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IEEE Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation

Sponsor
Electric Machinery Committee
of the
IEEE Power Engineering Society

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Abstract: The power factor tip-up testing of stator coils and bars for use in large electric is covered in this recommended practice.

Keywords: cell capacitance, electric generators, power factor, stator bar, stator winding, tan delta

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Introduction

(This introduction is not part of IEEE Std 286-2000, IEEE Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation.)

This power factor tip-up test for stator coils has been used by electric machinery manufacturers and users since the original standard was issued in 1968. The original versions discussed minimally the theory of measurements. In this updated version, additional theory of the measurement and additional procedures are given for individual stator coils and bars and completely assembled windings.

This recommended practice was prepared by the Materials Subcommittee of the Electric Machinery Committee, which had the following membership:

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IEEE Recommend Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation

1. Overview

1.1 Scope

This recommended practice applies to stator coils or bars (half coils) of electric machinery operating at any voltage level. It usually applies to machines with a voltage rating of 6 kV and higher. Individual stator coils outside a core (uninstalled), individual stator coils installed in a core, and completely wound stators are covered in this recommended practice.

The tests apply to all coil insulation systems: pre-impregnated coils, post impregnated coils (global impregnation), and fully-loaded (resin-rich) taped coils. This recommended practice is not applicable to non-impregnated individual coils.

The coil insulation under test is the major groundwall insulation that is external to the conductor structure. Only that part of the strand and turn insulation that is dielectrically in series with the groundwall insulation enters into the measurements. When testing individual coils and utilizing guard electrodes, only that part of the groundwall insulation under the low voltage electrode (outer electrode) enters into the measurement.

1.2 Purpose

The purpose of this recommended practice is to describe the power factor and the power factor tip-up of the coil insulation and to specify test procedures for their measurements.

2. References

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

ASTM D150-98, Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation.¹

ASTM D1868-93 (1998), Standard Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems.

IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing (ANSI).²

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

IEEE Std 62-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus—Part 1: Oil-Filled Power Transformers, Regulators, and Reactors.

IEC/TR 60894 (1987-03), Guide for Test Procedure for the Measurement of Loss Tangent of Coils and Bars for Machine Windings.³

3. Definitions

For the purposes of this recommended practice, the following terms and definitions apply. IEEE 100⁴ should be referenced for terms not defined in this clause.

The electrical equivalent circuit for an insulation system with a dielectric loss can be represented by either a parallel or a series arrangement of passive components. Both representations are given in Figure 1 and Figure 2. The insulation is represented by a lossless capacitor, and a resistor represents the dielectric loss.

To maintain consistency throughout this standard, the terms *power factor* and *power factor tip-up* are used. This is done with the understanding these terms may be used interchangeably with the terms *dissipation factor* and *delta tangent delta*, respectively. The specific definitions for these terms are given later in this section.

Comparison of the power factor and dissipation factor for phase angles and complementary loss angles is given in Table 1.

As is shown in this table, the two measurements are very nearly the same for a specimen with a power factor or dissipation factor of 0.1000 or less. The following equations show how power factor and dissipation factor can be converted into one another:

$$PF = \frac{DF}{\sqrt{1 + DF^2}}$$

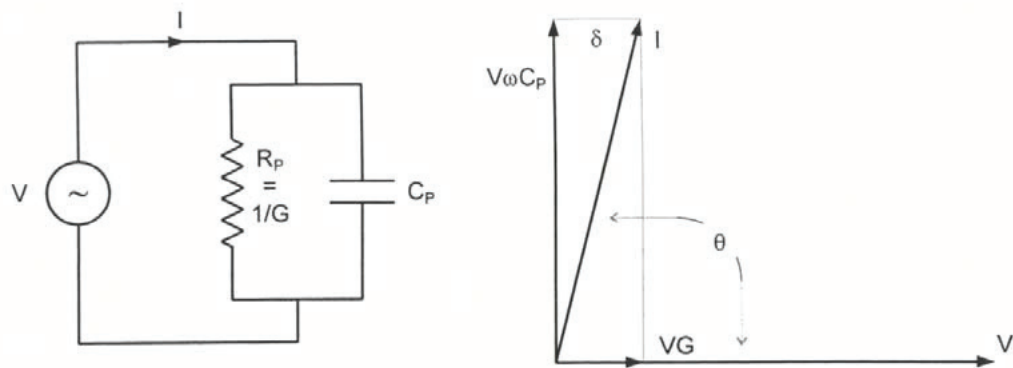
$$DF = \frac{PF}{\sqrt{1 - PF^2}}$$

¹ASTM 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/>).

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://www.standards.ieee.org/>).

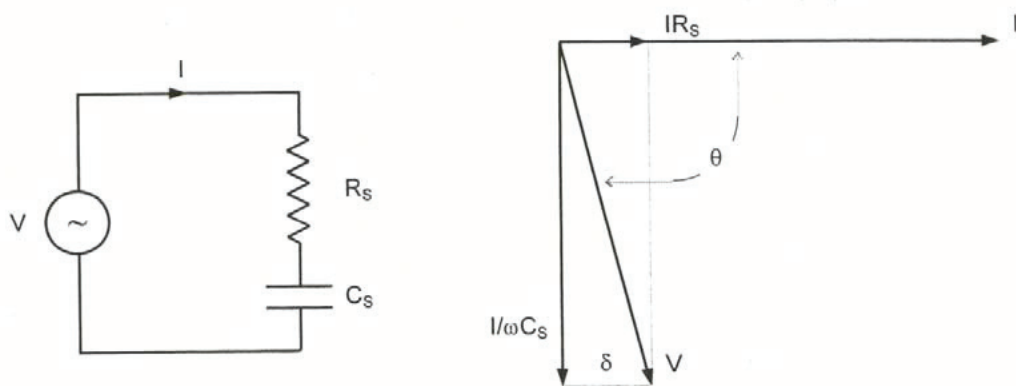
³IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

⁴Information on references can be found in Clause 2.



- C_P is parallel capacitance
- G is equivalent ac conductance
- R_P is equivalent ac parallel resistor
- X_P is parallel reactance
- ω is $2\pi f$ (for a sinusoidal wave)
- θ is phase angle
- δ loss angle

Figure 1—Parallel circuit and vector diagram



- C_S is parallel capacitance
- R_S is equivalent ac conductance
- X_S is equivalent ac parallel resistor
- ω is $2\pi f$ (for a sinusoidal wave)
- θ is phase angle
- δ loss angle

Figure 2—Series circuit and vector diagram

Table 1—Comparison of power factor and dissipation factor

Power factor, $\cos \theta$	Phase angle, θ , degree	Complementary loss angle, δ , degree	Dissipation factor, $\tan \delta$	Difference
0.000000	90.000000	0.000000	0.000000	0 part in 10^6
0.005000	89.713520	0.286480	0.005000	$< \pm 1$ part in 10^6
0.010000	89.427033	0.572967	0.010000	$< \pm 1$ part in 10^6
0.020000	88.854008	1.145992	0.020004	± 4 parts in 10^6
0.050000	87.134016	2.865984	0.050063	± 63 parts in 10^6
0.100000	84.260830	5.739170	0.100504	± 504 parts in 10^6
1.000000	0.000000	90.000000	infinity	

3.1 capacitance: That property of a system of conductors and dielectrics that permits the storage of electrically separated charges when potential differences exist between the conductors.

Capacitance, C , is the ratio of a quantity, q , of electrical charge stored in a capacitor to the potential difference, V .

$$C = \frac{q}{V}$$

The SI unit of capacitance is the farad, which is equal to one coulomb per volt.

3.2 complex relative permittivity, complex relative capacitivity (ϵ_r^*): If a dielectric medium is lossy, the relative permittivity under sinusoidal excitation can be represented by a complex number:

$$\epsilon_r^* = \epsilon_r' - j\epsilon_r'' = \frac{Y}{j\omega C_0}$$

where

Y is admittance of a given configuration of electrodes with the dielectric material
 ωC_0 is admittance with the electrodes in vacuum

In general, the complex relative permittivity will depend upon the frequency of excitation.

3.3 corona: Visual luminous discharge caused by ionization of the air surrounding a conductor with or without insulation caused by a voltage gradient exceeding a certain critical value.

3.4 delta tan delta ($\Delta \tan \delta$): Increment in the dielectric dissipation factor, $\tan \delta$, of the insulation measured at two designated voltages (see Figure 3).

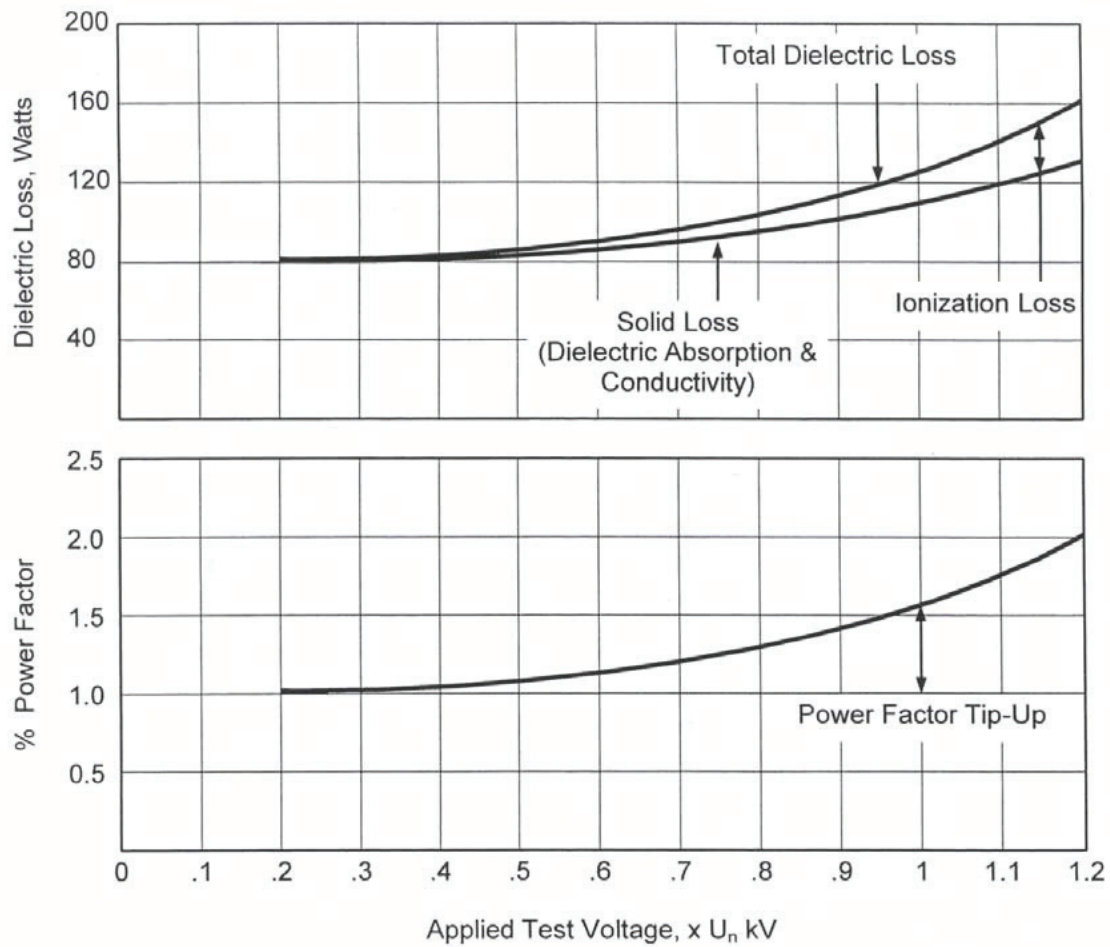


Figure 3—Power factor $\times U_n$ kV