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IEEE Trial-Use Standard for Voltage-Endurance Testing of Form-Wound Coils and Bars for Hydrogenerators

IEEE Power Engineering Society

Sponsored by the
Electric Machinery Committee

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Electric Machinery Committee
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IEEE Power Engineering Society

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Abstract: The test parameters and acceptance criteria for voltage-endurance testing of form-wound bars and coils for use in large hydrogenerators are covered in this standard.
Keywords: electrical insulation, form-wound bars, form-wound coils, hydrogenerators, voltage-endurance testing

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Introduction

(This introduction is not part of IEEE Std 1553-2002, IEEE Trial-Use Standard for Voltage-Endurance Testing of Form-Wound Coils and Bars for Hydrogenerators.)

Since the 1950s, various manufacturers and users have developed procedures that evaluated the ability of the electrical insulation of form-wound stator coils and bars to withstand electrical stress and high temperature operation [B1, B4, B11, and B12]. The test was referred to as a *voltage-endurance test*. The original purpose was to find those designs and manufacturing processes that could perform well under the test with combined electrical and thermal stresses. Over the years, some utilities started to apply the test to full-size coils, and bars and to use the results to either qualify a design from a vendor or as a quality control tool [B1, B2, B8, B10, and B11].

In 1989 the IEEE issued IEEE Std 1043™-1989, IEEE Recommended Practice for Voltage-Endurance Testing of Form-Wound Bars and Coils. This document defined the procedure for performing such tests on full-size bars and coils. The document was successful in that most organizations that performed such testing adopted the procedure, making the testing procedures more uniform. Consequently, the test results from different organizations could be realistically compared. Several utilities required the test to be performed on four or more coil legs per winding.

In 1996 the IEEE Standards Board approved a revision to IEEE Std 1043-1989. Most of the recent revisions to the 1989 document were to make the test procedure less ambiguous and to ensure that important aspects that can cause variations in results were more rigorously specified. Revisions also occurred in how the temperatures, voltage, and times-to-failure are to be recorded.

During the revision of IEEE Std 1043-1989, it became apparent that there was a desire that in addition to the "recommended practice" there be a "standard"—that is, with the test voltages, temperatures, and time-to-failures specified. The purpose of this standard is to define test and acceptance criteria for voltage-endurance testing of form-wound bars and coils used in hydrogenerators.

The voltage-endurance test by definition is an accelerated aging test in which elevated voltages are used. Establishing a standard with test temperatures, voltages, and acceptable test times will prevent the unnecessary increase in these parameters, which has happened in the past. Escalating the test parameters may result in failure mechanisms that are unlikely to occur in service, thus rendering the voltage-endurance test a poor indicator of winding quality. On the other hand, by making the test a standard, the test would become more widely specified and related to the industry's experience.

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IEEE Trial-Use Standard for Voltage-Endurance Testing of Form-Wound Coils and Bars for Hydrogenerators

1. Overview

This standard is comprised of six clauses. Clause 1 provides the scope and purpose of this standard. Clause 2 lists references to other standards, recommended practices, and guides that are useful in applying this standard. Clause 3 provides definitions that are either not found in other standards, recommended practices, and guides, or have been modified for use with this standard. Clause 4 establishes the sample size and test parameters, while Clause 5 defines the acceptance criteria. Clause 6 describes the data records that have to be maintained at the completion of the test.

1.1 Scope

This standard applies to voltage-endurance testing of form-wound stator winding bars and coils having a mica-based insulation system with thermo-setting polyester and/or epoxy resins used in hydrogenerators and pumped storage generators operating in air with a rated line-to-line voltage between 4 000 to 22 000 V, and a frequency of 50 Hz or 60 Hz.

1.2 Purpose

The purpose of this standard is to define the test parameters for the voltage-endurance test and the number of specimens to be used for each test. It also defines the acceptance criteria and the procedures for retesting in the event of a premature failure during the voltage-endurance test. The details of the test procedure are described in IEEE Std 1043™-1996.

2. References

The following publications shall be used in conjunction with this standard. When the following publications are superseded by an approved revision, the revision shall apply.

ASTM D 1868-1993, Standard Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems.[1]

[1]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

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IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing.[2,3]

IEEE Std 43™-2000, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

IEEE Std 286™-2000, IEEE Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation.

IEEE Std 930™-1987 (Reaff 1995), IEEE Guide for the Statistical Analysis of Electrical Insulation Voltage Endurance Data.

IEEE Std 1043-1996, IEEE Recommended Practice for Voltage-Endurance Testing of Form-Wound Bars and Coils.

IEEE Std 1434™-2000, IEEE Trial-Use Guide to the Measurement of Partial Discharges in Rotating Machinery.

3. Definitions

For the purposes of this standard, the following terms and definitions apply. IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition [B7], should be referenced for terms not defined in this clause.

3.1 groundwall insulation: The main high-voltage electrical insulation that separates the copper conductors from the grounded stator core in motor and generator stator windings.

3.2 half-coil: The slot portion and end arms comprising a complete Roebel bar or one half of a form-wound coil.

3.3 semiconductive slot coating: The partially conductive paint or tape layer in intimate contact with the groundwall insulation in the slot portion of the stator core. This coating ensures that there is little voltage between the surface of the coil and the grounded stator core.

3.4 stress control coating: The paint or tape on the outside of the groundwall insulation that extends several centimeters beyond the semiconductive slot coating in high-voltage stator bars and coils. The stress control coating often contains silicon carbide particles that tend to linearize the electric field distribution along the coil or bar end-turn. The stress coating overlaps the semiconductive slot coating to provide electrical contact between them.

3.5 test temperature: The temperature of the heater plates mounted on the stator coil or bar, as measured by a temperature sensor embedded within the heater plate.

3.6 top/bottom coil: The top half bar/coil is the one that is closest to the air gap. The bottom half bar/coil is the one that is furthest from the air gap.

3.7 voltage endurance: The time-to-failure of the groundwall insulation under a high electrical stress.

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4. Sample size and test parameters

4.1 Sample size

The number of specimens shall be at least four bars (two top and two bottom bars) or two coils, but not more than 1% of the number of bars/coils in the winding. Additional bars/coils may be needed in the case that a retest is required, as per Clause 5.

The specimens can be selected from the prototype stage and/or at different stages of the production cycle. The actual time at which the bars/coils will be selected depends on the agreement between the manufacturer and user.

4.2 Test parameters

The test voltage shall be selected from either of the two proposed schedules defined in Table 1. It is important to note that the test times for each test will depend on the test voltages selected from Schedules A or B. Schedule A is associated with a longer minimum acceptable test life (400 hours), whereas Schedule B is associated with a shorter minimum acceptable test life (250 hours). Generally, Schedule B test voltages are considered to be more severe, in spite of the shorter minimum acceptable test life expected.

Table 1—Test voltages for voltage-endurance test[a]

Rated line-to-line voltage of the windings (kV)	Rated line-to-ground voltage (kV)	Schedule A	Schedule B
		400 hours	250 hours
		Voltage-endurance test voltages (kV)	
Column 1	Column 2	Column 3	Column 4
4.0	2.31	8.7	10.1
6.6	3.81	14.3	16.7
11.0	6.35	23.9	27.9
11.5	6.64	25.0	29.1
12.0	6.93	26.1	30.4
12.5	7.22	27.1	31.7
13.8	7.97	30.0	35.0
15.0	8.66	32.6	38.0
15.5	8.95	33.6	39.3
16.0	9.24	34.7	40.6
17.0	9.82	36.9	43.1
18.0	10.39	39.1	[a]
19.0	10.97	41.2	[a]
22.0	12.70	[a]	[a]

[a]It is recommended that for test voltages above 43 kV the actual test voltage be negotiated between manufacturer and user.

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For machines with a voltage rating between the levels stated in Column 1 of Table 1, it is recommended that the test voltages (Column 3 and Column 4) be determined by interpolation. It is recommended that the same voltage ratio, namely 3.76 or 4.39 times line-to-ground rms voltage (Column 2 values), be used when specifying the test voltage.

The test temperature shall be the maximum specified temperature of the winding as measured by an embedded temperature sensor between the top and bottom bar/coil in the winding. It is suggested that the test temperature be discussed between the vendor and the purchaser and agreed upon before the test begins.

4.3 Test procedure

The voltage-endurance test shall be performed according to the procedures described in IEEE Std 1043-1996. The criteria for specimen failure are described in IEEE Std 1043-1996.

It shall be determined before beginning the test whether insulation failures involving the stress grading shall be considered as specimen failures for the purpose of the test. Some erosion or discoloration of the stress control coating during the voltage-endurance test is normal and is not considered to be an insulation failure. It shall be determined before beginning the test whether or not deterioration involving the stress grading and slot coatings is to be monitored and repaired periodically during the progress of the voltage-endurance test.

5. Acceptance criteria

It is recognized that the number of specimens used for the test represents a statistically very small sample size in comparison with the number of form-wound coils or bars normally manufactured for a machine. Therefore, conclusions reached about the insulation quality or manufacture may have some uncertainty. In cases where questionable results occur, efforts shall be made to increase the confidence in the results by testing additional bars/coils.

If all specimens survive test times greater than 400 hours (Schedule A) or 250 hours (Schedule B), the entire bar/coil population is deemed to have met the test requirements.

If fewer than 26% of the specimens fail between 50% and 100% of the minimum time-to-failure, then two additional bars/coil legs shall be put on test. All these remaining specimens must pass the test. If six or more bar/coil legs are originally tested, testing of additional specimens is not required. If any failures occur during the retesting, the complete production lot is considered as not complying with the requirements, and the corrective action has to be determined after dissection and discussions between the manufacturer and user.

When one or more failures occur prior to 50% of the specified minimum time-to-failure, dissection of the failure and microscopic examination should be done. The corrective actions have to be determined after discussions between the manufacturer and user.

Bars/coils that have been subjected to voltage-endurance tests shall not be used in-service or considered as spares.

6. Data records

The test temperature, applied voltage, and test time, or when applicable, the time-to-failure for each specimen shall be recorded. Also, where applicable, the exact location of the failure shall be included.

The general principles for data analysis shall be applied according to the procedures described in the IEEE Std 1043-1996.

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Annex A

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