

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

Sponsor

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Abstract: 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.

Keywords: delamination, form-wound stator bars and coils, similar design bar/coil, slot section, virgin bar/coil, thermal cycle testing

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Introduction

(This introduction is not part of IEEE Std 1310-1996, IEEE Recommended Practice for Thermal Cycle Testing of Form-Wound Stator Bars and Coils for Large Generators.)

Peaking duty and pump storage hydrogenerators, synchronous condensers, and gas turbine generators are generally subject to load cycling. This load cycling creates shear stress between copper and the groundwall insulation of the stator winding that can result in the delamination of the groundwall, and under certain circumstances, into the puncture of the insulation.

This standard provides a test procedure that can be performed within a reasonable amount of time for accelerated thermal aging of production, prototype, or similar design bars/coils under laboratory conditions. The effects of this accelerated thermal aging on the bars/coils would provide some indication of the thermal aging of the stator winding of generators subject to cyclic duty.

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

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 then are 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 ground-wall insulation operates at lower temperature than the copper, and has 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. When the bar/coil is heated, the shear stress relaxes; when it cools, the shear stress increases.

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. The mechanism is accelerated under the test procedure to give meaningful results in a reasonable amount of time. 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 effects on the thermal cyclic aging mechanism, if any, caused by the methods used to tighten the bar/coil in the stator core slot or 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. At the time of the preparation of this recommended practice, a Working Group of the International Electrotechnical Commission (IEC) was working on a test procedure that included the core model for thermal cycling testing. Those interested may refer to this IEC document, when available.

1.1 Scope

This procedure is intended for bars/coils for rotating machines rated 11 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 the following machines:

- Indirectly cooled combustion turbine generators
- Indirectly cooled pumped storage or peaking load hydrogenerators
- Indirectly cooled synchronous condensers

No pass/fail criteria are presented; rather, the test results on a variety of stator bars and coils are compared. Pass/fail criteria may be established by users of this recommended practice.

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. This procedure provides a recommended practice for performance of thermal cycle testing of form-wound stator bars and coils without the use of simulated core. Since thermal cycling tests will result in aging of the insulation of the bar or coil, prototype or spare bars or coils obtained from a normal production run must be used in the test.

Thermal cycle testing of bars and coils confined in a simulated core, that would simulate the effects of the core, would require different parameters and therefore is not covered by this procedure.

2. References

ASTM D 149-93a, Standard Test Methods for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies.¹

ASTM D 229-91, Standard Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation.

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