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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Electrical insulating materials and systems – AC voltage endurance evaluation

Systèmes et matériaux isolants électriques – Évaluation de l'endurance à la tension alternative

IEC 61251:2015-11(en-fr)

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ELECTRICAL INSULATING MATERIALS AND SYSTEMS – AC VOLTAGE ENDURANCE EVALUATION

FOREWORD

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International Standard IEC 61251 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems.

This first edition of IEC 61251 cancels and replaces the second edition of IEC TS 61251, published in 2008. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the second edition of IEC TS 61251:

a) upgrade from Technical Specification to an International Standard;
b) clarification of issues raised since publication of IEC TS 61251.

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

FDIS	Report on voting
112/338/FDIS	112/347/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.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website 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- withdrawn,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 covers insulating materials and systems. Voltage endurance tests are used to compare and evaluate insulating materials and systems. It is complex to determine the capability of electrical insulating materials and systems to endure a.c. voltage stress. The results of voltage endurance tests are influenced by many factors. Therefore this International Standard can be considered as an attempt to present a unified view of voltage endurance for simplified planning and analysis.

ELECTRICAL INSULATING MATERIALS AND SYSTEMS – AC VOLTAGE ENDURANCE EVALUATION

1 Scope

This International Standard describes many of the factors involved in voltage endurance tests on electrical insulating materials and systems. It describes the voltage endurance graph, lists test methods illustrating their limitations and gives guidance for evaluating the sinusoidal a.c. voltage endurance of insulating materials and systems from the results of the tests. This International Standard is applicable over the voltage frequency range 20 Hz to 1 000 Hz. The general principles can also be applicable to other voltage shapes, including impulse voltages. The terminology to be used in voltage endurance is defined and explained.

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 62539, *Guide for the statistical analysis of electrical insulation dielectric breakdown data*

3 Terms, definitions and symbols

3.1 Terms and definitions

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

3.1.1
voltage endurance
VE
measures of the capability of a solid insulating material to endure voltage

Note 1 to entry: In this International Standard, only a.c. voltage is considered.

Note 2 to entry: This note only applies to the French language.

3.1.2
life
time to dielectric breakdown

3.1.3
voltage endurance coefficient
VEC
numerical value of the reciprocal of the slope of a straight line log-log VE plot

Note 1 to entry: This note only applies to the French language.

3.1.4
specimen
representative test object for assessing the value of one or more physical properties

3.1.5
sample
group of nominally identical specimens extracted randomly from the same manufacturing batch

3.2 Symbols

c, c'	constants in the inverse-power model
E	electric stress
E_o	short-time electric strength
E_t	electric threshold stress
f	frequency
h, k	constants in the exponential model
L	life
m	scale parameter in the Weibull distribution (one variable)
M	scale parameter in the generalized Weibull distribution (two variables)
n	exponent of stress in the inverse-power model coinciding with the VEC
n_d	differential VEC
R	dimensional ratio
t	time
t_c	time to dielectric breakdown at constant stress
t_o	time to dielectric breakdown at constant stress E_o
t_p	time to dielectric breakdown with progressive stress
tan δ	dissipation factor
α	scale parameter (63,2 percentile) in the Weibull distribution of times to dielectric breakdown at constant stress
β	shape parameter in the Weibull distribution of times to dielectric breakdown at constant stress
γ	shape parameter of the Weibull distribution of the dielectric breakdown stresses from a progressive stress test

4 Voltage endurance

4.1 Voltage endurance testing

To evaluate the voltage endurance of insulating materials or systems, a number of specimens are subjected to a.c. voltage and their times to dielectric breakdown are measured. In practice, several samples of many specimens are tested at different voltages to reveal the effect of the applied voltage on the time to dielectric breakdown. The arithmetic mean time to dielectric breakdown of each sample is the average time to dielectric breakdown of all specimens tested at that voltage. The time at which a certain percentage of specimens break down is the estimated time to dielectric breakdown with a probability equal to this percentage.

The statistical treatment of the data (either by analytical or graphical methods) allows the extraction of additional data such as other failure percentiles or confidence bounds and, possibly, determination of the distribution (Gaussian, Weibull, lognormal, etc.).

4.2 Electrical stress

In general, reference to electrical stress (voltage per unit thickness) instead of voltage is required. For a uniform field, electrical stress is given by the voltage (effective value) divided by the thickness of specimens.

If the electric field is not uniform, the maximum value shall be considered by the relevant equipment committees.

4.3 Voltage endurance (VE) graph

The VE graph represents the time to dielectric breakdown (life) versus the corresponding value of electrical stress. In the VE graph, the electrical stress is plotted as the ordinate with either a linear or logarithmic scale. The times to dielectric breakdown are plotted on the abscissa with a logarithmic scale. The voltage endurance line on this graph gives the final result of the VE tests as it allows clear and complete evaluation of voltage endurance of the specimens under the specified test conditions. For maximum significance, materials or systems shall be compared at equal thickness and using the same type of electrodes, temperature, humidity and ambient gas, or as agreed by the relevant equipment committees.

An accurate plotting of the line requires more than three tests at different voltages and one or more tests are required at voltages which result in times to failure longer than 1 000 h. In any case, a minimum number of three tests is required to draw the VE graph.

The voltage endurance line is straight or curved. In the latter case, its trend can often be approximated by a few straight regions: sometimes a first part for short times with a low slope, a middle region (which can extend to long times) with a steeper slope and finally a further trend of the line showing a tendency to become horizontal (see Figure 1, where a general VE line is shown). It is likely that the shape of the VE graph changes significantly from one material or system to another. With a curve as shown in Figure 1, the VEC is not constant, and the VEC will be different at different times (see n_d in Figure 2).

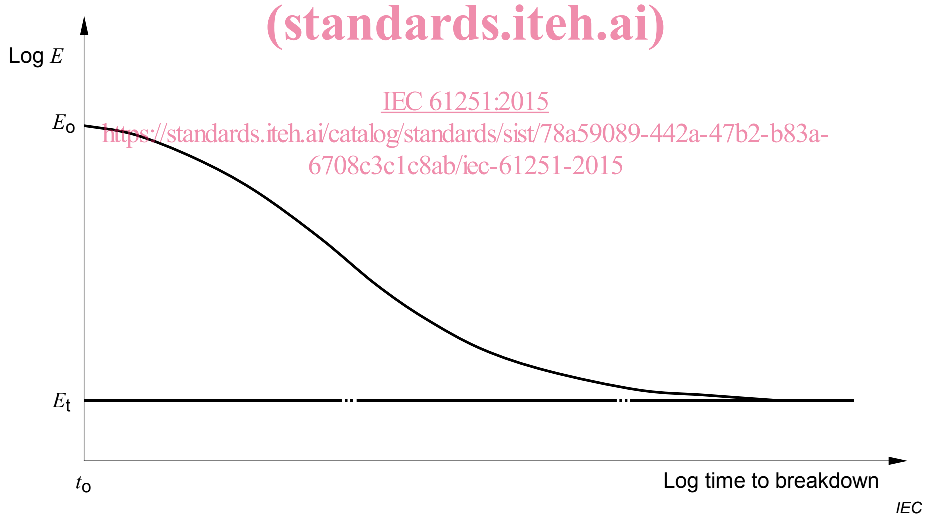

Figure 1 – General voltage endurance line

4.4 Short-time electric strength

The short-time electric strength is measured using a linearly increasing voltage. The duration of such a test, as used in this International Standard, is of the order of one minute up to some tens of minutes. The arithmetic mean value of the breakdown field for the tested sample is E_o.

The results of electric strength tests (or, in general, of tests with increasing voltage) are not represented directly in the VE graph. Instead, a constant voltage test at the same stress as the mean electric strength, E_o (or very close to it, 0,9E_o or as agreed), is made to determine the time to dielectric breakdown, t_o, with constant stress. The point (E_o, t_o) is the origin of the VE line. More details on this procedure are given in 5.5. However, when this procedure is used, the following precautions shall be taken.

a) The electric strength tests shall be carried out under the same conditions (humidity, temperature, etc.), in the same test cell and with the same procedures as for the voltage endurance tests.

b) The test specimens, the breakdown path and the conditions of the specimen after dielectric breakdown shall be examined and recorded for future use in the analysis of the results. The latter is to ensure that the mode of failure at high stress is the same as that of the other specimens tested later at lower stress.

4.5 Voltage endurance coefficient (VEC)

The slope of the VE line, n, is an indicator of the response of a material or system to electrical stress. The parameter n is dimensionless. With a small slope of the VE line (i.e. a large value of VEC), even a small reduction of stress produces a great increase in life. The reciprocal of the slope is taken to be consistent with the numerical value of the exponent n in Formula (1). A large value of the VEC does not correspond necessarily to high electric strength. It can happen that the material with lower VEC has a longer time to dielectric breakdown at a given stress if its short-time electric strength is so high that its poorer endurance is compensated for. The value of n shall be associated with a high mean electric strength before attributing a high endurance to the material. What is most significant is the retention of usable electric strength for long periods of time.

4.6 Differential VEC (n_d)

If the VE line is curved in log-log coordinates, its slope is measured by means of the tangent at any point. For any electrical stress, and thus for any point on the line, the differential voltage endurance coefficient, n_d, can be defined as the absolute value of the reciprocal of the slope of the curve at that point (Figure 2) according to the life model described in Clause 5.

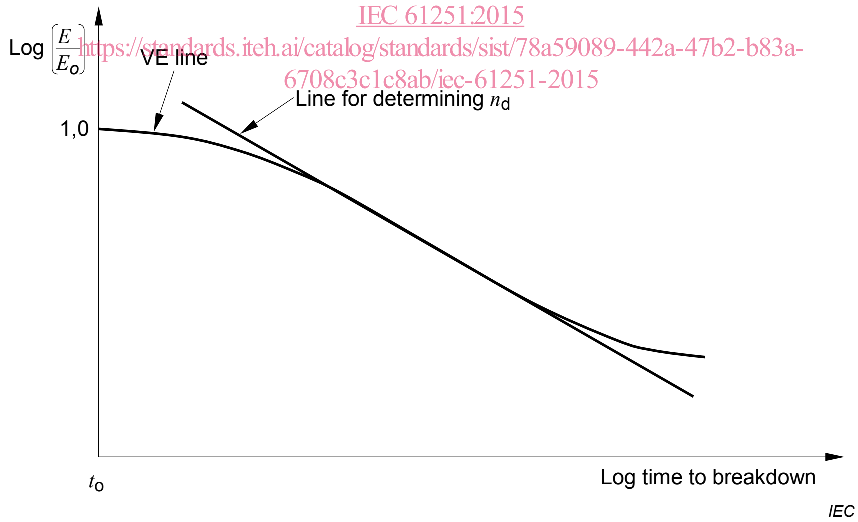

Figure 2 – Determination of the differential VEC n_d at a generic point P of the VE line

4.7 Electrical threshold stress (E_t)

If the VE line tends to become horizontal with decreasing stress within the test stress-times, this indicates the presence of a limiting stress, E_t, below which electrical ageing becomes negligible. This limit is called the electrical threshold stress. The tendency of the line to become horizontal is detected by means of tests of suitable duration. However, the tests do not always succeed in revealing such a trend in a reasonable time. Some insulating materials or systems do not show any electrical threshold stress even for very long test times.

4.8 Voltage endurance relationship

The VE relationship is the mathematical model of life under electrical stress or voltage, i.e. the formula relating electrical stress and time to dielectric breakdown, whose graphical representation is given by the VE line. If this line is straight on log-log graph paper, the formula is of the type:

$$L = c\,E^{-n} \tag{1}$$

where

L is the time to dielectric breakdown or time to failure or life;

E is the electrical stress;

c and n are constants dependent on temperature and other environmental parameters.

Formula (1) constitutes the so-called inverse-power model, which is the voltage-life model often encountered with voltage endurance data on solid electrical insulation. In this case the VEC is n, and it is constant. When data are available for time to dielectric breakdown at two constant-voltage stresses, this model shall be used to get a rough estimate of the value of n by using Formula (2):

$$\frac{L_1}{L_2} = \left(\frac{E_1}{E_2}\right)^{-n} \tag{2}$$

If the VE test data do not form a straight line on log-log paper, the use of the inverse-power model is incorrect. If the line approaches an electrical threshold stress, E_t, other models have been proposed, among them

$$L = c'\,(E - E_t)^{-n}, \tag{3}$$

which becomes the inverse-power model if E_t tends to 0 and is preferably used when the data for short and medium times fit a straight line on log-log coordinates. Alternatively, another model is

$$L = \frac{k \exp(-h\,E)}{E - E_t}, \tag{4}$$

which derives from the exponential model, corresponding to an approximately straight line in semilog coordinates for $E > E_t$ but gives infinite time to dielectric breakdown when E tends to E_t. In Formulas (3) and (4), constants c', n, k, h and E_t depend on temperature and other environmental conditions.

Formulas (3) and (4) generate two new formulas which define the trend of the VE line between any two points, (L_1, E_1) and (L_2, E_2). The following formulas are obtained:

$$\frac{L_1}{L_2} = \left(\frac{E_1 - E_t}{E_2 - E_t}\right)^{-n}, \tag{5}$$

$$\frac{L_1}{L_2} = \frac{\exp\{-h\,(E_1 - E_2)\}}{(E_1 - E_t)/(E_2 - E_t)}. \tag{6}$$

The formulas of the VE line for a straight line or a straight-line segment on log-log plot are Formulas (1) and (2). When there is a tendency toward a threshold after an approximately linear trend on log-log or semilog graph paper, Formulas (3), (4), (5) and (6) apply.

By taking the logarithms, the inverse-power model, Formula (1), becomes

$$\ln (L) = \ln (c) - n \ln (E) \; . \qquad (7)$$

This is the formula of the straight VE line in log-log coordinates. Its slope is $-1/n$. As the numerical value of the reciprocal of the slope is equal to n, the VEC can also be defined as the exponent n in the inverse-power model.

5 Test methods

5.1 Introductory remarks

Different methods of carrying out the VE test can be used. The differences concern the way of applying voltage (constant or increasing with time), the frequency (service or higher) and the time at which the test is interrupted (the time to dielectric breakdown for all sample specimens (complete life tests) or a shorter time for some of the specimens of the sample (censored life tests).

In general to enable comparisons to be made, the type of ageing cell or test object shall be the same, whatever the choice of the parameters above. However, with respect to the choice of the frequency of the applied voltage, the amount of heating from either dielectric loss or from partial discharges shall be such that the temperature rise from these causes is less than 3 K.

When testing materials, the ageing cell or test object should result in a uniform electric field. This can be achieved by electrodes having a flat surface rounded at the edges. To avoid partial discharges and flashover along the specimen surface, the specimen shall extend a suitable distance beyond the edges of the electrodes. If preliminary tests indicate that this extension beyond the electrodes is not enough to avoid partial discharges and flashover, the electrodes shall be immersed or embedded in an appropriate dielectric having the same or higher permittivity than that of the material under test.

The form and processing of the specimen will depend on the purpose of the test. For research purposes, internal degradation studies as a function of cavity size and shape have been performed. However, this lies outside the scope of this International Standard. Evaluation and comparison of materials from the point of view of degradation by external discharge are dealt with in IEC 60343.

For insulation systems, the test objects shall represent adequately the form taken in service and be determined by the relevant IEC equipment committee.

5.2 Tests at constant stress

5.2.1 Conventional VE test

In the constant stress test, the magnitude of the voltage applied to each specimen is kept constant during the test. This magnitude is usually selected in such a way that the arithmetic mean time to dielectric breakdown of the sample is between a few tens and a few thousands of hours. The time to dielectric breakdown of some specimens, especially at the lower stresses, can be so long that it is impracticable to wait for dielectric breakdown of all specimens of the sample. In this case, the interruption of the test after dielectric breakdown of some of the specimens requires the use of statistical procedures for censored data (see IEC 62539).