

Electrical insulating materials — A.C. voltage endurance evaluation — Introduction

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Technical Committee GEL/15, Insulating material, to Subcommittee GEL/15/3/2 Endurance tests, upon which the following bodies were represented:

- AEA Technology
- Adhesive Tape Manufacturers' Association
- Association of Manufacturers of Domestic Electrical Appliances
- British Cable Makers Confederation
- British Plastics Federation
- ERA Technology Ltd.
- University of Manchester

This British Standard, having been prepared under the direction of the Electrotechnical Sector Board, was published under the authority of the Standards Board and comes into effect on 15 July 1995

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The following BSI references relate to the work on this standard:
Committee reference GEL/15
Special announcement in *BSI News* April 1995

ISBN 0 580 24332 X

Amendments issued since publication

Amd. No.	Date	Comments

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National foreword

This British Standard has been prepared by Subcommittee GEL/15/2. It is identical with IEC 1251:1993 *Electrical insulating materials — A.C. voltage endurance evaluation — Introduction*, published by the International Electrotechnical Commission (IEC).

Cross-references

The Technical Committee has reviewed the provisions of IEC 243, IEC 343:1991 and IEC 727-2:1993 to which normative reference is made in the text, and has decided that they are acceptable for use in conjunction with this standard.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 16, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope and object

This technical report explains many of the factors involved in Voltage Endurance tests on electrical insulating materials. It describes the Voltage Endurance graph, lists test methods illustrating their limitations, and gives guidance for evaluating the a.c. Voltage Endurance of insulating materials from the results of the tests.

The terminology to be used in Voltage Endurance is defined and explained. It must be emphasized that this technical report is concerned with materials, and the results may not be directly applicable to the performance of insulating systems¹⁾.

Voltage Endurance tests are used to compare and evaluate insulating materials in view of their various applications in electrical systems. Determining the ability of electrical insulating materials to endure a.c. voltage stress is very complex. The results of Voltage Endurance test procedures are influenced by many factors, so this technical report should only be considered an attempt to present a unified view of Voltage Endurance for simplified planning and analysis. This report is an introduction with general purposes: some documents for the various practical cases exist and others are being developed.

It should be recognized, however, that it is not possible from the results of the test to draw conclusions about the performance of the materials in service in an insulating system.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this technical report. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this technical report are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 243, *Methods of test for electric strength of solid insulating materials*.

IEC 343:1991, *Recommended test methods for determining the relative resistance of insulating materials to breakdown by surface discharges*.

IEC 727-2:1993, *Evaluation of electrical endurance of electrical insulation systems — Part 2: Evaluation procedures based on extreme value distributions*.

3 Definitions and terms

3.1

Voltage Endurance (VE)

Voltage Endurance is a measure of the ability of solid insulating materials to endure voltage. In this report only a.c. voltage is considered

3.2

voltage life

the life of any technical system is the time until its failure. For solid insulating materials, the voltage life is the time to breakdown under constant voltage stress

3.3

voltage endurance testing

to evaluate the Voltage Endurance of insulating materials, a number of specimens of the material under consideration are subjected to a.c. voltage and their times to breakdown are measured. In VE testing practice, several samples of many specimens are tested at different voltages to reveal the effect of the applied voltage on the time to breakdown. The mean time to breakdown of each sample is the average time to breakdown of all specimens at that voltage. The time at which a certain percentage of specimens has broken down is the estimated time to 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 (e.g. Gaussian, Weibull, log normal, etc.)

¹⁾ For systems, see IEC 727.

3.4

electrical stress

in general, it is advisable to make reference to electrical stress (voltage per unit thickness) instead of voltage. For uniform field, electrical stress is given by the ratio of voltage (effective value) to the thickness of specimens

if the electric field is not uniform, its mean or maximum value can be considered. In this case, the uniform field ranking of materials may not be applied

3.5

Voltage Endurance (VE) graph

this is the graph of the time to breakdown versus the corresponding value of electrical stress²⁾. In the VE graph, the electrical stress is plotted as the ordinate with either a linear or logarithmic scale. The times to breakdown are plotted on the abscissa, usually 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

an accurate plotting of the line requires many tests at widely different voltages, thus some tests are usually required at low voltages, which result in long times to breakdown. However, it may be possible to reduce the time and cost of the VE test without an appreciable reduction of the reliability in evaluating the shape of the line (see clause 5)

the Voltage Endurance line may be 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 gentle slope, a middle region (which may be prolonged until very 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)

the shape of the VE graph may change greatly from one material to another

3.6

short-time electric strength

the short-time electric strength is generally measured using a linearly increasing voltage. The duration of such a test, as used in this document, is of the order of some tens of seconds up to some tens of minutes (and thus longer than the values suggested by IEC 243). These short-time electric strength measurements can be used to indicate the degree of ageing of specimens subjected to voltage, by comparing the values after voltage exposure with the initial ones

the results of electric strength tests (or, in general, of tests with increasing voltage) are not reported directly in the VE graph, but instead, a constant voltage test at the same stress as the mean electric strength, E_0 , is made to determine the actual time to breakdown, t_0 , with constant stress. The point (E_0 , t_0) is on the VE line. More details on this procedure are given in 5.4 and 5.6. However, when this procedure is used, the following precautions should be taken:

- i) the test should be carried out in the same conditions (ambient, temperature, etc.), in the same test cell and with the same procedures as for the Voltage Endurance tests, and
- ii) the specimens and the conditions of the specimen breakdown should be examined and recorded for future use in the analysis of the results. This latter is to assure that the mode of failure at high stress is not unduly assumed to be the same as that of the other specimens tested later at lower stress.

3.7

Voltage Endurance Coefficient — VEC (n)

this is defined as the numerical value of the reciprocal of the slope of the VE plot, if the line is straight in a log-log plot. In such a case, the slope of the VE line may be an index of the response of a material to electrical stress. The VEC n is dimensionless. With a gentle slope of the line, 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 equation (1) which has historical precedent. A large value of n often indicates a high level of Voltage Endurance. However, if it occurs together with a low stress, the high value of n can indicate a low electric strength, which should not be confused with high endurance

²⁾ For maximum significance, materials should be compared at equal thickness.

a low value of n indicates poor endurance. What is most significant is the retention of usable electric strength for long periods of time. See also equation (7) in 5.4

3.8

differential VEC (n_d)

if the VE line is curved in log-log co-ordinates its slope changes from point to point. Therefore, the slope may be 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 numerical value of the reciprocal of the slope of the straight line tangent to the curve at that point (Figure 2). The other coefficient, N , described in the figure, is defined in 5.5

3.9

electrical threshold stress (E_t)

the VE line may tend to become horizontal with decreasing stress, suggesting 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 can sometimes be detected by means of tests of suitable duration; however, the tests do not always succeed in disclosing such a trend. Some insulating materials do not show any electrical threshold stress even for very long test times

4 Voltage endurance relationship

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

$$L = C E^{-n} \quad (1)$$

where

L is time to breakdown and E electrical stress;

C and n are constants (depending on temperature and other environmental conditions).

Equation (1) constitutes the so-called inverse-power model, which is the voltage-life model often encountered with Voltage Endurance data on solid electrical insulation. When data are available for time to breakdown at two voltage stresses, this model can be used to estimate the value of n by using equation (1'):

$$\frac{L_1}{L_2} = \left(\frac{E_1}{E_2} \right)^{-n} \quad (1')$$

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:

$$L = C' (E - E_t)^{-n} \quad (2)$$

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 co-ordinates. Alternatively, another model is:

$$L = \frac{k \exp(-h E)}{E - E_t} \quad (3)$$

which derives from the simple exponential model, corresponding to an approximately straight line in semilog co-ordinates for $E > E_t$, but gives infinite time to breakdown when E tends to E_t . In equations (2) and (3), constants C' , n , k , h and E_t depend on temperature and other environmental conditions³⁾.

³⁾ Other models have been proposed where $(E - E_t)$ is raised to an exponent v , dependent on the material under consideration.