

IEEE General Principles for Temperature Limits in the Rating of Electric Equipment



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FOREWORD

Experience and continuing rapid development in electrical insulation have demonstrated the need for periodic review and revision of this document. During the time since the 1962 revision of this document, there has been a need for a more distinct separation of insulation systems and insulating materials. Confusion in nomenclature between insulating materials and insulation systems has continued to exist. This present document attempts to overcome this conflict through the complete separation of insulating materials from insulation systems and by the introduction of the temperature index concept for insulating materials. To clarify this separation a distinct section, Part IV, is now provided for insulating materials.

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IEEE General Principles for TEMPERATURE LIMITS IN THE RATING OF ELECTRIC EQUIPMENT

PART I—GENERAL CONCEPTS AND SCOPE

1-1. 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 that determine the selection of temperature limits, appropriate methods of temperature measurement, and a discussion of the factors to be considered in applying the principles to specific cases. Guiding principles are also included for the development of Test Procedures for the thermal evaluation and classification of electrical insulating materials and of insulation systems for use in electric equipment.

Insulating materials, as referred to herein, include processed compositions of raw materials and simple combinations thereof before they are fabricated into coils or other structures identified with specific parts of electric equipment.

Insulation systems, as referred to herein, include fabricated and processed combinations of insulating materials with the associated parts of electric equipment. Such equipment may contain more than one insulation system.

The recommendations are not mandatory, nor is it expected that they will be followed precisely. It is recognized that 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, USA, or other recognized Standards are available. The companion IEEE Standards Publications* Nos. 96, 97, 98, 99, and 101 complement and extend the concepts outlined in the present Standard.

1-2. General Concepts. Temperature-rise limits established for rating purposes are most useful if they correspond to the performance of electric equipment operating under usual service conditions.

The temperature limits for electric equipment should be so chosen that they will result in a satisfactory life under normal operating conditions. In addition, permissible emergency temperature limits and corresponding

ratings may be established including the durations and frequencies of emergency operation to which these limits apply. Temperature is not the only design criterion since the suitability of an insulation system for a specific application is influenced by other requirements, such as endurance under electric and mechanical stress, vibration, exposure to moisture, chemicals, etc., and by the atmosphere or enclosure in which the equipment operates.

In choosing temperature-rise limits suitable for particular conditions, the following general concepts may be helpful.

- (a) Marked changes in the electrical and mechanical properties of insulating materials may occur progressively as a result of prolonged exposure to high temperature. The materials may soften, lose weight, or become brittle, and their chemical composition and structure may change. The effects of high temperature may differ widely depending upon the particular environmental conditions. Insulation does not usually fail because of immediate breakdown at some critical temperature, but rather as a result of gradual deterioration with time.
- (b) 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 as well as upon the insulation used. A given 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.
- (c) The electrical properties of insulation cannot be directly correlated with mechanical strength. Generally, because of chemical changes and the removal of moisture, the dielectric strength of new insulation may increase initially with age. Subsequently, the dielectric strength begins to decrease, but it may not fall below its initial value until the insulation has lost much of its mechanical strength. This physical disintegration finally results in electric breakdown.

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 have become oxidized or embrittled under the influence of high temperature, successful operation of the equipment may continue for years if the insulation is not disturbed.

* IEEE No. 96 "General Principles for Rating Electric Apparatus for Short-Time, Intermittent, or Varying Duty."

IEEE No. 97 "Recommended Practice for Specifying Service Conditions in Electrical Standards."

IEEE No. 98 "Guide for the Preparation of Test Procedures for the Thermal Evaluation of Electrical Insulating Materials."

IEEE No. 99 "Guide for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment."

IEEE No. 101 "Guide for Statistical Analysis of Test Data."

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 have proven satisfactory in small equipment using similar insulating materials.

- (d) 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 its insulation structure. At a given temperature, therefore, the life of equipment may be longer if the windings are suitably protected than if they are freely exposed to industrial atmospheres. Favorable results are obtained by the use of chemically inert gases or liquids as cooling or protective media.
- (e) The life of equipment also depends upon the care it receives during manufacture and installation and upon maintenance during operation. Successful operation cannot be expected of insulation that has been damaged or displaced.
- (f) The rate of physical deterioration of insulation under the influence of temperature and time increases rapidly with an increase in temperature. A fairly precise method of determining insulation life at elevated temperature is provided by the modern concept that the logarithm of the insulation life is a function (usually linear) of the reciprocal of the absolute temperature. 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.
- (g) The ambient temperature directly affects the temperature attained by equipment in operation. Data recorded at various weather bureau stations in the United States are given in Appendix I.

1-3. 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 types 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

records. 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 atmospheric conditions met with in service. To what extent extreme conditions may be discounted without incurring unreasonable maintenance on standard equipment 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, additional operating experience, new measurement techniques, or changes in service requirements.

Important recent trends to which consideration has been given in preparing these revised principles include the following.

- (a) The growing tendency to rely on accelerated life tests, as provided in IEEE Test Procedures, to determine appropriate limiting temperatures and fields of usefulness for complete insulation systems and for individual insulating materials.
- (b) The availability of many new insulating materials whose characteristics and appropriate fields of use cannot be determined from their chemical composition alone and, therefore, must be determined by test.
- (c) The great expansion of new fields of application, such as equipment for nuclear-energy production, aviation and military duty, mobile use, and air conditioning, which are increasing the varieties of special-purpose equipment to be supplied by the electrical industry and which are also increasing the ranges of temperature that must be considered in their operation.
- (d) The continuing and greater use of enclosed types of equipment often operating in controlled gases or liquids.
- (e) A trend toward operating some electric equipment at or close to limiting insulation temperature.
- (f) A trend toward operating some electric equipment in 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 expectancy.

Standards for different types of electric equipment should be correlated with each other 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 as well as 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 economic 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 expectancy of equipment under particular service conditions. In the course of time it will be desirable to correlate further the various Standards to make the life expectancies of associated equipment more consistent with each other and better suited to give the desired degree of reliability.

PART II—TEMPERATURE CLASSIFICATION OF INSULATION SYSTEMS

1-4. Insulation Systems—General. Thermal aging of insulation is an important factor in the life of electric equipment, as such aging makes insulation more vulnerable to the various other degrading exposures encountered in service.

Experience has shown that the thermal life characteristics of composite insulation systems cannot be reliably inferred solely from information concerning component materials. To assure satisfactory service life, insulation specifications need to be supported by service experience or life tests. Accelerated life tests are being used increasingly to evaluate systems using the many new synthetic insulating materials that are available, 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 is made up of many different components selected to withstand the widely different electric, mechanical, and thermal stresses occurring in different parts of the structure. How long 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 as well as on the materials themselves and the service environment. Therefore, the length of useful life of the insulation system depends on the way that its individual components are arranged, their interactions upon each other, the contribution of each component to the electrical and mechanical integrity of the system, and the way the equipment is manufactured.

1-5. Definition of Insulation System Classes. An insulation system is an assembly of insulating materials in a particular type, and sometimes size, of equipment. In general, a specific piece of equipment has one insulation system, but for some types of equipment having

two or more distinct subassemblies, it may be desirable to consider that there are a corresponding number of insulation systems.

Most equipment Standards have previously classified the insulation in one or more insulating material classes and included 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 both observable temperature and hottest spot temperature between different types of equipment of 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, must have equal or longer thermal endurance than a service-proven system of the same class at the 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. It is hoped that eventually insulation system classes may be defined by test specifications rather than solely by comparison.

1-6. Thermal Evaluation 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 the 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 principal 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 tests 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 enough 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 principal 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 expectancy is the elapsed time-at-temperature whether the temperature is the result of continuous or cyclic loading, overloads, or operation at other than normal ambient temperature.

The test temperature-exposure conditions should be chosen to cover a reasonable range of temperature 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 Standards Publication No. 101 "Guide for Statistical Analysis of Test Data" should be employed.

For the sake of uniformity and standardization, it is suggested that the Technical Committees use the following outline in preparing the Test Procedures for the thermal evaluation of the insulation system used in the equipment. IEEE Standards Publication No. 99 "Guide for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment" explains in more detail the following considerations:

- (a) purpose
- (b) scope
- (c) models—construction and number
- (d) thermal aging
- (e) humidification
- (f) associated materials
- (g) mechanical stress
- (h) dielectric stress
- (i) special environments
- (j) method of cooling
- (k) test sequence
- (l) length of test cycle
- (m) failure criteria
- (n) mathematical treatment of thermal-aging data
- (o) interpretation of thermal life expectancy
- (p) specification of minimum life expectancy and variability
- (q) form and method for reporting results
- (r) identification of insulation systems.

1-7. Limiting Temperatures for Insulation Systems.

It is expected that the responsible Technical Committees will use the results of these thermal life tests 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.

PART III—TEMPERATURE AND ITS MEASUREMENT FOR EQUIPMENT-RATING PURPOSES

1-8. Definition of Terms. Terms are defined for purposes of standardization as follows.

- (a) Limiting insulation temperature (limiting hottest spot temperature) is the temperature selected for correlation with a specified test condition of the equipment with the object of attaining a desired service life of the insulation system.
- (b) Limiting ambient temperature is the upper or lower limit of a range of ambient temperatures within which equipment is suitable for operation at its rating. Where the term is used herein the upper limit is meant.
- (c) Limiting insulation temperature rise (limiting hottest spot temperature rise) is the difference between the limiting insulation temperature and the limiting ambient temperature.
- (d) Hottest spot temperature allowance is a conventional value selected to approximate the degrees of temperature by which the limiting insulation temperature rise exceeds the limiting observable temperature rise.
- (e) Limiting observable temperature rise is the limit of observable temperature rise specified in equipment Standards.
- (f) Ambient temperature is the temperature of the medium such as air, water, or earth into which the heat of the equipment is dissipated.
- (g) Observable temperature is the temperature of equipment obtained on test or in operation as measured by one of the methods of temperature determination defined in Section 1-14.
- (h) Observable temperature rise is the difference between the observable temperature and the ambient temperature at the time of the test.

1-9. Derivation of Temperature Rise. Steps to determine limits of temperature rise for purposes of standardization are:

- (a) classifying insulation systems by experience or preferably by accelerated life tests (refer to Section 1-10)
- (b) selecting a value of limiting ambient temperature (refer to Section 1-11)
- (c) subtracting the limiting value of ambient temperature from the limiting insulation temperature to obtain the limiting value of insulation temperature rise (refer to Section 1-13)
- (d) deciding on a hottest spot allowance