

IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)

IEEE Power and Energy Society

Sponsored by the
Insulated Conductors Committee



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IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)

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**Insulated Conductors Committee
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IEEE Power and Energy Society**

Approved 6 March 2013

IEEE-SA Standards Board

Abstract: Very low frequency (VLF) withstand and other diagnostic tests and measurements that are performed using VLF energization in the field on shielded power cable systems are described in this guide. Whenever possible, cable systems are treated in a similar manner to individual cables. Tables are included as an aid to identifying the effectiveness of the VLF ac voltage test for various cable system insulation problems.

Keywords: cable fault locating, cable system testing, cable testing, condition assessment, dielectric spectroscopy, grounding, hipot testing, IEEE 400.2™, partial discharge testing, proof testing, safety, tangent delta testing, very low frequency testing, VLF ac voltage testing

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Introduction

This introduction is not part of IEEE Std 400.2-2013, IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz).

A significant investment with respect to electric power systems is underground cables. A high degree of reliability and reasonable life expectancy of cable systems are necessary. In order to get the optimum performance, standards and guidelines have been developed which address the specific testing requirements for new and service-aged extruded and laminated dielectric cable insulations. This Guide is one part of a series of guides that discuss known diagnostic techniques for performing electrical tests in the field on shielded power cable systems. An omnibus guide (IEEE Std 400™) provides a general overview of all technique classes. It is intended that the technique-specific guides provide the definitive information on voltages, times and criteria.

Ideally, field withstand testing of cable systems would be done using the same power frequency as would normally applied to the cable under operating conditions, but at higher test voltage. However, because of the inherent capacitance of long runs of medium-/high-voltage concentric shielded cable, the excessive charging current is beyond the limits of normally available power sources and test equipment found in the field, except costly ac resonant test systems.

High-voltage dc testing would eliminate the charging current issue associated with ac tests, but would not subject the cable system to the voltage stress distribution that it is exposed to under normal operating conditions. Furthermore there are significant negative issues affecting the integrity of aged cross linked polyethylene (XLPE) cable after it is exposed to high-voltage dc tests and then placed back into service. There is also the unknown influence of elevated dc voltage on other extruded cables such as mineral-filled EPR. In addition, dc is not effective in detecting many forms of gross defects that may be present in a cable system that will otherwise be detected by VLF or at operating frequency.

When required to perform field testing on long lengths of medium-/high-voltage cable with an alternating current source, an alternative to applying power frequency is very low frequency (VLF, 0.01 to 1 Hz). The charging current at a very low frequency of 0.1 Hz is only 1/500 or 1/600 of that at 50 Hz or 60 Hz respectively so that significantly smaller and more portable VLF power sources have the capability to test cable systems of relatively long lengths.

This guide provides a definition of VLF, a description of the wave-shapes and their magnitudes and frequencies that can be applied as a source for overvoltage field testing, the issues with different wave shapes, the duration of testing and what diagnostic information can be learned when these VLF voltages are applied.

Contents

1. Overview	1
1.1 Scope	2
1.2 Purpose	2
2. Normative references.....	2
3. Definitions, acronyms, and abbreviations	3
3.1 Definitions	3
3.2 Acronyms and abbreviations	5
4. Safety.....	5
4.1 Safety practices.....	5
4.2 Grounding.....	6
5. Very low frequency (VLF) ac testing.....	7
5.1 General VLF ac withstand voltage testing.....	10
5.2 VLF ac withstand voltage testing with cosine-rectangular/bipolar pulse waveform	12
5.3 VLF ac withstand voltage testing with sinusoidal waveform	14
5.4 Tangent delta/differential tangent delta/tangent delta stability/leakage current/ harmonic loss current tests with VLF sinusoidal waveform	15
5.5 Partial discharge (PD) test with VLF sinusoidal waveform.....	24
5.6 Dielectric spectroscopy with VLF sinusoidal waveform.....	25
6. Conclusions	27
Annex A (informative) Bibliography	29
Annex B (normative) Wave shapes of VLF ac voltage testing voltages	32
Annex C (informative) Typical defects in fluid-filled and extruded cable systems	33
Annex D (informative) Effect of initial increase in voltage (ramp up).....	34
Annex E (informative) Figures of merit and range of available tangent delta and differential tangent delta (tip up) data	36
Annex F (informative) Comments on data interpretation and performance	38
Annex G (informative) Tan delta results of new cable systems	40
Annex H (informative) Development of utility/application specific criteria.....	43
Annex I (informative) Tangent delta criteria used outside North America	48

IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)

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1. Overview

This guide provides a description of the methods and practices to be used in the application of very low frequency (VLF) [ac](#) high-voltage excitation for field testing of shielded power cable systems (Bach [B1]¹ and [B2]; Baur, Mohaupt, and Schlick [~~B5~~ [B6](#)]; Gnerlich [~~B8~~ [B11](#)]). VLF [ac voltage](#) testing ~~techniques, effective~~ [is an alternative method of continuous ac voltage testing and is used](#) for a broad range of [accessory and](#) cable types ~~provide~~ [\(Kobayashi, et al. \[B26\], Steennis, Boone, and Montfoort \[B32\]\) as well as testing of rotating machinery, see IEEE Std 433T. It provides a new](#) method of evaluation, and helps to fill the need for more complete information on the cable system condition while minimizing or eliminating some potential adverse charging effects of the direct voltage high-potential test method (commonly known as the dc hi-pot test) ([Srinivas and Bernstein \[B31\]](#); Eager [et al. \[B8\]](#); [Hampton, et al. \[B19](#) ~~B6~~]; Groenefeld, von Olshausen, and Selle [~~B9~~ [B14](#)]; Steennis, Boone, and Montfoort. ~~This guide~~ [B32\]](#); [Gockenbach and Hauschild \[B12](#) ~~B19~~].[This guide](#) addresses VLF [ac voltage withstand and dielectric loss](#) testing in the frequency range from 0.01 Hz to 1 Hz. [The guide does not focus on the effects of insulation materials parameters: the nature of the differences between insulation materials, the subject of the peroxide crosslinking agent by-products, or on the influence of the VLF stress application on the cable system. Therefore, caution is recommended in interpretation of results.](#)

The information contained in this guide is intended to provide the methodology, voltages, and factors to be considered when utilizing VLF [ac voltage](#) testing, whether as a withstand test or as a diagnostic test. For general information regarding other field testing methods, refer to the omnibus standard, IEEE Std 400^{TM 2}.

¹ The numbers in brackets correspond to those of the bibliography in Annex A.

² Information on references can be found in Clause 2.

1.1 Scope

This guide describes ~~very low frequency~~ VLF withstand and other diagnostic tests and the measurements that are performed in the field on service-aged shielded medium and high-voltage cables rated 5 kV through 69 kV with extruded and laminated ~~dielectric~~ insulation. VLF test methods utilize ac signals at frequencies less than 1 Hz. The most commonly used, commercially available, VLF test frequency is 0.1 Hz. Whenever possible, cable systems are treated in a similar manner to individual cables. ~~Charts~~Tables are included ~~as an aid in identifying the effectiveness of~~ the ~~VLF~~ recommended test voltage levels for ~~various cable insulation problems~~ installation, acceptance, and maintenance tests.

1.2 Purpose

This guide is intended to provide troubleshooting and testing personnel with information to test shielded medium and high voltage cable systems rated 5 kV through 69 kV using ~~very low frequency~~ VLF ac techniques.

2. Normative references

~~This~~ 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.

Accredited Standards Committee [IEEE C2 2002](#), National Electrical Safety Code® (NESC®).³

[ANSI/NETA ATS: Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems \(Section 7.3.3: Cables , Medium, and High Voltage\).](#)⁴

[ANSI/NETA MTS: Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems \(Section 7.3.3: Cables , Medium, and High Voltage\).](#)

~~IEC 60060-1, High Voltage Test Techniques—Part 1: General Definitions and Test Requirements.~~⁴

~~IEC 60060-2, High Voltage Test Techniques—Part 2: Measuring Systems.~~

IEC 60060-3, High Voltage Test Techniques ~~Part 3~~: Definitions and requirements for on-site tests.⁵

[IEC 60270-3, High Voltage Test Techniques: Partial Discharge Measurements.](#)

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IEC 60885-3. Electrical test methods for electric cables. Part 3: Test methods for partial discharge measurements on lengths of extruded power cables.

IEC 61230, Live working—Portable equipment for earthing or earthing and short-circuiting.

~~IEEE Std 4TM, IEEE Standard Techniques for High Voltage Testing.~~^{5,6}

IEEE Std 400, IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems.^{6,7}

IEEE Std 433TM, IEEE Recommended Practices for Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency.

IEEE Std 510TM, IEEE Recommended Practices for Safety in High Voltage and High Power Testing.

[IEEE Std 400.3TM, IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment.](#)

[IEEE Std 1617TM, IEEE Guide for Detection, Mitigation, and Control of Concentric Neutral Corrosion in Medium Voltage Underground Cables.](#)

[NFPA 70E, Standard for Electrical Safety in the Workplace.](#)⁸

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3. Definitions, acronyms, and abbreviations

3.1 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.²

acceptance test: 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 detect installation damage and to show any gross defects or errors in installation of other system components.

~~3.1.2 breakdown: Disruptive discharge through insulation.~~

cross linked polyethylene (XLPE): A thermoset filled or unfilled polymer used as electrical insulation in cables. ~~If filled, it is referred to as a filled XLPE.~~

diagnostic test: A field test made during the operating life of a cable system. It is intended to determine and for some tests, locate degraded regions that may cause cable and accessory failure.

electrical trees: Tree-like growths, consisting of non-solid or carbonized micro-channels, that can occur at stress enhancements such as protrusions, contaminants, voids, or water trees subjected to electrical stress ~~for extended time periods~~. The insulation is damaged irreversibly ~~partial discharge may be present, and complete insulation breakdown may be only a question of time~~ at the site of an electrical tree.

ethylene propylene rubber (EPR): A type of thermoset filled polymer used as electrical insulation in cables and accessories.

² [IEEE Standards Dictionary Online subscription is available at:
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html](http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html).

NOTE—There are several different formulations of mineral-filled EPR and they have different characteristics. For purposes here, the term also encompasses ethylene propylene diene monomer rubber (EPDM).¹⁰

extruded dielectrics: Insulation such as ~~polyethylene~~ PE ~~cross-linked polyethylene~~, XLPE ~~tree retardant cross-linked polyethylene~~, TRXLPE ~~ethylene propylene rubber~~, EPR, etc. applied using an extrusion process.

installation test: A field test conducted after cable installation but before jointing (splicing) or terminating or energizing. The test is intended to detect shipping, storage, or installation damage. It should be noted that temporary terminations may need to be added to the cable to successfully complete this test, particularly for cables rated above 35 kV.

laminated dielectrics: Insulation formed in layers typically from tapes of either cellulose paper or polypropylene or a combination of the two. Examples ~~is~~ are the paper insulated lead covered (PILC) and mass-impregnated non-draining (MIND) cable designs.

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

mass-impregnated non-draining (MIND): A cable design using impregnated paper insulation. The impregnating compound has a sufficiently high viscosity at maximum operating temperature to preclude migration or draining of compound.

¹⁰ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

monitored withstand: A test in which a voltage of a predetermined magnitude is applied for a predetermined time. During the test other properties of the test object are monitored and these are

used, together with the withstand results, to determine its condition.

paper insulated lead covered (PILC): A cable design using impregnated paper insulation. The paper tapes are applied unimpregnated, the complete insulation being subsequently dried and impregnated with a compound as a whole.

polyethylene (PE): A thermoplastic polymer used as electrical insulation in cables.

shielded cable: A cable in which an insulated conductor is enclosed in a conducting envelope.

simple withstand test: A test in which a voltage of a predetermined magnitude is applied for a predetermined time. If the test object survives, the test it is deemed to have passed the test. Syn: non- monitored withstand test.

tree retardant cross linked polyethylene (TRXLPE): A thermoset polymer used as electrical insulation in cables. It is based on XLPE and contains an additive, a polymer modification, or a filler that retards the development and growth of water trees in the insulation.

U_0 : Normal phase-to-ground operating voltage.

water trees: Tree-like ~~Chemically modified, in the presence of moisture, dendritic~~ pattern of electro-oxidation that can occur at stress enhancements such as ~~protrusions,~~ ionic contaminants, protrusions, or voids in polymeric materials subjected to electrical stress and moisture. ~~At~~ Within the ~~site-of-a~~ water tree the insulation is degraded due to chemical modification in the presence of moisture. There is no evidence of partial discharge ~~is not present, and complete~~ (see NOTE) inside the water tree branches. Complete insulation breakdown may subsequently occur ~~when-the if a~~ water tree either induces an electrical tree and the electrical tree grows a channel of sufficient length to fail the insulation or leads to thermal runaway. The water tree growth under service conditions is a very slow process, usually taking many years to completely penetrate the insulation from the inside or outside. ~~While there have been no cases documented of partial~~

~~discharge detectable in the field from water trees, water trees can convert to electrical trees as a result of a lightning impulse, switching surges, or excessive test voltage levels.~~

NOTE—There have been no cases documented of partial discharge detectable in the field from water trees. Water trees can cause electrical trees to form as a result of a lightning impulse, switching surges, or excessive test voltage levels and durations. When this occurs, partial discharge may be detectable.

3.2 Acronyms and abbreviations

EPR ethylene propylene rubber

NOTE—In the cable industry also includes: EPDM (Ethylene-Propylene-Diene) with the “M” referring to the classification in ASTM D-1418 monomers.

MIND mass-impregnated non-draining, a cable design

PE polyethylene

PILC paper insulated lead covered, a cable design

TRXLPE tree retardant crosslinked polyethylene

VLF very low frequency (for the purpose of this guide 0.01 Hz to 1.0 Hz)

~~VLF-DF~~ ~~very low frequency—dissipation factor~~

VLF-DS very low frequency-dielectric spectroscopy

VLF-LC very low frequency-leakage current

VLF-LCH	very low frequency-loss current harmonics
VLF-MW	very low frequency-monitored withstand
VLF-PD	very low frequency-partial discharge
VLF-PDIV	very low frequency-partial discharge inception voltage
VLF-PDEV	very low frequency-partial discharge extinction voltage
VLF-TD	very low frequency-tangent delta (dissipation factor ~~tan delta~~)
VLF-DTD	very low frequency-differential tangent delta (delta tangent delta or tip up)
VLF-TDTS	very low frequency-tangent delta temporal stability
XLPE	crosslinked polyethylene

4. Safety

4.1 Safety practices

~~When testing cables,~~ Personnel safety is of utmost importance. [during all testing procedures.](#) All cable and equipment tests shall be performed on ~~isolated and~~ de-energized [and isolated](#) systems, except where otherwise specifically ~~required~~ [recommended](#) and [properly](#) authorized. ~~Some switches~~

~~may be connected to a cable end and serve to isolate the cable from the rest of the system. The ability of the switch to sustain the VLF test voltage while the other end is under normal operating voltage shall be checked with the manufacturer.~~ Appropriate safety practices must be followed. The safety practices shall include, but not be limited to, the following requirements:

- Applicable ~~user~~ national, state, local, and company safety operating procedures e.g., National Electrical Safety Code® (NESC®).
- IEEE Std 510, IEEE Recommended Practices for Safety in High Voltage and High Power Testing.
- NFPA 70E—Standard for Electrical Safety ~~Requirements for Employee in the~~ Workplace.
- ANSI/NETA ATS-2009: Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems (Section 7.3.3: Cables, Medium and High Voltage).
- ANSI/NETA MTS-2011: Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems (Section 7.3.3: Cables, Medium and High Voltage).
- ~~d) Applicable state and local safety operating procedures~~
- Physical protection of utility and customer property.

Prior to testing, determination of safe clearances must consider both the test voltage and voltage of nearby energized equipment:

- a) At the ~~While testing,~~ one or more cable ends ~~will be~~ remote from the manned testing site ~~therefore, before testing is begun~~ 1) cable ends under test must be cleared and guarded cordoned off; 2) cables that are ~~must be~~ de-energized ~~and~~ should be grounded when not being tested; and 3) remote cable ends must be marked to indicate a high-voltage test is in

progress.

- b) When a switch or disconnect type device is used to isolate the cable circuit from the rest of the system, the ability of the device to sustain the VLF ac test voltage and maintain isolation while the other end is under normal operating voltage shall be checked with the manufacturer.
- c) When isolation is an air gap, such as when a cable terminator connection is removed, the clearance distance must be sufficient to maintain isolation with the cable system at the VLF ac test voltage and the surrounding equipment at normal line voltage.
- d) All ancillary equipment such as lightning arrestors and motors should be disconnected from the cable terminals if possible.

At the conclusion of high-voltage testing, attention should be given to the following:

- 1) Discharging cables and cable systems including test equipment. The discharging of the cable should be carefully monitored for the time needed to fully discharge.
- 2) Grounding requirements for cables and test equipment to help eliminate the after effects of recharging the cables due to dielectric absorption and capacitance characteristics.

4.2 Grounding

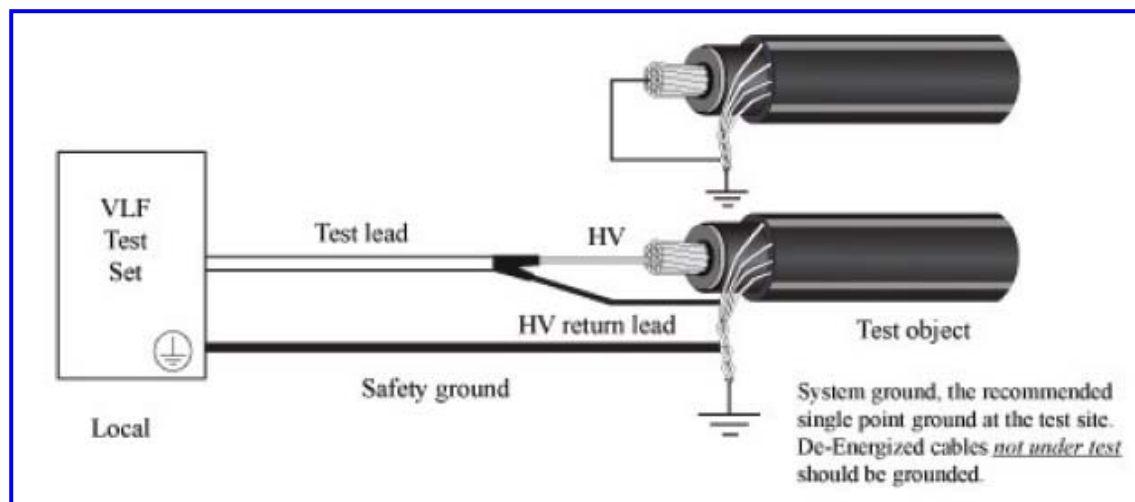
Cable systems can be ~~considered~~ de-energized and grounded when ~~a~~ among other things, conductor and metallic shield are connected to system ground at the test site and, if ~~possible~~ shield continuity has not been confirmed, at the far end of the cable.

When testing, a **single system ground at the test site** is recommended, see Figure 1. The metallic shield ~~or concentric conductor~~ of the cable to be tested is connected to ~~a~~ system ground. If this

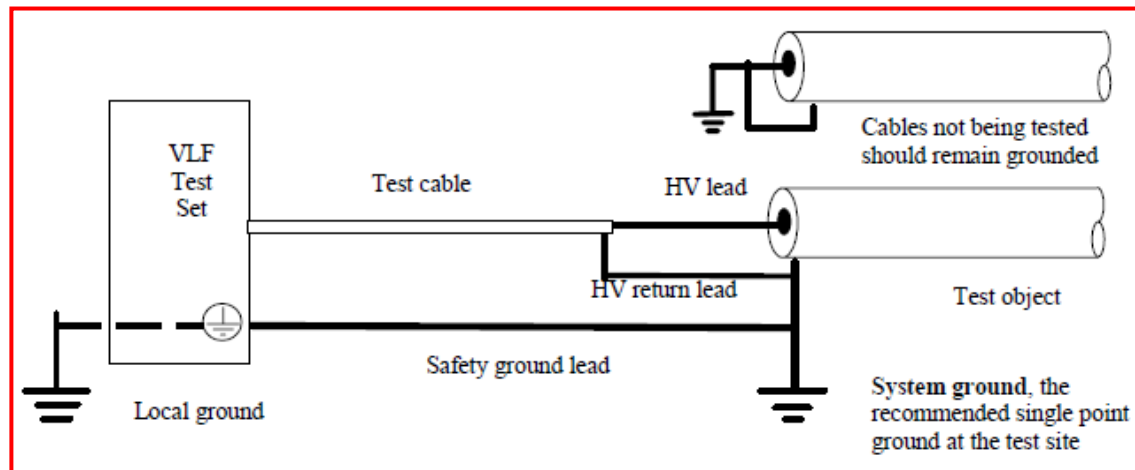
connection is missing or deteriorated, ~~or has been removed~~, it must be replaced at this time. A safety ground cable must connect ~~the~~ all test instrument cases with ~~the~~ system ground. All exposed conductive parts of the test system must be bonded to the common ground point. If the test instrument is a high-voltage device, ~~the~~ an external safety ground cable should be ~~at least a braided or stranded #2 AWC (34 mm²) copper~~ used to ground the cable ~~capable of carrying available to be tested.~~ This cable should be able to accommodate the fault current. ~~Only after the safety ground cable of the system. Once the test lead from the VLF test equipment is in place, should the test cable be~~ connected to the ~~conductor and metallic shield; the conductor~~ cable to be tested, this safety ground ~~connection shall now~~ can be removed so that testing can commence.

Should a local ground be advisable or ~~required~~ recommended for the test equipment, ~~the~~ case ground must remain connected to ~~the~~ system ground in order to maintain an acceptable single-ground potential.

Care should be taken to ensure that all ground connections cannot be disconnected accidentally. Grounding connections that can be securely tightened are recommended. Portable ground clamps and grounding assemblies built and tested per IEC 61230 are recommended.



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Figure 1 — Recommended test hook-up ~~diagram~~

5. Very low frequency (VLF) [ac](#) testing

VLF [ac](#) testing methods utilize ac signals in the frequency range from 0.01 Hz to 1 Hz. ~~VLF testing methods can be categorized as withstand or diagnostic (Gnerlich [B8]).~~ In withstand testing, ~~(Gnerlich [B11]),~~ the test object must ~~withstand~~ [survive](#) a specified voltage applied across the insulation for a specified period of time without breakdown of the insulation ~~(Hampton, et al. [B19]).~~ The magnitude of the withstand voltage is usually greater than ~~that of the applied~~ [operating](#) voltage. If the [accessory or](#) cable insulation is sufficiently degraded a breakdown can occur. The cable system may be repaired and the insulation retested until it passes the withstand test. Diagnostic testing allows the determination of the relative amount of degradation of a cable system section and establishes, by comparison with figures of merit or accumulated data, whether a cable system section is likely to continue to perform properly in service. It should be noted that values of the diagnostic quantity measurements obtained during VLF [ac voltage](#) tests may not correlate with those values obtained ~~during power tests at other~~ frequencies, for example, the ~~dissipation factor~~ [tangent delta](#) is ~~much~~ larger at 0.1 Hz than at power frequency and partial discharge (PD) may differ in terms of magnitude and inception voltage. ~~Diagnostic tests may be nondestructive and are usually performed at lower voltages than withstand tests. However, when the cable system insulation is in an advanced condition of degradation, the diagnostic tests can cause breakdown before the test can be terminated.~~

There are risks associated with high-voltage testing and diagnostics. Diagnostic tests can be non-destructive if they are performed at voltages at or below the normal operating voltage. However, there is a trade-off between gathering additional information about the cable under test and going to elevated voltage levels, with the associated higher risk that the cable may fail as the voltage is increased. It should be noted that at the prescribed withstand levels in Table 3, a failure indicates that the cable is already in a highly compromised condition. In addition, should a failure occur under test, the resultant fault current and collateral damage to the cable and surrounding assets may be limited. This may not be the case should the cable fail under operating conditions.

Examples of the various waveforms (shown in Annex B) are as follows:

~~The VLF withstand test methods of cable systems are:~~

- VLF [ac voltage](#) testing with cosine-rectangular waveform.
- VLF [ac voltage](#) testing with sinusoidal waveform.
- ~~— VLF testing with bipolar rectangular waveform~~
- ~~— VLF testing with alternating regulated positive and negative DC step voltages~~

The VLF diagnostic test methods of cable systems are [as follows](#):

- 1) VLF ~~dissipation factor~~ tangent delta measurement (VLF- ~~TD DF~~); [see 5.4](#).
- 2) VLF differential ~~dissipation factor~~ [tangent delta](#) measurement (VLF-DTD); [see 5.4](#).
- 3) [VLF tangent delta temporal stability \(VLF-TDTS\)](#); [see 5.4](#).
- 4) VLF dielectric spectroscopy (VLF-DS); [see 5.6](#).
- 5) VLF loss current harmonics (VLF-LCH).
- 6) VLF leakage current (VLF-LC).
- 7) VLF partial discharge (PD) measurement (VLF-PD); [see 5.5](#).
- 8) [VLF monitored withstand \(VLF-MW\)](#).

[Methods 5\) and 6\) are in limited use at present.](#)

Field testing techniques frequently employ a combination of diagnostic ~~and withstand~~ test methods. Test methods should be selected based on ~~their~~ [considerations such as](#) ease of operation, operator training requirements, cost/benefit ratio, the cable system age and condition, and [the capability of the cable owner to endure and accommodate a possible cable failure. Diagnostic test results can be used for asset management decision support, e.g., different maintenance activities, replacement, and condition assessment steps.](#)

CAUTION

The [potential](#) consequences of a cable system insulation failure during any high-voltage test should be considered prior to undertaking any such test.

The consideration of various VLF ac voltage testing methods should be based upon the following guidelines [as tabulated](#) in Table 1.

The density and severity of the defects in a cable system influence the effectiveness of any diagnostic method including the VLF [ac voltage](#) test methods (Bach [B1] and [B2]; Baur, Mohaupt, and Schlick, [B5] B6]; [Goodwin, Oetjen, and Peschel \[B13\]; and Hampton, et al. \[B17\] and \[B19\]](#)). As a general rule, the more severe the defects, the lower the ac dielectric strength, ~~and the larger the loss and harmonic loss currents. Severe~~ [Typical](#) defects ~~are, for example, large water trees, large contaminants, large voids, or sharp protrusions that can initiate partial discharges and/or electrical trees at test voltages. Less severe defects are small water trees, small contaminants or voids, fluid-impregnated and less sharp protrusions. These extruded cable conditions can be grouped as shown systems are listed in Table 2 Annex C.~~

In extruded cable systems severe defects are, for example, large water trees, large contaminants, large voids, or large sharp protrusions that can initiate partial discharges and/or electrical trees at test voltages. The loss and harmonic loss currents increase with the severity of water treeing. Less severe defects—those that have a longer elapsed time to failure—are, for example small water trees, small contaminants or voids, and less sharp protrusions that may not initiate partial discharges and/or tracking or electrical trees at test voltages.

~~The consideration of various VLF testing methods should be based upon the guidelines in Table 1.~~

**Table 1 — Criteria considerations: ~~for~~ various VLF ac
voltage testing methods**

Comparison	Withstand test methods			<u>Other</u> diagnostic test methods	
Equipment	VLF Cosine-Rectangular/Bipolar Pulse power source	VLF Sinusoidal power source	~~VLF~~ ~~DC-step~~ ~~pos/neg~~	VLF power source plus one or more of the following measuring equipment: <u>VLF-TD/VLF-DTD/VLF-TDTS/VLF-LCH, VLF DS,</u> VLF-LC, <u>VLF-MW</u>	~~VLF power~~ ~~source plus~~ ~~PD~~ ~~measuring~~ ~~equipment~~ VLF PD ~~DS~~
Ease of operation	Connect HV power supply and apply voltage of specified magnitude for specified time ~~Straightforward pass/fail~~ ~~criterion.~~			Connect HV power supply and ancillary equipment, if <u>recommended</u> ~~required~~ , to make diagnostic measurements. The effectiveness of these methods relies on the effectiveness of noise filtering of the test equipment. ~~Care is needed~~ ~~to eliminate unwanted interference~~ ~~or stray signals.~~	
<u>Detect</u> <u>overall</u> <u>condition/</u> <u>localized</u> <u>defect</u>	<u>Localized defect in insulation or at interface</u>			<u>Overall condition of</u> <u>insulation</u>	<u>Localized</u> <u>defect in</u> <u>insulation or</u> <u>at interface</u>

Table 2—VLF tests used for different cable conditions

Defect severity/ defect number	Less severe	More severe
Few	• Withstand • Dissipation factor • Differential dissipation factor • Harmonic loss current • Partial discharge • Dielectric spectroscopy (See Note 1)	• Dissipation factor • Differential dissipation factor • harmonic loss current • Partial discharge • Dielectric spectroscopy (See Note 2)
Many	• Dissipation factor • Differential dissipation factor • Harmonic loss current • Partial discharge • Dielectric spectroscopy (See Note 3)	• Withstand • Dissipation factor • Differential dissipation factor • Harmonic loss current • Partial discharge • Dielectric spectroscopy (See Note 4)

NOTES

1—These diagnostic tests may be used to establish baseline values for future test comparisons.

2—In a planned and scheduled outage, withstand tests may be used to “fault” the cable defects without jeopardizing the cable system integrity. These diagnostic tests may be used after the faults are repaired, retested, and returned to service.

3—Repeat tests to establish trends will determine the rate at which such cables are degrading.

4—These cables should be replaced as soon as practicable.

All types of VLF [ac voltage](#) tests are applicable to jacketed ~~cables and unjacketed cable systems~~ with all types of shields. VLF withstand, [tangent delta](#), and partial discharge tests can also be applied to extruded cables with bare metallic shields. ~~Other diagnostic tests listed in Table 1 are possible on extruded cables with unjacketed metallic shields if a floating power supply is used (see 5.7.4).~~ Corrosion of the metallic shield can limit the sensitivity of PD tests due to the attenuation of [high frequency signals](#). If the corrosion is so severe that there is no continuity, the tests are not valid. [Refer to IEEE Std 1617 for guidance to determine the extent of metallic shield corrosion.](#) The usefulness of various VLF [ac voltage](#) testing methods for selected cable and/or insulation conditions is tabulated in Table 2.

Table 2 — Usefulness of VLF [ac voltage](#) testing methods for selected cable and/or insulation conditions

Cable condition	Diagnostic test methods				
	Simple withstand test methods	VLF-MW	VLF-TD VLF-DTD VLF-TDTS VLF-DS	VLF-PD	VLF-LC VLF-LCH
Cables with metallic shield corrosion	Acceptable	Acceptable	Acceptable	Poor (see Note 1)	Poor
Extensive water treeing	Acceptable	Good	Good	Poor (See Note 2)	Good
Few large defects or few localized electrical trees	Good	Acceptable/ Good (see Note 3)	Acceptable/ Good (see Note 2)	Acceptable/ Good	Acceptable/ Good (see Note 3)
Defective splices and terminations	Acceptable/ Good (see Note 4)	Acceptable/Good (see Note 3)	Acceptable (see Note 3)	Acceptable (see Note 2)	Acceptable (see Note 3)
Mixed insulation (extruded and/or laminated)	Good	Good (see Note 4)	Poor/Good (see Note 4)	Good (See Note 5)	Poor/Good (see Note 4)

[\(New\)](#)

Cable condition	Withstand test methods			Diagnostic test methods		
	VLF cosine-rectangular/ bipolar pulse	VLF sine	VLF DC step pos-neg	VLF-DF VLF-DTD VLF-DS	VLF-PD	VLF-LC VLF=LCH
Cables with metallic-shield corrosion	Acceptable	Acceptable	Acceptable	Poor	Poor	Poor
Extensive water-tree contamination	Not advised; Will likely cause multiple failures	Not Advised; Will likely cause multiple failures	Not Advised; Will likely cause multiple failures	Good	Poor (See Note 1)	Good
Few large defects or few localized electrical trees	Very good	Very good	Very good	Acceptable/ good (see Note 2)	Very good	Acceptable/ good (see Note 2)
Defective splices and terminations	Acceptable/ good (see Note 3)	Acceptable/ good (see Note 3)	Acceptable/ good (see Note 3)	Acceptable (see Note 2)	Good	Acceptable (see Note 2)
Mixed insulation (extruded and/or laminated)	Very good	Very good	Very good	(see Note 4)	Good	(see Note 4)

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NOTE 1—PD testing can be less sensitive on aged taped shielded cables due to corrosion of the shield overlaps that causes attenuation of the PD signals (Guo and Boggs [B15]). PD sensitivity can decrease with increasing length of the cable under test.

NOTE 2—PDs are detectable only if there are one or more ~~electrical trees have initiated~~ active electrical trees or tracking sites or there are gas-filled voids in the cable insulation or accessories. Moreover it should be noted that PD inception conditions at VLF can be different from ~~water trees~~ those at other frequencies.

NOTE 3—Supplemental testing is ~~required~~ recommended to distinguish a severe localized defect from general overall deterioration.