

**BS EN 60505:2011**

*Incorporating corrigendum March 2017*



**BSI Standards Publication**

# **Evaluation and qualification of electrical insulation systems**

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## National foreword

This British Standard is the UK implementation of EN 60505:2011. It is identical to IEC 60505:2011, incorporating corrigendum March 2017. It supersedes BS EN 60505:2004 which is withdrawn.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by IEC corrigendum March 2017 is indicated in the text by C1 C1.

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.

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|--------------|----------------------------------------------|
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EUROPEAN STANDARD  
NORME EUROPÉENNE  
EUROPÄISCHE NORM

# EN 60505

August 2011

ICS 29.080.30

Supersedes EN 60505:2004

English version

## Evaluation and qualification of electrical insulation systems (IEC 60505:2011)

Evaluation et qualification des systèmes  
d'isolation électrique  
(CEI 60505:2011)

Bewertung und Kennzeichnung von  
elektrischen Isoliersystemen  
(IEC 60505:2011)

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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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European Committee for Electrotechnical Standardization  
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## Foreword

The text of document 112/174/FDIS, future edition 4 of IEC 60505, prepared by IEC TC 112, Evaluation and qualification of electrical insulating materials and systems, was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60505:2011.

The following dates are fixed:

- latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2012-05-15
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2014-08-15

This document supersedes EN 60505:2004.

The main change with respect to EN 60505:2004 is that Annex A: Glossary is now available in an Internet version (<http://std.iec.ch/iec60505>) as well as a hardcopy version. The internet version contains an abridged text version and a multimedia supplement.

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The text of the International Standard IEC 60505:2011 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 60068-1        | NOTE | Harmonized as EN 60068-1.                   |
| IEC 60068-2 series | NOTE | Harmonized in EN 60068-2 series.            |
| IEC 60068-2-1      | NOTE | Harmonized as EN 60068-2-1.                 |
| IEC 60068-2-2      | NOTE | Harmonized as EN 60068-2-2.                 |
| IEC 60068-2-10     | NOTE | Harmonized as EN 60068-2-10.                |
| IEC 60068-2-14     | NOTE | Harmonized as EN 60068-2-14.                |
| IEC 60068-2-27     | NOTE | Harmonized as EN 60068-2-27.                |
| IEC 60112          | NOTE | Harmonized as EN 60112.                     |
| IEC 60212          | NOTE | Harmonized as EN 60212.                     |
| IEC 60216 series   | NOTE | Harmonized in EN 60216 series.              |
| IEC 60216-1        | NOTE | Harmonized as EN 60216-1.                   |
| IEC 60243-1        | NOTE | Harmonized as EN 60243-1.                   |
| IEC 60243-2        | NOTE | Harmonized as EN 60243-2.                   |
| IEC 60243-3        | NOTE | Harmonized as EN 60243-3.                   |
| IEC 60664-4        | NOTE | Harmonized as EN 60664-4.                   |
| IEC 60270:2000     | NOTE | Harmonized as EN 60270:2001 (not modified). |

|                  |      |                                 |
|------------------|------|---------------------------------|
| IEC 60371-2      | NOTE | Harmonized as EN 60371-2.       |
| IEC 60587        | NOTE | Harmonized as EN 60587.         |
| IEC 60721 series | NOTE | Harmonized in EN 60721 series.  |
| IEC 60811-3-1    | NOTE | Harmonized as EN 60811-3-1.     |
| IEC 61033        | NOTE | Harmonized as EN 61033.         |
| IEC 61710        | NOTE | Harmonized as EN 61710.         |
| IEC 62231        | NOTE | Harmonized as EN 62231.         |
| IEC 62271-304    | NOTE | Harmonized as CLC/TS 62271-304. |
| ISO 62           | NOTE | Harmonized as EN ISO 62.        |
| ISO 175          | NOTE | Harmonized as EN ISO 175.       |
| ISO 877-1        | NOTE | Harmonized as EN ISO 877-1.     |
| ISO 877-2        | NOTE | Harmonized as EN ISO 877-2.     |
| ISO 4611         | NOTE | Harmonized as EN ISO 4611.      |

## 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.

| <u>Publication</u> | <u>Year</u> | <u>Title</u>                                                                                                                                                                              | <u>EN/HD</u> | <u>Year</u> |
|--------------------|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|-------------|
| IEC 60216-2        | -           | Electrical insulating materials - Thermal endurance properties -<br>Part 2: Determination of thermal endurance properties of electrical insulating materials -<br>Choice of test criteria | EN 60216-2   | -           |
| IEC 60216-3        | -           | Electrical insulating materials - Thermal endurance properties -<br>Part 3: Instructions for calculating thermal endurance characteristics                                                | EN 60216-3   | -           |
| IEC 60216-5        | -           | Electrical insulating materials - Thermal endurance properties -<br>Part 5: Determination of relative thermal endurance index (RTE) of an insulating material                             | EN 60216-5   | -           |
| IEC 60493-1        | -           | Guide for the statistical analysis of ageing test -<br>data -<br>Part 1: Methods based on mean values of normally distributed test results                                                |              | -           |
| IEC 60544-1        | -           | Electrical insulating materials - Determination of the effects of ionizing radiation -<br>Part 1: Radiation interaction and dosimetry                                                     | EN 60544-1   | -           |
| IEC/TS 61251       | -           | Electrical insulating materials - A.C. voltage endurance evaluation - Introduction                                                                                                        | -            | -           |
| IEC 62539          | -           | Guide for the statistical analysis of electrical insulation breakdown data                                                                                                                | -            | -           |

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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

**EVALUATION AND QUALIFICATION  
OF ELECTRICAL INSULATION SYSTEMS**

## FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60505 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems.

This fourth edition cancels and replaces the third edition, published in 2004, and constitutes a technical revision.

**[C1]** The main change with respect to the previous edition is the addition of a Glossary in the form of Annex A to this standard. **[C1]**

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

| FDIS         | Report on voting |
|--------------|------------------|
| 112/174/FDIS | 112/184/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 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.

**IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.**

## INTRODUCTION

The life of an electrical insulation system (EIS) or systems frequently determines the life of electrical equipment which can be affected by electrical, thermal, mechanical or environmental stresses acting either individually or in combination.

Intended, estimated or proven service life times are essential parameters for describing the life of electrical insulation systems. In the early days of electrotechnical engineering, life figures were rather vague. The limitation of the life of the insulation under thermal stress was one of the first indicators of the effect of ageing in some equipment in service. As experience in using EIS increased, it was appreciated that there was a need to select specific materials having satisfactory life time at a given temperature, to enable the required service life to be achieved and to allow for the calculation of the thermal capability of equipment.

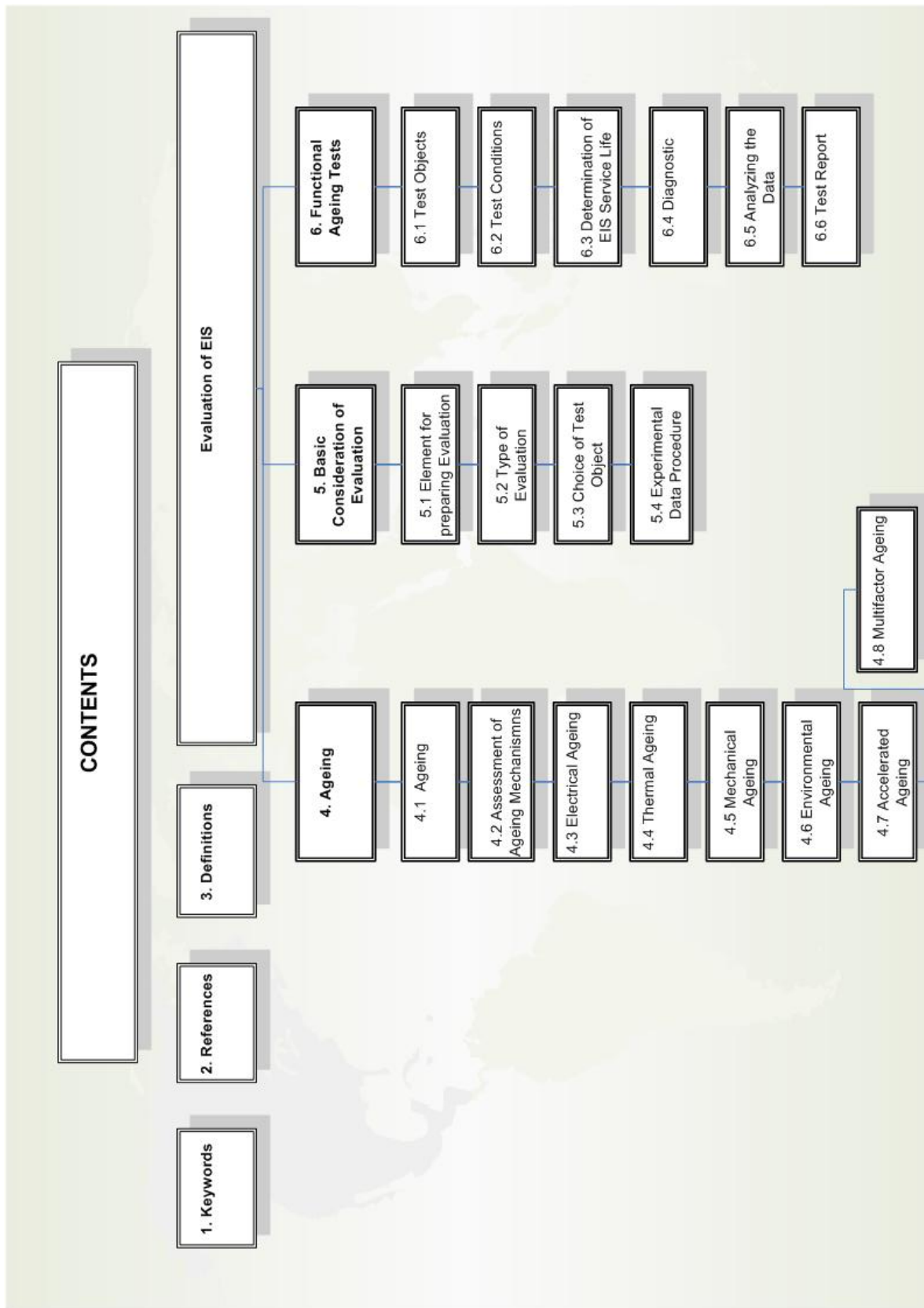
The user of this standard may evaluate existing test methods and provide correlation with his equipment. Therefore, the user of this standard is responsible for demonstrating the validity of the existing test method in accordance with the principles of this standard.

The determination of the prospective life is a fundamental task when developing and designing an EIS. Estimated service life of an EIS needs to be established for several reasons:

- for type testing when introducing a new EIS into production;
- for quality assurance of production;
- for estimating the life expectancy of new equipment;
- for estimating the remaining life for maintenance purposes.

“Ageing” focuses on the mechanisms affecting the EIS performance. “Evaluation” links these potential mechanisms by “Analysis” and “Diagnostics” to the design of a specific kind of evaluation test procedure.

The keyword structure below meets such requirements and allows an easier choice of the parts of interest.



## EVALUATION AND QUALIFICATION OF ELECTRICAL INSULATION SYSTEMS

### 1 Scope

This International Standard establishes the basis for estimating the ageing of electrical insulation systems (EIS) under conditions of either electrical, thermal, mechanical, environmental stresses or combinations of these (multifactor stresses).

It specifies the principles and procedures that shall be followed, during the development of EIS functional test and evaluation procedures, to establish the estimated service life for a specific EIS.

This standard should be used by all IEC technical committees responsible for equipment having an EIS.

### 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 60216-2, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

IEC 60216-3, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-5, *Electrical insulating materials – Thermal endurance properties – Part 5: Determination of relative thermal endurance index (RTE) of an insulating material*

IEC 60493-1, *Guide for the statistical analysis of ageing test data – Part 1: Methods based on mean values of normally distributed test results*

IEC 60544-1, *Electrical insulating materials – Determination of the effects of ionizing radiation – Part 1: Radiation interaction and dosimetry*

IEC/TS 61251, *Electrical insulating materials – AC voltage endurance evaluation – Introduction*

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

### 3 Terms and definitions

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

### 3.1 General terms

#### 3.1.1

##### **electrical insulation system**

EIS

insulating structure containing one or more electrical insulating materials (EIM) together with associated conducting parts employed in an electrotechnical device

#### 3.1.2

##### **electrical insulating material**

EIM

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

[IEC 60050-212:2010, 212-11-01, modified]

#### 3.1.3

##### **reference EIS**

established EIS evaluated on the basis of either a known service experience record or a known comparative functional evaluation

#### 3.1.4

##### **candidate EIS**

EIS under evaluation to determine its service capability (with regard to electrical, thermal, mechanical, environmental or multifactor stresses)

#### 3.1.5

##### **intended life**

design life of an EIS under service conditions

#### 3.1.6

##### **estimated life**

expected service life derived from either service experience or the results of tests performed in accordance with appropriate evaluation procedures, or both, as established by the responsible organization or technical committee

#### 3.1.7

##### **evaluation**

establishment of relationships between service requirements and life data obtained from service experience analysis or from the results of functional tests

### 3.2 Terms related to service stresses and ageing

#### 3.2.1

##### **ageing stress**

electrical, thermal, mechanical or environmental stress whose action on an EIS causes irreversible property changes

#### 3.2.2

##### **potentially destructive stress**

stress in service which can cause the failure of the aged EIS, alone or in combination with other stresses

#### 3.2.3

##### **service conditions**

combination of stresses and duty that are to be expected in a specific application of an electrical device

**3.2.4****reference operating conditions**

service conditions of the equipment to which the test conditions of the functional test procedure are related

**3.2.5****service requirements**

specified stresses, intended performance and duty of an electrical device

**3.2.6****service experience**

the quantitative and/or qualitative record during service, with or without failure of an EIS

**3.2.7****ageing**

irreversible changes of the properties of an EIS due to action by one or more stresses

NOTE 1 Some changes (e.g. hydrolytic changes) can be partly reversible if the ambient conditions change.

NOTE 2 Ageing leads to degradation of the EIS.

**3.2.8****intrinsic ageing**

irreversible changes of fundamental properties of an EIS caused by the action of ageing factors on the EIS

**3.2.9****extrinsic ageing**

irreversible changes of properties of an EIS caused by action of ageing factors on unintentionally introduced imperfections in the EIS

**3.2.10****interaction**

modifications of the type or degree of ageing produced by the combination of two or more stresses relative to their ageing effect if acting individually on separate objects

**3.2.11****direct interaction**

interaction between simultaneously applied stresses that differs from that occurring with sequentially applied stresses

**3.2.12****indirect interaction**

interaction which occurs between simultaneously applied stresses, which remains unchanged when the factors are applied sequentially

**3.3 Terms related to testing****3.3.1****functional test**

procedure to obtain information about the suitability of an EIS under specified conditions

**3.3.2****test object**

sample of original equipment or part thereof, or model representing the equipment completely or partially, including the EIS, to be used in a functional test

**3.3.3****accelerated ageing**

ageing resulting of an increase in the level and/or frequency of application of the stress beyond normal service conditions

**3.3.4****accelerated test**

functional test applying accelerated ageing to shorten testing time

**3.3.5****conditioning**

subjecting a specimen to an atmosphere of a specified relative humidity or complete immersion in water or other liquid, at a specified temperature for a specified period of time

**3.3.6****prediagnostic conditioning**

variable or fixed stresses, which can be applied continuously or periodically to an EIS to enhance the ability of a functional test to detect the degree of ageing

NOTE Prediagnostic conditioning may cause additional ageing.

**3.3.7****diagnostic factor**

variable or fixed stress which is applied to an EIS to establish the degree of ageing

**3.3.8****diagnostic test**

periodic or continuous application of a specified level of a diagnostic factor to a test object to determine whether or when the end-point criterion has been reached

**3.3.9****end-point criterion**

moment when a system is no longer able to fulfil its service purposes

**3.3.10****life**

time for a property to reach the end-point criterion for objects in functional tests

**3.3.11****test cycle**

in a test, repetitive period of application of one or more stresses, either sequentially or simultaneously, and of diagnostic factors

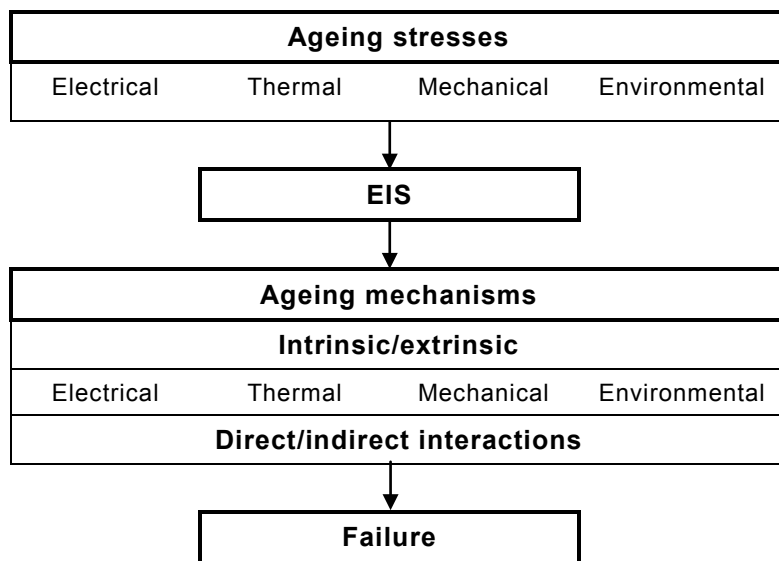
**3.3.12****subcycle**

defined period within test cycle

NOTE The subcycle may be, for instance, a period of application of high temperature and humidity for influencing the system properties, or application of high voltage for diagnostic purposes

**4 Ageing****4.1 Ageing mechanism**

Ageing is defined as the irreversible changes of the properties of an EIS due to action by one or more stresses. Ageing stresses may cause either intrinsic or extrinsic ageing. A schematic representation of the basic process is shown in Figure 1.



IEC 1231/11

**Figure 1 – Ageing of an EIS**

The type and level of contamination and/or the extent of imperfections in an EIS will, in many types of electrical apparatus, significantly affect the service performance. In general, the fewer and less severe the contaminant and/or defects in the EIS, the better is its performance. To avoid obtaining misleading results from functional tests, a candidate EIS should contain, as far as practicable, the full range of contaminants and/or defects expected when the actual system is used in service.

The ageing stresses produce electrical, thermal, mechanical or environmental ageing mechanisms that eventually lead to failure. During ageing, applied stresses, which initially do not affect the EIS, can cause additional ageing and, as a result, modify the rate of degradation.

When ageing is dominated by one ageing factor, this is referred to as single-factor ageing. Multifactor ageing occurs when more than one ageing factor substantially affects the ageing of the EIS. Ageing factors can act synergistically, i.e. there can be direct interactions between the stresses. Interactions may be either positive or negative.

The ageing of a practical EIS may be complex and failure is usually caused by a combination of ageing mechanisms, even if there is only one dominant ageing factor as, for example, in single-factor ageing.

Where experience or existing knowledge of how a specific EIS will perform in service is limited, the user of this standard shall decide whether single or multifactor test procedures are appropriate for his specific equipment or apparatus.

**NOTE** The classification of the operational environments of electrical equipment is dealt with in IEC publications prepared by IEC technical committee 75, and methods for environmental endurance testing of electrical equipment are described in IEC publications prepared by IEC technical committee 50 (notably IEC sub-committee 50B), see bibliography.

When speaking of environmental effects, this is understood to comprise environments other than the normal standard laboratory atmospheres specified in IEC 60212.

A number of other standards that provide methods of exposure or characterization of insulation are listed in the bibliography.

## 4.2 Assessment of ageing mechanisms

Figures 2, 3, 4 and 5, present four flow charts which describe respectively in some detail intrinsic and extrinsic electrical, thermal, mechanical and environmental ageing of an EIS. Each chart is based on the service experience of different types of EIS and shows possible mechanisms of deterioration and failure that can occur for the different types of ageing and the interactions between ageing factors. Although several failure mechanisms are shown, the charts are not intended to be exhaustive of mechanisms that might be found in actual service conditions of all equipment. It is important to note that ageing that leads to possible failure is usually caused by more than one mechanism.

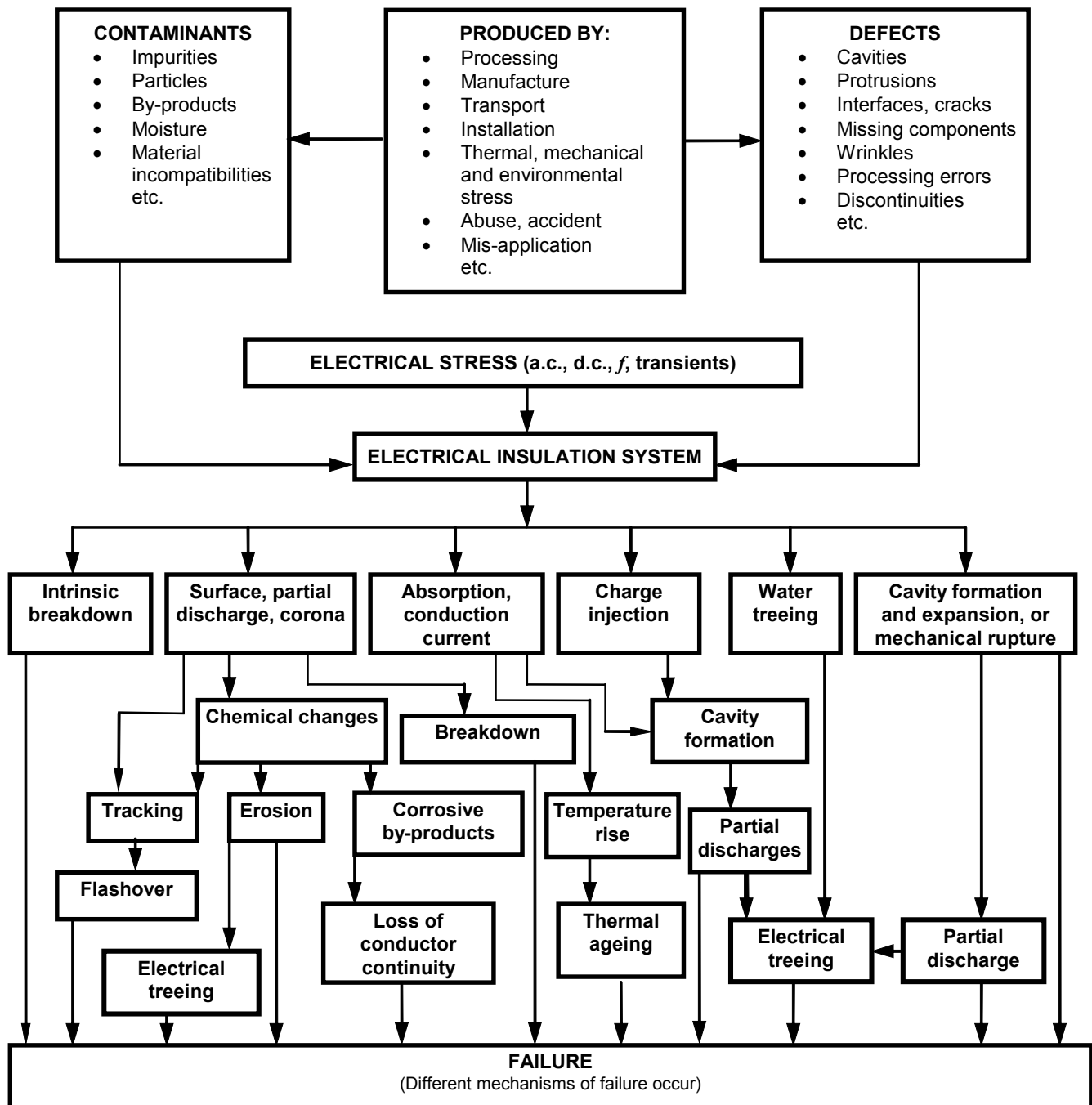
These charts should be used as follows:

- a) as a checklist to determine the ageing mechanisms of equipment and apparatus. The mechanisms can occur sequentially or simultaneously;
- b) to develop functional and accelerated ageing tests or test cycles. The magnitudes and types of applied stresses and their duration will depend upon how they affect the ageing mechanisms;
- c) to develop suitable diagnostic tests or test cycles to assess the condition of the EIS.

Based on knowledge of service experience, operating conditions and the properties of the components of the EIS under consideration, the user of this standard should select one or more charts that show the main ageing factor or factors. The various ageing mechanisms that lead to failure should be carefully examined, taking into account the levels of contaminants and defects in the EIS. A revised chart, which only includes the relevant ageing mechanisms, should then be produced as an aid in the development of the functional ageing and diagnostic test cycles.

If there is insufficient information available concerning service experience and/or the possible ageing mechanism, then the ageing conditions should be based upon the most severe levels of stresses expected in service for which the EIS has been designed.

### 4.3 Electrical ageing



IEC 1232/11

NOTE Other stresses may contribute to failure.

**Figure 2 – Intrinsic/extrinsic electrical ageing of practical EIS**

Electric ageing (either a.c., d.c. or impulse) involves:

- the effects of partial discharges when the local field strength exceeds the breakdown strength in the liquid or gaseous dielectric adjacent to, or included in, the EIS;
- the effects of tracking;
- the effects of treeing;
- the effects of electrolysis;

- e) the effects, related to those above, on adjacent surfaces of two insulating materials where tangential fields of relatively high value can occur;
- f) the effects of increased temperatures produced by high dielectric losses;
- g) the effect of space charges.

Figure 2 shows intrinsic/extrinsic electrical ageing where electrical stresses are considered to be the main ageing factor. Consider the example of a simple EIS consisting of two parallel plane conductors embedded in an insulating material. Protrusions are known to occur on the surfaces of conductors, and impurities (e.g., dust particles, etc.) can be included within the insulation. The accelerated ageing should, therefore, be carried out by using ageing factors that increase charge injection, for example by high voltage, and the diagnostic tests should be designed to enable measurement of the effect of the injected charge and/or the partial discharge characteristics.

In many practical EIS, the electrical ageing process that leads to failure is complex. No rigid mathematical models have yet been developed which predict fully how the ageing factors affect the life of an EIS. However, one empirical relationship, the inverse power model, is often used to relate a.c. and d.c. electrical stress with life. This states that:

$$L \propto V^{-n}$$

where

$L$  is the life (time to failure or time to end-point);

$V$  is the voltage;

$n$  is the voltage life exponent.

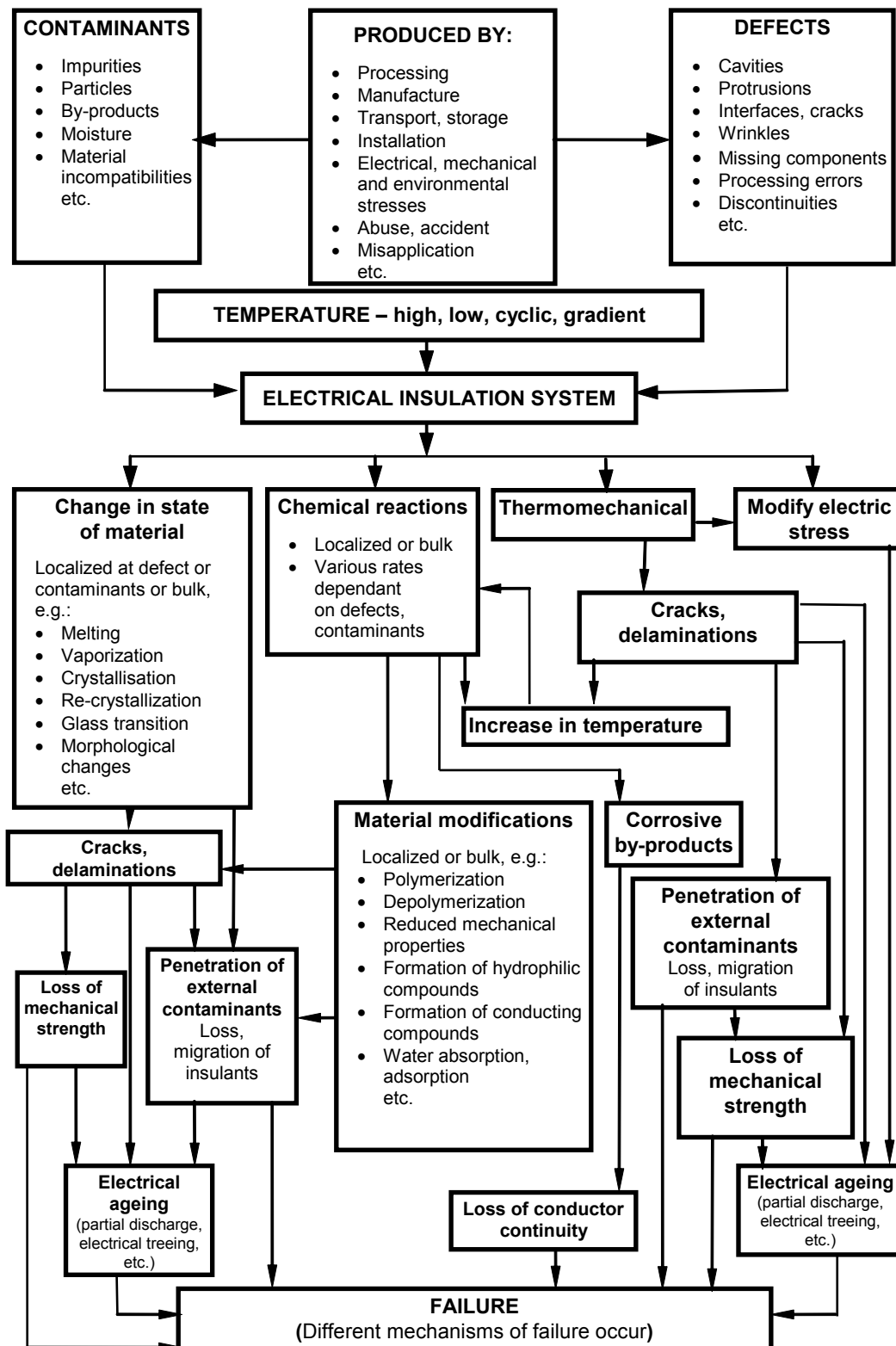
The inverse power law model predicts a linear relationship between life and voltage when plotted on log-log graph paper. Other models may be used.

Electrical ageing may also be accelerated by testing at a higher frequency than that experienced in normal service. The frequency increase shall have been shown to provide no change of the ageing mechanism, in the stress range, for either the candidate or the reference system.

In special cases it may be possible to perform electrical endurance tests with stepwise increasing stress for each test object. It is also necessary to specify a definite mathematical relationship between stress level and time to failure, as well as a method for reducing test results to a common time or a common stress level value. Either fixed or increasing stress levels may be used in cyclic tests.

For data processing and life line presentations, refer to IEC/TS 61251 and IEC 62539.

#### 4.4 Thermal ageing



IEC 1233/11

NOTE Other stresses may contribute to failure.

Figure 3 – Intrinsic/extrinsic thermal ageing of practical EIS

Thermal ageing involves

- a) the progress of chemical and physical changes as a consequence of chemical degradation reactions, polymerization, depolymerization, diffusion, etc.,
- b) thermomechanical effects caused by the forces due to thermal expansion and/or contraction.

The increases in the rate of chemical and physical processes proceeding towards the state of thermodynamic equilibrium are the major causes of thermal ageing. Many uncomplicated ageing processes (e.g. first order chemical reactions) follow within restricted temperature intervals the Arrhenius equation, i.e.:

$$L = A \exp(-E/kT)$$

where

$L$  is the life expectancy;

$A$  is a constant;

$E$  is the activation energy;

$k$  is the Boltzmann constant;

$T$  is the thermodynamic temperature.

The expected life at a particular temperature can be found by extrapolation of data plotted using log life versus  $1/T$  coordinates. For further information, see IEC 60216-3.

The suggested values for the evaluation of the EIS can be selected from those shown in Table 1. To produce accelerated ageing, a minimum of three temperatures shall be chosen from the appropriate column in the table for the tests. The lowest temperature shall be selected such that a failure criterion will be reached after a minimum of 5 % of the intended service life of the candidate system or a minimum of 5 000 h for the lowest temperature. The next two highest temperatures shall be chosen at 20 K intervals. If more than three test temperatures are needed, then 10 K intervals may be used. Preferred ageing temperatures are listed in Table 1.

NOTE 1 Testing has confirmed that for many EIS, the life is halved for a rise in temperature, which is approximately constant within a restricted temperature range dependent on the EIM involved. For the majority of these EIS, the temperature rise halving the life has a value between 8 K to 15 K.

NOTE 2 In some cases, the above test procedure may not be optimal, for instance in the case of short-life equipment where it may lead to unrealistic high ageing temperatures.

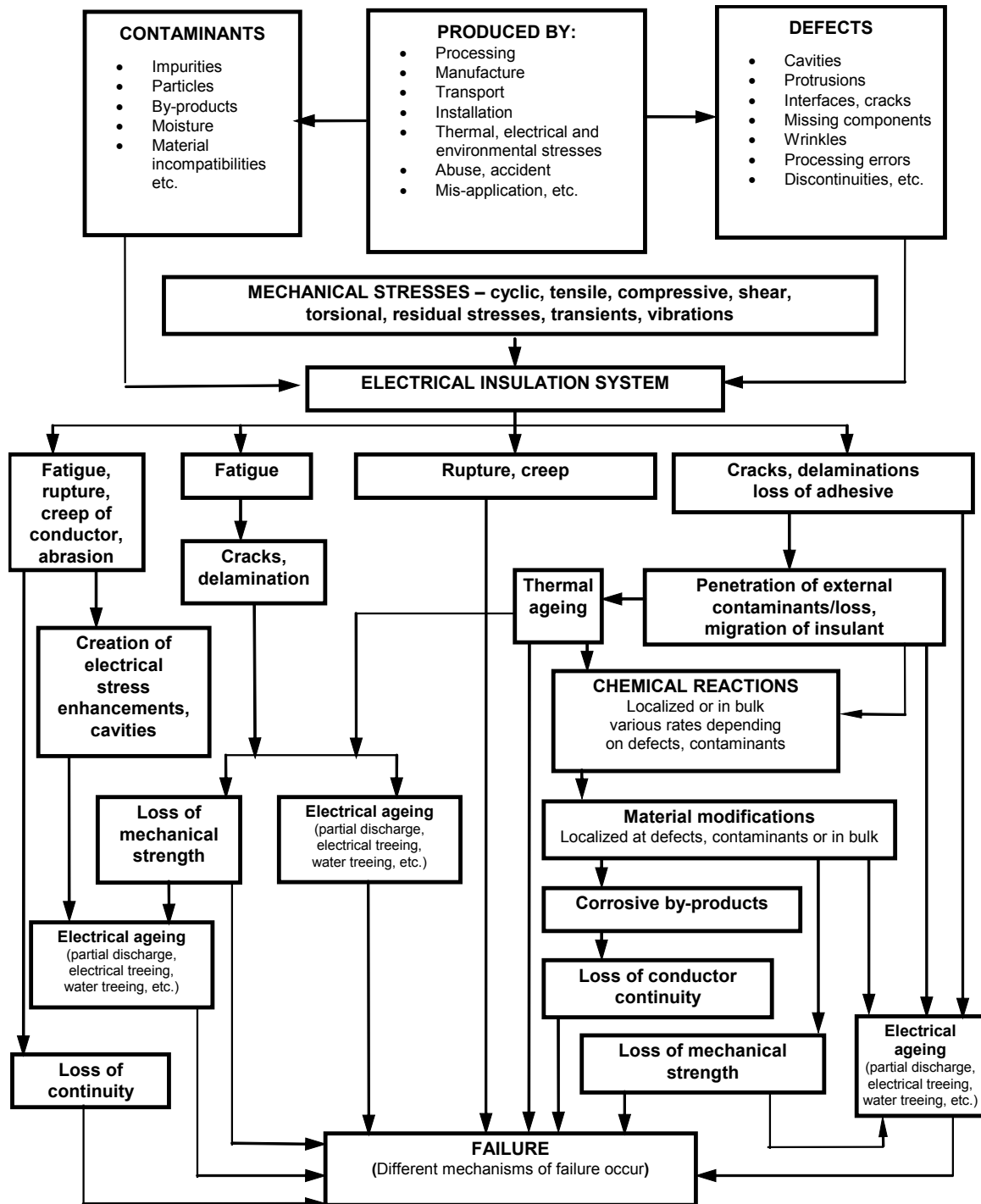
For EIS, where one or more EIM have transition temperatures (e.g. melting, boiling, crystallization), the maximum test temperature should be below the relevant transition temperature(s).

**Table 1 – Ageing temperatures**

| <b>Service temperatures<br/>°C</b> | <b>55</b> | <b>75</b> | <b>90</b>         | <b>105</b>         | <b>120</b>         | <b>130</b>         | <b>155</b>         | <b>180</b>         | <b>200</b>         | <b>220</b>         | <b>250</b> |
|------------------------------------|-----------|-----------|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|------------|
| <b>Thermal class</b>               | <b>55</b> | <b>75</b> | <b>90<br/>(Y)</b> | <b>105<br/>(A)</b> | <b>120<br/>(E)</b> | <b>130<br/>(B)</b> | <b>155<br/>(F)</b> | <b>180<br/>(H)</b> | <b>200<br/>(N)</b> | <b>220<br/>(R)</b> | <b>250</b> |
| <b>Ageing temperatures<br/>°C</b>  | 135       | 155       | 170               | 185                | 200                | 210                | 235                | 260                | 280                | 300                | 330        |
|                                    | 125       | 145       | 160               | 175                | 190                | 200                | 225                | 250                | 270                | 290                | 320        |
|                                    | 115       | 135       | 150               | 165                | 180                | 190                | 215                | 240                | 260                | 280                | 310        |
|                                    | 105       | 125       | 140               | 155                | 170                | 180                | 205                | 230                | 250                | 270                | 300        |
|                                    | 95        | 115       | 130               | 145                | 160                | 170                | 195                | 220                | 240                | 260                | 290        |
|                                    | 85        | 105       | 120               | 135                | 150                | 160                | 185                | 210                | 230                | 250                | 280        |
|                                    | 75        | 95        | 110               | 125                | 140                | 150                | 175                | 200                | 220                | 240                | 270        |

#### 4.5 Mechanical ageing

Electrotechnical equipment may experience mechanical stresses from many causes during manufacture, transport, installation and operation. In certain types of equipment the presence, during operation, of mechanical stresses from electrodynamic, electromagnetic and thermal forces, has been shown to be one of the main causes of changes in their EIS.



IEC 1234/11

NOTE Other stresses may contribute to failure.

**Figure 4 – Intrinsic/extrinsic mechanical ageing of practical EIS**

Mechanical ageing involves

- fatigue failure of insulation components caused by a large number of low-level stress cycles,
- thermomechanical effects caused by thermal expansion and/or contraction,
- rupture of insulation by high levels of mechanical stress such as can be caused by external forces or operating conditions of the equipment,
- abrasive wear caused by relative motion between equipment components,

- insulation creep or flow under electrical, thermal or mechanical stresses,
- presence of other factors,
- types of mechanical testing

NOTE These phenomena can be localized and unevenly distributed throughout the volume of the insulation.

In practice, in many EIS, the mechanical ageing processes that lead to failure are complex, as shown by Figure 4. No rigid mathematical models have yet been developed which predict fully how the ageing factors affect the life of an EIS. However, one first approach empirical relationship is the inverse power model, which is often used to relate mechanical stresses with life:

$$L \propto M^{-m}$$

where

$L$  is the life (time or number of cycles to failure or to end-point criterion);

$M$  is the mechanical stress;

$m$  is the life line exponent.

The inverse power law model predicts a linear relationship between life and voltage when plotted on log-log graph paper. Other models may be used.

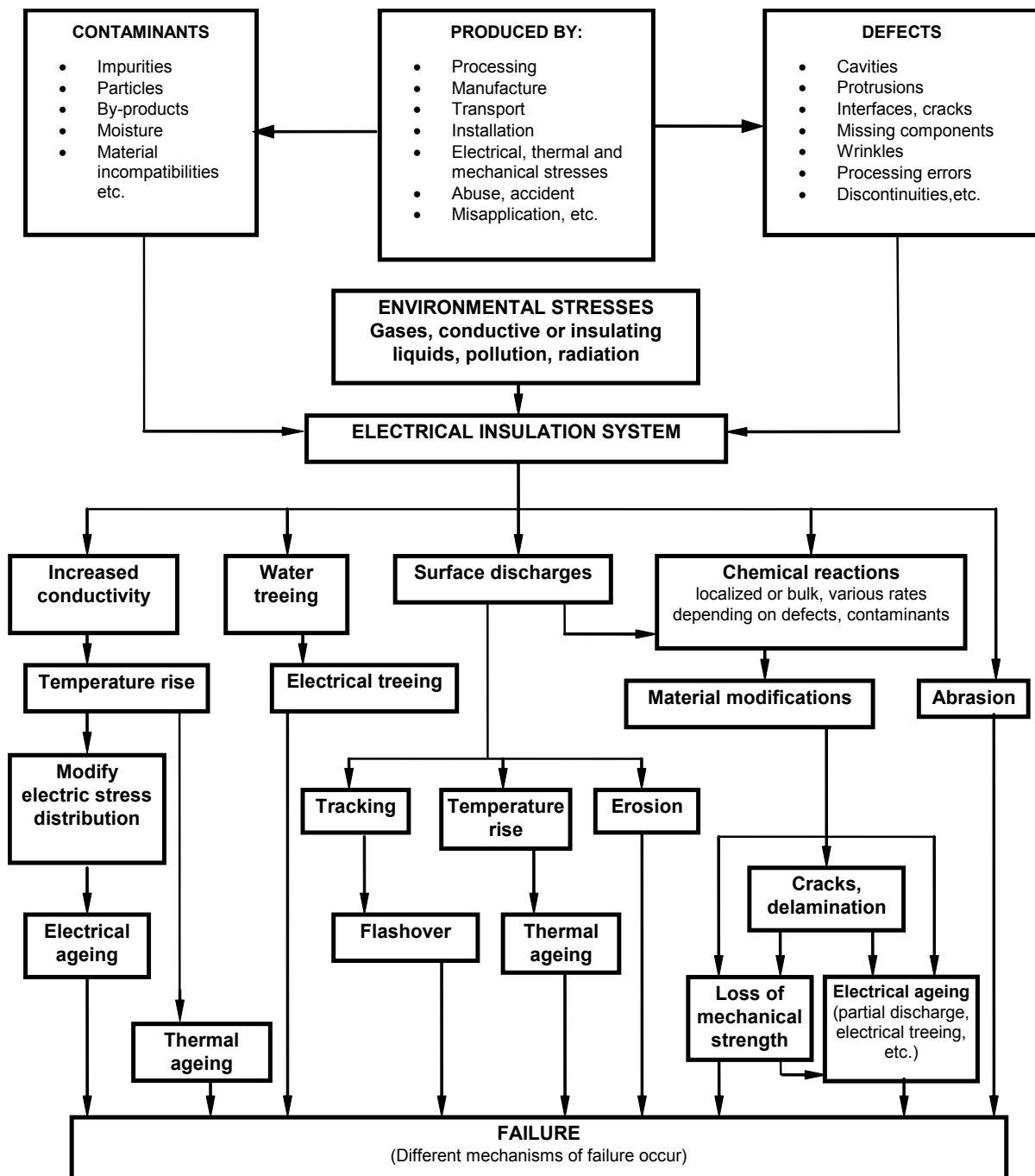
For data processing and life line presentations refer to IEC/TS 61251 and IEC 62539.

#### 4.6 Environmental ageing

The following influences contribute to environmental ageing:

- moisture;
- oxygen;
- chemicals;
- biological agents;
- weathering;
- contaminants;
- radiation;
- aerospace conditions;
- vacuum conditions.

As there may be different mechanisms for environmental ageing (see Figure 5) there are no general models. When environmental stresses affect chemical reaction rates, then the thermal ageing model and the Arrhenius equation may be used (see 4.4)



IEC 1235/11

NOTE Other stresses may contribute to failure.

**Figure 5 – Intrinsic/extrinsic environmental ageing of practical EIS**

#### 4.7 Accelerated ageing

Application of life models to fit accelerated life tests is to provide quantities for the evaluation of EIS (or performance under service conditions), particularly in relation to comparative tests performed on a reference material, of known service performance.

Among the factors that influences accelerated ageing are

- acceleration by frequency increase,
- repetition rate acceleration,
- acceleration by stress level increase.

## 4.8 Multifactor ageing

Multifactor ageing occurs when more than one ageing stress substantially affects the ageing of the EIS. Ageing stresses can act synergistically, that means, there can be direct interactions between the stresses. Interactions may be either positive or negative and therefore the ageing models can be very complex.

When ageing is dominated by a single stress, then refer to 4.3 to 4.5 for relevant ageing models.

## 5 Basic evaluation considerations

### 5.1 Elements for preparing an evaluation method

The preparation of methods for EIS evaluation requires careful consideration of the elements shown in Figure 6:

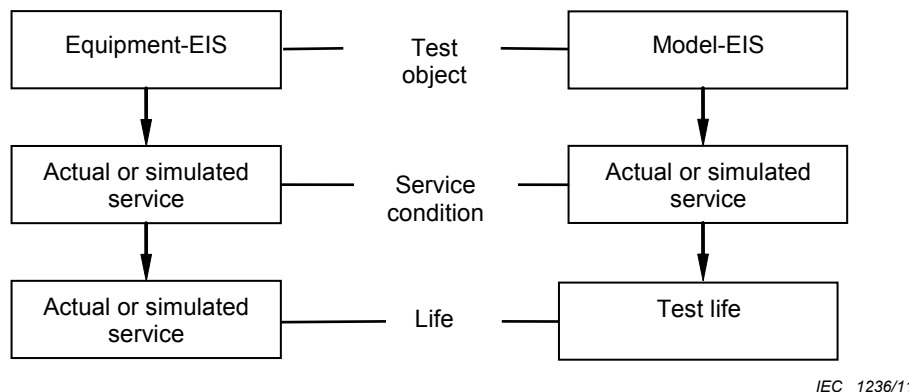


**Figure 6 – Elements of evaluation methods**

#### 5.1.1 Object

The EIS object can be either a service-proven, a new (candidate) EIS, a component part or a model of the original electrical equipment. Generally, a maximum of technical information about the EIS will be advantageous, as such information may be necessary if EIS models are to be built.

#### 5.1.2 Service conditions

Service conditions for the electrical equipment, of which the EIS forms a part, should be known, and may be available from the following:

- the designated stress figures when new equipment and/or an EIS are designed for special service conditions, including environment and duty;
- service records when a service-proven EIS has to be evaluated. Stress levels may then be defined by stress intervals or by reported maximum stress limits related to duty figures indicating the stress-time relation;
- the known service conditions of a reference system that has already been qualified on the basis of service records and to which a candidate EIS will be compared by parallel functional testing under comparable or even equal service conditions.

**NOTE** Accelerated testing requires verification of identical or equivalent ageing mechanisms compared to the mechanisms under operating service conditions.

### 5.1.3 Life values

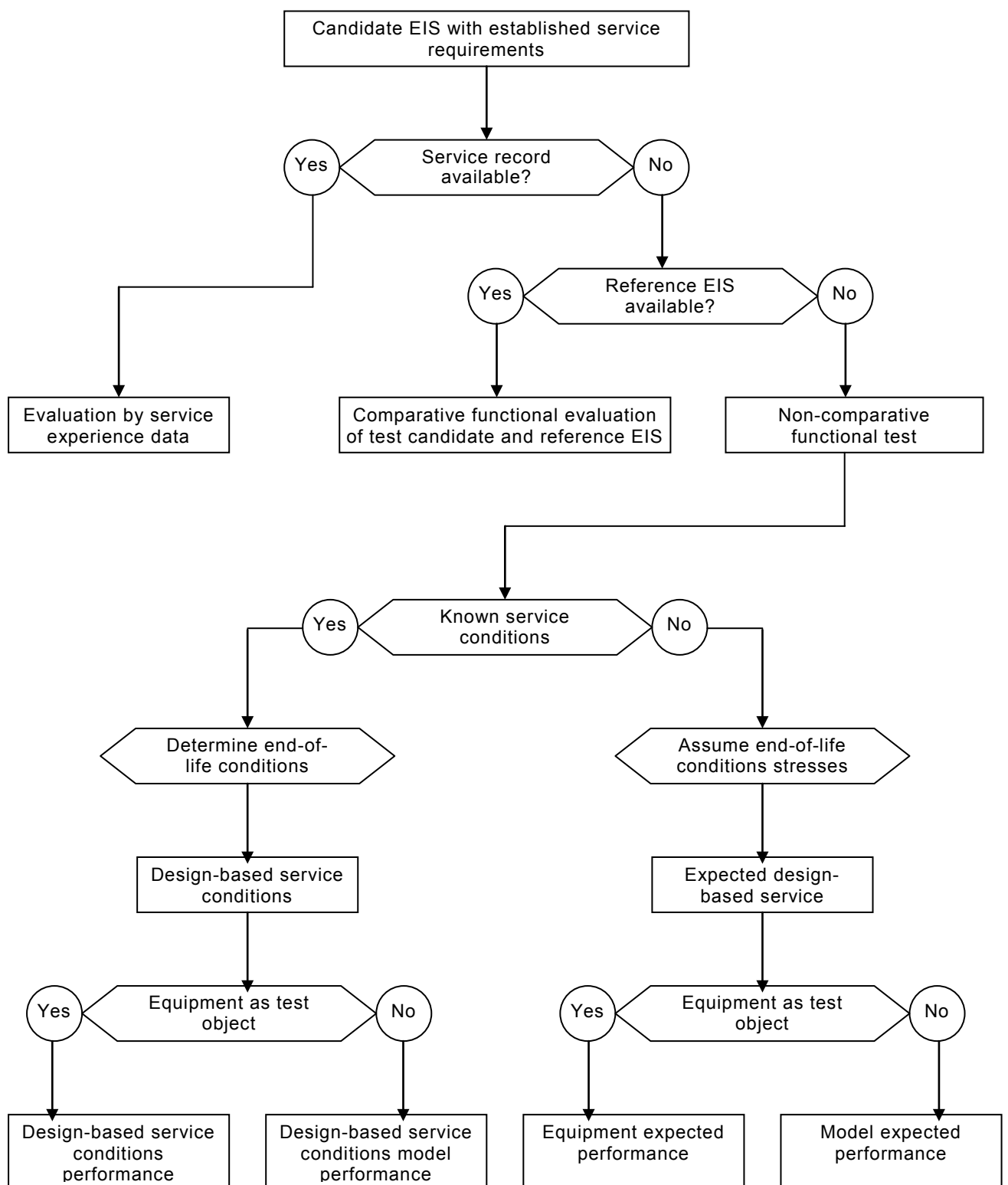
Life values are related to EIS, service conditions, and user considerations. They shall be available as one of the following variants:

- a) EIS service time to failure (end-of-life defined by end-point criterion);
- b) functional test life of EIS to end-point criterion, with or without test acceleration.

NOTE The knowledge of the failure rate of any system is fundamental for system reliability inference.

## 5.2 Types of evaluation procedures

Depending on what source supplies the necessary data for the evaluation of a candidate EIS, three types of procedure are distinguished (see Figure 7). When selecting the test procedure, the user of this standard may use the flow chart in Figure 1, which presents, from left to right, a sequence of "performances" with decreasing influence of direct service experience and increasing influence of defined service conditions.



IEC 1237/11

Figure 7 – Type of evaluation procedure

### 5.3 Choice of the test object

The choice of the test object can influence the test results and will also influence the cost of functional evaluation. The flow chart of Figure 8 demonstrates the criteria for the choice.

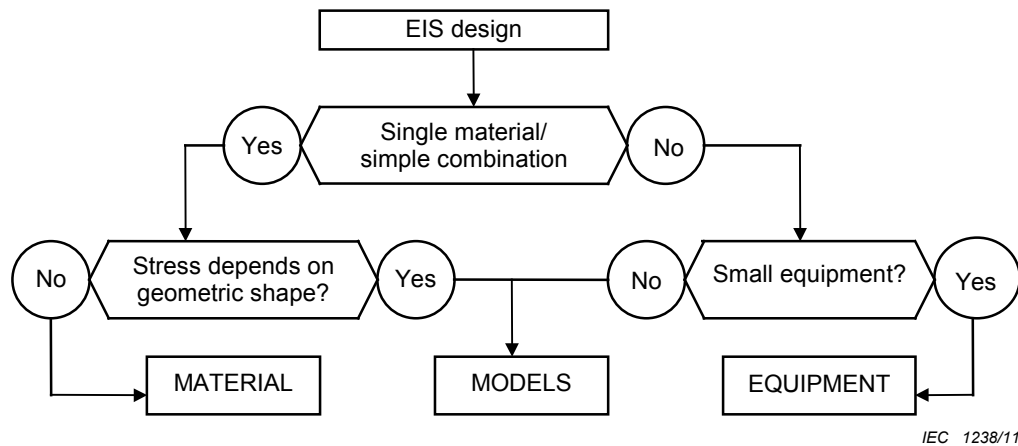


**Figure 8 – Selection of test object**

Depending on the size of the object and other practical considerations, a functional test on equipment, components or models can be used. If a “simple” EIS contains a single EIM or a simple combination of materials that has been thermally evaluated as a single EIM, and the stress distribution is independent of the insulating part’s shape or size, the EIS life may be derived by means of appropriate EIM endurance tests. The user of this standard should decide when such simplified procedures are appropriate.

### 5.4 Experimental test procedures

In functional testing, with or without a reference EIS, the test objects are submitted to specified ageing stress schedules, usually in stress cycles, to simulate service ageing. Diagnostic procedures are periodically applied to establish its progress. The complexity of the test influences the required test effort and cost. The flow diagram of Figure 9 points to three different types of tests, with increasing effort from left to right. The criteria are the number of ageing factors, the test object and possible interactions between stresses.

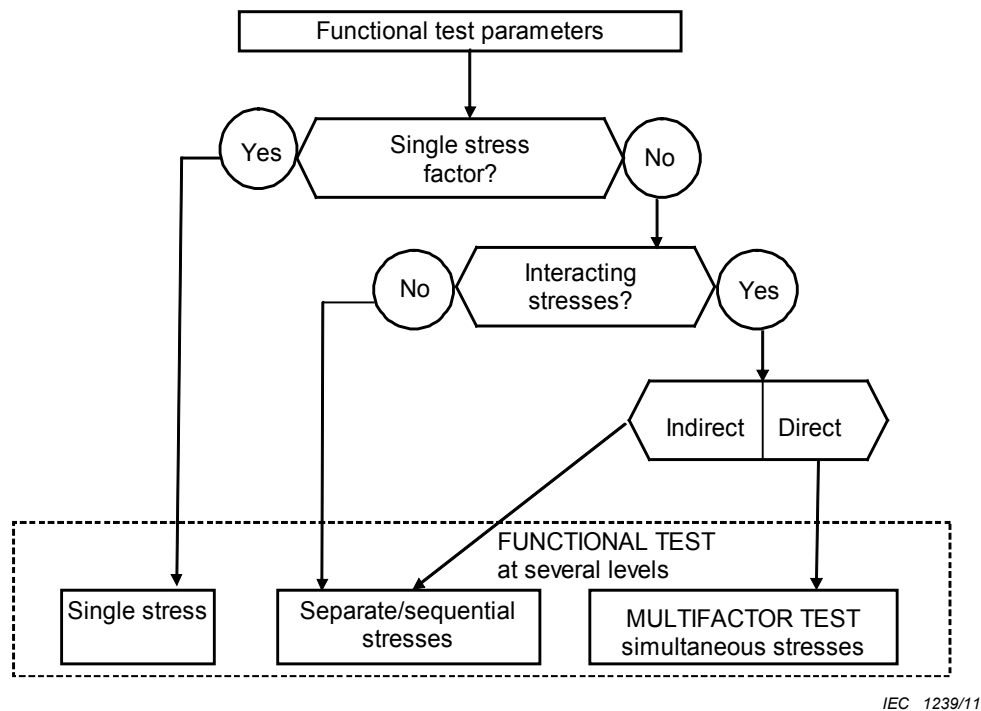


**Figure 9 – Establishing the test method**

## 5.5 Conclusions for standardization practices

Figure 8 and 9, will help the user of this standard to decide about the cases to be considered before starting development of standards for EIS evaluation.

Possible cases include the following:

- service experience data are available for direct evaluation; requires the formulation of special rules about the necessary information and how to analyse it;
- a simplified life test on an EIM; may be used when existing material test procedures are available for the candidate EIS;
- comparative functional testing using a model or part of the equipment as the test object; requires analysis of the ageing mechanisms under simulated service conditions in order to decide on the appropriate type of test.

In principle, comparative functional testing is possible without detailed knowledge of the ageing mechanisms. The essentials of functional testing are knowledge of the acting service stresses, their correct simulation and maintenance of the equivalence of the ageing effects.

## 6 Functional ageing tests

### 6.1 Test objects

#### 6.1.1 Construction of test objects

Test objects shall be either complete units that incorporate the EIS or shall be models, constructed to adequately represent the configuration of the finished component to be evaluated. All objects shall be subjected to the full normal or intended manufacturing processes as far as is practicable. Where components that will use the candidate EIS have mechanical attachments in service that are considered to influence the ageing processes, these shall be simulated on the test object.

Test objects that include several internal conducting component parts that will have electric stress applied between them, either during the ageing or the diagnostic subcycle, shall be designed and constructed to enable verification of the ageing effect.

#### **6.1.2 Number of test objects**

Where feasible, a minimum of five test objects shall be aged for each of the electrical, thermal, mechanical, environmental or multifactor stress combinations included in the evaluation programme.

NOTE As a minimum number of five samples is required to reach the end-point criterion, to obtain statistically significant results, it may be necessary to include more than five samples in each sub-test.

#### **6.1.3 Quality assurance tests**

Before starting the first ageing subcycle, a visual inspection and all normal product quality assurance tests shall be carried out on all test objects.

#### **6.1.4 Preconditioning subcycle**

If appropriate, test objects should be preconditioned to better represent the condition of the EIS in service.

#### **6.1.5 Initial diagnostic tests**

Each test object shall be subjected to the diagnostic tests selected for the evaluation procedure before starting the first ageing subcycle.

#### **6.1.6 Reference EIS**

A reference EIS shall be tested using the same test procedure as that used for the candidate EIS, in the same laboratory, using the same type of test equipment. The performance of the reference EIS shall have been established either by service experience under typical operating conditions, or by appropriate functional testing in the range of the reference operating conditions.

### **6.2 Test conditions**

#### **6.2.1 Continuous and cyclic testing**

Functional tests may be performed as a continuous ageing test if the end-point criterion is given as time to electrical or mechanical failure or breakdown, either at ageing stress level or caused by a continuously applied diagnostic stress. Alternatively, a fixed time test followed by either a breakdown or other diagnostic test can be appropriate.

More universally applicable are cyclic life tests composed of a repeated sequence of different ageing and diagnostic subcycles. This sequence of functional tests permits the application of either single or multifactor ageing tests with a minimum of unintended interference between different ageing factors and mechanisms.

The seasonal and daily variations of the outdoor environment result, to a higher or lower degree depending on the level of protection, in corresponding cyclic variations of the environmental conditions at the location of the equipment insulation.

In the absence of complete encapsulation, the risk of periodic condensation ought always to be considered. The "breathing" caused by periodic temperature variations may cause a unidirectional motion of particulate contamination from the outside to the inside of equipment that is not hermetically enclosed.

When these effects are simulated in functional tests, acceleration may be obtained through reduction of the cycle duration. A limitation is, however, given by the thermal inertia and diffusion constants of the test object and its parts.

### **6.2.2 Levels of test stresses, ageing factors and diagnostic factors**

Test stress conditions shall consider the most severe overall stress conditions experienced in service for which the EIS is designed. These conditions need not occur necessarily at the maximum values of the individual stresses. The reference operating conditions shall be clearly defined for the evaluation procedure and the levels and types of diagnostic factors shall be pertinent to these reference operating conditions.

Stress levels for the ageing subcycles shall be selected so that the mechanisms of ageing are not significantly different from those operating at the most severe stress levels in normal service. Increasing the stress level to accelerate ageing, may be permissible when it does not significantly change the ageing mechanism.

NOTE Knowing the ageing mechanism is fundamental to establish which stresses are predominant and to refer to them to design a functional test and choose the appropriate ageing models.

Multifactor ageing tests are preferred as they best simulate normal service. When this procedure is not adopted, then either a sequential subcycle or a programme of single stress subcycles should be used.

Following each ageing subcycle, a conditioning subcycle and a diagnostic subcycle shall be performed where necessary. Failure of any part of the test specimen during a diagnostic test constitutes failure of the whole system and shall be reported as such. Electric stress shall be used as the main diagnostic factor in assessing the condition of the aged test objects. On low-voltage equipment it is often necessary to include a pre-diagnostic procedure to ensure that the electric stress, used as the diagnostic factor, helps to detect weaknesses developed during the ageing cycle.

## **6.3 Determination of EIS service life**

### **6.3.1 Extrapolation of life test results**

Results from testing performed at a minimum of three elevated stress levels may allow extrapolation of the stress-life-function into the range of the intended service stresses. For optimal extrapolation the coordinates of the graphical diagram of the stress/life function should be selected, whenever possible, such that a linear stress/life diagram is achieved. The degree of extrapolation should not exceed two orders of magnitude on the time scale of the log time plot.

For electrical, thermal and mechanical ageing, mathematically formulated laws of life are presented in 4.3, 4.4 and 4.5, respectively.

### **6.3.2 Comparison of life test data**

Valid comparison testing of candidate and reference EIS requires that both systems be tested according to 6.3.1. When comparing these results, the candidate EIS may be considered an acceptable alternative if the life obtained, at selected stress levels, is comparable to or better, than the one obtained for the reference EIS.

NOTE 1 Comparable or better may mean, e.g. that the 95 % lower confidence bound of the candidate EIS falls within or above the 95 % confidence interval of the reference EIS.

NOTE 2 The significance of the test result can be assessed by means of statistical analysis (see e.g. IEC 60216-5 for thermal ageing).

This will then justify the declaration: “Candidate EIS-service life is expected to be either equal to or greater than the experienced service life of the reference EIS for the specified conditions”.

## 6.4 Diagnostics

### 6.4.1 Diagnostic tests – End point criteria

The user of this standard responsible for evaluation of an EIS for a specific type of equipment shall define the end-point criteria in either absolute or relative terms (e.g. for thermal evaluation, see IEC 60216-2 and IEC 60216-3).

The fundamental requirement for the diagnostic test procedure is that it shall include the specification of an end-point. The endurance test procedure may be cyclical or continuous, depending on the required diagnostic tests and ageing complexity, as depicted in Table 2.

**Table 2 – Cyclical and continuous procedures**

| Case number                      | 1        | 2   | 3   | 4   | 5          | 6   |
|----------------------------------|----------|-----|-----|-----|------------|-----|
| Procedure:                       | Cyclical |     |     |     | Continuous |     |
| Single factor ageing             | Yes      | No  | No  | No  | Yes        | No  |
| Multi-factor simultaneous ageing | No       | Yes | No  | No  | No         | Yes |
| Multi-factor sequential ageing   | No       | No  | Yes | Yes | No         | No  |
| Diagnostic tests                 | Yes      | Yes | Yes | No  | No         | No  |

Cyclical procedures, cases 1 to 4 in Table 2, are suitable when other than ageing stresses are expected to cause failure, or when the ageing stresses are being applied sequentially. They usually consist of several test cycles, each cycle being composed of subcycles.

- The ageing subcycles, conducted at elevated stress levels, serve to age the insulation on an accelerated basis. The degree of acceleration is selected in relation to the service stress level of the ageing factor.

NOTE In such cases when exceptional ageing stress levels occur in service more or less regularly (for example overload periods, raising the temperature appreciably), the ageing subcycle may be divided correspondingly into periods of lower and higher stress levels.

- After each ageing subcycle, the test specimens are subjected to a diagnostic test subcycle (except for case number 4 of Table 2), which may include voltage tests, partial discharge tests, mechanical stress tests, exposure to humidity or chemicals and other diagnostic tests. Some ageing stresses may not directly cause failure, whereas some (for example voltage) can, when acting simultaneously as ageing and diagnostic factors.

The extent and severity of the diagnostic tests should correlate with actual or expected potentially destructive stresses. For this purpose, guidelines are given in 4.3.2 that enable the user of this standard to select the appropriate test procedure. When feasible, the equipment technical committee may select the relevant test procedures to be used in its domain.

Continuous procedures, case numbers 5 and 6 in Table 2, are suitable when the ageing factor, or several ageing factors in combination, are expected simultaneously to be the most important failure-causing factor. The end-point may be the detection of a physical weakness that has developed during the period. It may also be an event or condition, such as failure during a diagnostic treatment or attainment of a limiting value of a specific property. The end-point may be characterized either by a single condition (e.g. level X of property A), or by one of several alternatives (e.g. level X of A or level Y of B, etc.) or it may be given as a combined condition (e.g. level X of A and level Y of B, etc.).

Typical criteria are given below:

- a) high-voltage proof tests at  $N$  times the normal service voltage (where  $N$  is either 1,5; 2; 3 or 4);
- b) impulse or surge proof test at  $S$  times the normal maximum service level (where  $S$  is either 1; 1,5; 2 or 3);
- c) percentage increase in incremental loss tangent, partial discharge level, etc., above the value for the system before ageing at a defined voltage or over a given voltage range;
- d) appearance of partial discharge (e.g. in solid organic insulation);
- e) leakage current above value before ageing at a defined voltage and temperature;
- f) percentage loss of a selected property.

#### 6.4.2 Additional specific tests

Additional diagnostic tests may be necessary to define the end-point criteria of specific equipment or apparatus. When doing this, all information available from stress analysis, properties of the insulation, and failure analysis, shall be used as well as from typical operating conditions. The decision on whether to include a more comprehensive diagnostic shall be decided by the user of this standard.

#### 6.5 Analysing the data

The specific rules for analysing the test data obtained from either single or multifactor stress evaluation programmes shall be the responsibility of the user of this standard. The level of complexity will be dependent on the type of apparatus for which the EIS has been designed. If design service parameters of the candidate EIS indicate stresses higher than those of the reference EIS, then functional tests of the candidate EIS shall reach the same EIS test-life as the reference EIS at the lower level. Analysis of the data should be carried out in accordance with Clauses 4 and 5.

For data processing and life line presentations, refer to IEC/TS 61251 and IEC 62539.

#### 6.6 Test report

The test report should include:

- a) identification of the applicable evaluation standard;
- b) description of the EIS, including manufacturing of the specimens;
- c) description of the service experience concerning the reference system, including interactions (when necessary);
- d) identification of model, if used; or of type of coordinate system used for life data;
- e) reference operating conditions;
- f) description of any preconditioning or pre-ageing used;
- g) ageing stresses and their levels and acceleration in the tests;
- h) test sequence and duration and number of samples;
- i) diagnostic treatments, tests and measurements;
- j) end-point criteria selected;
- k) ageing curves (to confirm whether or not the candidate EIS may be accepted, the procedure for checking the linearity of the test data, specified in IEC 60493-1, shall be carried out);
- l) times to reach the end-points, individual values and medians and statistical treatment when feasible;
- m) summarized conclusion of the new system in comparison to the reference EIS.

## Annex A (informative)

### Glossary

#### A.1 General remark

This glossary contains terms and definitions taken from various sources.

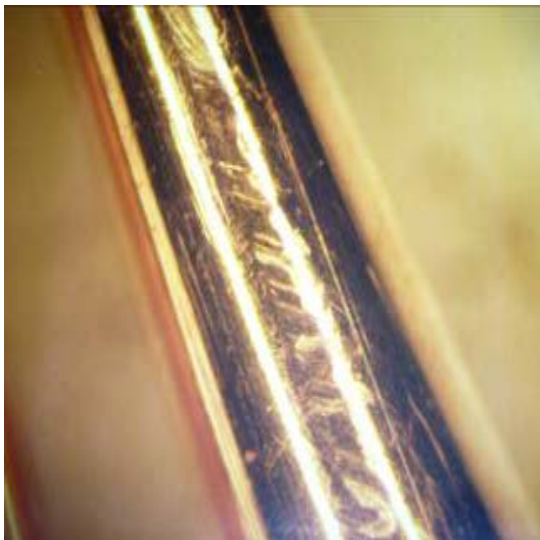
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#### A.2 Abrasion

Erosion of material from a solid surface by the action of another material. Abrasion can be measured as loss of mass by the Taber abrasion test according to ISO 9352 or ASTM D 1044.

Example below, Figure A.1 and A.2: During the process of magnet wire manufacturing, the transfer machine tool is causing abrasion of the wire surface, like a capstan, resulting in surface failure.



IEC 1240/11

**Figure A.1 – Surface abrasion damage**



IEC 1241/11

**Figure A.2 – Surface enamel peeling  
like string**

**References – Figures A.1 and A.2**  
SAKANO, T., *unpublished pictures*.

### A.3 Absorption (chemical)

A physical or chemical phenomenon or a process in which atoms, molecules, or ions enter some bulk phase – gas, liquid or solid material. This is a different process from adsorption, since the molecules are taken up by the volume, not by surface. A more general term is “sorption” which covers adsorption, absorption, and ion exchange.

### A.4 Absorption (dielectric)

Dissipation of electrical energy into thermal energy in a dielectric.

### A.5 Absorption current (including electrical absorption)

The absorption current is the transient current, associated with the polarization mechanisms, that appears in a dielectric when a step voltage is applied. Indeed, applying a DC voltage to a dielectric specimen between two electrodes, the total current which flows,  $i$ , presents three components:

$$i = i_i + i_c + i_{abs}$$

where

$i_i$  is the charging current, associated with a change in the electric field amplitude;

$i_c$  is the conduction current, that is measurable in the steady state;

$i_{abs}$  is the absorption current, related to polarization and decreasing exponentially with very slow decay time.

The absorption current can be measured through DC charging/discharging current tests, using, as an example, the measurement set-up shown in Figure A.3 and preparing the insulating sample as shown in Figure A.4. Charging/discharging current on high-density polyethylene (HDPE) is shown in Figure A.5.

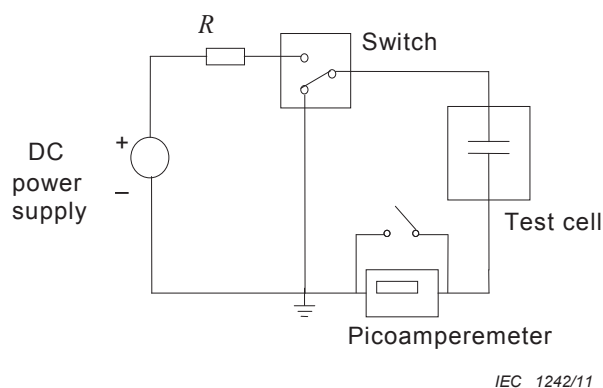
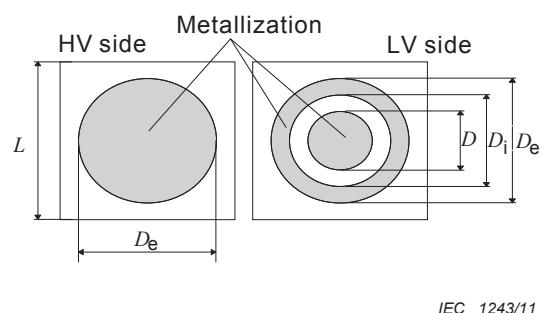


**Figure A.3 – Scheme of the measurement set-up for the charging/discharging current**



NOTE Metallization is necessary to connect the sample to the electrodes.

**Figure A.4 – Example of sample preparation**

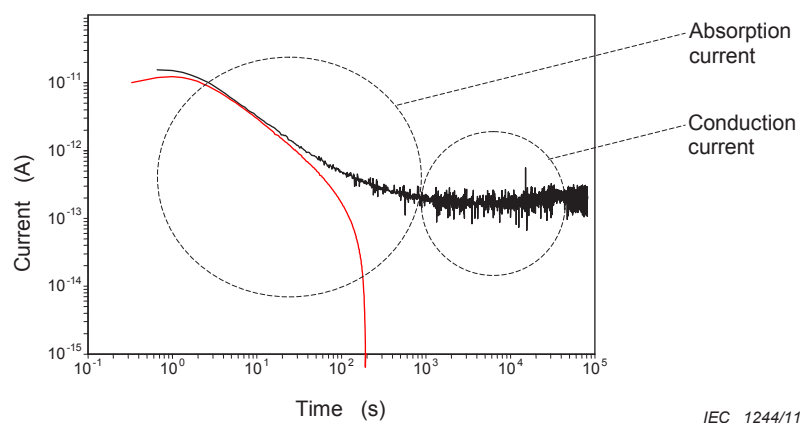


Figure A.5 – Charging/discharging current on HDPE film

#### References – Figures A.3, A.4 and A.5

CLARK, Frank M., *Insulating Materials for Design and Engineering Practice*, J. Wiley & Sons, 1962 (Figure A.3)

MONTANARI, G.C., MAZZANTI, G., PALMIERI, F., MOTORI, A. *Investigation of charge transport and trapping in LDPE and HDPE through space charge and conduction current measurement*, ICSD, June 2001, pp. 97-100

#### A.6 Adsorption

An increase in concentration of any component at the surface of a liquid or solid. Attachment of a gas, liquid or dissolved substance to a solid surface.

#### A.7 Ageing

Irreversible changes of the properties of EIS (electrical insulation system), that accumulates with time, due to action of one or more stresses.

#### A.8 Ageing (mechanical, thermal, electrical, environmental)

Irreversible changes of the properties of EIS (electrical insulation system), that accumulates with time, due to action of thermal, electrical, mechanical, environmental stresses.

Any property  $p$ , which has have a time trend correlated to the ageing state of the EIS (e.g. increasing as the electrical loss angle, or decreasing as the dielectric strength), is called diagnostic property or ageing marker.

When  $p$  reaches, under a given value of stress  $S_i$ , a certain value, known as end point  $p_L$ , the EIS has reached the end of the corresponding life  $L_i$  (see Figure A.6). The life line, intended as the time-to-failure (or time to maintenance) of the EIS, is generally plotted on a log-log graph for electrical and mechanical stresses, in a semilog graph, or Arrhenius graph, for thermal stress. The arithmetic mean or median point for each electrical ageing stress, obtained by having selected an end point value for the property  $P$  (see Figure A.7), may constitute the life line plot. Any failure time percentile can be used however.

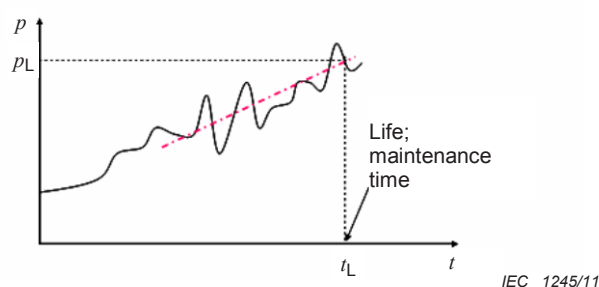


**Figure A.6 – Property versus time behaviour, detection of threshold (end point,  $p_L$ ) and maintenance time**

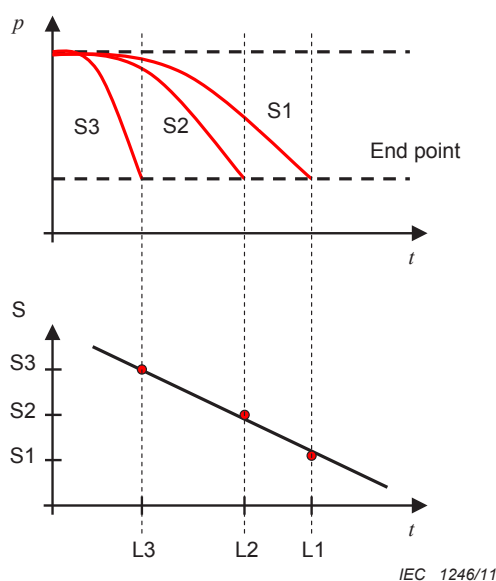


**Figure A.7 – Correspondence between the ageing plots of the property  $p$  (in red), obtained at different stress levels, and the resulting life line**

#### References – Figures A.6 and A.7

DISSADO, L.A., FOTHERGILL, J. C., *Electrical Degradation and Breakdown in Polymers*, Peter Peregrins, London, 1992 (Figure A.6)

MONTANARI, G.C., *Insulation Diagnosis of High Voltage Apparatus by Partial Discharge Investigation*, 8th International Conference on Properties and applications of Dielectric Materials, 2006, June 2006 Page(s):1 – 11 (Figure A.7)

#### A.9 Bulk

Intrinsic volume – the main mass or body; the largest or principal portion. Some measurements such as resistance or dissipation factor (tan delta) give values of the bulk properties of the insulation.

#### A.10 By-product

A substance that is produced during the process of making, using or destroying an object, e.g. when burnt, plastic produces dangerous by-products.

## A.11 Cavity

A small void or space inside a material.

## A.12 Charge injection

The process by which charge carriers are forced to move into an insulating material, generally from the electrodes, under the effect of an electric field. Charges have to overcome a potential barrier to be injected. The injection mechanism is strongly affected by the electrode-insulator interface properties, and thus by the electrode-insulator contact, the temperature, the electric field amplitude and the polarity. The injected charge can be measured by various techniques, such as pulsed electro-acoustic method (PEA), laser-induced pressure pulse (LIPP), etc. An example of a charge injection is shown in Figure A.8.

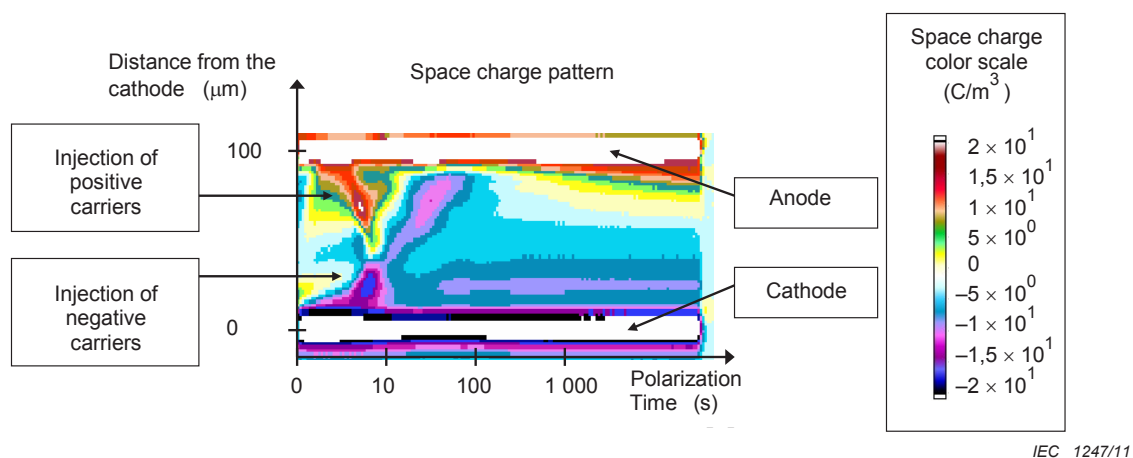


**Figure A.8 – Example of charge injection of positive carriers (holes) from the anode and of negative charge carriers (electrons) from the cathode in a PE flat specimen, detected by space charge measurement performed by PEA method**

### References – Figure A.8

DISSADO, L.A., FOTHERGILL, J.C. *Electrical Degradation and Breakdown in Polymers*, Peter Peregrins, London, 1992

MONTANARI, G.C., *The electrical degradation threshold of polyethylene investigated by space charge and conduction current measurements*, IEEE Trans. on Diel. El. Insul., Vol. 7, No. 3, pp. 309-315, June 2000

MONTANARI, G.C., *Dielectric material properties investigated through space charge measurements*, IEEE Trans. on Diel. El. Insul., Vol. 11, pp. 56-64, 2004

BOUFAYED, F., TEYSSÉDRE, G. LAURENT, C., LE ROY, S., DISSADO, L.A., SEGUR, P., MONTANARI, G.C., *Models of bipolar charge transport in polyethylene*, Journ. Appl. Phys., Vol. 100, pp. 104105.1-10, 2006

## A.13 Compressive stress

Force that acts on a material in such a way that it tends to compress the material in the direction of the force.

Compressive stress ( $\sigma$ ) = Compressive force ( $F$ )/Original cross-sectional area ( $A$ )

Compressive force is opposite to tensile force.

The compressive strength of a material is the value of uniaxial compressive stress reached when the material fails completely (red point on curve). A stress–strain curve would look similar to the curve shown in Figure A.9:

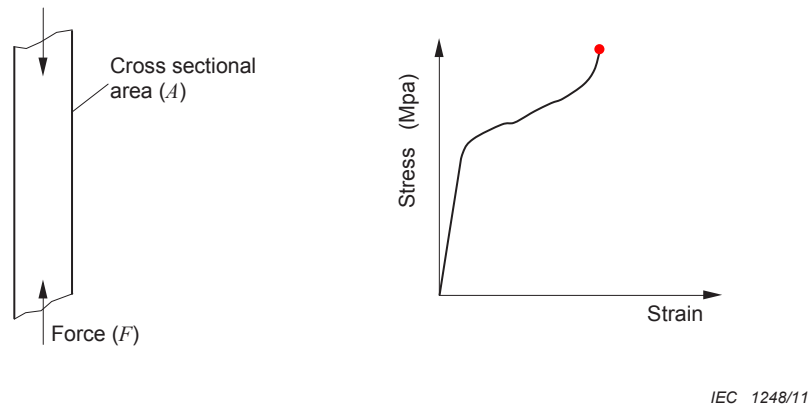


**Figure A.9 – Stress-strain curve for a typical material**

- Yield point defines the end of the linear region.
- Below yield point  $\sigma = E\varepsilon$  (Hooke's law) where  $E$  is the Young's Modulus for compression.
- Above yield point material behaves plastically and will not return to its original length once the load is removed.
- Measured in units of Pascals.

#### References – Figure A.9

IEC 60371-2, *Specification for insulating materials based on mica – Part 2: Methods of test*

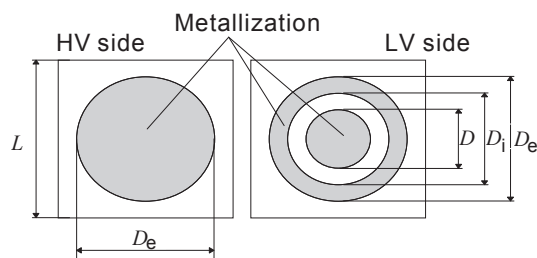
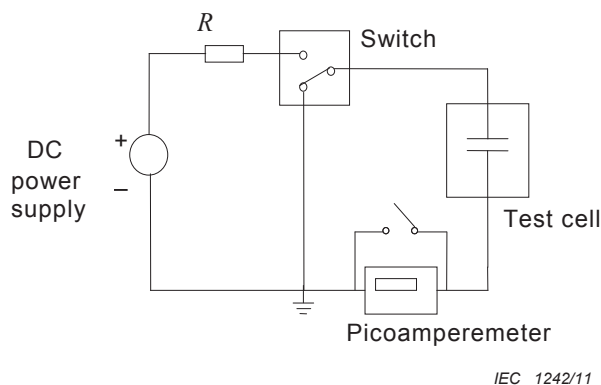
IEC/TR 62039, *Selection guide for polymeric materials for outdoor use under HV stress*

### A.14 Conduction current

Applying a voltage step to a dielectric between two electrodes, a current flows which has three components: the charging current, that represents the fast response associated with a change in the electric field amplitude, the absorption current, associated with the polarization transient and the conduction current, which represents the steady state of the current depending upon the applied field and temperature.

The conduction current is measurable applying a d.c. voltage to an insulating specimen and waiting for the steady state, when all the contributes given by the charging and absorption currents become negligible.

The example of measurement set-up, shown in Figures A.10, A.11, and A.12 is the same used for the absorption current measurement.

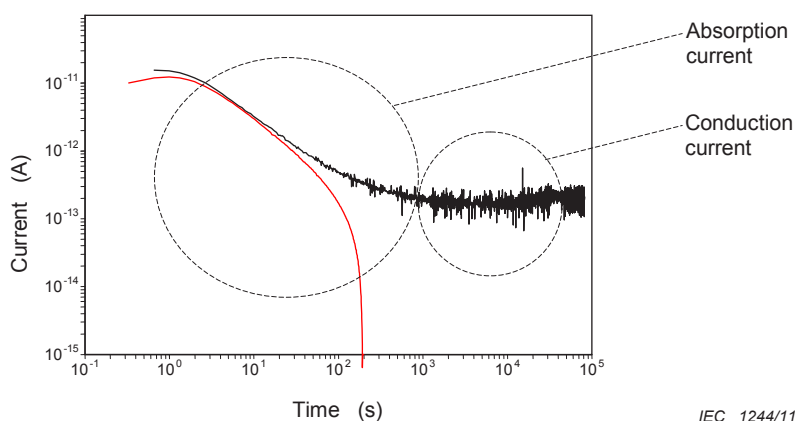


IEC 1243/11

NOTE Metallization is necessary to connect the sample to the electrodes.

**Figure A.10 – Scheme of measurement set-up for charging/discharging current**

**Figure A.11 – Example of sample preparation**



IEC 1244/11

**Figure A.12 – Charging/discharging current on HDPE film**

Conduction current measurements can be performed at different values of electrical field,  $E$ , in order to estimate the threshold value,  $E_T$ , after which the insulating current-voltage characteristics show a transition from ohmic behaviour (where the conductivity depends only on temperature) to high field behaviour (where space charge accumulation affects conduction mechanism).

The temperature and field dependency of conductivity,  $\sigma$ , are taken into account in the following equation:

$$\sigma(T, E) = A \exp\left(-\frac{\Delta U}{k_B T}\right) \frac{\sinh(B|E|)}{|E|} \quad (\text{A.1})$$

where  $\Delta U$  is the thermal activation energy,  $k_B$  Boltzmann's constant and  $A$  and  $B$  are constants.

Examples of current measurements on PET films are shown in Figures A.13 and A.14, in order to emphasize the strong dependency of conductivity on temperature and electrical field.

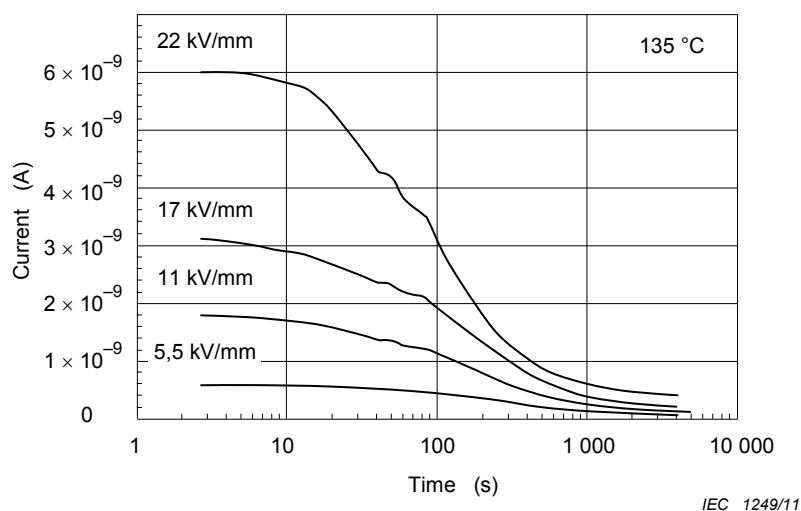


**Figure A.13 – Charging current at  $135\text{ °C}$  and different values of DC electrical field**

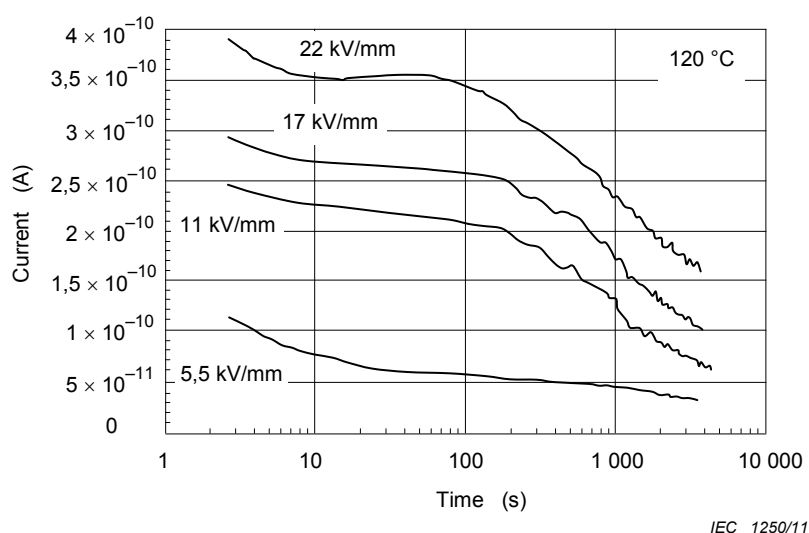


**Figure A.14 – Charging current at  $120\text{ °C}$  and different values of DC electrical field**

#### References – Figures A.10, A.11, A.12, A.13 and A.14

CLARK, Frank M., *Insulating Materials for Design and Engineering Practice*, J. Wiley & Sons, 1962 (Figure A.10)

MONTANARI, G.C., MAZZANTI, G., PALMIERI, F., MOTORI, A. *Investigation of charge transport and trapping in LDPE and HDPE through space charge and conduction current measurement*, ICSD, June 2001, pp. 97-100 (Figure A.10)

DISSADO, L.A., FOTHERGILL, J.C., *Electrical degradation and breakdown in polymers*, Peter Peregrinus Ltd, ISBN 0-86341-196-7, 1992 (Figure A.10)

KUMAR, A., PERLMAN, M.M., *Steady-state conduction in high density polyethylene with field-dependent mobility*, Jour. App. Phys., Vol. 71, No.2, pp. 735 – 738, 1992 (Figure A.10)

MONTANARI, G.C., GHINELLO, I., MOTORI, A., DAS GUPTA, D. *An investigation of conduction mechanisms at high-field in PET*, IEEE Conf. Electr. Insul. Diel. Phen., pp. 451-454, 1997 (Figures A.10, A.13 and A.14)

BODEGA, R., MONTANARI, G.C., MORSHUIS, P.H.F., *Conduction current measurements on XLPE and EPR insulation*, IEEE Conf. Electr. Insul. Diel. Phen., pp. 101-105, 2004 (Figures A.10, A.11 and A.12)

### A.15 Contaminant (impurity)

A foreign substance of material in an insulating solid, liquid or gas which usually has deleterious effect on one or more properties.

### A.16 Continuity fault/discontinuity

The presence of a change of properties between two points of the same material.

### A.17 Corona

According to ASTM D 1868-73, corona is a type of localized discharge resulting from transient gaseous ionization in an insulation system when the voltage stress exceeds a critical value.

Corona can occur at electrical conductors, such as HV lines. The high electrical field gradients at conductors having curved shape, sharp points or edges will lead to breakdown of the surrounding air. There exist positive and negative corona processes having different ignition and breakdown behaviour. Corona is gas ionization and is accompanied by light emission and detectable sound waves (example Figure A.15).

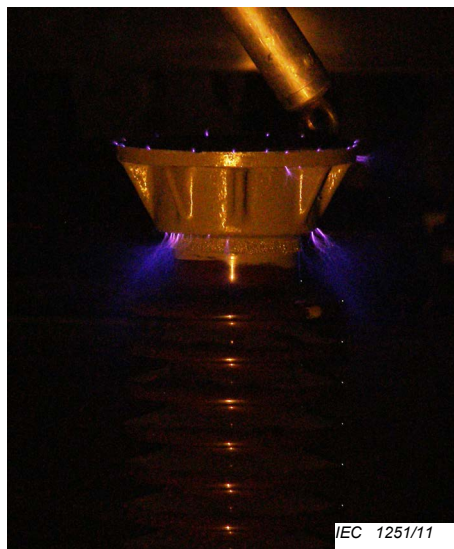


Figure A.15 – Corona at post insulator head



Figure A.16 – Corona on top and arcing to ground

### References – Figures A.15 and A.16

SMIT, J. University of Technology Delft, *unpublished pictures*.

### A.18 Corrosion

Surface attack or impairment caused by ionic transfer under a potential difference.

Corrosion means the breaking down of essential properties in a material due to chemical reactions with its surroundings. Corrosion also includes the dissolution of ceramic materials and can refer to discoloration and weakening of polymers by the sun's ultraviolet light.

### A.19 Corrosive substance

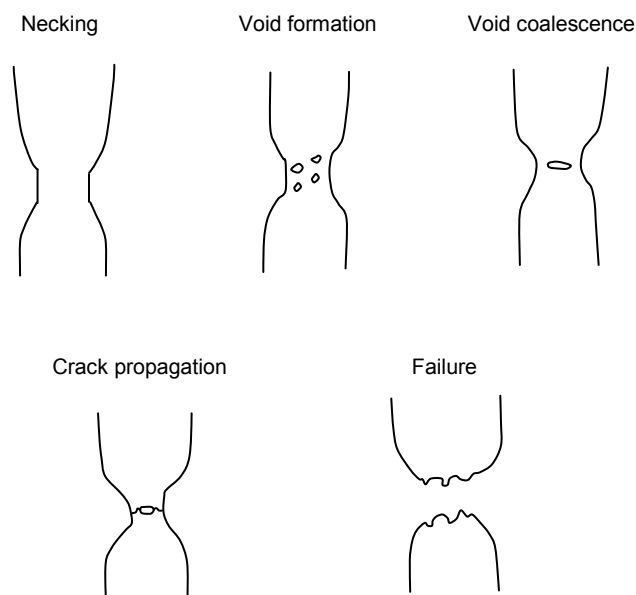
Will destroy or irreversibly damage another substance with which it comes in contact.

### A.20 Crack, crack(ing)

To break, with or without quite separating into parts. The rupture of a material/insulator to depths equal to or greater than 0,1 mm.

Crack separation – there are three stages of fracture:

- Stage I, or the opening mode, is characterized by a stress perpendicular to the crack faces.
- Stage II, the sliding or forward shear stage, has a shear stress normal to the crack front.
- Stage III is the tearing stage, with a shear stress parallel to the crack front.



IEC 1253/11

**Figure A.17 – Stages of mechanical ductile fracture (cracking)**  
(source unknown)

### References – Figure A.17

IEC 60811-3-1, *Common test methods for insulating and sheathing materials of electric cables – Part 3: Methods specific to PVC compounds – Section One: Pressure test at high temperature - Tests for resistance to cracking*

### A.21 Creep

Continued deformation of material under constant stress. Creep is the term used to describe the tendency of a solid material to slowly move or deform permanently under the influence of stress. It occurs as a result of long term exposure to levels of stress that are below the yield strength or ultimate strength of the material. Creep always increases with temperature.

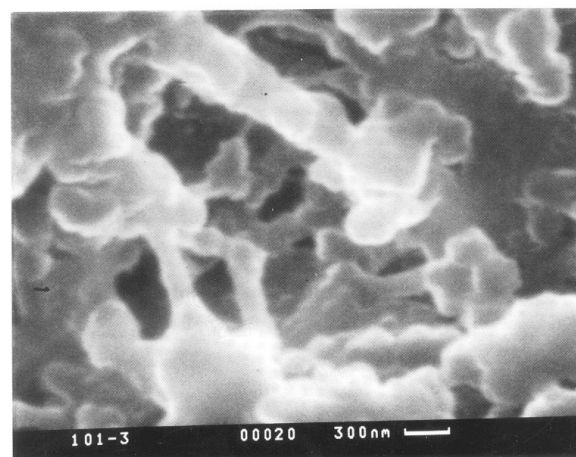
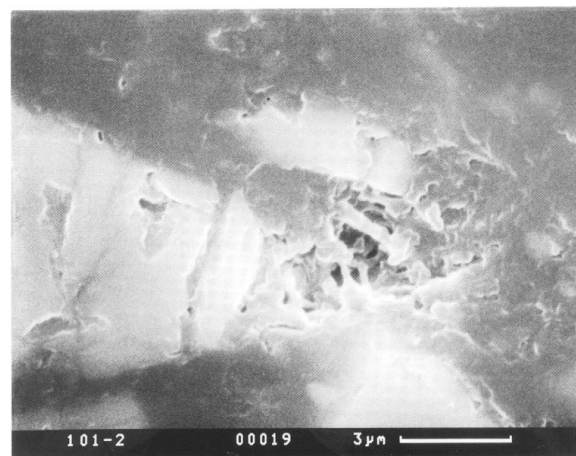
### A.22 Defect

Imperfection in the state of an item (or inherent weakness) which can result in one or more failures of the item.

An imperfection, deficiency, deformity or any kind of shortcoming in the structure of a material that leads to a partial loss of functionality of that material.

An insulating material may contain a void due to improper mixing and degassing in the manufacturing stage. Depending on the shape and size of such a gas containing a void, a partial discharge may occur at a certain voltage stress.

In an epoxy resin structure, for example, the polymer chains are randomly oriented. Due to cross-linking, internal stress causes locally oriented or so-called crystallized areas with other mechanical or electrical properties. This might function as the initiation point for an internal weakness of mechanical or electrical kind.



IEC 1254/11

Figure A.18 – Photo showing orderings in epoxy structure and void

## References – Figure A.18

SMIT, J.J., courtesy of KEMA, NL

### A.23 Delamination

Separations of layers of material. Delamination is a mode of failure of laminated composite materials. Repeated cyclic stresses, impact, and so on can cause layers to separate, forming a mica-like structure of separate layers, with significant loss of mechanical toughness. Delamination is an insidious kind of failure as it develops inside of the material, without being obvious on the surface, much like metal fatigue.

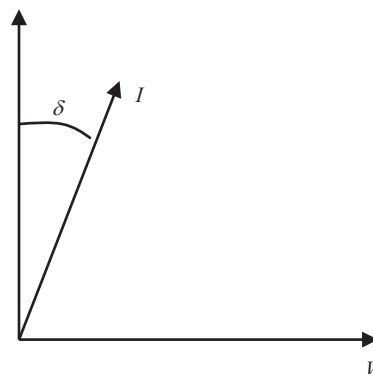
### A.24 Depolymerization

A chemical process that separates a polymer in monomers or a polymeric compound. An example of depolymerization is the breakdown of cellulose paper due to thermal ageing.

### A.25 Dielectric loss

The power absorbed from a time-varying electric field in a dielectric and usually dissipated as heat.

$$\begin{aligned}\tan(\delta) &= \frac{\text{Real power}}{\text{Reactive power}} \\ &= \frac{V \times I \sin(\delta)}{V \times I \cos(\delta)}\end{aligned}$$



IEC 1255/11

Dielectric loss angle = the value of arc tan of the dielectric dissipation factor. Dielectric loss = power absorbed from a time-varying electric field by a polarized substance, excluding absorbed power due to the conductivity of the substance.

### A.26 Discharge

A discontinuous movement of electrical charges through an insulating medium, initiated by electron avalanches and supplemented by secondary processes.

A discharge can develop into an arc, which occurs at high field emission conditions.

A so-called partial discharge occurs when a discharge is not fully bridging the insulation gap. It may cause the formation of electrical trees in the bulk or along the surface of an insulation (see tracking).