaluations cannot be used to predict the time to failure of a stator winding insulation.

ROTATING ELECTRICAL MACHINES –

Part 27-3: Dielectric dissipation factor measurement on stator winding insulation of rotating electrical machines

1 Scope

This part of IEC 60034 provides guidelines for the test procedures and the interpretation of test results for dielectric dissipation factor measurements on the stator winding insulation of rotating electrical machines. These guidelines are valid for rotating electrical machines with conductive slot coatings operating at a rated voltage of 6 kV and higher.

This standard applies to individual form-wound stator bars and coils outside a core (uninstalled), individual stator bars and coils installed in a core and complete form-wound stator winding of machines in new or aged condition.

This International Standard applies to all kind of vacuum impregnated or resin-rich (fully-loaded) taped bars, coils and complete windings. It is not applicable to non-impregnated individual bars and coils or non-impregnated complete windings.

Requirements for the dielectric dissipation factor characteristics of individual form-wound stator bars and coils of machines with rating voltages from 6 kV and higher when tested with 50 Hz or 60 Hz alternating voltages are given.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60060-2, *High-voltage test techniques – Part 2: Measuring systems*

3 Terms and definitions

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

3.1
rated voltage
U_N
voltage or voltage range between lines at the terminals (also called line-to-line voltage) assigned, generally by a manufacturer, for a specified operating condition of a machine

3.2
dielectric dissipation factor
tan δ
tangent of the dielectric loss angle δ (complement of the insulation power factor angle) at predetermined values of temperature, frequency, and voltage or dielectric stress

Note 1 to entry: Other terms sometimes used for this property are tan delta, loss tangent, dielectric loss factor or dielectric power factor. Between the dielectric dissipation factor and the power factor (the cosine of power factor angle or the sine of the dielectric loss angle) a physical difference exists, but the two measurements are very nearly the same, when the dielectric dissipation factor is lower than 100×10^{-3} (see 4.1).

Note 2 to entry: Although the dielectric dissipation factor tan δ is expressed in absolute value in this standard, it is also expressed in percentage in other documents.

3.3
delta tan delta
Δ tan δ
the difference in dielectric dissipation factor measured at two successive test voltages in steps of 0,2 U_N intervals

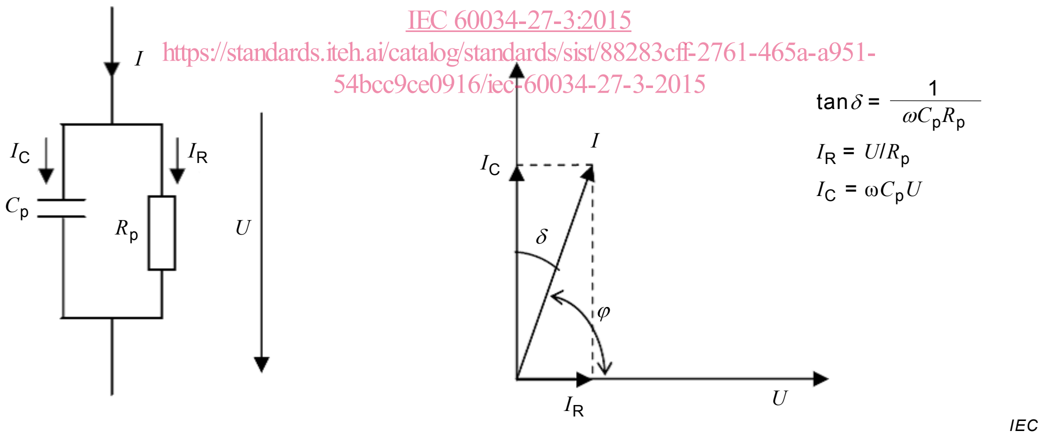
3.4
tan delta tip-up
the difference in dielectric dissipation factor measured at the two voltages 0,6 U_N and 0,2 U_N

Note 1 to entry: Dielectric dissipation factor differences with other voltage steps than mentioned in 3.3 and 3.4 may be used but the limits suggested in Table 1 will not be valid in that case.

4 Theory and measuring techniques

4.1 Dielectric dissipation factor measurement

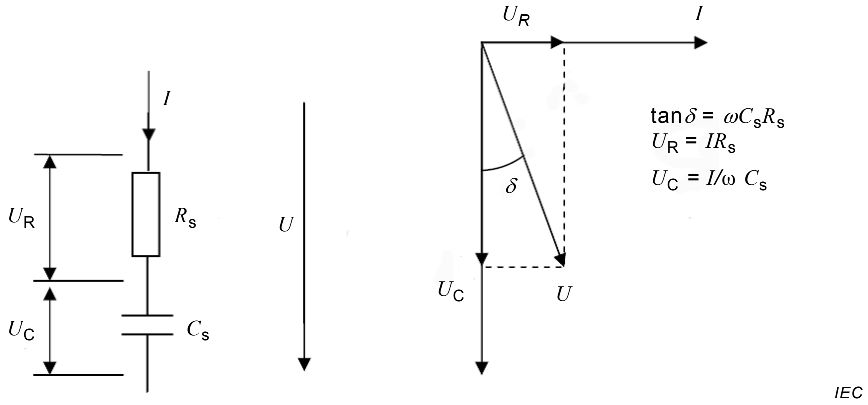
As defined in 3.2, the dielectric dissipation factor tanδ is the tangent of the dielectric loss angle δ (complement of the insulation power factor angle φ) at a predetermined voltage U, frequency and temperature. The dielectric loss of the insulation system can be represented by either a parallel (C_p, R_p) or a series (R_s, C_s) equivalent circuit diagram of elements respectively (see Figure 1 and Figure 2).



Key

C_p	parallel capacitance
R_p	parallel resistor
ω	$2\pi f$ angular frequency
I_C	current in capacitive path
I_R	current in resistive path
U	voltage at insulation system
I	total current through insulation system

Figure 1 – Parallel circuit and vector diagram



Key

C_s series capacitance

R_s series resistor

U voltage at insulation system

I total current through insulation system

U_C voltage at capacitance

U_R voltage at resistor

Figure 2 – Series circuit and vector diagram

Comparison of the dielectric dissipation factor tan δ and the sometimes otherwise used insulation power factor cos φ show that these values are very nearly the same, if the dielectric dissipation factor tan δ is less than 100×10^{-3}, which may be presumed for all modern stator winding insulation systems.

NOTE The preferred and exclusive used loss characteristic in this standard is the dielectric dissipation factor tan δ. But in order to make possible a comparison between insulation power factor cos φ and dielectric dissipation factor tanδ values, a table is given in Annex A.

As shown in Figure 1, the vector of insulation current I can be divided in two perpendicular components, which represent a capacitive current I_C (90° leading to voltage U) and a resistive current I_R (in phase with voltage U). The phase shift angle δ is caused by a resistive component in addition to the capacitive component of the insulation. The dielectric dissipation factor tanδ can be expressed in the following equation:

$$\tan\delta = \omega C_S R_S = \frac{1}{\omega C_p R_p}$$

The capacitive component C_S or C_P represents the lossless capacitance of the tested insulation while the resistive component R_S or R_P summarizes the different kind of losses. The loss characteristics under consideration are those mainly relating to the main ground-wall insulation between the conductor structure (including inner conductor shield, if such exists), the conductive slot coating and the earthed enclosure. In the case of measurements on single stator bars or coils, only that part of the insulation which is dielectrically in series with the ground-wall insulation enters into the measurement result because guard ring electrodes can be used. In the case of dissipation factor measurements on complete windings, the action of the stress control coating and ambient surface condition have to be considered. These influencing factors may be important when comparing test results from different measurements.

Dielectric dissipation factor measurement at voltages below the inception of partial discharges represents the magnitude of dielectric losses in the solid insulation (dielectric absorption and conductive losses) and the conditions of electrical contact to the earthed measuring electrode. The dielectric dissipation factor component arising from the dielectric losses generally changes very little with voltage, but a significantly higher than normal loss measured indicates some difference in the structure of the insulation, such as may arise from incorrect resin composition or inadequate cure.

When the test voltage is raised two different types of dielectric losses increase (see Figure 3):

- dielectric losses of the solid insulation material (polarization, conductivity);
- partial discharges within gaseous inclusions (voids) in the insulation structure cause an increase in dielectric dissipation factor and increasingly larger number of voids begin to undergo discharge with rising applied voltage. The value of dielectric loss and therefore the value of tan δ will continue to increase.

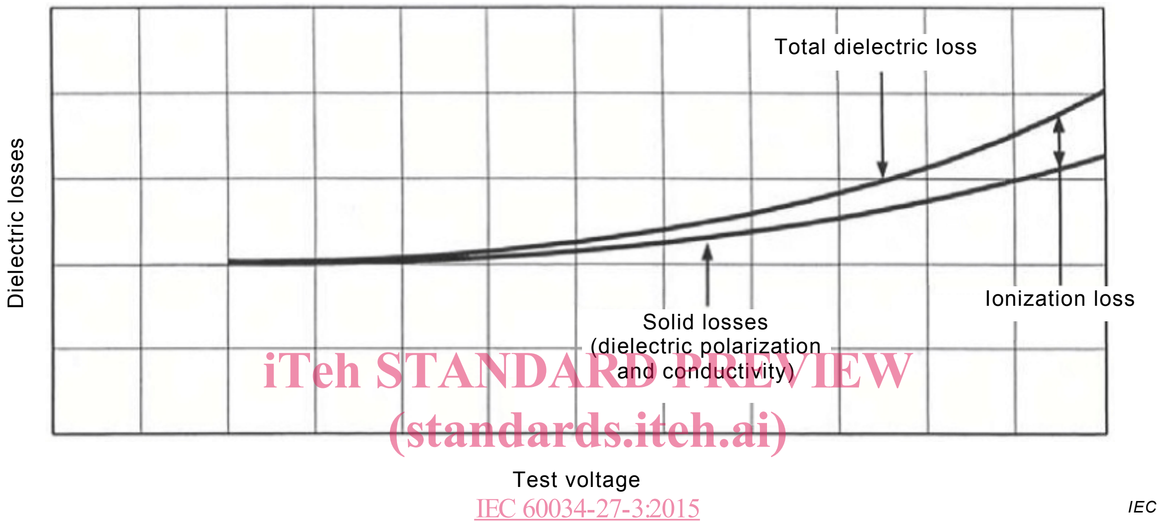
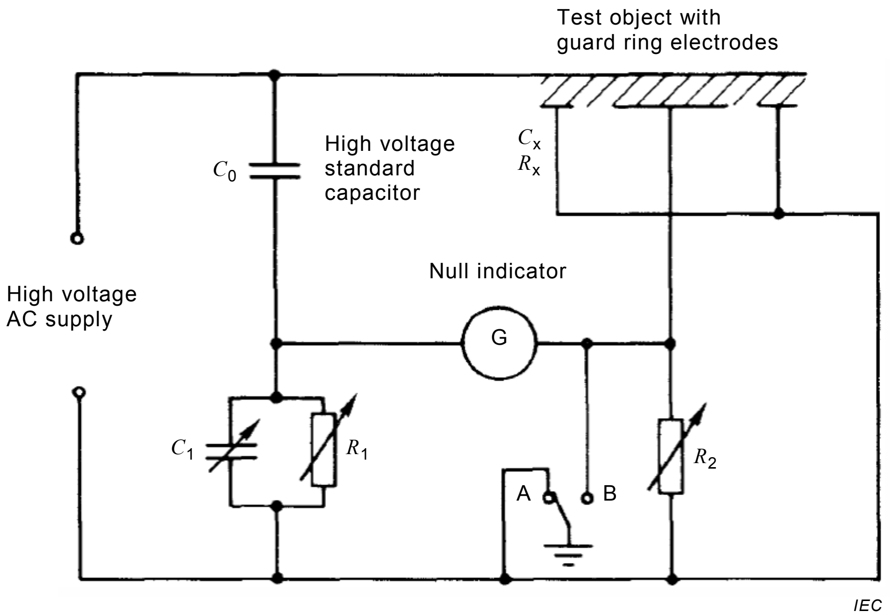


Figure 3 – Dielectric losses with increasing voltage (schematic)

4.2 Analogue Schering bridge

Measurement is carried out by means of the analogue Schering bridge or an equivalent type of bridge like a transformer ratio arm bridge (see 4.3) or by means of modern digital measurement facilities (see 4.4). A variable amplitude alternating voltage supply is used, having sufficient rating to provide the measured voltage across the capacitance of the test object and complying with the requirements of IEC 60060-2. Figure 4 shows the basic circuit diagram for a high voltage Schering bridge, when measuring a stator winding bar or coil with an assumed lossless capacitance C_x and resistive losses of R_x, using a test circuit with guard ring electrodes. The high voltage branch of the bridge includes the high voltage standard capacitor (C_0) with very low dielectric losses. The Schering bridge instrument itself consists of the low voltage branches with variable sets of resistive (R_1 and R_2) and capacitive (C_1) decades of high precision. The balanced condition of the bridge, which is a necessary requirement for correct measurement, is monitored by a sensitive “Null indicator” (see Figure 4).



Key

Positions of earthing switch:		A for testing coils or bars not earthed	
		B for testing windings in earthed condition	
C_0	Capacitance of standard capacitor	C_x	Capacitance of test object
C_1	Variable capacitance of balancing branch 1	R_2	Variable resistance of balancing branch 2
R_1	Variable resistance of balancing branch 1	R_x	Resistance of test object

Figure 4 – High voltage Schering bridge – Basic circuit

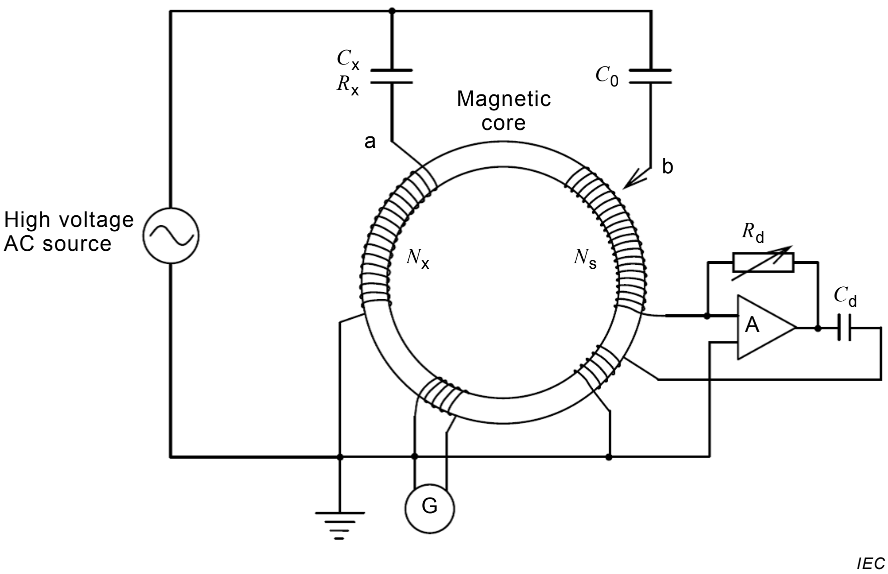
The analogue Schering bridge is very sensitive to disturbances produced by stray capacitance to earth potential. Therefore it is recommended to use double screened coaxial measuring cables with an active screen potential compensator, i.e. Wagner earth circuit.

Today, most analogue bridges like high voltage Schering bridge use an automated balancing procedure for that part of the bridge equipment which includes the low voltage branches with the variable bridge elements C_1, R_1 and R_2.

A high-voltage standard capacitor is used as a reference standard C_0 in the bridge circuit. The nominal value of the capacitance is typically 100 pF or 1 000 pF within a tolerance less than 5 % in long term behaviour. The dielectric dissipation factor of this standard capacitor should be less than $0{,}01 \times 10^{-3}$ up to the maximum test voltage.

4.3 Transformer ratio arm bridge

Another typical example of the analogue bridge is the transformer ratio arm bridge. The bridge is automated by applying a current comparator consisting of operational amplifiers and transformers. An example circuit is shown in Figure 5. Windings under the standard capacitor C_0 and the capacitance of test object C_x are wound in the reverse direction with each other around a magnetic core of high permeability. When the bridge is balanced by adjusting turn number N_s and adjustable resistor R_d, the flux or magnetomotive force in the magnetic core becomes zero. Then the potential of the points a and b is developed by the voltage drop across very small DC resistances of windings N_x and N_s and becomes virtually zero. This method eliminates influence of stray capacitances to the ground. Therefore this bridge method does not require the Wagner earth circuit which the Schering bridge requires.



Key

C_x capacitance of test object

R_x insulation resistance of test object

C_0 standard capacitor

N_x number of turns of coil in test object branch

N_s number of turns of coil in reference branch

R_d adjustable resistance for balancing the bridge

C_d adjustable capacitance for balancing the bridge

G instrument to check balanced condition of the bridge

A amplifier

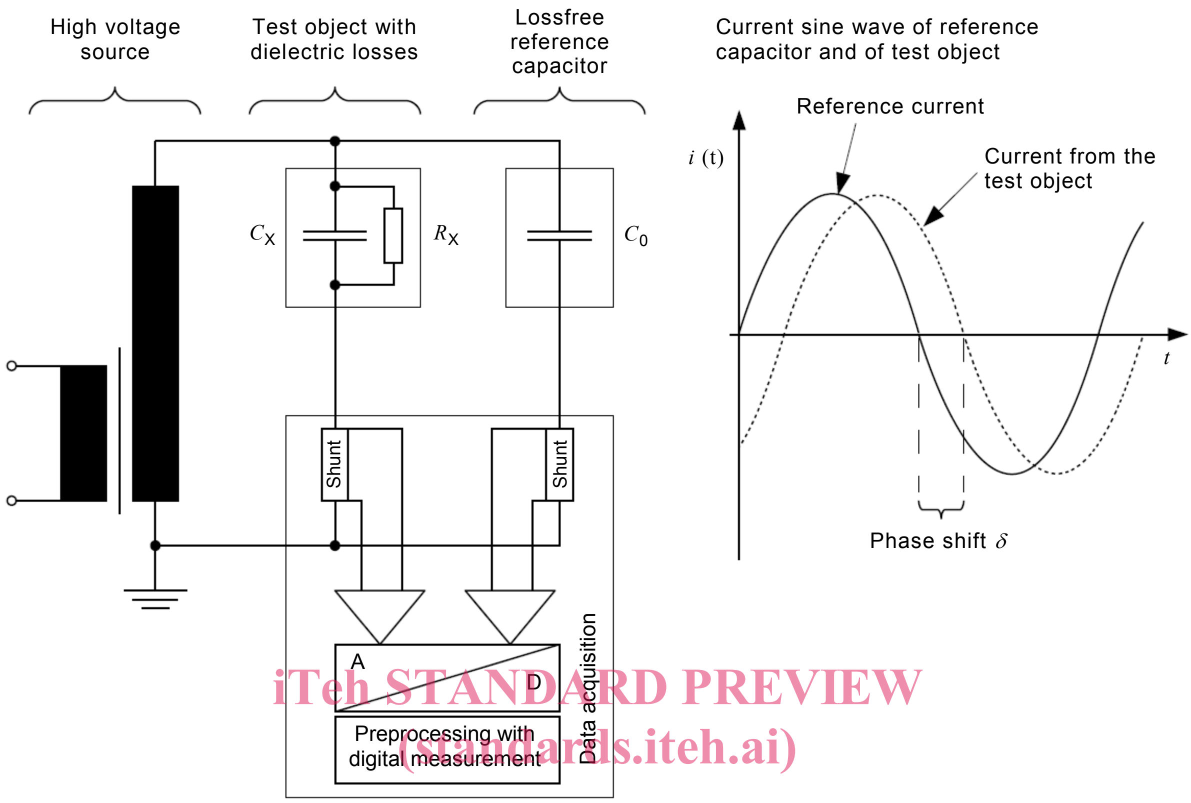
Figure 5 – Transformer ratio arm bridge

4.4 Digital phase shift measurement

The development of digital electronics, particularly high resolution AD-converter and filter devices, resulted in digital dissipation factor and capacitance measuring systems which are completely computer controlled. One example of a test set-up with the high voltage circuit consisting of the test object (C_x, R_x) path and the reference path with standard capacitor C_0 and the electronic measuring equipment on the low voltage side is shown in Figure 6. The measuring principle is based on precise recording of the currents through the standard capacitor (reference) and the test object path with the high voltage as a reference marker. The dielectric dissipation factor is calculated from these currents, or by measurement of the phase difference between these currents. High sensitivity digital equipment for dissipation factor measurement can be characterised by the following parts:

- simultaneous measurement of sinusoidal wave current and voltage in both high voltage paths with high amplitude and time precision;
- suppression of harmonics and external noise at current and voltage sine-wave with digital filtering in time or frequency domain;
- sensitive and reliable measurement of current phase shift between reference path and test object path;
- calculation of dissipation factor tan δ and capacitance C_x based on phase shift and amplitude information extracted from digital current measurement;

- display actual tan δ and Cx values of stator winding insulation in correlation to the applied test voltage during computer controlled test procedure.



Key

C_0 capacitance of high precision standard capacitor without losses

C_x, R_x insulation capacitance and resistance of bars or coils with dielectric losses

Figure 6 – Schematic test set-up of a digital dissipation factor measuring system with principle current oscillogram

If the measurement system uses high voltage insulated tools like e.g. fibre optic data links between measuring units and the control computer it can easily perform dissipation factor measurements on permanently earthed test objects like rotating machines in the field. Because the fibre optic cables act as a HV insulator, the battery powered measuring devices may be placed on high potential leads instead of low voltage connections to earth.

5 Test procedures

5.1 General

The dielectric dissipation factor test is applicable to stator winding components (bars or coils) in which the insulation is cured. This test is usable for single vacuum pressure impregnated or resin-rich (fully-loaded) bars, coils and complete windings including global vacuum pressure impregnation (VPI) technology. The test is not applicable to non-impregnated individual bars and coils or non-impregnated complete windings.

Dissipation factor measurement should be performed with AC line frequency voltage of sinusoidal wave shape and a low amount of harmonics according to IEC 60060-1.