

400™

IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems

IEEE Power Engineering Society

Sponsored by the
Insulated Conductors Committee



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**Insulated Conductors Committee
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IEEE Power Engineering Society**

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Abstract: This Guide lists the various field test methods that are currently available or under development with guidance on HOW to perform each test. The Guide covers shielded, insulated power cable systems rated 5 kV through 500 kV unless these voltages are modified by the specific “point” document.

Keywords: alternating-polarity dc-biased ac voltage, dissipation factor testing, field tests, high-voltage dc testing, low-voltage dc testing, oscillating wave, partial discharge, propagation characteristics spectroscopy, underground residential distribution, very low frequency

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Introduction

(This introduction is not part of IEEE Std 400-2001, IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems.)

This is a new omnibus Guide that has been in preparation for nine years. It provides an overview of known techniques for performing electrical tests in the field on shielded power cable systems. It is intended to help the reader select a test that is appropriate for a specific situation of interest. It provides a brief description of all the known sources used to perform field tests with a short discussion of specific tests. The material presented is descriptive and tutorial and does not address the evaluation of test results nor the specification of test voltage levels nor time of application.

Additional details will be provided in “point” documents (that are presently under preparation), such as IEEE P400.1™, direct voltage testing; IEEE P400.2™, very low frequency testing; and IEEE P400.3™, dissipation factor testing.

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Contents

1.	Overview.....	1
1.1	Scope.....	1
1.2	Purpose.....	2
2.	References.....	2
3.	Definitions.....	3
4.	Introduction.....	3
4.1	Environmental influences.....	3
4.2	Summary of direct voltage testing.....	4
4.3	Summary of alternative testing.....	4
4.4	Need for testing.....	6
4.5	Safety awareness.....	6
5.	Direct voltage testing.....	7
5.1	Introduction.....	7
5.2	Rationale for using dc.....	7
5.3	Performing LVDC tests.....	8
5.4	Performing HVDC tests.....	9
5.5	Summary of advantages and disadvantages.....	9
6.	Power frequency testing.....	10
6.1	Introduction.....	10
6.2	Test apparatus requirements.....	11
6.3	Characteristics of test systems.....	11
6.4	Test procedures.....	12
6.5	Advantages and disadvantages.....	13
7.	Partial discharge testing.....	13
7.1	Introduction.....	13
7.2	Fundamentals.....	13
7.3	Partial discharge characterization.....	13
7.4	Measurement of partial discharge.....	14
7.5	Advantages and disadvantages.....	14
8.	Very low frequency (VLF, less than 1 Hz) testing.....	15
8.1	Introduction.....	15
8.2	VLF testing with cosine-pulse waveform.....	16
8.3	VLF testing with sinusoidal waveform.....	18
8.4	Dissipation factor testing with VLF (0.1-Hz) sinusoidal waveform.....	19
8.5	Conclusions.....	21

9.	Dissipation factor testing	21
9.1	Introduction.....	22
9.2	Dielectric loss	22
9.3	Method	23
9.4	Measurement and equipment	24
9.5	Advantages and disadvantages	24
9.6	Method and assessment	25
9.7	Dissipation factor with VLF sinusoidal waveform.....	25
9.8	Advantages and disadvantages	25
10.	Oscillating wave testing	25
10.1	Introduction.....	26
10.2	General description of test method.....	26
10.3	Advantages and disadvantages	26
10.4	Test apparatus	27
10.5	Test procedure.....	27
10.6	Safety precautions.....	28
10.7	Further development work.....	28
Annex A	(informative) Power frequency testing	29
Annex B	(informative) Bibliography.....	31

IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems

1. Overview

This omnibus Guide provides an overview of known techniques for performing electrical tests in the field on shielded power cable systems. It is intended to help the reader select a test that is appropriate for a specific situation of interest. Field applied tests can be broadly divided into the following categories:

- a) Type 1 Field Tests are intended to detect defects in the insulation of a cable system in order to improve the service reliability after the defective part is removed and appropriate repairs are performed. These tests are usually achieved by application of moderately increased voltages across the insulation for a prescribed duration. Such tests may be categorized as “pass/fail” or “go/no go.”
- b) Type 2 Field Tests are intended to provide indications that the insulation system has deteriorated, hence, are “diagnostic.” Some of these tests will show the overall condition of a cable system, and others will indicate the locations of discrete defects that may become the sites of future service failures. Both varieties of such tests are usually performed by means of moderately increased voltages applied for relatively short duration, or by means of low voltages.

This Guide provides a brief description of all known voltage sources used to perform both categories of tests as well as a brief introduction to specific tests. The material presented is descriptive and tutorial and does not address the questions of evaluation of test results nor the specification of test voltage levels. Some of the methods described are well known and widely accepted. Other methods are still in development stages, with limited field experience. Each method described has advantages and disadvantages that are discussed in their respective clauses.

1.1 Scope

This Guide lists the various field test methods that are currently available or under development with guidance on HOW to perform each test. The Guide covers shielded, insulated power cable systems rated 5 kV through 500 kV unless these voltages are modified by the specific “point” document. A complete tutorial or debate forum for one method versus another is not being attempted. A brief listing of “advantages” and “disadvantages” is included, but the users should avail themselves of the technical papers that are referenced, the material listed in the bibliography in Annex B, manufacturers' literature, and recent research results to make decisions on whether to perform a test and which test method to use. In making such decisions, consideration should be given to the performance of the connected cable system, including joints, terminations, and associated equipment.

(The manufacturers of the associated equipment should be consulted, or their instruction bulletins read, for the applicability of the chosen test to that particular type of equipment.)

This Guide does not propose to cover, but may apply to, communication cables, control cables, high-frequency cables, and other special purpose cables, or unshielded power cables.

1.2 Purpose

The purpose of this Guide is to provide an overview of the various tests available for evaluating the insulation of cable systems in the field, and to set the stage for a series of guides covering each test method.

2. References

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

AEIC G7-90 (1st Edition), Guide for Replacement and Life Extension of Extruded Dielectric 5-35 kV Underground Distribution Cables, May 1990.¹

ASTM D 150-1998, Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Dielectric Insulation.²

IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing.^{3, 4}

IEEE Std 48™-1996, IEEE Standard Test Procedures and Requirements for Alternating-Current Cable Terminations 2.5 kV Through 765 kV.

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

IEEE P400.1™, IEEE Draft Guide for Making High-Direct-Voltage Tests on Shielded Power Cable Systems in the Field.⁵

IEEE Std 404™-2000, IEEE Standard for Cable Joints for Use with Extruded Dielectric Cable Rated 5000–138,000 V and Cable Joints for Use with Laminated Dielectric Cable Rated 2500–500,000 V.

IEEE Std 510™-1983 (Reaff 1992), IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing.

¹AEIC publications are available from the Association of Edison Illuminating Companies, 600 N. 18th Street, P. O. Box 2641, Birmingham, AL 35291-0992, USA (<http://www.aeic.org/>). AEIC publications are also available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112-5704, USA (<http://global.ihs.com/>).

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⁵This IEEE standards project was not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE.

3. Definitions

For the purposes of this Guide, the following terms and definitions apply. IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms and Definitions*, Seventh Edition [B30]⁶ should be referenced for terms not defined in this clause.

3.1 acceptance tests: A field test made after cable system installation, including terminations and joints, but before the cable system is placed in normal service. The test is intended to further detect installation damage and to show any gross defects or errors in installation of other system components. (IEEE Std 48-1996 and IEEE Std 404-2000).⁷

3.2 basic impulse level (BIL): Impulse voltage that electrical equipment is required to withstand without failure or disruptive discharge when tested under specified conditions of temperature and humidity. They are designated in terms of crest voltage of $1.2 \times 50 \mu\text{s}$ full-wave impulse voltage test. (IEEE Std 4-1995).

3.3 installation tests: Field tests that are conducted after cable installation but before jointing (splicing) or terminating. The test is intended to detect shipping, storage, or installation damage.

3.4 maintenance tests: A field test made during the operating life of a cable system. It is intended to detect deterioration of the system and to check the serviceability so that suitable maintenance procedures can be initiated.

4. Introduction

4.1 Environmental influences

4.1.1 Temperature

The dielectric strength of some cable insulation is reduced at increased temperatures. This may necessitate a reduction of the test voltage at those higher temperatures. Temperature gradients in the cable system insulation, caused by heat dissipation from the conductor, can result in abnormal potential distribution upon application of voltage, especially with direct voltage.

4.1.2 Atmospheric conditions

High humidity or other conditions favoring condensation on exposed surfaces can affect test results to a marked degree. Contamination of termination surfaces can greatly increase conduction current and reduce flashover levels. Relative air density affects the measurement of test voltage by gaps or similar means and the flashover at terminations. At elevations higher than 1 000 m, additional insulation at terminations is required to withstand both working voltages and prescribed test voltages. Wind can cause erroneous leakage current readings, as described in IEEE Std 48-1996, IEEE Std 62-1995, and IEEE P400.1. The bibliography, Annex B, provides some specifics for cables and cable systems.

4.1.3 Other energized conductors

Precautions should be taken to allow adequate voltage clearance when testing conductors in close proximity to other energized conductors. Failure to maintain safe clearances may lead to flashover between the test conductor and other live conductors, particularly when test voltages above the rated operating voltage are

⁶The numbers in brackets correspond to those in the bibliography in Annex B.

⁷Information on references can be found in Clause 2.

used. This consideration must be made for dc, ac, or very low-frequency (VLF) test voltages. When spacing is marginal, special precautions may be required to prevent flashover.

4.2 Summary of direct voltage testing

DC testing has been accepted for many years as the standard field method for performing high-voltage tests on cable insulation systems. Whenever dc testing is performed, full consideration should be given to the fact that steady-state direct voltage creates within the insulation systems an electrical field determined by the geometry and conductance of the insulation, whereas under service conditions, alternating voltage creates an electric field determined chiefly by the geometry and dielectric constant (or capacitance) of the insulation. Under ideal, homogeneously uniform insulation conditions, the mathematical formulas governing the steady-state stress distribution within the cable insulation are of the same form for dc and for ac, resulting in comparable relative values; however, should the cable insulation contain defects in which either the conductivity or the dielectric constant assume values significantly different from those in the bulk of the insulation, the electric stress distribution obtained with direct voltage will no longer correspond to that obtained with alternating voltage. As conductivity is generally influenced by temperature to a greater extent than the dielectric constant, the comparative electric stress distribution under dc and ac voltage application will be affected differently by changes in temperature or temperature distribution within the insulation. Furthermore, the failure mechanisms triggered by insulation defects vary from one type of defect to another. These failure mechanisms respond differently to the type of test voltage utilized. For instance, if the defect is a void where the mechanism of failure under service ac conditions is most likely to be triggered by partial discharge, application of direct voltage would not produce the high partial discharge repetition rate that exists with alternating voltage. Under these conditions, dc testing would not be useful. However, if the defect triggers failure by a thermal mechanism, dc testing may prove to be effective. For example, dc can detect the presence of contaminants along a creepage interface.

In the case of joints and accessories, their dielectric properties may differ from that of the cable with regard to conductivity. This may result in a dc stress distribution at the interfaces between the cable and the accessory that is very different from the stress under ac voltage. A careful examination of the system is necessary prior to a dc test in order to avoid difficulties.

Testing of cables that have been service aged in a wet environment (specifically, XLPE) with dc at the currently recommended dc voltage levels (see IEEE P400.1) may cause the cables to fail after they are returned to service (see Fisher, et al. [B23], and Stennis, et al. [B48]). The failures would not have occurred at that point in time if the cables had remained in service and not been tested with dc (see Eager, et al. [B21], and Srinivas, et al. [B47]). Furthermore, from the work of Bach, et al. [B7], we know that even massive insulation defects in extruded dielectric insulation cannot be detected with dc at the recommended voltage levels.

After engineering evaluation of the effectiveness of a test voltage and the risks to the cable system, high direct voltage may be considered appropriate for a particular application. If so, dc testing has the considerable advantage of being the simplest and most convenient to use. The value of the test for diagnostic purposes is limited when applied to extruded insulations, but it has been proven to yield excellent results on laminated insulation systems.

4.3 Summary of alternative testing

Alternating voltage tests at power line frequencies stress the insulation in a similar manner to normal operation, and the test is similar to that used in the factory on new reels of cable.

A serious disadvantage of power frequency ac tests at increased voltage levels is the requirement for heavy, bulky, and expensive test transformers that may not be readily transportable to a field site. This problem may be mitigated through use of resonant (both series and parallel) test sets, compensated (gapped core) test sets that are designed to resonate with a cable of average length at power frequency, the range of resonance being

adjustable to a range of cable lengths through a moderate change of the excitation voltage frequency, or a pulse resonant system. Power frequency ac tests are ideally suited for Type 2 Field Tests, such as partial discharge location, and dissipation factor ($\tan \delta$) evaluation.

Some of the practical disadvantages of power frequency tests are reduced while retaining the basic advantages by the use of VLF (0.1 Hz) voltage or by the use of other time-varying voltages. Examples of these latter are the oscillating wave (OSW, Clause 10) and the alternating-polarity dc-biased ac voltage (APDAC). When such variations of power frequency test sets are used for conducting Type 1 Tests, it is necessary to establish the equivalence of the results obtained at various voltage levels and test durations with corresponding results obtained by testing at power frequency.

A major objection to Type 1 Field Tests is the concern that application of increased voltages without any other accompanying diagnostic measurements triggers failure mechanisms that will not show during the test but that may cause subsequent failures in service. The selected test voltages can be used not only to force cable systems to fail at the sites of defects, but also to provide a useful evaluation of the condition of the insulation system.

As cable system insulations age, their dielectric properties undergo characteristic changes. These can be used to perform various Type 2 (Diagnostic) Field Tests. A brief overview of the known methods follows:

- For defective cable insulation, the dc leakage current versus voltage plot departs from linearity as the voltage is increased beyond some threshold value (tip-up curve), allowing a simple diagnostic test to be performed in the field.
- Another set of tests consists of applying a moderately elevated direct voltage across the cable insulation, removing the voltage source, shorting the cable while monitoring the short-circuit current as a function of time (depolarization current test), or measuring the voltage buildup as a function of time after the removal of the short (return voltage test). The rate of depolarization current decay or the rate of return voltage buildup can be used as indicators of the degree of insulation aging. Measurement of polarization index (Ratio of insulation resistance after 10 min to resistance after 1 minute of a voltage application) can also be utilized as an insulation diagnostic test.
- As a cable deteriorates, its dissipation factor ($\tan \delta$) versus voltage plots can assume a gradually higher rate of increase (tip-up) beyond some threshold voltage. This test can be conducted either by means of a power frequency voltage or by means of a VLF voltage.
- Water treeing in extruded cables causes a slight rectification of the ac voltage impressed across their insulation, producing a very small dc component in the ac leakage current. The magnitude of this component has been shown to increase with the severity of treeing.
- Another developing diagnostic test, propagation characteristics spectroscopy (PCS), monitors the changes in the wave propagation characteristics (attenuation versus frequency spectrum) of a cable by means of a low-voltage pulse that can be applied while the cable is energized and in service. Experiments have shown that the attenuation spectrum changes characteristically as the insulation ages.

The Type 2 Field Tests previously described are intended to monitor the overall condition of a cable insulation throughout its length. At least two additional diagnostic methods are intended to identify the locations of discrete defects that may be the sites of future failures in service. Service-aged cables with water trees have been shown to produce partial discharge (PD) signals from the tips of their longest trees when subjected to time-varying voltage in the range of one to three times service level. The exact identification of these discharge sites is now possible by means of equipment capable of functioning even in high ambient noise environments. The severity of defects is assessed by the closeness of the PD inception voltage to service voltage. Partial discharge location in installed cables is usually performed by means of power frequency excitation voltage sources, but it also has been shown to be possible by means of APDAC, VLF, impulse voltage, or oscillatory voltage. A guide covering the use of this method using VLF voltage will be