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IEEE Recommended Practice for Thermal Cycle Testing of Form-Wound Stator Bars and Coils for Large Rotating Machines

IEEE Power & Energy Society

Sponsored by the
Electric Machinery Committee

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IEEE-SA Standards Board

Abstract: This procedure is intended for form-wound bars/coils for rotating machines rated 10 kV or more at 50 Hz or 60 Hz that are subjected to many transitions from no-load to full-load current during normal operations, and where rapid load variations are typical. Only the thermal cyclic degradation within the groundwall insulation and/or the conductor package and delamination of the groundwall insulation from the conductor are addressed by this test. The procedure is applicable to indirectly-cooled machine types such as:

— combustion turbine generators
— pumped storage or peaking duty hydrogenerators
— synchronous condensers
— cyclic duty water pump motors

Various pass/fail criteria are presented, and the ones that apply in a specific circumstance must be agreed between user and manufacturer prior to commencement of testing.

Keywords: cyclic duty, delamination, groundwall degradation, IEEE 1310, indirectly cooled machines, peaking duty, stator winding, thermal cycling

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When the IEEE-SA Standards Board approved this recommended practice on 29 March 2012, it had the following membership:

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Introduction

This introduction is not part of IEEE Std 1310-2012, IEEE Recommended Practice for Thermal Cycle Testing of Form-Wound Stator Bars and Coils for Large Rotating Machines.

In some applications, large rotating machines are subjected to rapid transitions from low power to full power, and vice versa. For example, hydrogenerators (peaking duty and pumped storage), synchronous condensers, and gas turbine generators are often raised from idle to full power in a matter of minutes, are operated at full power for hours, and are then rapidly reduced to zero output. This load cycling leads to rapid temperature changes within the stator winding. As a result, an alternating shear stress develops within the ground insulation system.

If the bond between the copper and the insulation is not adequate, the copper may separate from the insulation. This results in the formation of voids between the insulation and the copper that may permit relative movement of the copper strands/turns, leading to abrasion of the insulation. Also, voids can develop between the layers of the groundwall insulation as a result of delamination. In high-voltage bars/coils, these voids can lead to partial discharges, and, under certain circumstances, to puncture of the insulation.

The test procedure described in this recommended practice is intended to simulate this thermal cyclic aging mechanism under controlled conditions. To give meaningful results in a reasonable time, acceleration is achieved by repeatedly applying heating and cooling cycles to the test samples without any hold time at the maximum or minimum temperatures. The test is performed on production, prototype, or similar design bars/coils that are not planned for subsequent use in a winding since the test produces aging of the insulation.

Note that this test procedure is not intended to evaluate the relative performance of the end-winding or the methods used to support the end-winding or the effects on the thermal cyclic aging mechanism, if any, caused by the methods used to support the end-winding. Other thermal cyclic aging mechanisms of abrasion of the coil by the core iron and cracking of insulation at the slot exit are not addressed. This recommend practice is not appropriate for direct liquid cooled machines since it is not likely that rapid winding temperature swings will occur even if the load changes rapidly. This recommended practice is not intended for direct gas cooled machines, but this may change in future revisions. This recommended practice does not apply to windings processed by the global vacuum pressure impregnation (GVPI) method.

The test procedure described in this document is not a multifactor aging stress as described in IEC 60505, since the only accelerating factor is the rate of change of temperature.

This is the first revision of this recommended practice. However, in most material respects, this test procedure is the same as described in the first edition. Based on experience, some changes were made to the diagnostic tests.

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IEEE Recommended Practice for Thermal Cycle Testing of Form-Wound Stator Bars and Coils for Large Rotating Machines

1. Overview

In some applications, large rotating machines are subjected to rapid transitions from low power to full power, and vice versa. For example, hydrogenerators (peaking duty and pumped storage), synchronous condensers, and gas turbine generators are often raised from idle to full power in a matter of minutes, are operated at full power for hours, and are then rapidly reduced to zero output. This load cycling leads to rapid temperature changes within the stator winding.

Increasing the machine output from no-load to full-load causes the stator current to increase from zero to full-load current. This current raises the temperature of the stator winding copper conductors due to I^2R (copper) losses. As the temperature increases, the copper will expand, especially in the axial direction. The longer the stator bar (or coil), the greater will be the total expansion of the copper. The high-voltage groundwall insulation operates at lower temperature than the copper and may have a lower coefficient of thermal expansion. Therefore, the thermally-induced expansion of the insulation is less than the copper. The difference in expansion is greater when the machine power level is rapidly changed since thermal inertia of the stator iron causes the insulation temperature to lag behind the copper temperature. The difference in expansion between the insulation and the copper creates a shear stress within the insulated bar/coil. In particular, during the manufacturing process, a shear stress between the copper and the insulation of the bar/coil is formed as the bar/coil cools from its groundwall curing temperature. In general, when the bar/coil is heated, the shear stress relaxes; when it cools, the shear stress increases. If the glass transition temperature is exceeded during the test, this general rule may not apply. For more information, refer to [B11].

If the bond between the copper and the insulation is not adequate, the copper may separate from the insulation. This results in the formation of voids between the insulation and the copper that may permit relative movement of the copper strands/turns, leading to abrasion of the insulation. Also, voids can develop between the layers of the groundwall insulation as a result of delamination. In high-voltage bars/coils, these voids can lead to partial discharges, and, under certain circumstances, to puncture of the insulation.

The test procedure described in this recommended practice is intended to simulate this thermal cyclic aging mechanism under controlled conditions. To give meaningful results in a reasonable time, acceleration is achieved by repeatedly applying heating and cooling cycles to the test samples without any hold time at the maximum or minimum temperatures. The test is performed on production, prototype, or similar design bars/coils that are not planned for subsequent use in a winding since the test produces aging of the insulation.

Interpretation of test results depends on the analysis of the diagnostic and post-thermal cycle test data and/or comparison of the data to past results on the same insulation system. The slot sections of stator bars/coils similar to those that have performed well under diagnostic and post-thermal cycle tests are expected to withstand load cycling duty better than slot sections similar to those that have tested poorly.

Note that this test procedure is not intended to evaluate the relative performance of the end-winding, or the methods used to support the end-winding, or the effects on the thermal cyclic aging mechanism, if any, caused by the methods used to support the end-winding. Also, there is no hold period at the maximum or minimum temperature as exists in a generator since this would greatly complicate the temperature-control scheme. Other thermal cyclic aging mechanisms of abrasion of the coil by the core iron and cracking of insulation at the slot exit are not addressed. Including a core model, slot filler materials, and the end-winding support structure would greatly increase the cost and complexity of the test. IEC 60034, Part 18, Section 34 describes a test procedure that includes a core model for thermal cycling testing. Those interested may refer to this IEC document. This recommend practice is not appropriate for direct liquid cooled machines since it is not likely that rapid winding temperature swings will occur even if the load changes rapidly. This recommended practice is not intended for direct gas cooled machines, but this may change in future revisions. This recommended practice does not apply to windings processed by the global vacuum pressure impregnation (GVPI) method.

The test procedure described in this document is not a multifactor aging stress as described in IEC 60505 since the only accelerating factor is the rate of change of temperature. A multifactor aging test may also have mechanical and electrical stresses as aging factors. Although a multifactor aging test method may simulate more accurately the stresses encountered in service, it is very expensive to perform and is not in common use.

1.1 Scope

This procedure is intended for form-wound bars/coils for rotating machines rated 10 kV or more at 50 Hz or 60 Hz that are subjected to many transitions from no-load to full-load current during normal operations, and where rapid load variations are typical. Only the thermal cyclic degradation within the groundwall insulation and/or the conductor package and delamination of the groundwall insulation from the conductor are addressed by this test. Examples of machine types that typically exhibit rapid load transitions include:

— Combustion turbine generators
— Pumped storage or peaking duty hydrogenerators

— Synchronous condensers

— Cyclic duty water pump motors

Various pass/fail criteria are presented, and the ones that apply in a specific circumstance must be agreed between the user and the manufacturer prior to commencement of testing. Whether a particular bar or coil has passed or failed is best determined by comparing the test results from a number of stator bars or coils.

1.2 Purpose

A test method to determine the relative ability of high-voltage form-wound stator bars and coils of large rotating machines to resist deterioration due to rapid heating and cooling resulting from machine load cycling is described. The test procedure is primarily intended for machines where the stator windings are indirectly cooled by air or hydrogen. This procedure provides a recommended practice for performing thermal cycle testing of form-wound stator bars and coils without the use of a simulated core. To ensure the results of the thermal cycling test accurately represent the insulation deterioration expected in service, the bars or coils used in the test should represent in every way the characteristics of the production lot. Thermal cycle testing of bars and coils confined in a simulated core would require different parameters and therefore is not covered by this procedure.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM D 149, Standard Test Methods for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies.[1]

ASTM D 229, Standard Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation.

ASTM D 352, Standard Test Methods for Pasted Mica Used in Electrical Insulation.

ASTM D 494, Standard Test Method for Acetone Extraction of Phenolic Molded or Laminated Products.

ASTM D 619, Standard Test Methods for Vulcanized Fiber Used for Electrical Insulation.

ASTM D 790, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.

ASTM D 1868, Standard Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems.

ASTM D 2344, Standard Test Method for Apparent Interlaminar Shear Strength of Parallel Fiber Composites by Short-Beam Method.

ASTM D 3846, Standard Test Method for In-Plane Shear Strength of Reinforced Plastics.

[1]ASTM International publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.