

# IEEE Guide for Making High-Direct-Voltage Test on Power Cable Systems in the Field

## 1. Introduction

### 1.1 Need for Testing

While cable is thoroughly tested by the manufacturer before shipment, it may be subject to damage or improper treatment in shipment or installation. Consequently, further testing of completed installations before they are placed in service is widely practiced.

Additionally, many users find that alternating voltage, coupled with other factors such as impulse voltages, water exposure, etc., will cause deterioration over time.

Maintenance testing may reveal damage caused in manufacturing or installation that was undetected by factory and installation tests.

Hence, periodic testing after time in service has been found to be a useful practice.

Just as the factory and installation test voltages are frequently too low to detect minute defects, maintenance test voltages have often been found to be too low to locate defects that subsequently lead to cable failure in service. Since users tend to mix cable types in service, it has also become evident that the test voltage should be related to the circuit basic impulse level (BIL) rather than to the type and thickness of the insulation. These principles have been followed in the development of this guide.

The traditional method of testing the insulation of high-voltage cable has been to subject it to a high alternating potential at the factory. Because of the size and weight of the test transformer and equipment, it has not been practical to employ alternating voltage testing on cable at its installed location. Many installed cable systems have therefore not been tested, or a high-direct-voltage has been used. The supply unit for the direct voltage may be relatively small and light, suitable for transporting to most field locations. The direct voltage used has been related to the prescribed alternating test voltage by a ratio, fixed for an individual insulation type, but varying between types of insulation. The establishment of such a ratio lacks a scientific basis, and many engineers believe that the direct test voltage should be related to the ultimate dielectric strength of the insulation.

Experience has shown that the application of high-direct-voltage deteriorates solid insulation very slowly, if at all, so the duration of the direct voltage test is not highly important.

Since the direct voltage strength of cable insulation approaches the impulse strength, it is logical to relate the direct voltage test levels to system BIL as shown in Table 1. For effectively grounded systems with a reduced BIL, the test voltage to be applied should therefore be selected to accord with the BIL rather than with the rated voltage.

Most users of appreciable quantities of cable apply tests to newly installed cable systems before placing them in service. Many users do not practice maintenance testing. Maintenance testing has been found practical in reducing service failures from faults of the cable or its accessories. Such maintenance tests are found at least partially effective in detecting cables that are approaching failure. When such maintenance test procedures are followed, some users note substantial reductions of service failures, particularly with polymeric cable systems.

The decision to employ maintenance testing must be evaluated by the individual user, taking into account the cost of service failure, including intangibles and the cost of testing.

This guide does not purport to require that testing be performed, either at the time of installation or periodically thereafter for maintenance. It sets forth the consensus of presently known good practice in testing methods, with interpretation of results.

**CAUTION** — The consequences of experiencing a failure during performance of a maintenance test should be considered prior to undertaking any such test. A faulted circuit would be out of service until repairs or possibly even cable replacement could be completed. This could result in a delay for circuit availability.

## 1.2 Purpose

The purpose of this guide is

- 1) To provide uniform procedures for performing high-direct-voltage acceptance tests and maintenance tests on shielded power cable systems (including accessories) in the field
- 2) To provide guidelines for evaluation of the test results

## 1.3 Scope

This guide presents procedures and recommended test voltage values for acceptance and maintenance high-direct-voltage testing of shielded power cable systems. It applies to all types of shielded insulated power cable systems rated 5 kV and above and is intended primarily for the transmission or distribution of power. The tabulated test levels assume the usual effectively grounded neutral system or a grounded shield. Consideration may be given to modifying the test voltage levels as may be appropriate for overinsulated cables and accessories. This guide is not intended to apply to unshielded power cables, communication cables, control cables, and high frequency or other special purpose cables.

It is recognized that the procedures and tests outlined here may be applied to cables outside this scope and that information of some value may thereby be obtained.

## 1.4 Special Cases

Further, it should be recognized by the user of this guide that there is disagreement among both users and manufacturers as to the possible deleterious effects of high-direct-voltage testing, especially of cables that have been operated under environmental conditions that may give rise to formation of water trees. Similarly, there is disagreement on the possibly deleterious effects of trapped space charges and potentially high local stress concentrations in thick polymeric insulations, especially those of high purity and very high-volume electrical

resistivity such as used in certain transmission and subtransmission circuits. In these cases, the user of this guide is urged to avail himself or herself of current knowledge and opinion as it evolves from industry research and development programs and, whenever practical, seek consensus with supplier(s) on suitable test levels.

## 2. Definitions and Terminology

**absorption current:** Current resulting from charge absorbed in the dielectric that results from polarization [9].<sup>1</sup>

**acceptance test:** A test made after installation but before the cable system is placed in normal service. This test is intended to detect shipping or installation damage and to show any gross defects or errors in workmanship or splicing and terminating.

**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. BILs are designated in terms of the crest voltage of a 1.2–50  $\mu$ s full-wave impulse voltage test [8].

**capacitance current:** Current that charges the capacitor that is formed by the capacitance of the cable under test [9].

**conduction (leakage) current of the cable insulation:** Current resulting from conduction through the insulating medium or over surfaces (such as terminations). Corona discharge from external energized elements will be indicated as conduction current.

**direct current (dc):** Unidirectional current; as used in this guide, the term denotes a practically nonpulsating current [9].

**field:** The terms *field* or *in the field* refer generally to apparatus installed in the operating location. However, this may include material not yet installed or material that has been removed from the operating environment.

**high-direct-voltage:** A direct voltage above 5 000 V supplied by test equipment of limited capacity.

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

**rated voltage:** For cables, either single-conductor or multiple-conductor, the rated voltage is expressed in terms of phase-to-phase voltage of a three-phase system. For single-phase systems, a rated voltage of the square root of three times the voltage to ground should be assumed.

## 3. References

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

[1] AEIC CS1-90, Specifications for Impregnated-Paper-Insulated Metallic Sheathed Cable, Solid Type.<sup>2</sup>

[2] AEIC CS2-90, Specifications for Impregnated Paper Laminated Paper Polypropylene Cable, High Pressure Pipe Type.

[3] AEIC CS3-90, Specifications for Impregnated-Paper-Insulated Metallic Sheathed Cable, Low Pressure-Gas Filled Type.

[4] AEIC CS4-79, Specifications for Impregnated-Paper-Insulated Low and Medium Pressure Self-Contained Liquid Filled Cable.

<sup>1</sup>The numbers in brackets correspond to those of the references in Section 3.

<sup>2</sup>AEIC publications are available from the Association of Edison Illuminating Companies, 600 N. 18th Street, P. O. Box 2641, Birmingham, AL 35291-0992, USA.

- [5] AEIC CS5-87, Specifications for Thermoplastic and Crosslinked Polyethylene Insulated Shielded Power Cables Rated 5 Through 35 KV.
- [6] AEIC CS6-87, Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 Through 69 KV.
- [7] AEIC CS7-87, Specifications for Crosslinked Polyethylene Insulated Shielded Power Cables Rated 46 Through 138 KV.
- [8] IEEE Std 4-1978, IEEE Standard Techniques for High Voltage Testing (ANSI).<sup>3</sup>
- [9] IEEE Std 62-1978, IEEE Guide for Field Testing Power Apparatus Insulation.
- [10] IEEE Std 141-1986, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book) (ANSI).
- [11] IEEE Std 493-1990, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book).<sup>4</sup>
- [12] IEEE Std 510-1983, IEEE Recommended Practices for Safety in High-Voltage and High Power Testing.
- [13] Lee, R. H. "Installation Problems and Testing of Cable 5 to 35 kV." *IEEE Transactions on Industry Applications*, vol IA-11, Nov./Dec. 1975, pp. 654–663.
- [14] Morrison, W. G. and Lee, R. H. "Testing of Cable Systems for Improvement of Reliability." *Conference Record of the Industrial and Commercial Power Systems Conference*. Milwaukee, April 1972.

## 4. General Considerations

### 4.1 Environmental Influences

#### 4.1.1 Temperature

The dielectric strength of some cable insulations is reduced at elevated temperatures. This necessitates a reduction in the test voltages at higher temperatures. Temperature gradients in the cable insulation, caused by heat dissipation from the conductor, can result in unusual potential distribution upon application of a high direct voltage.

#### 4.1.2 Atmospheric Conditions

High humidity and 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 a test voltage by gaps or similar means and also affects the flashover at terminations. At elevations higher than 3 300 ft (1 000 m), overinsulation of terminations is required to withstand both working voltages and prescribed test voltages. Wind can cause erroneous current readings as described in 6.2.

<sup>3</sup>IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

<sup>4</sup>Chapter 3 of this standard, "Summary of Equipment Reliability Data," contains reliability data from an IEEE survey of industrial plants that is more recent than that contained in [14].

### 4.1.3 Extraneous Electric Fields

Although field tests on cable are often made in the vicinity of energized equipment, extraneous electrical fields will have little influence on direct-voltage test results. Due to the stress and ionization of air between the circuit on test and nearby energized circuits, it is possible that flashover may occur. When spacing is marginal, unusual precautions may be required to prevent this. Such precautions may include insertion of shielding to protect adjacent circuits in service.

## 4.2 Test Equipment

### 4.2.1 High-Direct-Voltage Test Set

The test voltage source should

- 1) Provide the maximum (negative polarity) test voltage required [9], plus some margin
- 2) Provide a means of increasing voltage continuously or in small steps
- 3) Have the capability of providing satisfactory voltage regulation
- 4) Have output sufficiently filtered to provide an acceptably pure direct voltage [9]
- 5) Provide voltage and current indications that can be read precisely (resolution of 0.1  $\mu\text{A}$  on the lowest current range is desirable)

### 4.2.2 Power Supply

A well-stabilized power supply for the high-direct-voltage generator is essential. Even minor variations in this supply will cause major variations in the output current indication.

### 4.2.3 Discharge Resistor

A resistor with a resistance not less than 10 000  $\Omega/\text{kV}$  of test voltage shall be used to discharge the cable system after testing (see 5.2) [12]. This resistor should be designed to withstand the full test voltage without flashover and to handle the discharge energy without overheating.

An insulating hook stick and a flexible conductor should be provided to connect the resistor across the cable circuit and ground.

## 4.3 Safety of Personnel

High-direct-voltage field testing of cable systems involves all of the hazards normally associated with working on energized circuits, as well as several unique hazards that must be addressed.

Cable circuits will normally have one or more ends remote from the location of the test equipment and the test operator. These ends must be cleared and guarded to ensure the safety of personnel. Reliable voice communication should be established between all such locations and the test operator.

The use of a circuit voltage indicator suitable for safe application to an energized circuit is recommended to ensure that the circuit is completely de-energized before starting any testing work.

Cables have high capacitance and dielectric absorption characteristics. Particular attention must be directed to the special techniques required for discharging cables after testing to eliminate personnel hazards.

**CAUTION** — Cables subjected to high-voltage testing that are not grounded for sufficiently long periods of time following such tests can experience dangerous charge buildups as a consequence of the very long time constant associated with dielectric absorption currents. For this reason, the grounding procedures recommended in 5.2 should be followed.