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INTERNATIONAL STANDARD

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colour inside

Rotating electrical machines –
Part 27-4: Measurement of insulation resistance and polarization index of winding insulation of rotating electrical machines

Machines électriques tournantes –
Partie 27-4: Mesure de la résistance d’isolement et de l’index de polarisation sur le système d’isolation des enroulements des machines électriques tournantes

IEC 60034-27-4:2018-01(en-fr)

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ROTATING ELECTRICAL MACHINES –

Part 27-4: Measurement of insulation resistance and polarization index of winding insulation of rotating electrical machines

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

FDIS	Report on voting
2/1880/FDIS	2/1890/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 60034 series, published under the general title *Rotating electrical machines*, can be found on the IEC website.

NOTE A table of cross-references of all IEC TC 2 publications can be found in the IEC TC 2 dashboard 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- withdrawn,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.

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INTRODUCTION

This document provides guidelines for measurement of the insulation resistance and the polarization index on stator and rotor winding insulation of rotating electrical machines. The document also describes typical insulation resistance characteristics, the effect of influential factors which impact or change these characteristics, and how these characteristics indicate winding condition. It recommends minimum acceptable values of insulation resistance for AC and DC rotating machine windings. Interpretation will depend on the nature of the insulation materials – specifically if the insulation is of the thermoset or thermoplastic type.

Insulation resistance measurement has been recommended and used for over 50 years to evaluate the condition of electrical insulation. It is recommended to track periodic measurements, accumulated over months and years of service or in connection with servicing and overhaul of rotating machines.

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, possible repair options and the recommended time interval between tests. These measurements give no indication of local weak points in the insulation system and the trend evaluations cannot be used to predict the time to failure of the winding insulation.

ROTATING ELECTRICAL MACHINES –

Part 27-4: Measurement of insulation resistance and polarization index of winding insulation of rotating electrical machines

1 Scope

This part of IEC 60034 provides recommended test procedures for the measurement of insulation resistance and polarization index of stator and rotor winding insulation of rotating electrical machines.

This document recommends minimum acceptable values of insulation resistance and polarization index of winding insulation valid for fully processed low and high voltage AC and DC rotating electrical machines with a rated power of 750 W or higher.

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 60050-411, *International Electrotechnical Vocabulary – Chapter 411: Rotating machinery*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-411 and the following apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
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3.1
rated voltage
<for an electric machine> rated line-to-line voltage for a three-phase AC machine, line-to-earth voltage for a single phase machine and rated direct voltage for DC machines or field windings

3.2
insulation resistance
R_{it}
<for an electric machine> capability of the electrical insulation of a winding to resist direct current and is determined by the quotient of the applied direct voltage divided by the total current across the machine insulation, taken at a specified time *t* from start of voltage application

Note 1 to entry: The voltage application time is usually 1 min (R_{i1}) and 10 min (R_{i10}); however other values can be used. Unit conventions: subscript values of 1 through 10 are assumed to be in minutes, subscript values of 15 and greater are assumed to be in seconds.

Note 2 to entry: Insulation resistance is sometimes abbreviated as IR.

3.3
polarization index
PI
quotient of the insulation resistance measured at two different times, usually t_1 = 1 min and t_{10}, = 10 min after application of the direct voltage, that is an indicator of the condition of the insulation

Note 1 to entry: Other times are discussed in Clause E.2.

3.4
polarization current
I_P
current resulting from polarization processes, which decays with time of DC voltage application at a decreasing rate from an initial value to essentially zero

Note 1 to entry: The polarization current is also called absorption current.

3.5
conduction current
I_G
<for an electric machine> ohmic current that is constant with time and passes through the bulk of the main insulation

3.6
surface leakage current
I_L
ohmic current that is constant with time and passes over the surface of the end windings of the stator winding or between exposed conductors and the rotor body in insulated rotor windings if there are depositions of conductive materials, e.g., moisture or contamination

3.7
capacitive current
I_C
<for an electric machine> current of comparatively high magnitude and short duration (typically < 1 s), which decays exponentially with time of DC voltage application

3.8
stress control coating current
I_S
ohmic current that is constant with time, flowing in parallel to the surface leakage current through a continuous stress control coating on the surface of the end winding insulation between conductor and earth

3.9
total current
I_T
time dependent current, which is usually measured during insulation resistance measurement and is the sum of all current components

Note 1 to entry: The total current is the basis for the determination of the insulation resistance R_it and the polarization index *PI*.

3.10
polarity effect
effect of obtaining different values of the insulation resistance R_it when the polarity of the insulation resistance meter leads are reversed

Note 1 to entry: This is observed when humidity is present in the insulation. It is caused by a phenomenon known as electro-endosmosis.

4 Insulation resistance – components and influence factors

The insulation resistance of a rotating machine winding is a function of the type and condition of the insulating materials, the insulation system design and the techniques used to manufacture the winding.

The insulation resistance is measured with DC voltage. The measurement of the resistance over time provides information on current components caused by different physical mechanisms. Figure 1 is a schematic showing the different direct current components. Information on the various current components is provided in Annex A.

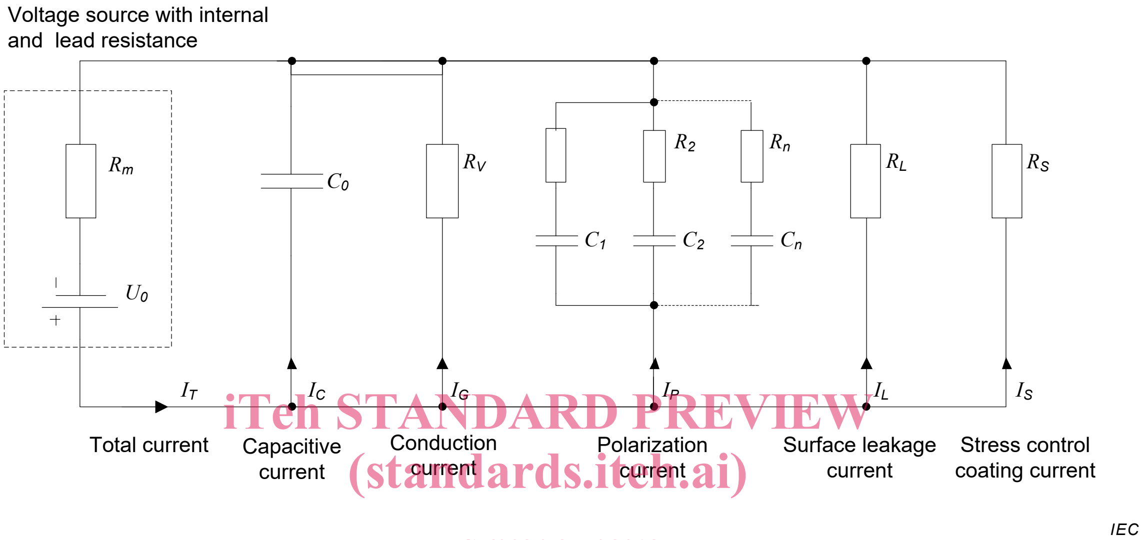

Figure 1 – Equivalent circuit diagram of winding insulation in a DC voltage test

5 Polarization index

The polarization index is the quotient of the insulation resistances measured at two different times t_1 = 1 min and t_{10} = 10 min after application of direct voltage:

$$PI = \frac{R_{\mathrm{i}10}}{R_{\mathrm{i}1}} \qquad (1)$$

Variants of the polarization index definition with a quotient of insulation resistance of other measuring times may be used in special applications and need to be indicated (see Annex E). More measurement points during the 10 min interval may yield additional information.

The polarization index describes the variation of the IR between two specific points in time and therefore, better than with a single insulation resistance value, it may indicate contamination and/or moisture deposition on the winding, or absorbed moisture in the winding. However, it may not indicate internal voids caused by improper impregnation or thermal deterioration.

The polarization index can be used to estimate the suitability of the winding for application of a voltage withstand test or for operation. It may provide information for assessing the condition of the insulation system.

Owing to the negligible polarization currents in the time interval from 1 min to 10 min, the determination of the polarization index may not apply for small machines with random-wound windings, for the field windings in generator rotors, for non-insulated field and squirrel-cage rotor windings and for DC machine armatures.

The polarization index depends on the type of the insulation system, especially on the nature of the insulation materials and procedures used for winding manufacture (for synthetic resin based or shellac- and asphalt based, see 7.1). Furthermore it depends on the kind of stress control coating (see Clause C.3) and the magnitude of the test voltage (see 6.4.1). The influence of the temperature on the polarization index is not significant under the condition that the winding temperature is constant between the 1 min and 10 min readings of the insulation resistance (see 6.1.2).

Before a winding is recommended for a voltage withstand test or for operation, the polarization index should have a minimum value (see recommendations in 8.3).

6 Measurement

6.1 Influences on the measurement of the insulation resistance

6.1.1 General

The resistance measurement result depends on environmental factors, mainly on the winding temperature and on the humidity content of the air. The winding temperature influence can be obtained from empirical data or an experimental measurement and used for the correction of measurement results taken at different temperatures (see 6.1.2).

The air relative humidity affects the surface leakage current and can usually not be estimated, as its effect further depends on the air temperature, surface properties of the insulation and the nature of any surface contamination. For this reason it is generally recommended to perform insulation resistance measurements at winding temperatures above the dew point.

6.1.2 Winding temperature correction

The variation of temperature affects all of the identified current components, except the capacitive current I_C, because an increase in temperature supplies thermal energy, which frees additional charge carriers and so reduces resistivity. Therefore the insulation resistance value of a winding depends on the winding temperature.

To allow a comparison of insulation resistance values obtained at different temperatures it is recommended that all IR values measured be corrected to a common base temperature of 40 °C, if applicable (see Table 1). If the R_i after 1 min of voltage application is > 5 GΩ, or if the R_i for a synthetic resin based insulation system is measured at a temperature less than 40 °C, then no correction is needed [4]. Otherwise the correction factor is calculated using Formula (2):

$$K_T = 0{,}5^{\frac{40-T}{X}} \tag{2}$$

Where

40 is the base temperature (°C);

T is the winding temperature (°C);

X is the slope parameter for an insulation system (K).

Formula (2) is based on Formula (A.3), taking into account all relevant current components.

NOTE 1 This formula expresses that the IR is reduced by half, if the winding temperature T increases by X Kelvin. The same empirical relation can be equally expressed by exponential functions with other bases, like e. The slope parameter can be directly transformed, in case of a basis e by dividing X with -ln(0,5).

NOTE 2 Base temperatures other than 40 °C can be used, e.g. 20 °C.

R_i at the base temperature is obtained by multiplying the resistance value measured at a winding temperature T with the correction factor K_T (Formula (3)):

$$R_{ic} = R_{iT} \times K_T \qquad (3)$$

where

R_{ic} is the insulation resistance corrected to the base temperature (MΩ);

R_{iT} is the measured insulation resistance at winding temperature (MΩ);

K_T is the temperature correction factor.

The slope parameter X in Formula (2) characterizes the degree of insulation resistance temperature dependency of an individual insulation system. Preferably, this parameter is estimated experimentally. The recommended method is by performing IR measurements at several winding temperatures in the expected range where measurements may be made, including 40 °C, all above the dew point, and plotting the results on a semi-logarithmic scale. From the result of an exponential approximation the slope parameter X can be derived. An example for the procedure is given in Annex B. If experimental data are not available for an insulation system, the values for X in Table 1 can be used, Table 1 is based on empirical data, and there is no apparent reason for the discontinuity at 40 °C.

The temperature correction with an exponential approximation by equations 2 and 3 can cause significant errors with an increasing difference between winding temperature and base temperature. It is recommended to apply this method only for a winding temperature range as given in Table 1, which is derived from experimental measurements.

NOTE 3 If different insulation systems are used in the slot and the end winding regions, then it is the insulation system in the slot region that is relevant for temperature correction.

Table 1 – Values of the parameter X for the temperature correction

Types of insulation system	Slope parameter X K	Temperature range °C
Shellac and asphaltic based	10	10 to 60
Synthetic resin based (e.g. epoxy, polyester, polyesterimide and others)	No correction (K_T = 1)	10 to 40
	17	40 to 60

These values are based on experiments and are considered to be a conservative approach, i.e. minimum values. Typically the temperature dependency (Formula 2) is smaller, i.e. the slope parameter is higher.

For the estimation of the polarization index PI, the temperature correction is not required as the difference in winding temperature during the measurement of R_{i1} and R_{i10} is considered to be negligible.

6.2 Measuring equipment

For direct measurement the preferred equipment is an insulation resistance meter. For R_{i1} readings below 5 000 MΩ, a digital instrument should have at least the following characteristics:

- Display: 3 digits
- Accuracy: ± 5 % of reading, ± 5 digits

If no insulation resistance meter is available, the insulation resistance can be obtained from a measurement of voltage and current (indirect measurement). For such indirect measurements a stabilized DC voltage source, a voltmeter and a micro ammeter can be used. The voltage fluctuation of a real DC voltage source will introduce a variation of $i_c(t) = C_0 \, dU_0/dt$. Since the capacitance C_0 of most high voltage machines is large, a minimum stability and noise is required for the DC supply to neglect this effect. The insulation resistance is calculated from the volt- and ammeter readings using Formula (4).

$$R_{\mathrm{it}} = U / I_{\mathrm{t}} \tag{4}$$

where

R_{it} is the insulation resistance (MΩ) at time t;

U is the measured voltage (voltmeter reading) of the DC voltage source (V);

I_{t} is the measured current (ammeter reading) (µA) at time t.

For the measurement of high IR values a meter with guard option is recommended, to avoid leakage and capacitive influences from the measuring cable.

The instrumentation shall take no more than 5 s to reach the test voltage.

6.3 Test object and measuring circuit

6.3.1 General

Depending on the aim of the test and the design of the test object, different measuring circuits apply. For checking the recommended minimum IR the test shall be performed on the entire winding. In order to check for insulation problems on each phase winding and between phase windings, measurements shall be performed phase by phase if each phase winding can be easily disconnected from one another. For trending purposes, the same connection shall always be applied.

If possible, external elements such as cables, switches, capacitors, current transformers, etc. shall be disconnected from the winding. Items still connected to the winding need to be recorded.

To obtain insulation resistance measurements on directly water-cooled windings, the water should be removed and the internal circuit thoroughly dried. In some water-cooled windings the manufacturer may have provided a means of measuring the insulation resistance without the need for the coolant to be drained. In general, if the water is not removed then the conductivity of the water should be less than what is recommended by the machine manufacturer. In this case, the water conductivity will largely dominate the insulation resistance; and thus $PI = 1$ and $R_{\mathrm{i10}} = 1$ MΩ may be expected.

In any case the winding elements that are not under test shall be connected with short leads to machine earth to avoid any undesirable effects, such as equalizing currents or AC current induced to test circuit.

6.3.2 Three-phase stator windings

6.3.2.1 Connection for measurements of the entire winding to earth

All phase windings are connected together as shown in Figure 2.