GUIDE FOR HIGH DC VOLTAGE FIELD TESTING OF INSULATED POWER CABLE

1. PREFACE

Although factory tests normally assure initial quality and condition, insulated cables are subject, during shipment, installation, and operation, to influences which shorten the useful life of the insulation and other components of the cable. As a result, there is a need for some method of testing or inspection after installation and during its operating life to determine its suitability for continued services and/or initiate suitable maintenance procedures.

2. PURPOSE OF GUIDE

2.1 To provide uniform procedures for performing high DC voltage acceptance tests on power cables (including accessories) in the field.

2.2 Provide guidelines for evaluation of the test results.

2.3 Define terms which have specific meaning in the guide.

3. SCOPE

3.1 This guide presents suggested procedures and test voltage values for acceptance and maintenance testing of power cable systems with high DC voltages.

3.2 The guide applies to all types of insulated cable systems above 2,000 volts and is intended primarily for the transmission or distribution of power.

3.3 It is recognized that these procedures and tests may be applied to cables outside this scope and information of some value may be obtained from the test.

4. DEFINITIONS AND TERMINOLOGY

4.1 BIL

Basic Impulse Insulation Level - Impulse voltage which electrical equipment is required to withstand without failure or disruptive discharge, when tested under specified conditions of temperature and humidity. Basic impulse levels are designated in terms of the crest voltage of 1.2 x 50 microseconds full wave impulse voltage test.

4.2 Current

Absorption Current - Current resulting form charge absorbed in the dielectric as a result of polarization.

Capacitance Current - Current flow which charges the capacitor formed by the geometric capacitance of the cable under test.

Conduction (Leakage) Current of the Cable Insulation - Current flow resulting from conduction through the insulating medium or over surfaces (such as terminations). Corona discharge from energized elements will be indicated as conduction current, though technically it is not a conduction component.

Direct Current (DC) - Unidirectional current, as used in this guide, denotes a practically nonpulsating current.

standards coordinator	*standards supervisor*	*unit director*
Aida Diop	John Shipek	Darnell Cola

4.3 **Voltage**

Rated Voltage - The rated voltage is expressed in terms of phase-to-phase voltage of a three-phase system and$\sqrt{3}$ times the voltage to ground for a single-phase system.

High DC Voltage - A DC voltage above 5,000 volts supplied by test equipment.

4.4 **Field**

The term "field" or "in the field" refers generally to apparatus installed in operating position. However, it may include material not yet installed or material that has been removed from its operating environment.

4.5 **Cable Accessories**

Those components of a cable system which cannot be readily disconnected from the cable and will be subjected to the test voltage.

4.6 **Tests**

Proof Test - A test of the insulation of a cable system made to determine if the electrical strength of the insulation is above a minimum value.

Withstand Test - A test made by applying a specified potential to a circuit for a specified time.

Acceptance Test - A test made after installation but before the cable is energized. This test is intended to detect shipping or installation damage and defects in workmanship on splicing and terminations.

Maintenance Test - A test to detect deterioration of the system.

5. GENERAL CONSIDERATIONS

5.1 **Environmental Influences**

Temperature - The dielectric strength of cable insulation is reduced at higher temperatures. Temperature gradients in the cable insulation, caused by heat dissipation from the conductor, can result in unusual potential distributions at high DC voltage. (Wait until the cable cools down. This would normally be taken care of by the time the cable was disconnected.)

Atmospheric Conditions - High humidity and conditions favoring condensation on exposed surfaces can affect test results to a marked degree. Contaminated terminations can greatly increase conduction.

Relative air density has little effect on cable testing, but it will affect the measurement of test voltage gaps or similar means.

Wind can cause erroneous current readings as referred to in paragraph 7.2.5.

Extraneous Electrical Fields - It is possible that, due to the stress and ionization of air between the circuit on test and nearby energized circuits, flashover may occur. To prevent this, precautions may include insertion of grounded shielding to protect adjacent circuits in service.

5.2 **Test Equipment**

High DC Voltage Generator - The test voltage source should have the following features:

a. The maximum (negative polarity) test voltage required plus some margin.

b. A means of increasing voltage gradually or in small steps.

c. Have sufficient volt-ampere output capacity to provide satisfactory voltage regulation.

d. Have output sufficiently filtered to provide an acceptable pure DC voltage.

5.2 e. Provide voltage and current indications that can be read precisely. Resolution of tenths of microamperes on the lowest current range is desirable.

5.3 Safety of Personnel

High potential testing of cables embodies all of the normal hazards associated with working energized circuits. There are two facets involving additional hazards. Cable circuits normally will have one or more ends remote from the test area. These ends must be cleared and guarded for personnel safety. A circuit voltage indicator suitable for safe applications to an energized circuit is recommended. This is to assure that circuits are de-energized before starting tests. Cables have much higher capacitance and dielectric absorption than most other types of electrical equipment. Particular attention and special techniques are required in discharging cables after testing to eliminate personnel hazards.

Dielectric desorption following application and subsequent discharge of a high DC voltage can result in a charge buildup in an underground cable. For this reason, grounding procedures are recommended in paragraph 6.2.7.

6. TEST METHOD

6.1 Precautions

All components require de-energizing before testing. Checking with a reliable voltage indicator is recommended. While the indicator is in contact with each component, a ground connection should be applied to the component to remain attached at all times except when test voltage is being applied. This applies to all un-energized metallic parts in the vicinity.

All ends of components being tested require guarding from accidental contact by such means as barriers, enclosures, or watchman at all such points. The ends require separation from all elements not to be subjected to test, and by distances not less than 1" per 10 kV of test potential.

With higher voltage cables, rated 115 kV and above, flashover at terminations or ends may generate abnormally high-voltage surges, so it is desirable to install suitable gaps at each end with a 50 ohm non-inductive resistor in series with the cable electrode to provide relief from such overvoltages. This resistor must be capable of dissipating the energy stored in the charged cable and must not flash over. Gap dimensions may be determined from IEEE Std 4 and should be set to spark over at 125% of the maximum test voltage to be used. Such a gap, even at the test set end, may be necessary to protect the test set against transient overvoltages.

It may be desirable to cover bare metal extremities of cable or terminations with plastic or glass containers to contain the space charge, reducing or eliminating corona.

6.2 Procedures

6.2.1 Prepare cable for testing in accordance with paragraph 6.1. Clean insulator surfaces with a dry cloth and if necessary apply silicone grease to minimize leakage currents. If necessary, wrap exposed conductor surfaces with several layers of polyethylene film to minimize corona (see paragraph 7.2.6).

6.2.2 Check the operation of the test set in accordance with manufacturer's recommendations. The current indication can be checked by connecting a short piece of small wire to the test lead and raising the potential until corona is heard from the ends of the wire; a microammeter of 0-10 or 0-50 microamps should indicate current. If leakage is apparent in the test leads, one should take steps to eliminate the leakage or note the amount to be deducted.

6.2.3 Connect the high-voltage test lead to the first conductor or conductors to be tested. Remove the ground lead from this conductor.

6.2.4 Voltage may be increased continuously or in steps to the maximum test value. If in steps, use five or more steps with duration at each step long enough for the current to attain reasonable stabilization (one minute suggested), or to show unreadable low-current values. Current readings at each voltage step should be taken at the end of the step duration. Apply voltage slowly enough in accordance with the test set manufacturer's recommendation to prevent overloading the power supply.

6.2.5 Maximum test voltage should be maintained for at least five minutes. Current magnitudes should be recorded one minute and five minutes after the maximum test voltage has been reached.

6.2.6 The test voltage to be used relates to the voltage rating of the rated voltage of the cable rather than the voltage of the system on which it is used. The recommended maximum test voltages for all types of insulation including installation or maintenance tests shall be:

System Description	System Voltage (RMS)	Cable Rating (RMS)	Cable BIL (Crest)	Maximum Applied Test Voltage (DC)
Other	-	2.5 kV	na	4.3 kV
Other	-	5 kV	60 kV	8.7 kV
Downtown core network, including Mass Substation circuits	13.8 kV - 3-wire, delta	15 kV	110 kV	16 kV
Kerite type cable	26.4 kV, 4-wire, grounded wye	27 kV	na	32 kV
University District network	26.4 kV - 3-wire, delta	28 kV	150 kV	32 kV
Looped radial	26.4 kV, 4-wire, grounded wye	28 kV	150 kV	32 kV
First Hill network	26.4 kV, 4-wire, grounded wye	28 kV	150 kV	32 kV
Other	-	35 kV	200 kV	60 kV

6.2.7 At the completion of the test period, potential can be reduced by returning the control of the high DC voltage generator to zero and permitting the cable to discharge through the cable system and the test set. For cable lengths exceeding about 1,000 feet, the time required for this discharge may be burdensome. To expedite the process, a resistor having not less than 10,000 ohms resistance per kV of test voltage may be placed between the conductor and ground. The resistor must be capable of withstanding the test voltage without flashover and of handling the discharge energy. It can conveniently be built or supported on the end of an insulated "hook" stick, the lower end of the resistor being grounded with a flexible conductor.

After the voltage is reduced to 10% or less of the original value, the conductor should be solidly grounded and should remain grounded until ready for service or further testing.

7. EVALUATION OF RESULTS

7.1 Current Time Relationship

7.1.1 The test current will momentarily increase for each voltage increment due to the charging of the capacitance, and dielectric absorption characteristics of the cable. Both of these factors decay, the first in just a few seconds, the latter more slowly, leaving ultimately only the leakage current plus any corona current.

7.1.2 In normal circumstances a current decrease with time will occur such that the one-minute current ratio will be from 1.2 to 2. However, erratic changes in corona current may mask actual leakage current, making the 1.0 factor a practical compromise.

If without any increase in applied voltage the current starts to increase, slowly at first, but at an increasing rate, this is an indication of progressively failing insulation. This process will likely continue to actual failure within a few minutes unless the potential is reduced. One criterion of satisfactory test in high DC voltage testing is the decrease of current with time at a fixed voltage application. While this may be partially obscured by corona current, voltage regulation and insufficient meter damping, the absence of a current steadily increasing with time is generally a practical acceptable test criterion (also see paragraph 7.2.7). Rubber and oiled-paper insulations will usually exhibit this type of insulation failure. Polyethylene liquid gases very seldom fail in this fashion.

7.1.3 If at any time during the test a violent increase in current occurs, accompanied by tripping of the test set circuit breaker, failure or flashover has probably occurred in the cable, a splice, or at a termination. A failure can be confirmed by the inability to re-apply the test voltage. This behavior with insulation other than polyethylene is usually associated with the breakdown of an air path rather than the breakdown of solid insulation. If any residual solid insulation had remained, the "runaway" type of failure outlined in paragraph 7.1.2 above might have been the mode.

7.1.4 In event of the indication described in paragraph 7.1.2 or 7.1.3 above, it may be practicable in some cases to return the cable to service, if the distress potential reached was at least 2.8 times the rms phase-to-ground potential, and a second test up to this value proved satisfactory.

7.2 **Resistance Values**

7.2.1 Readings of voltage (E) and leakage current (I) observed during the high DC voltage test may be used to calculate the effective resistance (R) of the cable circuit by means of Ohms Law, R = E/I. A useful relation is:

$$\text{Thousands of Megohms} = \frac{\text{kilovolts}}{\text{microamperes}}$$

Calculating and plotting resistance vs. voltage, in conjunction with step-voltage test, is an aid in evaluating the insulation condition, and is frequently an even more sensitive indicator of approaching current avalanche failure than the dynamic behavior of the micro-ammeter itself. A substantial reduction in insulation resistance with increasing voltage as compared with the lower voltage increments is such an indication.

7.2.2 The comparison of the calculated resistance of the three conductors of a circuit is a useful indicator of an anomalous condition of the insulation of one or more of the cables. If there is more than a 3-to-1 difference between the resistance of the conductor insulation of a circuit over 2,000 feet long, or over 5-to-1 for a shorter circuit, some unusual insulation condition is indicated.

The insulation resistance characteristics vary so widely, and with varying termination conditions, that statement here of absolute values of resistance would be misleading. Comparison of resistance values with those obtained when the cable system was installed is useful.

7.2.3 All cable insulations have a negative temperature resistance coefficient, so increased temperature will always indicate lower insulation resistance. Oil-base rubber is the most extreme in this respect, polyethylene the least. Several types of compounds used for filling potheads have very low resistance compared to the oil-paper cable they terminate, and have a very high temperature resistance coefficient. For this reason, after installation these potheads should never be tested until they have been cooled to cable temperature. The elastomeric filling of some factory prefabricated terminators also has relatively low resistance and moderately high temperature resistance coefficient.

7.2.4 Humidity, condensation, and actual precipitation on the leakage surface of a termination can increase the apparent leakage current by several orders of magnitude. Humidity also increases the corona current, which indication is included in the total leakage current.

7.2.5 Wind prevents the accumulation of space charge at bare energized terminals. This results in an increase of corona. A plastic envelope or container tends to retain this space charge even in the presence of wind.

7.2.6 Additional leakage current of the order of ten to several hundred times the cable leakage current can be caused by equipment included in the test beyond the cable and its terminations. This current can be largely eliminated by wrapping all the conductor surfaces with several layers of polyethylene film and cleaning all insulating surfaces with a silicone greased cloth. When such equipment is included, for all practical purposes, the insulation being measured thus is that of the connected equipment, not that of the cable. Since most equipment to which cable is connected is not rated to withstand even normal cable direct test potentials, the potential which may be applied will be limited. In this case, the degree of effectiveness of the cable test is severely limited when such equipment is included in the test zone.

7.2 **Resistance Values, continued**

7.2.7 When equipment in addition to the cable and its terminations is being included in the test, the sensitivity required to note approaching "avalanche" conditions outlined in paragraph 2 above may not be attained due to the preponderance of the equipment leakage current. In such cases, "avalanche" or runaway conditions may be noted only when the failure mechanism is far advanced, and reduction of voltage may not be possible before actual breakdown occurs.

7.2.8 All of the above factors should be considered when comparing or evaluating the apparent insulation resistance of a cable circuit.

8. REFERENCES

Final Report, “Condition Assessment of 15 kV Distribution Cables, October 6 to 9, 2007 Field Tests in Seattle, Washington”; Powertech Labs, Inc.; April 2008

IEEE Std. 4-1995, “IEEE Standard Techniques for High-Voltage Testing”

E6-1.0/NGE-70 (cancelled), “Properties of Medium Voltage Cables”; *Construction Guideline*; SCL

9660.04, “Properties of Medium Voltage Cables” (replaces E6-1.0/NGE-70); *Design Standards*; SCL

APPENDIX

A. REASONS FOR TESTING

1. Cable with Extruded Dielectric

a. Acceptance Tests

A high DC voltage test made before placing a cable in service normally reveals imperfections, almost complete perforations of the insulation, improper materials or practices used in splicing, terminating, etc., but will not indicate the small imperfections that may exist from installation and handling (oversharp bending, etc.) or built-in defects such as gaps in semi-conducting coverings. The acceptance test will, in most cases, reveal defects that would otherwise cause failure within one or two years.

b. Maintenance Tests

Exposure to normal alternating voltage for a moderate period is required before the progressive insulation deterioration of imperfections can be revealed by high DC voltage testing.

The action of power frequency corona at an insulation defect weakens this protection of the insulation. The principle of high DC voltage testing as a maintenance practice is to apply high enough test voltage to cause test failure of insulation which is so weak (and deteriorating) as to risk failure in service before the next test period. Factors to be considered are:

(1) Deterioration rate of insulation in service,
(2) Interval between test periods, and
(3) Safe withstand voltage of sound cable insulation.

Deterioration rate is highly variable, and not susceptible to scientific analysis. Experience indicates that deterioration rates of defects and damaged insulation are highest for new or newly-installed cables, and a major proportion of this deterioration is detectable by test during the first three years of service. Frequent testing during the first three years will detect the bulk of advancing deterioration, permitting longer intervals between tests.

2. **Laminated Dielectric Cables**

a. **Acceptance Tests**

As with cable with extruded dielectric, an acceptance test before placing in service normally reveals dielectric defects, weakness, or errors, which would result in failure within the first year or so.

b. **Maintenance Tests**

Laminated dielectric cable, when pressured, is much less susceptible to progressive deterioration from corona action at imperfections. When the dielectric is not pressurized, migration of oil and subsequent dry-out of the insulation will permit degradation from corona action. A major cause of failure of these types of cable is failure of the enclosing sheath, and ingress of water. This condition is aggravated by cyclic loading of the cable. Actual failure does not occur immediately after a breach of the sheath. Insulation resistance decreases and dielectric losses increase progressively after the initial moisture encroachment. Actual failure may not occur for several months. The usefulness of maintenance tests on this cable type depends on the frequency of the testing.

It is apparent that rather frequent maintenance tests are required to attain useful reduction in service failures with this cable.

B. PROTECTION AGAINST POSSIBLE SEVERE VOLTAGE CONDITIONS DUE TO FLASHOVER

1. **Possible Severe Voltage Conditions**

If during a high-voltage test a flashover should occur, either in the cable itself or at the terminations, voltage surges of a polarity opposite to the test voltage are initiated. These travel along the cable and produce reflections at the terminals in accordance with traveling wave theory. Before any reflections occur, the traveling wave voltage tends to neutralize the cable test voltage and relieves the prevailing voltage stress. However, at an open circuited terminal, the surge voltage doubles with the same polarity and produces a polarity reversal at the terminal. This polarity reversal is subsequently imposed on the cable. While the maximum possible voltage magnitude is approximately equal to the test voltage and will not exceed equipment BIL, even for 100% tests, there is some uncertainty of its effects because of the polarity reversal. Some opinions indicate that underground plant can be damaged unduly by this means and that protection should be provided.

2. **Protection Requirements**

The effects of test flashover occurrences can be minimized by preventing reflections at the terminals. This can be accomplished by installing a protective device which will withstand a negative test voltage, if the flashover is subjected to a positive voltage of the same magnitude or significantly less (60 or 70%). Such a device can be connected to ground through a resistor equal to the cable surge impedance, thereby minimizing reflections at terminals.

For this purpose, a special gap is required. Some experiments have been conducted on a gap comprising of a five-foot ring with a sphere in the center. Such a gap exhibits a positive polarity breakdown much lower than for negative polarity. Before gap designs can be suggested, more development work is required.