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IEEE Recommended Practice for Quality Control Testing of External Discharges on Stator Coils, Bars, and Windings

IEEE Power and Energy Society

Sponsored by the
Electric Machinery Committee

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Approved 19 October 2012

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Abstract: The procedure for quality control testing of external discharges on stator coils, bars and windings of large air-cooled ac electric machines is described in this recommended practice.
Keywords: ac, corona-imaging instrument, discharge inception voltage, electrical insulation, external discharges, IEEE 1799, stator winding, ultraviolet radiation

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Introduction

This introduction is not part of IEEE Std 1799-2012, IEEE Recommended Practice for Quality Control Testing of External Discharges on Stator Coils, Bars, and Windings.

External discharges in the end-windings are caused by inadequate workmanship for globally vacuum-pressure impregnated (VPI) stators or problems on stators assembled on-site. Poorly finished lashes with an insufficient gap between bars produces coil-to-coil or bar-to-bar discharges. Misalignment between adjacent coils or bars may also reduce the gap distance and generate a high electric stress larger than the air breakdown strength. Sometimes misplaced resistance temperature detector (RTD) or air gap monitor leads have been seen to cause partial discharges (PDs) with high-voltage bars or coils. External discharges for the individual coil/bar could also be a result of improper design, improper material, or improper workmanship. After many years, the deterioration induces surface degradation that may lead, in the long run, to a phase-to-ground fault and reduce the overall reliability of the system. More detail on the theory of external discharges and their effects is given in Annex A. Some utilities have seen deterioration of the junction between the stress control coating and semiconducting slot coating of stator windings after only a few years of operation. Other secondary effects, such as the production of a large quantity of ozone, which may be deleterious to the equipment and dangerous to personnel, is also of concern. In addition, over the years, the ground-wall insulation thickness of stator coils and bars has been reduced to improve heat transfer through the ground-wall insulation. This optimization does, however, increase the dielectric stress on the insulation and on the end-winding stress grading system making them more susceptible to developing electrical discharges.

In the current recommended practice, the term “semiconducting slot coating” is preferred to “semiconductive slot coating” often used in the industry. These coatings, composed of resin, varnish, enamels, or other compounds, are filled with carbon black powder, graphite, or other filler and should have electrical resistivity per unit of surface of $1 \times 10^2 - 5 \times 10^5$ Ohms per square. The semiconducting slot coating applied on the insulation surface of the slot parts of winding must have uniform tight contacts with the grounded walls of the stator slot. This coating provides minimum voltage between the surface of the coil or bar and the grounded stator core.

A stress control coating must be applied on the end turns of high-voltage stator winding and overlap the semiconducting slot coating to provide electrical contact between them. The stress control coating has a non-linear resistance with voltage.

This recommended practice presents two methods for evaluating the quality of materials and design, factory workmanship, and on-site workmanship. The first one, the blackout test, has been used for many years. The second one, the corona-imaging inspection, is more recent and presents several advantages. Each method has its advantages and disadvantages.

IEEE Std 1434 mentions these two inspection methods but with very little detail. The current recommended practice includes a more elaborate description of sample preparation, bench tests, test conditions, and acceptance criteria in the factory and on-site.

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Contents

1. Overview 1
1.1 Scope 2
1.2 Purpose 2

2. Normative references 2

3. Definitions 3

4. Test preparation and safety 5

5. Test equipment and connections 5
5.1 Sensitivity of the corona-imaging instruments 6

6. Quality control test of external discharges with corona-imaging instrument or blackout test 7
6.1 Factory test on coils and bars 8
6.2 Stator model test 10
6.3 Test on fully assembled stator windings 14

7. Data records 20
7.1 How to fill the data logging tables 20

Annex A (informative) Theory of optical emissions from external discharges 24

Annex B (informative) Variability of discharge inception and extinction voltages 27

Annex C (informative) Example of determination of the maximum voltage for a specific winding diagram 28

Annex D (informative) Example of correction factor to apply to the test voltage of a stator model and VPI stator for a machine which will operate at altitudes of more than 1000 m 31

Annex E (informative) Example of operating-voltage table and bar/coil identification table used during test 33

Annex F (informative) Bibliography 35

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1. Overview

This quality control test is used to confirm that the insulation system of the stator winding of generator and motor operating in air, including the semiconducting slot and stress control coatings, are free of external discharges. Quality control of the semiconducting slot coating, stress control coating, and manufacturing process is best done in the factory. For stators assembled on-site, such as those for large hydro-generators, additional tests can be performed on the fully assembled generator in order to control the quality of the assembly and workmanship. This control includes:

a) evaluation of the spacing between end-arms and with the phase circuit rings or connections to the main phase terminals

b) confirming proper alignment of the ground plane made by the semiconducting slot coating on the straight portion of the bar/coil with regard to the core pressure finger

c) the positioning of all cables (RTD, air gap monitor) with respect to high voltage and

d) inspection of imperfections that may have been introduced during assembly (presence of foreign objects, misplaced slot center filler, chips and scratches to bars or coils coating)

In the case of machines assembled in the factory, such as VPI machines, the complete quality control test can be done in the factory. However, special care should be taken so that no change in the machine's

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conditions occur during transportation (contamination by water and dust, or damage to end-arms during movement). The use of this recommended practice may eliminate the need for users to specify minimum clearances between bars/coils in the end-winding to avoid surface discharge activity.

1.1 Scope

This recommended practice provides a procedure to detect external discharges in form-wound bars and coils and complete stator windings of rotating machines operating in air with a rated line-to-line voltage greater than 4200 V at power frequency. The recommended practice is applicable to bars, coils, and complete stator windings. The recommended practice covers two inspection methods: the visual blackout test, and the use of corona imaging instruments.

1.2 Purpose

The purpose of this recommended practice is to suggest specimen preparation, test parameters, and procedures for detecting external discharges associated with bars, coils, and complete stator windings using the above mentioned methods. It also recommends acceptance criteria and a procedure for retest in the event of a test failure.

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.

IEC 60204-1, Safety of machinery—Electrical equipment of machines—Part 1: General requirements.

IEC 61508, Functional safety of electrical/electronic/programmable electronic safety-related systems.

IEEE Std 4, IEEE Standard Techniques for High-Voltage Testing.[1, 2]

IEEE Std 4a, Amendment to IEEE Standard Techniques for High-Voltage Testing.

IEEE Std 510-1983 (Withdrawn), Recommended Practice for Safety in High-Voltage and High-Power Testing.[3]

ISO 14121-1, Safety of Machinery—Risk Assessment—Part 1: Principles.

ISO/TR 14121-2, Safety of Machinery—Risk Assessment—Part 2: Practical Guidance and Examples of Methods 2.

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3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[4]

blackout test: A test performed after eliminating all ambient light, specifically on energized electrical equipment, to detect external or surface discharges visible with the human eye (naked eye) after at least 15 min of acclimatization.

conducting materials: Composition materials which usually have a dielectric binder and conductive filler (e.g., electrical insulation coating or compound filled with copper, silver powder, etc.).

conductive materials: Solid materials which have a large number of free electrons that can easily be put into motion to create an electric current (e.g., metal [as steel, copper] sheet, copper foil, copper, silver powder, etc.).

corona (air): A luminous discharge due to ionization of the air surrounding a conductor or insulated conductor caused by a voltage gradient exceeding a certain critical value.

corona imaging instrument: An instrument used for visual detection of corona or external surface discharges on energized test objects in ambient light, frequently using ultraviolet radiation emitted by the discharge source.

discharge extinction voltage (rotating machinery) DEV (ionization or corona-extinction voltage): The voltage at which discharge pulses that have been observed in an insulation system, using a discharge detector of specified sensitivity, cease to be detectable as the voltage applied to the system is decreased.

discharge inception voltage (rotating machinery) DIV (ionization or corona inception voltage): The voltage at which discharge pulses in an insulation system become observable with a discharge detector of specified sensitivity as the voltage applied to the system is raised.

external discharge: In rotating machines, external discharges may occur on the surface of bars/coils or in any air gap present between the bar/coil surface and the stator core, or in the end-winding of the stator.

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

high-potential test (power operations): A test that consists of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of high voltage insulation system and spacing under normal conditions. *Syn:* **high pot; hipot.**

NOTE—The test is used as a proof test of new apparatus, a maintenance test on older equipment, or as one method of evaluating developmental insulation systems.[5]

ionization: (A) A breakdown that occurs in parts of a dielectric when the electric stress in those parts exceeds a critical value without initiating a complete breakdown of the insulation system. **(B)** The process by which an atom or molecule receives enough energy (by collision with electrons, photons, etc.) to split into one or more free electrons and a positive ion. Ionization is a special case of charging.

NOTE—Ionization can occur on both internal and external parts of a device. It is a source of radio noise and can damage insulation.

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