IEEE Recommended Practice for Insulation Testing of AC Electric Machinery with High Voltage at Very Low Frequency

433™

IEEE Power & Energy Society

Sponsored by the
Electric Machinery Committee

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Acknowledgments

The Insulation Testing of AC Electric Machinery with High Voltage at Very Low Frequency Working Group especially acknowledges the contributions of Guy Halldorson, who passed away shortly before the publication of this recommended practice.

Abstract: This recommended practice describes very low frequency withstand and diagnostic tests that are performed on the stator windings of ac electric machines.
Keywords: ac electric machines, ac electric machine testing, diagnostic test, high-potential (hipotential) test, over potential test, proof testing, safety, very low frequency testing, VLF testing, withstand test

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Introduction

This introduction is not part of IEEE Std 433-2009, IEEE Recommended Practice for Insulation Testing of AC Electric Machinery with High Voltage at Very Low Frequency.

Voltage withstand tests, particularly in the field, are generally carried out with dc power sources, because in terms of weight, size, and cost they have a decided advantage. However the dc test data obtained on ac machines have a serious disadvantage in that the dc breakdown mechanism differs appreciably from that which occurs under ac conditions. In practice, it is found that the dc breakdown strength is substantially higher than the ac breakdown strength. The dc breakdown process is principally an electronic conduction mechanism, with the free electrons injected into the insulation from either sharp points or the electrodes (where high field enhancement is created) or at space charge build-up sites within the dielectric. In contradistinction, the ac breakdown process involves a thermally controlled-type mechanism and results directly either from the thermal losses associated with the dielectric losses or from the partial discharge (PD) induced heating and physical erosion mechanism at the sites where repeated discharges can take place. Both of these are frequency- and voltage-dependent effects; also note that the dissipation factor at a given insulation site is determined by the dielectric losses of both the solid insulation and the power loss contribution from the repetitive PD pulses.

Evidently, it is more meaningful to evaluate the insulating systems of ac machines using ac voltage sources. For tests in the field, such ac voltage sources must be readily transportable, low weight, moderate size, and requiring lower amounts of power. This is accomplished by making use of low-frequency ac power supplies, which were first introduced in the 1950s for the purpose of high-potential testing and insulation resistance and capacitance measurements (see Bhimani [B3], [B4]).[a] Although since that time, the low-frequency source equipment has undergone substantial improvements, some uncertainties remain when it is attempted to relate the test data obtained at low frequencies to that at power frequencies. This becomes particularly apparent when one considers the dissipation factor and PD measurements at low frequencies with respect to those at the power frequency.

The dissipation factor may be expressed by the quotient, $\sigma/\omega\varepsilon'$, where σ represents the conductivity, ε' represents the real permittivity (dielectric constant) of the dielectric, and ω is the frequency term. At power frequencies under constant ambient temperature, the conductivity is more or less constant and governed by the conduction losses of free-charge carriers. Since ε' is also relatively constant, then as the frequency ω is first decreased , the dissipation factor will exhibit an increase with falling frequency, ω. Once the falling frequency enters the space charge polarization region over the lower frequencies, the conductivity σ will commence increasing, thereby further augmenting the value of the dissipation factor. As a consequence, the low-frequency value of the dissipation factor will be substantially higher than that at the power frequencies (see *Engineering Dielectrics, Vol. IIB, Electrical Properties of Solid Insulating Materials: Measurement Techniques* [B5]).

When diagnostic measurements are carried out in terms of the dissipation factor to determine the dielectric loss behavior of an insulating system, it must be borne in mind that the measured $\tan\delta$ value is an indicator of the total loss in the insulating system. The PD contribution can be calculated in terms of the PD pulse-phase distribution at a given applied voltage and frequency or be measured using the pulse charge-voltage parallelogram technique (see *Engineering Dielectrics, Vol. I, Corona Measurement and Interpretation* [B6]). The dielectric loss component in the solid insulation of the ac machine can then be determined by subtracting the dissipation factor value due to the PD loss from that resulting from that of the overall insulation system loss.

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[a] The numbers in brackets correspond to those of the bibliography in Annex C.

The PD intensity at power frequencies is substantially greater than at 0.1 Hz, because there are more discharges occurring per unit time, i.e., per 1 s, at 60 Hz. However, it is most remarkable that studies, which have been carried out over an extended frequency range, indicate that as the frequency of the power source is reduced, the total PD pulse charge transfer per cycle is augmented as the number of PD pulses per cycle exhibits an increase with falling frequency (see Bartnikas and Morin [B2] and Radu et al. [B18]. It is likely that the observed behavior is due to the change in the rate of dielectric surface charging and discharging within the cavities. Nevertheless, the total PD energy dissipated over a 1 s period at the power frequency is appreciably higher than that at 0.1 Hz; if the ac breakdown strength at 60 Hz is a result of thermal instability and degradation caused by PDs, then it will be lower than that at 0.1 Hz, which in turn will be still lower than the dc breakdown strength.

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1. Overview

1.1 Scope

This document describes very low frequency (VLF) testing of ac electric machines. It covers acceptance testing of new machines in the factory or on-site after erection. Also covered is the routine maintenance testing of machines that have been in service. In order to facilitate communication and comparison among investigators, this document recommends that the VLF used be 0.1 Hz ± 10%.

1.2 Purpose

The purposes of this recommended practice are as follows:

a) To provide a uniform procedure for testing the stator (armature) insulation of ac electric machines with VLF voltage, in order to obtain consistent results

b) To recommend constants for relating VLF tests to power-frequency and direct-voltage tests to obtain equally effective test levels

c) To describe VLF test equipment and wave shape

d) To define terms that have specific meaning in VLF testing