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IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation

Sponsor

IEEE Standards Coordinating Committee 4, Thermal Rating

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Foreword

(This Foreword is not a part of ANSI/IEEE Std 1-1986, IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.)

Technical progress since 1969 revision of this standard has resulted in general agreement that a number of service stresses or factors, influence the life of electrical insulation, in materials tests and in systems used in electric equipment. While earlier editions of this standard made note of this fact, no guidance was provided to equipment committees who found a need to incorporate these additional factors into specific test guides.

With the text of the newly revised 1969 version of this standard as a starting point, the first meeting of International Electrotechnical Commission Technical Committee No 63, Insulation Systems, began the development of IEC Publication 505, Guide for the Evaluation and Identification of Insulation Systems of Electrical Equipment, which was published in 1974. This standard provides a guide for equipment committees to use in devising test procedures for insulation systems exposed in service to aging caused by thermal, electrical, environmental, and mechanical stresses.

During the revision process of IEEE Std 1 international attention was focused on a much needed revision of IEC Publication 85, Thermal Evaluation and Classification of Electrical Insulation. The available 1957 edition of this IEC document was similar to the 1954 revision of IEEE No 1. The contributions of experts from the United States to the revision of IEC Publication 85, who were also members of the Standards Coordinating Committee No 4, delayed work on the current revision of IEEE Std 1. However, the experience gained by this diversion has been utilized to make this edition of ANSI/IEEE Std 1-1986 a better standard and in harmony with the IEC publications.

At the time this standard was approved the IEEE Standards Coordinating Committee 4, Thermal Rating, had the following membership:

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An American National Standard

IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation

Part I General

1. Purpose and Scope

These principles are intended to serve as a guide in the preparation of IEEE and other standards that deal with the selection of temperature limits and the measurement of temperature for specific types of electric equipment. They include an outline of the fundamental considerations and a review of the elements to be considered in applying the principles to specific cases. Guiding principles are included for the development of test procedures for

1) Thermal evaluation of electrical insulating materials
2) Thermal evaluation of insulation systems
3) Thermal classification[1] of insulation systems for use in rating electric equipment.

For many types of equipment proper evaluation of their electrical insulation for service conditions requires controlled exposure to a range of aging stresses which may or may not include thermal aging. The aging factors of influence may include thermal, electric, ambient (environmental), and mechanical stresses. Thermal aging has been widely used as a single factor test method. The other factors may also be evaluated by single factor tests or they may be combined with or without thermal aging into a multifactor test. Guiding principles for developing insulation systems test procedures for single and multifactor aging are included in this standard.

Insulating materials, as referred to herein, are substances in which the electric conductivity is very small (approaching zero) and provide electric isolation.

Insulation systems, as referred to herein, include an insulating material or a suitable combination of insulating materials specifically designed to perform the functions needed in electric and electronic equipment.

Other definitions necessary for the use of these principles are listed in Section 1..

The Principles are presented in the following order:

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[1] Historically, the term *thermal classification* has been used in reference to both insulation systems and to electric equipment. Thermal classification should always be used in combination with the words *system* or *equipment* to clearly denote to which the term applies. For example, Class 155 System.

Part I.	General
Part II.	Evaluation of Thermal Capability of Insulating Materials
Part III.	Limiting Temperatures and Their Measurement for Electrical Insulation Systems
Part IV.	Evaluation of Electrical Insulation Systems

n the application of these principles, variations will be necessary to suit the widely different types of equipment and service conditions that are considered in equipment standards. The temperature limits and other, provisions given herein are not intended to be used for rating or testing equipment for which specific IEEE, or other recognized standards based on these principles, are available.

2. Definitions

2.1 General Definitions

2.1.1 electrical insulating material: A substance in which the electrical conductivity is very small (approaching zero) and provides electric isolation.

2.1.2 electrical insulation system: An insulating material or a suitable combination of insulating materials specifically designed to perform the functions needed in electric and electronic equipment.

2.1.3 simple combination of insulating materials: A number of insulating materials, which together make possible the evaluation of any interaction between them.

2.1.4 useful service life: The length of time (usually in hours) for which an insulating material, insulation system, or electric equipment performs in an adequate or specified fashion.

2.1.5 estimated life (performance): The expected useful service life based upon service experience or the results of tests performed in accordance with appropriate evaluation procedures established by the responsible technical committee, or both.

2.1.6 aging: The irreversible change (usually degradation) that takes place with time.

2.1.7 thermal aging: The aging that takes place at an elevated temperature.

2.1.8 factor of influence: A specific physical stress imposed by operation, environment, or test that influences the performance of an insulating material, insulation system, or electric equipment (Appendix B.1).

2.1.9 aging factor: A factor of influence that causes aging.

2.1.10 service condition: A combination of factors of influence, which are to be expected in a specific application of electric equipment.

2.1.11 service requirement: The specified performance to be expected in a specific application under a specified service condition.

2.2 Definitions Related to Electric Equipment

2.2.1 ambient: The medium (for example, air, gas, liquid, earth) in which electric equipment operates.

2.2.2 ambient temperature: The temperature of the ambient medium.

2.2.3 limiting ambient temperature: The highest (or lowest) ambient temperature at which electric equipment is expected to give specified performance under specified conditions, for example, rated load.

2.2.4 observable insulation temperature: The temperature of the insulation in electric equipment, which is measured in a specified way, for example, with a thermometer, embedded thermocouple, resistance detector, or by winding resistance or other suitable procedure.

2.2.5 observable temperature rise: The difference between the observable insulation temperature and the ambient temperature.

2.2.6 hottest-spot temperature (*hot spot*): The highest temperature attained in any part of the insulation of electric equipment. (Difficulties in its determination are encountered. See Section 4.).

2.2.7 limiting hottest-spot temperature: The highest temperature attained in any part of the insulation of electric equipment, which is operating under specified conditions, usually at maximum rating and the upper, limiting ambient temperature.

2.2.8 hottest-spot temperature allowance: The designated difference between the hottest-spot temperature and the observable insulation temperature. (The value is arbitrary, difficult to determine, and depends on many factors, such as size and design of the equipment).

2.3 Definitions Related to the Evaluation of Thermal Capability

2.3.1 functional test: A means of evaluation in which an insulating material, insulation system, or electric equipment is exposed to factors of influence. which simulate or are characteristic of actual service conditions.

2.3.2 test model: A representation of equipment. a component or part of equipment, or the equipment itself, that is suitable for use in a functional test.

2.3.3 accelerated test: A functional test in which one or more factors of influence are increased in magnitude or frequency of application so as to decrease the time needed for the test.

2.3.4 diagnostic factor: A variable or fixed stress, which can be applied periodically or continuously during an accelerated test, to measure the degree of aging without in itself influencing the aging process.

2.3.5 end-point criterion: A value of property or property degradation (either absolute or percentage change) which defines failure in a functional test.

2.3.6 proof test: A means of evaluation in which an arbitrary fixed level of a diagnostic factor is applied periodically. In this case, the number of failures among multiple test specimens (rather than the magnitude of the diagnostic factor, see 2.3.4) defines the end-point of the test.

2.3.7 thermal endurance relationship: The expression of aging time to failure as a function of test temperature in an aging test.

2.3.8 thermal endurance graph: The graphical expression of the thermal endurance relationship in which time to failure is plotted against the reciprocal of the absolute test temperature. See Fig. A.1.

2.3.9 temperature index (TI): The number that corresponds to the temperature in °C, derived mathematically or graphically from the thermal endurance relationship at a specified time (often 20 000 h). The temperature index (TI) may be reported for materials and insulation systems. However, for insulation systems it may be preferable to make comparison at a particular temperature, for example, 130 °C, 155 °C, or over a range of temperatures (The TI is not used for equipment.). See Fig A.1.

2.3.10 relative temperature index (RTI): The temperature index of a new or candidate insulating material, which corresponds to the accepted temperature index of a reference material for which considerable test and service experience has been obtained. Both new and reference material are subjected to the same aging and diagnostic procedure in a comparative test. See Fig A.1.

2.3.11 halving interval (HIC): The number corresponding to the interval in °C determined from the thermal endurance relationship expresses the halving of the time-to-end-point centered on the temperature of the TI or RTI. In case of graphical derivation the times corresponding to the TI RTI (for example, 20 000 h) and one half that value (for example, 10 000 h) will usually produce an acceptable approximation. See Fig A.1.

2.3.12 temperature class: A standardization designation of the temperature capability of the insulation in electric equipment, as defined by the appropriate technical committee. It may be determined by experience or test and expressed by letters or numbers.

2.3.13 material temperature class: The lowest value of a range of temperature indices for insulating materials.

3. References

This standard shall be used in conjunction with the following publications:

[1] ANSI/IEEE Std 98-1984, IEEE Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials.[2]

[2] ANSI/IEEE Std 99-1980, IEEE Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment.

[3] ANSI/IEEE Std 853-1984, IEEE Recommended Practice for Voltage-Endurance Testing of Enameled Wire.

[4] ANSI/IEEE Std 943-1986, IEEE Guide for Aging Mechanisms and Diagnostic Procedures in Evaluating Electrical Insulation Systems.

[5] IEEE Std 97-1969, IEEE Recommended Practice for Specifying Service Conditions in Electrical Standards.[3]

[6] IEEE Std 101-1972 (R 1980), IEEE Guide for the Statistical Analysis of Thermal Life Test Data.

[7] IEEE Std 119-1974, IEEE Recommended Practice for General Principles of Temperature Measurements as Applied to Electrical Apparatus.

4. General Concepts

The temperature limits for electric equipment should be selected so that the equipment will result in a satisfactory life under normal operating conditions. In addition, permissable emergency temperature limits and corresponding ratings may be established, including the durations and frequencies of emergency, or peak-load operation to which these limits apply. In the establishment of temperature limits, it should be recognized that:

1) The ambient temperature is unlikely to be maintained at its minimum or maximum value for long periods of time
2) Load cycles are generally such that the average load for a period of days to months is appreciably lower than the rated continuous load.

Standards for electric equipment usually specify temperature rise rather than maximum temperature. While it is beyond the scope of this standard to specify the permissable temperature rise of insulated parts, or to prescribe the methods by which such temperature rises shall be determined, it should be noted that in normal practice the maximum temperature (hottest spot) attained by an insulated part is seldom measured directly. The permissable temperature rise is, therefore, generally specified to be less than the differences between the temperature recognized in this standard and the temperature of the ambient air or other cooling medium.

The method of measurement to be used for determining the temperature rise of insulated parts should bc prescribed in the standards for the equipment.

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[2] ANSI publications are available from the Sales Department of American National Standards Institute, 1430 Broadway, New York, NY 10018.
[3] IEEE publications are available from IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

When specifying permissable temperature rises and measurement methods in standards for electric equipment it is generally useful to take into consideration constructional factors, such as method of cooling, although it is understood that these factors are normally not included in the standard proper.

The ability of an insulating material, or an insulation system to fulfill its function is also affected by the presence of other aging factors of influence. These factors will vary from one type of equipment, or application, to another, but, may include electric stresses, mechanical stresses, and ambient (environmental) stresses. Mechanical stresses imposed upon the system and its supporting structure by vibration and differential thermal expansion may become of increasing importance as the size of the apparatus increases. Electrical stresses will be more significant with high-voltage apparatus, or with equipment exposed to voltage transients. Moisture in the equipment environment and the presence of dirt, chemicals, radiation, or other contaminents may have an injurious effect. All such factors should be taken into account in establishing the standards of temperature rise for particular classes of apparatus.

In choosing temperature-rise limits suitable for specific equipment and particular conditions, the following general concepts may be followed:

4.1

The electric and mechanical properties of insulating materials are temperature dependent. In many applications where organic-based materials are used, the melting point shall be higher than the maximum operating temperature in service. In most polymeric insulating materials, a sharp transition from solid to liquid does not occur and softening increases as the temperature increases. Many polymeric insulating materials will undergo a second order transition from a partially crystalline, or hard glassy state to a softer, rubbery, or viscous state when exposed to rising temperatures and will experience marked changes in properties over a narrow temperature range. In these cases, the functionally important softening temperature, which is generally known as the glass transition temperature T_g, may relate to the mechanical stresses imposed in service and the amount of deformation and creep that can be tolerated. Limits for the loss of these properties may be developed through systems tests or service experience.

Dielectric loss may also be temperature dependent so that, in high-voltage equipment, the dielectric loss alone at elevated temperatures may lead to a destructive thermal runaway condition.

4.2

Marked changes in the electric and mechanical properties of insulating materials also occur progressively as a result of prolonged exposure to high temperature. The materials may soften, lose weight, or become brittle, and the chemical composition and structure may change. The effects of high temperature may differ widely, depending upon the particular environmental conditions. While infant mortality may occur with equipment, insulation does not usually fail because of immediate breakdown at some critical temperature, but rather as a result of gradual deterioration with time.

4.3

The limiting temperature at which an insulation system may be operated depends upon the degree and intermittency of the loading, the degree of reliability required, and the length of life desired. A specific material as part of a system may be satisfactory for use at different limiting temperatures, depending upon the type and size of equipment in which it is used and the kind of service to which the equipment is subjected.

The temperature limit for an insulation system may not be directly related to the thermal capability of the individual material included in it. In systems, the thermal performance of insulating materials may be improved by the protective character of other materials used with them. On the other hand. problems of incompatibility between materials may decrease the appropriate temperature limit of the system for the individual materials.

4.4

The electric and mechanical properties of insulating materials and insulation systems may be influenced in different ways and to different degrees as a function of temperature and with thermal aging. In some cases, the electric properties and mechanical strength of insulating materials initially improve as thermal aging progresses. However, elongation to rupture generally progressively decreases with thermal aging so that embrittlement finally leads to cracking and may contribute to electric failure.

Thus, how long insulation is serviceable depends not only upon the materials used, but also upon the effectiveness of the physical support for the insulation and the severity of the forces tending to disrupt it. Even though portions of insulation structures may have become embrittled under the influence of high temperature, successful operation of the equipment may continue for years if the insulation is not disturbed.

Because of the effects of mechanical stress, the forces of thermal expansion and contraction may impose temperature-rise limitations on large equipment even though higher temperature-rise limits proved satisfactory in small equipment when similar insulating materials were used.

4.5

The life of equipment is dependent to a considerable extent upon the degree of exclusion of oxygen, moisture, dirt, and chemicals from the interior of the insulating structure. At a given temperature, therefore, the life of equipment may be longer if the insulation is suitably protected than if it were freely exposed to industrial atmostpheres. The use of chemically inert gases or liquids, as cooling or protective media, may increase the temperature capability of an insulation system.

4.6

The life of equipment also depends upon the care it receives during manufacture, transportation, storage and installation, and upon maintenance during operation. Successful operation cannot be expected of insulation that has been damaged or displaced.

4.7

The rate of physical deterioration of insulation under thermal aging increases rapidly with an increase in temperature. A fairly precise method of determining insulation life at elevated temperature is provided by the concept that the logarithm of the insulation life is a function (often linear) of the reciprocal of the absolute temperature. A straight line plot of aging data indicates that the nature, or order, of the chemical reaction causing aging remains unchanged. Departure from linearity normally suggests that the type of chemical reaction is changed. When the logarithms of the hours of life, found by thermal evaluation tests at three or more different temperatures, are plotted against the reciprocals of the absolute temperatures, they will usually, but not always, form a straight line. Individual time-temperature life curves for different insulating materials and insulation systems should be determined by thermal evaluation tests.

4.8

The ambient temperature directly affects the temperature attained by equipment in operation. Data recorded at various weather bureau stations in the United States and Canada are given in IEEE Std 97-1969 [4].

5. Basic Considerations in the Preparation of Standards

The desired life of electric equipment depends upon the initial investment, reasonable maintenance, needed reliability, obsolescence, importance of size and weight, and other factors. In considering such factors, predominant conditions rather than extreme requirements should be used as a basis for standards. For some type of equipment and service, the user may expect a life of thirty years or more with a high degree of reliability. For other types of equipment a life of only a few years, or a few hours, may be satisfactory.

The great variety of physical factors and economic considerations entering into the problem of standardization makes it essential to give much weight to experience. Standard values that are entirely safe for extreme conditions or that allow for very improbable combinations of unfavorable factors will result in products too costly for the majority of applications and consequently will not be respected. No laboratory, or factory test, can fully simulate the many combinations of temperatures, loads, mechanical stresses, voltage surges and environmental conditions met in service. The response to test or service conditions will also change as insulation ages--often in a complex manner. To what extent extreme conditions may be discounted, without incurring unreasonable maintenance, can only be determined by practical experience over a considerable period of time.

The temperature-rise values generally used for electric equipment are the results of long experience and have proved to be reasonably satisfactory. The general principles outlined herein suggest that major changes in existing standards should be made only when they are indicated to be desirable in the light of new test data, availability of new or improved materials, additional operating experience, new measurement techniques, or changes in service requirements.

Important trends to which consideration has been given in preparing these principles are as follows:

1) Reliance on accelerated life tests, as provided in ANSI/IEEE Std 99-1980 [2], to determine appropriate limiting temperatures and fields of usefulness for complete insulation systems or individual insulating materials.
2) The availability of many new insulating materials with characteristics and appropriate fields of use that shall be determined by tests.
3) The great expansion in many areas of application, such as equipment for nuclear-energy, aerospace, computers and other electronic applications, industrial and domestic airconditioning, and domestic appliances of many kinds, which are increasing the varieties of special-purpose equipment supplied by the electrical industry and that are also increasing the ranges of temperature that shall be considered in their operation.
4) The continuing and greater use of enclosed types of equipment, often operating in controlled gases or liquids.
5) A trend toward operating some electric equipment at, or close to, limiting insulation temperature.
6) A trend toward operating some electric equipment for short-time duty periods at higher than normal temperature in such a way as to make the average rate of thermal deterioration over the total elapsed time consistent with the desired life expectance.

The various standards for different types of electric equipment should be correlated to ensure that the thermal performance and life expectancies of associated elements in a complete electric system will be consistent under short-time overload and emergency conditions and in normal service. However, it is important to allow freedom in using different temperature-rise limits for individual types of equipment and for specific applications in accordance with their individual requirements.

A principal purpose of the development and use of test procedures for life-testing insulation systems and insulating materials is to enable more accurate estimates to be made of the life expectance of equipment under particular service conditions. In the course of time it will be desirable to correlate further the various standards to achieve more consistent life expectancies for associated equipment and be better suited to give the desired degree of reliability.

Only carefully evaluated service experience, or adequate accepted tests, provide the bases for rational thermal classification of electrical equipment and the thermal identification and temperature limits of insulation.

Part II Evaluation of the Thermal Capability of Insulating Materials

1. Purpose and Scope

Part II of this standard is intended to serve as a guide in the preparation of IEEE standards and other standards that are principally concerned with the thermal endurance of insulating materials and simple combinations thereof. A simple combination includes two or perhaps three materials that may be used in many types of equipment and a form that is not specifically related to use. Magnet (winding) wire insulation and varnish is illustrative. The scope does not include insulation systems (for insulation systems see Part IV) which are combinations of insulating materials with related structural parts as used in specific types of electrical equipment or in a form representative of such use.

While the thermal capability of insulating materials is the principal concern of this part of the standard, it is recognized that other aging stresses or factors, that is, mechanical, electric, and environmental may be limitations in determining the life of a material in service (Appendix B.1). Single and multifactor aging and testing of insulating materials is being actively developed in the industry. While knowledge of the response of a material to these other factors, and their interaction with thermal aging, may be important in particular cases, there is no general classification method for these capabilities.

The recommendations herein are intended as a guide and are not mandatory. It is recognized that they are not precise. Many variations will be necessary to suit the variety of requirements imposed by a tremendous number of very different types of electric and electronic equipment used under varying operating and ambient conditions. For specific requirements, such as operating temperature limits, reference should be made to the appropriate specifications on materials or equipment for which specific standards are available.

2. Thermal Aging

The process of thermal aging in insulating materials is complex and the mechanisms vary with different materials and under different service conditions. Typical mechanisms include

1) Loss of volatile constituents such as low molecular-weight components intially present or formed in the aging process
2) Oxidation that can lead to molecular cross-linking, chain-scission, embrittlement, and the production of volatile components
3) Continuous molecular polymerization that may increase physical and electric strength at first, but may subsequently lead to decreased flexibility, embrittlement, and earlier failure under mechanical stress.
4) Hydrolytic degradation in which moisture reacts with the insulation under the influence of heat, pressure, and other factors to cause molecular deterioration.
5) Chemical breakdown of constituents with formation of products which act to degrade the material further, such as hydrochloric acid. Such processes, once started, may become autocatalytic.

Because different insulating materials react in different ways to the various aging processes, it is essentially impossible to predict the thermal performance from the chemical composition of the material. Rapid advances in polymer chemistry have produced insulating materials, which are so numerous and complex, that simple chemical description has become almost completely meaningless. Consequently, the traditional procedure of dividing insulating materials into several thermal classes based upon broad descriptive statements according to general chemical composition is inadequate, must be deprecated, and should be discounted and discontinued as rapidly as practical.

In general, the thermal aging process leads first to increased strength but subsequently to loss of strength and embrittlement. In some cases, thermal aging may cause softening, particularly in closed spaces where the insulation is exposed to the effects of its own products of degradation. Often the electrical properties improve as thermal aging progresses. Electric failure usually takes place only after mechanical failure occurs, either immediately or after moisture, and contaminents penetrate the cracked structure.

Thus, the thermal life of insulating materials in electric and electronic equipment may depend on a very large extent upon the way in which the materials are applied and the conditions to which they are exposed. Exclusion of moisture and dirt, the presence of an inert ambient atmosphere, limitation of mechanical and electric stresses, and freedom from mechanical or thermal shock will tend to increase the life of insulating materials and the systems in which they are used. When oxidation mechanisms are important factors, the geometry of the materials (that is, thickness) may be significant.

Other factors being equal, thermal degradation is accelerated as the temperature is increased. For many insulating materials the life is an exponential function of the reciprocal of the absolute operating temperature over a limited range of temperatures.

However, for some materials[4] such simple relationships do not hold. In the case of thermoplastic materials or those that lose strength markedly at elevated temperatures, the softening point rather than the thermal stability may limit the temperature capability.

3. Temperature Designation of Insulating Materials

A very useful characteristic of an insulating material, the temperature index (TI), is determined by a thermal aging test. The relative temperature index (RTI) for a new or candidate material is determined by conducting comparative thermal-aging tests with a well-known insulating material for which considerable test and service experience has been obtained.

The temperature index TI and the relative temperature index (RTI) provide a technical basis for comparing the thermal capability of insulating materials. The RTI affords better reproducibility with fewer errors from experimental factors such as those often introduced by aging ovens. Neither the TI nor the RTI can be related directly to the appropriate operating or service temperature, which depends on many factors including environment, service severity, and the design of the insulation system in which the material is used.

However, for practical reasons, to promote standardization, to permit the use of different end-point criteria, and to provide continuity with past procedures it is reasonable that thermal indices, TI and RTI, for insulating materials be grouped in material temperature classes, as given in Table 1. Responsible technical committees may elect to use other numbers.

Where other than these material temperature classes are used, great care should be taken that the increments are not too small to avoid the impression that a high degree of precision is inherent in the procedure or that a very fine discrimination can be made among insulating materials.

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[4] Those in which a different type of clinical breakdown takes place, such as polyvinyl chloride after the exhaustion of the stabilizer (acid absorber), when the formation of hydrochloric acid may be autocatalytic.

Table 1 —Relationship of Temperature Index to Material Temperature Class

Range of the Temperature Index	Material Temperature Class
90-104	90
105-129	105
130-154	130
155-179	155
180-199	180
200-219	200
220-249	220
250 and above	None established

For comparison purposes it is frequently of interest to know the slope of the thermal endurance graph. Although many measures of the slope can be derived, the most practical one is the halving interval (HIC), which is the number corresponding to the interval in °C determined from the thermal endurance relationship between the time at the temperature index (for example, 20000 h), and half that time (for example, 10 000 h). See Definition 2.3.11 (Part I) and Fig A.1.

NOTE — The halving interval (HIC) is a measure derived from the slope of the thermal endurance graph. It is not a constant but varies with temperature when the thermal endurance relationship is linear. In many practical cases the error incurred by using the HIC within the temperature range of interest remains within acceptable limits.

The characterization of the material, thus, consists of either a TI-HIC or RTI-HIC.

The temperature index is a value obtained by test, which may be used as a guide and does not imply a thermal classification or a limitation on use in equipment. It is used most suitably for comparing materials that have been evaluated under controlled conditions. Temperature classification for the purpose of rating electric machines should be defined in terms of the thermal endurance of the insulation system.

Where possible, the temperature index and the relative temperature index will be based upon results obtained from standard test procedures for determining the thermal endurance. In cases where standard test procedures are not developed, the TI and the RTI may be assigned based on a relevant test, provided that the test method and the end point are described. Determination by test is described in Section 4.. A temperature index may also be determined from service experience as described in Section 5..

An insulating material may be assigned more than one temperature index, each of which is based upon different properties or environmental conditions or material geometry, such as thickness. For example, a material can be assigned a temperature index based upon retention of mechanical properties after aging. Thus the temperature index describes performance characteristics that provide the designer with information for the selection of materials based upon engineering data, rather than arbitrary classification.

Conditions encountered in the use of insulation, such as voltage stress, corona, mechanical stress, and environmental factors may degrade and limit the life of some insulating materials irrespective of thermal degradation. These effects and the physical and chemical properties of insulating materials shall be evaluated separately to ensure the suitability of insulating materials, for a particular application. The evaluation of these other aging factors is beyond the present scope of this part of the standard although the development of such standards is encouraged. See ANSI/IEEE Std 853-1984 [3] as an example. However, other factors of influence (for example, voltage stress) may be combined with thermal aging, possibly in nonlinear, cumulative fashion, to determine the temperature index under the applied environment.

4. Determination of Temperature Index by Test

4.1 General

Test procedures for determining the temperature index of insulating materials should be developed by the appropriate technical committees. The many factors to be considered and the philosophy underlying the development of material test procedures are described in detail in ANSI/IEEE Std 98-1984 [1].

This standard should be followed when preparing test procedures.

The test procedures for material cannot take into account all of the many different influences that affect the life of insulation in different equipment and applications. The useful life of a material in a particular electric or electronic equipment may be quite different from the life determined by testing the material alone. It is also recognized that the life of a material used in one type of electric equipment may be different from the life of the same material applied in another type of equipment. The suitability of insulating materials in electric equipment, and in combination with other materials, is determined by experience or by insulation system tests.

The test procedures for materials will, however, provide thermal-life data that can be used to compare the relative thermal life (RTI) of insulating materials. Using a relevant test procedure, the test life of an accepted material as a function of temperature can be determined. Since the nominal temperature of a material that has been accepted for a long time will have been established by experience, its life-temperature characteristic determined by test, provides a basis for comparison with the thermal endurance of a new material.

The severity of the tests and their duration are arbitrarily chosen for convenience, accuracy, and economy in resting. Therefore, the life expectancy under test conditions may be shorter than, and may have no uniform relation to, the life expectancy of the material in actual service. Materials of a given temperature index may be used as components of complete insulation systems that are assigned widely different limiting temperatures, depending upon the results of thermal evaluation tests of the insulation system.

Appropriate technical or standards groups may wish to establish the time for use in establishing the temperature indices.

4.2 Statistical Criteria

Thermal aging tests are used to evaluate the thermal capability of insulating materials as described in ANSI/IEEE Std 98-1984 [1]. Normally, test results at several higher temperatures are extrapolated to lower temperatures. The TI or RTI for insulating materials is derived by the application of mathematical operations, including appropriate statistical analysis, to the test data. Care needs to be exercised so that projections, estimations, extrapolations, and other procedures are based on valid statistical processes. However, the derivation of a temperature index often should be permitted even if all of the statistical criteria, such as linearity and equality of variances are not satisfied. In this way the loss of useful information, obtained with a substantial economic investment, can be avoided. In this case the TI or RTI should include a notation that specified statistical requirements have not been met.

Detailed considerations for the preparation of test procedures for the thermal evaluation of insulating materials are given in ANSI/IEEE Std 98-1984 [1], and the statistical aspects are considered in IEEE Std 101-1972 (R1980) [5].

4.3 Acceleration of Thermal-Aging Tests

Acceleration is obtained by intensifying the test parameters. Rules enabling estimation of the acceleration factor can be deduced when the mechanism of the aging process is known (for example, that the logarithms of life-time is proportional to the reciprocal absolute temperature).

For long-life applications, a high acceleration is desired to obtain a relatively short test time, but the correlation between test and reality becomes increasingly uncertain with increasing acceleration.

5. Determination of Material Temperature Class by Experience

5.1 General

Thermal aging tests of insulating materials, as described in Section 4., provide quantitative data. However, the relationship of such data to the life of electric or electronic equipment or the results of thermal-aging tests on insulation systems is always to some degree qualitative. For this reason the temperature index for insulating material is expressed simply as a number that provides a useful basis for comparison, but is not a design temperature value.

lt is recognized that it is not practical or even possible to make thermal-aging tests on every insulating material to represent every condition of use. It is also apparent that the service lye of electric and electronic equipment does provide the most significant basis for determining the thermal capability of insulating materials. The analysis and evaluation of service lye is difficult and time consuming. Truly quantitative information is seldom obtained. Moreover, the equipment user with the most direct and immediate knowledge of service life may not transmit such information adequately to the equipment manufacturer or to the maker of insulating materials. Nevertheless, after several years of extensive use, a qualitative knowledge of the thermal capability of an insulating material is developed. More often such knowledge is based on comparison with information of insulating materials that have been used in service for even longer periods of time. Thus it becomes possible to compare the thermal capabilities of new insulating materials with older established ones and thereby group them in preferred temperature categories.

The determination of a material temperature class for an insulating material from service experience is qualitative. The adequacy of such a determination depends on the amount of experiences and the reliability of the source. Such factors are difficult to define or to specify, but the service experience is preferred.

Thermal aging tests on insulation systems also are useful in determining the thermal performance of insulating materials and provide another type of experience. The results from such tests can be used in much the same way as service life in establishing material temperature classes for insulating materials. Tests on systems (see Part IV) gives more quantitative results but the correlation with service life is subject to interpretation.

A knowledge of the chemical nature and structure of insulating materials by experienced individuals also provides additional information for the comparison of thermal capability. Such experience alone does not provide an adequate basis for establishing a material temperature class but it may be supplemental to other information.

Experience becomes most useful for establishing material temperature classes for insulating materials when service experience, the knowledge of chemical structure, tests on systems, and tests on materials are compared and interrelated. To establish a reliable and material temperature class by experience, data should be collected from many sources; these data need to be evaluated by experienced and responsible individuals.

5.2 Service Experience Data

When service experience data are used to establish the material temperature class of an insulating material the data should include all relevant service conditions to which the insulating material is exposed. Before service experience can be treated in a quantitative way it is necessary that data collection be restricted to closely similar systems employed in essentially indentical functions.

Although presentation of detailed data is desirable it must be recognized that presentation of precise numerical data will not be possible in the majority of practical cases. It may be better in such cases to use all available information regarding service experience which provide a frank assessment of its positive aspects and limitations.

Part III Limiting Temperatures and Their Measurement for Electrical Insulation Systems

1. Purpose and Scope

It is intended that responsible technical committees will use the results of thermal life tests and service experience to establish limiting temperatures for the insulation systems used in equipment. The requirements for insulation systems and the limiting temperatures assigned to them will be suited to the equipment considered and will be based on obtaining a desired life expectancy.

2. Derivation of Temperature Rise

Steps to determine limits of temperature rise for pusposes of Standardization are as follows:

1) Classify insulation systems by experience or by accelerated life tests.
2) Select a value of limiting ambient temperature.
3) Subtract the limiting value of ambient temperature from the limiting insulation temperature to obtain the limiting value of insulation temperature rise.
4) Decide on a hottest-spot allowance.
5) Derive an observable temperature rise to be used for assigning a rating under standard conditions of test.

These five steps are illustrated in Fig 1.

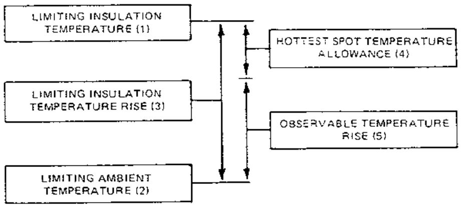

Figure 1—Derivation of A Value of Limiting Insulation Temperature for Equipment-Rating Purposes

Alternatively, the limiting value of observable temperature rise may be selected first on the basis of economic or other considerations. The five steps of the procedure should then be carried through in the reverse order to find the corresponding hottest-spot temperature and thence to determine from life test data the insulation required to give the desired expectancy in service.

2.1 Limiting Insulation Temperature

The limiting insulation temperature of an insulation system may be established by test or by service experience with the particular insulation system.

The limiting insulation temperature is useful as a point of reference or benchmark and is of primary importance in selecting the practical limits of observable temperature rise that are included in specific equipment standards for rating and testing. It is not usually measurable in the ordinary course of testing or operation of electrical equipment.

2.2 Ambient Temperature[5]

The time, location, and methods of measurement shall be standardized for each type of equipment under consideration.

Experience indicates that ambient outdoor-air temperatures at most locations where electrical equipment is operated seldom exceed 40 °C. The average outdoor-air temperature during any 24 h period is usually 5 °C-10 °C lower than the maximum. For purposes of assigning a rating when the temperature of the outdoor air is taken as the ambient, 40 °C normally is chosen as the value of the maximum ambient temperature. When daily average ambient air temperature is specified, 30 °C is generally recommended.

For self-ventilated (self-cooled) equipment, the ambient temperature is the average temperature of the air in the immediate neighborhood of the equipment.

For self-ventilated equipment operated in an enclosure as a complete unit, the ambient temperature is the average temperature of the air outside the enclosure in the immediate neighborhood of the equipment.

For equipment with a heat exchanger that is not integral with the equipment, the ambient temperature is that of the ongoing cooling medium to the equipment.

For equipment completely buried in the earth, the ambient temperature is the temperature of the earth near the equipment but sufficiently remote so as not to be affected by the heat dissipated. lt also is the temperature of the earth adjacent to the equipment when the equipment is not contributing heat to the surrounding medium.

2.3 Hottest-Spot Temperature Allowance

Limiting values of insulation temperature rise are not usually applicable for use as standards for rating or testing because the observable temperature rise is less than the actual temperature rise by an amount that may be widely different for equipment of various types and sizes. Some factors that cause the observable temperature rise to be different are as follows:

1) Inaccessibility of the hottest spot
2) Nonuniformity of cooling
3) Kind and thickness of insulation
4) Form of winding
5) Rate of treat flow
6) Relative locations of heat generation and dissipation
7) Method of temperature measurement

Under varying load conditions, the time lag of the measured temperature behind the actual temperature is also an important factor.

Experience and reasoning indicate that an embedded detector, properly placed, should give the highest obtainable temperature indication. Temperature measurements by the resistance method give the average temperature of the winding, which should be lower than the temperature obtained by a well-placed embedded temperature detector.

In view of these variable factors, no single value of the hottest-spot temperature allowance will apply exactly to different types or sizes of equipment. Therefore, it is recommended that the organization responsible for each standard covering each specific type of equipment select the hottest-spot allowance method of temperature measurement most appropriate for the conditions and determine the limiting observable temperature rise from this value.

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[5] See IEEE Std 97-1969 [4].

2.4 Observable Temperature Rise

To arrive at the observable temperature rise for use in a particular standard it is necessary to determine the method or methods of temperature determination that are most suitable. It is desirable, where practicable, to standardize on one method for each type and size of equipment so that measurements will be comparable.

The selection of an observable temperature rise for rating or testing a particular type of equipment depends largely upon practical experience obtained in the application and upon the considerations mentioned in Part I, Section Auto. Different values may be appropriate for different types of equipment using the same insulating materials. For example, in the case of small, low-voltage coils, higher temperature rises are recognized than are recognized for insulating conductors (cable) in general, using the same insulating materials. Also, low-voltage, firmly contained mica-flake insulated coils have been found suitable in service at materially higher temperatures than is suitable for large, high-voltage coils. Further, some insulating materials enclosed in a nitrogen atmosphere have been found to withstand higher temperatures than they do in air.

In selecting the final value of temperature rise for a particular type of equipment and service, it is important to recognize the need for uniformity and simplicity among the various standards. The least number of different values of temperature rise and methods of measurement should be adopted as practical.

It is recommended that values of observable temperature rise be selected from Table 1.

Table 1—Suggested Values of Observable Temperature

Rise °C			
30	55	80	160
35	60	90	180
40	65	100	200
45	70	120	220
50	75	140	240

It is recognized that temperature-rise values permissible in service may differ from those established for rating purposes. Such conditions may be defined by service factors, recommendations in operating guides, or by standards for assembled equipment different from the standards for individual components.

3. Methods of Temperature Determination

Five fundamental methods of temperature determination that are in use are listed in Table 2. Specific methods of temperature determination are the responsibility of the equipment subcommittees.

Table 2—Methods of Temperature Determination

Method	Description of Method
Thermometers	(Thermometers normally provide the poorest accuracy and should be limited to applications where only general information is required.) The thermometer method consists in the determination of the temperature by mercury or spirit thermometers or other suitable temperature measuring instruments when applied to the hottest parts accessible to ordinary mercury thermometers without alteration of the structure. NOTE: When the thermometer method of temperature determination is called for, it is intended that the temperature-measuring instrument used shall indicate substantially the same temperature as obtained by a liquid in glass thermometer in the same location.
Applied Thermocouple	The applied thermocouple method consists in the determination of the temperature by thermocouples or other suitable temperature-measuring instruments of comparable size when applied to the hottest parts accessible to thermocouples in locations normally inaccessible to liquid-in-glass thermometers. NOTE: Depending upon the thickness of insulation separating thermocouples from current-carrying conductors, thermocouples may give readings comparable to those obtained by the resistance method or may give the considerably lower readings, characteristics of the thermometer method. Accordingly, in the measurement of winding temperatures by the use of thermocouples, the method will be defined as the applied thermocouple method only if the thermocouples are applied directly to the conductors or are separated from the metallic circuit only by the integrally applied insulation of the conductor itself.
Contact thermocouple	The contact thermocouple method consists in the determination of the temperature by the application of pointed prods made of dissimilar metals, to an exposed bare-metal surface so that the metal whose temperature is to be measured forms part of a thermocouple circuit.
Resistance	The resistance method consists in the determination of the temperature by comparison of the resistance of a winding at the temperature to be determined with the resistance at a known temperature.
Embedded detector	The embedded detector method consists in the determination of the temperature by thermocouples, or resistance temperature detectors, or other temperature-measuring devices built into the equipment, either permanently or for test purposes, in specified locations inaccessible to mercury or spirit thermometers.

3.1 Other Temperature-Measuring Devices

A variety of other methods or instruments, or both, are available or under development for temperature measurement. Sensor development, including thermal sensors, is one of the more active areas of current research because of the obvious need for such devices in a variety of industries. Some optical and electro-optical devices are already state of the art and will undoubtedly be married to electrical apparatus in the future for measuring temperature and other phenomena. Thermal imaging (infrared cameras) has been widely used as a nondestructive test technique to monitor thermal loads.

NOTE — IEEE Std 119-1974 [6] includes recommendations concerning the determination of operating temperatures and of temperature rise of all electrical equipment, instruments, and apparatus in common use where temperatures do not exceed 500 °C.

3.2 Selection of Methods of Temperature Determination

The applied thermocouple method is suitable for measuring the temperature of surfaces that are accessible to thermocouples. The contact thermocouple method is suitable for measuring temperatures of bare-metal surfaces such as those of commutator bars and slip rings. The resistance method is suitable for measuring the temperature of insulated windings. For windings of low resistance, special precautions are necessary to obtain accurate results.

The embedded detector method is suitable for measuring the temperature at designated interior locations as specified in the standards for some kinds of equipment such as large rotating machines.

The hottest-spot temperature allowance may vary depending on the capability of measuring the internal temperatures. Stators and similar equipment can usually be measured with a good degree of confidence; however, it is impossible to ensure that the hottest-spot temperature was determined. A large number of measurement points may provide temperature data closer to the hottest-spot temperature, therefore, a different hottest-spot temperature allowance is used in comparison to when a small number of temperature points are taken.

4. Effects of Altitude[6]

Equipment is usually rated for use at an altitude not exceeding a value specified in the standards.

The reduced air density at high altitudes causes an increased temperature rise in all equipment cooled wholly or partially by free or forced convection. This effect may or may not be compensated for in whole or in part by the lower ambient temperatures usually found at the higher altitudes. The effect of reduced air density is greatest on equipment cooled principally by forced convection of a substantially constant volume of air. This is the usual case of a constant-speed self-ventilated open or fan-cooled enclosed machine or a machine cooled by an external constant-speed fan or blower.

The increase in temperature rise with altitude as determined in various investigations[7] varies from approximately one percent per 1000 ft for certain air-cooled equipment, where a large part of the cooling is by radiation, to approximately 5% for other machines where the cooling is almost entirely by forced-air convection. It is generally considered that the increase in temperature rise with altitude may be neglected in the operation of standard equipment up to 3300 ft (1000 m) in altitude. For some stationary equipment for which the percentage increase is low it may be negligible at any altitude normally encountered.

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[6] See IEEE Std 97-1969 [4].

[7] Appendix C: Doherty and Carter 1924, Montsinger 1924, Fechheimer 1926, Montsinger 1945, Velnott 1946.

Part IV Evaluation of Electrical Insulation Systems

1. Purpose and Scope

This part of the standard is a guide for IEEE and other technical committees when developing specifications for evaluation of insulation systems in particular equipment. The basic philosophy of this publication may be applicable for any application that uses dielectric materials, that is, rotating machines, transformers, switch gear, circuit boards, electronic devices, insulated wire, and cables. The objectives of Part IV are as follows:

1) Provide general principles for temperature classification of insulation systems.
2) Provide general principles for multifactor functional testing of insulation systems.

Historically, functional evaluation of insulation systems has primarily been based on thermal stresses. This evaluation has frequently been made using models containing the new or candidate insulation system and on older systems established through service experience. In addition to the insulation systems, models contain the associated electric and mechanical parts needed to simulate the conditions found in equipment. Stresses, other than thermal, have normally been used only as diagnostic aids to help determine when thermal aging of the insulation system has reached the point where it is unreliable when exposed to normal levels of these other stresses. This has sometimes been supplemented by inclusion of other accelerated stresses in series or together with the thermal stress cycle. and also by testing complete equipment. This experience has provided the basis upon which the general principles for temperature classification of insulation systems were developed.

Thermal functional evaluation of insulation systems has been very successful. However, with many types of equipment other aging stresses or factors, that is, mechanical, electric, and environmental, etc, may be dominant and significantly influence service life (Appendix B.1). Multifactor functional testing of insulation systems in models or equipment provide important information and broaden the knowledge of the relationship between factors of influence and service life.

2. Temperature Classification of Insulation Systems

2.1 General

Thermal aging of insulation is an important factor in the life of electrical equipment. Such aging makes insulation more vulnerable to the various other degrading stress exposures encountered in service.

Experience has shown that the thermal life characteristics of composite insulation systems for particular equipment cannot be reliably inferred solely from information concerning component materials. To ensure satisfactory service life, insulation specifications need to be supported by service experience or life tests. Accelerated life tests are used as comparative methods to evaluate systems, thus shortening the period of service experience required before they can be used with confidence. Tests on complete insulation systems, representative of each type of equipment, are necessary to confirm the performance of materials for their specific functions in the equipment.

The electrical insulation of equipment may be made up of many different components selected to withstand the widely different electric, mechanical, thermal, and environmental stresses occurring in different parts of the structure. The duration an insulation system will be serviceable depends on the effectiveness of the physical support for the insulation and the severity of the forces acting on it and the materials themselves, and the service environment. Therefore, the length of useful life of the insulation system depends on the arrangement of individual components, the interactions upon one another, the contribution of each component to the electric and mechanical integrity of the system, and the process used in manufacturing the equipment.

2.2 Insulation System Classes

Most equipment standards have previously classified the insulation in one or more insulating material classes and include appropriate limiting temperature rise standards for equipment using each of these classes. Although this classification has nominally been by material classes, the wide divergence in expected performance and in both observable temperature and hottest-spot temperature between different types of equipment using the same material class indicates that the real classification was by insulation systems.

Insulation system classes may be designated by letters, numbers, or other symbols and may be defined as assemblies of insulating materials in association with equipment parts. If numbers are used, the use of material identifying numbers should be avoided. These systems may be assigned a system temperature rating based on service experience or on an accepted test procedure that can demonstrate an equivalent life expectancy. Existing insulation systems have generally been service-proven. New or modified systems may be evaluated by accepted test procedures and when so evaluated, shall have equal or longer thermal endurance than a service-proven system of the same class at the prescribed test conditions. A new insulation system may also be classified in a higher class by test if it has equal or greater thermal endurance at appropriately higher test temperatures when compared to a service-proven insulation system under the same test conditions.

2.3 Thermal Evaluation Functional Test Procedures for Insulation Systems

It is the responsibility of each technical committee to develop test procedures suitable for the temperature-life evaluation of the insulation systems used in their equipment. These test procedures should be in general accord with the principles outlined herein, but, they may differ for the various types of equipment, in whatever ways are appropriate, to allow for differences in their insulation systems and for the many conditions to which the equipments are exposed in service. A principle objective of these test procedures is to enable the performance of new and old insulation systems to be compared directly in a practical way and in a reasonable time, thus providing a sound basis for introducing new insulation systems into service.

The test for the evaluation of insulation systems should be chosen so that each component of the system will perform under the test conditions in a manner similar to its operation in service. However, the severity of the tests should be substantially greater than the conditions encountered in service to enable the performance of the system to be determined in a reasonable time. Prolonged exposure to high temperature is the single accelerated aging factor employed in these tests. Other factors, such as exposure to moisture and voltage are chosen in such a way as to develop and disclose promptly any significant weakness or deterioration of the insulation system. So far as practicable, the atmospheric and other environmental conditions should be similar to those usually encountered in service. When such conditions are made more severe, at the discretion of the responsible technical committee, the effect on acceleration of the test should be considered.

The chief criterion of life expectance is the elapsed time-at-temperature, whether the temperature is the result of continuous or cyclic loading, overload, or operation at other than normal ambient temperature.

2.3.1 Acceleration of Thermal Aging Procedures

The test temperature-exposure conditions should be chosen to cover a reasonable range of temperatures to facilitate reasonable extrapolation of data. The severity of the test exposures should be selected to provide reasonable acceleration and positive determination of insulation system life. In evaluating and comparing life expectancies determined by tests, the regression analysis methods given in IEEE Std 101-1972 (R 1980) [5] should be employed.

2.3.2 Test Procedure Outline

For the sake of uniformity and standardization, it is suggested that technical committees use the following outline in preparing the test procedures for the thermal evaluation of the insulation system used in the equipment. ANSI/IEEE Std 99-1980 [2], explains in more detail the following considerations.

1) Purpose
2) Scope
3) Models—construction and number
4) Thermal aging
5) Humidification
6) Associated materials
7) Mechanical stress
8) Electric stress
9) Special environments
10) Method of cooling
11) Test sequence
12) Length of test cycle
13) Failure criteria
14) Mathematical treatment of thermal-aging data
15) Interpretation of thermal life expectancy
16) Specification of minimum life expectancy and variability
17) Form and method for reporting results

3. Multifactor Functional Evaluation of Insulation Systems

3.1 General Principles

This section of the standard is based on the principle that service life of an insulation system shall be demonstrated either by evaluation of service experience, functional tests on full-scale equipment or part thereof, or on models.

Service experience is the preferred basis for evaluating insulation systems. However, this can be limiting, depending on the parameters of the equipment and service with which one has experience.

Multifactor functional testing provides the opportunity to evaluate insulation systems using either full-scale equipment or models that reproduce appropriate stresses, which are typical of a particular application. Intensification of one or more of the aging stresses (factors of influence) permits comparative results to be obtained in a shorter time (see 3.2.4). The aging stresses should, where possible, act simultaneously if they do so in service.

Multifactor functional test procedures should be proven to give statistically acceptable reproducibility before being introduced by an equipment techical committee.

For long-life applications, an evaluation of a new insulation system by means of these functional tests requires comparison with a service-proven insulation system subjected to corresponding experimental conditions. For short-life applications, the insulation system in the actual equipment may be evaluated without comparison with a known insulation system.

The evaluation of the capabilities of known insulation systems for radically new conditions or, possibly, of radically new insulation sytems for known conditions, is sometimes necessary. The results may be generally accepted if the guidelines of this standard are observed.

The behavior of an insulation system under conditions of test is expressed by means of an estimated life. Rules for translating the test results into estimated life shall be given in a test specification. Procedures need to be specified for relating estimated life from available service experience.

The reader is alerted to the probability that in the future the design, study, and analysis of the behavior of electrical insulation systems and materials may utilize finite element analysis methods. Finite element analysis is a critical constituent tool of the emerging sciences of CAD-CAM (integrated computer aided manufacture). The technique is already widely used for the structural design of large electrical equipment, such as rotating machines and transmission towers. It is a powerful tool for studying the distribution of stress (thermal, mechanical, or electric) on a local basis and can be used to study time-dependent effects. A variety of computer codes are already available to model processes that are linear and can handle multiple-load inputs. Nonlinear codes are also currently under development for a variety of purposes. Finite element codes, however useful, should not be used without ensuring that their underlying algorithms are correct and that their accuracy for a given application can be verified experimentally.

3.2 Procedures for Multifactor Functional Evalution

3.2.1 General

It is recognized that procedures for the multifactor functional evaluation of insulation systems need to be developed, which provide confidence in utilizing the results for intended applications. Care shall be taken that the test specification does not restrict the freedom of the equipment designer when selecting the best test condition compromise, using his experience and knowledge.

Insulation systems for equipment with a service life exceeding a reasonable testing time will normally require accelerated testing, with an evaluation procedure based on extrapolation, equipment or parts thereof, or models. In the present state of the art, such tests are based on comparisons with a known (reference) insulation system, which is service-proven in similar equipment. More than one test level will usually be required to provide the data necessary for extrapolation.

For short-life equipment, tests may be made on equipment or models without acceleration or extrapolation of the test results. In such cases, one test level corresponding to the specified service conditions may be sufficient.

3.2.2 Test Specimens

When practical, the equipment itself should be used for the determination of the estimated performance of the insulation system. However, insulation systems may be evaluated by models rather than by full-size equipment when required because of economy. Models should be made to embody the essential elements of the equipment they simulate, taking care to provide that aging processes similar to those in service can be imposed. In many cases, the behavior of the insulation system depends significantly on the design of the essential elements (for example, design of the cooling ducts in the slot of the stator of air-cooled generators). All relevant characteristic details should be represented in the model.

3.2.3 Aging Procedure

A characteristic of multifactor functional testing is the applications of all relevant factors of influence to the test model. Ideally, stresses that act at the same time in service should be applied simultaneously.

It is recognized that the rigorous application of this general rule may not always be possible because sufficient technical knowledge may not be available to permit the interpretation of results of functional tests involving the simultaneous acceleration of several aging stresses. Moreover, simultaneous application of stresses, in many cases, make functional tests unacceptably complicated and expensive.

Therefore, simplified procedures may have to be adopted, even though it is known that simultaneously acting stresses may cause interactions or synergisms that change the aging mechanisms. The absence of such interactions during tests when only single stresses are applied prevents the results of such tests from exactly representing the results of simultaneous application of those stresses.

3.2.4 Acceleration of Functional Tests

Acceleration is obtained by intensifying the aging stress. In some cases, transformation rules enabling estimation of the degree of acceleration can be deduced when the mechanism of the aging process if known (for example, that the logarithm of life-time is proportional to the reciprocal absolute temperature, if aging takes place by a first order chemical reaction).

In the present state of the art, test acceleration is usually obtained by intensifying or acclerating only one of the several aging stresses applied simultaneously. For long-life applications, a high rate of acceleration is desired to obtain a relatively short test time, but the correlation between test and reality becomes increasingly uncertain with more rapid acceleration.

3.2.5 Test Procedure Outline

The outline in 2.3.2 is preferred for most tests. Special consideration shall be given to (5), (7), (8), (9), and (11) as they relate to simultaneous application of each type of stress, (for example, peak-to-peak or average stress level, or both) and which type of stress predominates for a given application.

Annex A

Illustration of Thermal Endurance Graph, Temperature Index, Relative Temperature Index, and Halving Interval

(Informative)

(These Appendixes are not a part of ANSI/IEEE Std 1-1986, IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.)

The temperature index is deduced from the graph, at the desired time, for example, at 20 000 h and is expressed as follows: TI/128 (see Fig A.1).

If any time other than 20000 h is used for obtaining the index, the number of thousands of hours so used shall prefix the index. This will be expressed, for example, TI 5 kh/151.

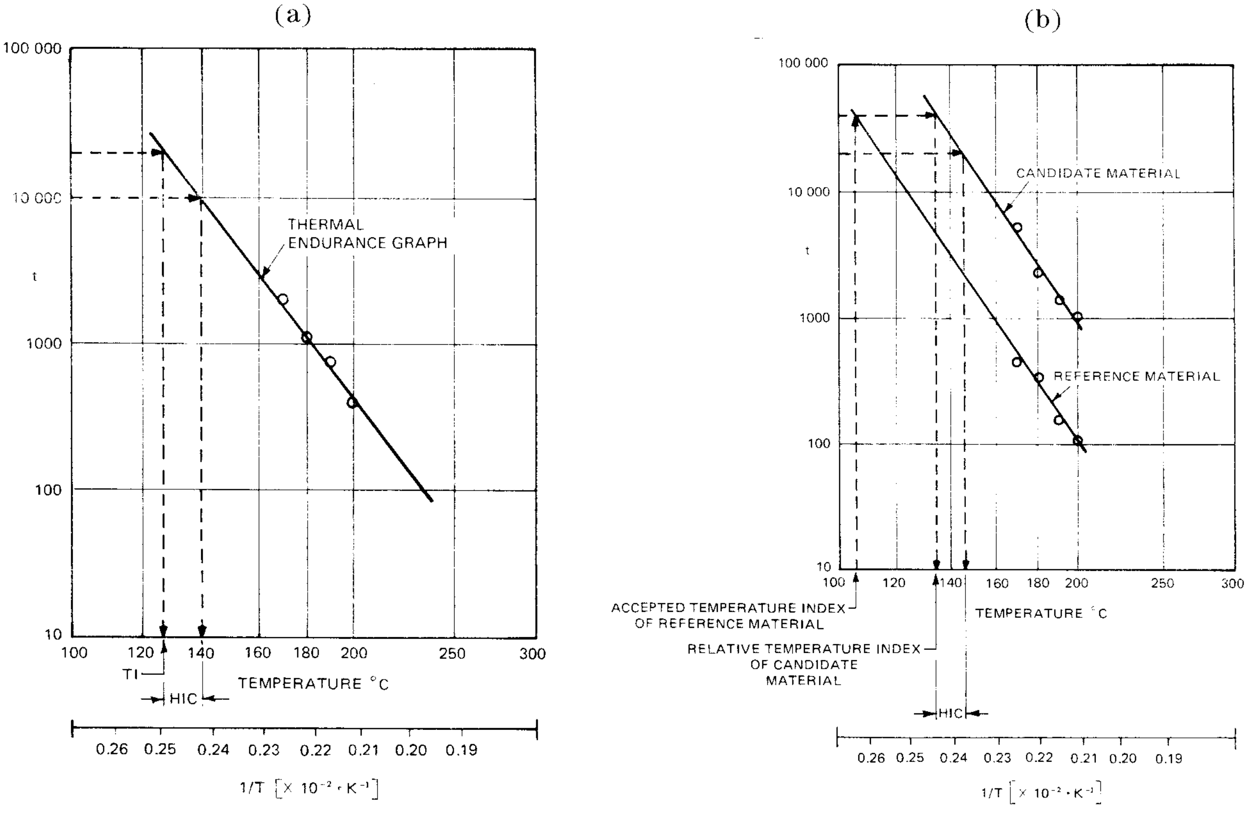

Figure A.1—(a) Thermal Endurance Graph, Temperature Index and Halving Interval (b) Relative Temperature Index and Halving Interval

Annex B

List of Some Important Factors of Influence and Duty Relevant to Insulation in Electrical Equipment

(Informative)

B.1 Thermal

Maximum temperature[8]

Low-ambient temperature[9]

High-ambient temperature

Temperature gradient

Rate of temperature change (thermal shock)

B.2 Electrical

Working voltage

Over-voltage (transients)

Frequency

Partial discharges[10]

Tracking

Flash-over

Creeping

B.3 Ambient (Environmental)

Air

Oxygen

Hydrogen

Nitrogen

Inert gases

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[8] *Maximum* refers to the hottest part of the insulation system of a particular type of equipment.

[9] *Low ambient* is meant for temperature below 0 °C.

[10] Includes partial discharges inside the insulation and along outside surfaces.

Sulphur hexafluoride

Different corrosive atmospheres (specify which)

Pressure

Vacuum

Lubricants

Insulating liquids

Water (humidity)[11]

Semiconductive dust

Dust and sand

Fungi

Rodents

Termites

Humidity

B.4 Mechanical

Vibration, electrodynamic

Impact, electrodymanic

Vibration, mechanical[12]

Impact, mechanical[12]

Bending

Pressure

Tension

Repeated compression

Torsion

B.5 Duty

Continuous

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[11] Indicates kind and length of storage, if unusual, for example *very humid, very hot, twelve months.*
[12] Also takes into account stresses occurring during transportation.

Short-time

Intermittent

Intermittent with starting and electric braking

Storage and transportation[11]

Annex C

Bibliography

(Informative)

For an annotated Bibliography refer to BRANCATO. E. L., Insulation Aging, a Historical and Critical Review. *IEEE Transactions Electrical Insulation* vol EI-13, no 4, Aug 1978.