# FIELD TESTING

The purpose of this chapter is to summarize procedural and technical information for the performance of field testing of cable systems. The procedural aspects cover subjects related to personnel and safety, but are not intended to be all-inclusive.

Manufacturers perform various electrical tests on finished wire and cable products to ensure they can safely handle their maximum voltage and current ratings. Some installation procedures- such as pulling through conduit, installation into cable trays, or framing members- can damage conductors and cables enough to create an electrical hazard. For example, incorrect calculations of pulling force, sidewall pressure, or conduit fill may lead to tearing of a conductor's insulation as it is pulled through conduit. Because post-installation testing is a good general practice, some installation contracts may require testing by the installer.

## SAFETY

Electrical tests can be dangerous and should be conducted by personnel who are qualified to perform the tests. Both low potential and high potential testing have inherent hazards to personnel and equipment. Thus, a thorough understanding of the safety rules, test equipment, wiring system, and connected equipment is essential in preventing damage to the conductors and equipment, and in preventing electrical shock to the persons performing the tests. IEEE Standard 510 typifies recommended industry practices for safely conducting field testing.[1]

## PREPARATION FOR TESTING

Before conducting tests on any cable system, verify that the cable system is properly de-energized. If the cable system has been previously energized, you must follow the prescribed rules for conducting the switching necessary to de-energize, lock-out, tag, and ground the cable system.

High voltage conductors that are energized can induce voltage in ungrounded conductors in close proximity. It is good practice to disconnect cables from non-cable system equipment and to ground all conductors not under test for safety concerns and to prevent erroneous test results. In the case of High Voltage testing, disconnecting the cable will prevent damage to equipment and apparatus.

Check that adequate physical clearances exist between the cable ends and other equipment, other energized conductors, and to electrical ground.

At all ends remote from where the test equipment is to be connected, position a personnel guard or barricade the area to prevent unauthorized access to the cable system under test.

**Note:** Verify the procedures are taken to clear all tap(s) or lateral(s) in the circuit.

Remove grounds from the cable phase to be tested. Phases not under test are to remain grounded at all ends.

[1] IEEE Standard 510-1992, "Recommended Practices for Safety in High Voltage and High Power Testing."

## CONDUCTING TEST

Follow the instructions provided by the manufacturer of the test equipment for its proper operation.

Conduct test in accordance with prescribed procedures and instructions.

Record test results and retain for future reference.

## CONCLUSION OF TESTING

Maintain grounds on all conductors until the test equipment is disconnected and packed for removal.

**Caution:** For HVDC tests, the accumulation of a potentially dangerous voltage can remain on the cable system if the conductors have not been grounded for a sufficient time period after the completion of the test. A rough guide is to maintain the grounds for one to four times the test duration before they are removed and the cable are reconnected into the circuit.[2]

Follow prescribed procedures to return or place the cable circuit into service.

## FIELD ACCEPTANCE TESTS

### Cable System Integrity

During the design of the power cable system, it is appropriate to evaluate the requirements of the field acceptance tests that can determine the integrity of the installed system. The following types of tests may be readily conducted.

#### Conductor Continuity

Tests for conductor continuity can include a simple check with an ohmmeter, 500 Volt megohm meter, or a device that measures conductor resistance. This test determines if the conductors complete an electrical circuit by ensuring the conductor metal has not been broken.

#### Dielectric Condition of the Cable

The electrical integrity of the system dielectric can be measured by the use of ohmmeters or megohm meters for insulation resistance. A more complex high voltage dc test, commonly referred to as a dc high-pot test, can also be done to evaluate "leakage currents."

[2] IEEE Standard 400-1991. "Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems."

## Metallic Shield Condition

For shielded cables, the metallic component of the insulation shield of jacketed cables can be tested for its condition. A continuity test can be accomplished with an ohmmeter or megohm meter tester. A more complex test arrangement is required to measure the value of the shield resistance. A comparison of the shield resistance value can then be made against specified values.

## Jacket Integrity

Insulating jackets of directly buried or water-submerged cables can be tested for insulation resistance (IR). It may be possible to test integrity of conductive, nonmetallic jackets or sheaths.

# Low Potential Testing of Dielectric

## Insulation Resistance (IR)

The IR of the insulation components of the cable system is commonly tested using an unidirectional (dc) potential as opposed to using the ac operating frequency. Low voltage, nonshielded cables can be tested using a battery-powered ohmmeter. The reading from an ohmmeter for shielded higher voltage cables may be questionable as it does not have the capability to promote an inherent defect into an electrical fault, even though it can detect a low-resistance or bolted fault.

A megohm meter is commonly employed for the detection of questionable conditions in shielded and nonshielded cables.

## Equipment and Voltage Output

Hand-held ohmmeters generally have outputs from 6 to 24 volts. They are excellent for detecting direct “shorts” such as bolted faults and low resistance measurements in the kilohm range.

Manual- or motor-driven megohm meters are available for a range of fixed dc voltages. Typical fixed dc voltages are 500, 1000, 2500, and 5000 volts. These instruments are also available with multi-voltage selections within the same device.

## Interpretation of Results

Industry practice recognizes tests with a dc potential of 500 or 1000 volts dc. The insulation resistance reading should be taken after 1 minute to allow the reading to stabilize.

- For spot short time readings, IR readings should be evaluated with respect to the test conditions to determine if the results should be considered acceptable. IR readings can vary greatly depending on the environmental conditions. Conditions such as humidity, moisture in the conduits, and leftover residue on the conductor from pulling compounds are among some of the factors that influence IR readings and make detection of problems more difficult. The following “2 to 50 Megohm Rule” is a good indicator to use for evaluating IR readings.

**Acceptable:** A megohm meter reading of 50 megohms or higher should be considered acceptable.

**Investigate:** A megohm meter reading of 2 to 50 megohms may be used for deciding when to investigate the cable installation. In most cases, a 2 to 50 megohm reading does not indicate the insulation quality, therefore, 2 to 50 megohms should not be specified as a pass/fail value. These readings are usually associated with long circuit lengths, moisture, or contamination. Ends of conductors that are dirty or damp may need to be cleaned and dried.

**Unacceptable:** Readings less than 2 megohms will most likely indicate damaged insulation or severe test conditions.

- A more technically oriented evaluation is to use the "time resistance" technique. Good insulation shows an increasing IR with respect to time at a constant dc voltage. This is commonly called an "absorption" test.
- Some credence is given to determining the "dielectric absorption ratio." This is the ratio of the 60-second megohm meter reading divided by the 30-second reading. This method is common for coil insulation, but is not widely accepted for cable system insulation.
- Some standards recognize a "polarization index." This method typically is a 10-minute reading divided by the 1-minute reading.
- For tests requiring several seconds to minutes, it is important that the voltage be constant. Typically, a motor-driven megohm meter is used.

If further sophistication is desired, use the previous techniques at varying voltage levels. A downward trend of results at a higher voltage(s) is an indication of a questionable condition.

### High Voltage Withstand Testing

High voltage withstand tests help determine whether a conductor can withstand a prescribed test voltage without breakdown or failure. One way to ensure that a conductor is free from major defects or installation damage is to test it at a higher ac or dc voltage than the maximum operating voltage of the conductor. The cable either withstands the voltage or it breaks down. The test does not indicate how close the cable came to failure.

## High Potential DC Testing of Dielectric

The normal high potential testing procedure is to employ direct current voltages.[2] The use of alternating current voltages requires that the test equipment be of sufficient kVA capacity to supply the charging

current requirements of the circuit under test. Direct current voltage test equipment is much smaller and lighter than ac test equipment of equivalent test voltage output. Thus, for reasons of economics and handling, dc test equipment is predominantly used.

It is common practice when conducting high potential testing to use high voltage direct current levels (HVDC). For these situations, personnel should be familiar with IEEE Standard 400.[2]

[2] IEEE Standard 400-1991. "Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems."

## Withstand Test

### *During Installation*

Tests should be conducted on the cable prior to installation for damage that may have occurred during transit and subsequent handling. This minimizes labor and productivity losses. Applicable cable specifications define limitations on voltage and time of test. These limitations are generally within those presented in IEEE Standard 400.

### *Field Acceptance*

After installation of the cable and prior to installing terminations or splices, it is recommended to test the cable for possible damage that may have occurred during installation. This test can be performed at a reduced level as defined in the applicable specification. The cable system may be subjected to a final acceptance test after the system is assembled, terminated, and spliced, and before connection to any non-cable equipment or devices. This test will reveal any errors in final termination of the cable system. As for the previous test, applicable specifications define voltage and time limits. These specifications also are generally within those presented in IEEE Standard 400.

### *Periodic Maintenance*

Although not a design criteria, this topic is presented here for completeness on the types of HVDC tests that can be conducted. After the system has been in service, some organizations conduct periodic tests as a maintenance procedure to evaluate any possible deterioration of the system dielectric.

### *Interpretation of Results*

With any HVDC testing, it is highly recommended that IEEE Standard 400 be understood and that the manufacturers of the cables, terminals, and splices concur prior to the performance of any proposed testing.

The test voltages and times for HVDC tests are defined in IEEE Standard 400. For convenience, Table 9-1 is a reproduction of a part of Table 1 of IEEE Standard 400.

## TABLE 9-1

**FIELD TEST VOLTAGES FOR SHIELDED POWER CABLE SYSTEMS FROM 5 KV TO 35 KV SYSTEM VOLTAGE**

| System Voltage (kV rms) (phase-phase) | System BIL (kV) (crest) | Acceptance Test Voltage* (kV dc) (cond-gnd) | Maintenance Test Voltage* (kV dc) (cond-gnd) |
|---|---|---|---|
| 5 | 75 | 28 | 23 |
| 8 | 95 | 36 | 29 |
| 15 | 110 | 56 | 46 |
| 25 | 150 | 75 | 61 |
| 28 | 170 | 85 | 68 |
| 35 | 200 | 100 | 75 |

*Acceptance test voltage duration is normally 15 minutes. Maintenance test voltage duration is normally not less than 5 minutes or more than 15 minutes.

IEEE Standard 400 tests are "go, no-go" tests. The system is required to withstand the specified voltage for the specified time duration. These tests will normally reveal gross imperfections resulting from improper field handling such as excessive bending or air gaps between the insulation and shield interfaces.

## TABLE 9-2

### DC TEST VOLTAGES AFTER INSTALLATION PER ICEA[3]

| Rated Circuit Voltage (Phase-to-Phase Voltage in Volts) | Conductor Size (AWG or kcmil) | Maximum dc Field Test Voltage (kV) | |
|---|---|---|---|
| | | 100 Percent Insulation Level | 133 Percent Insulation Level |
| 2001-5000 | 8-1000 | 28 | 28 |
| | 1001-3000 | 28 | 36 |
| 5001-8000 | 6-1000 | 36 | 44 |
| | 1001-3000 | 36 | 44 |
| 8001-15000 | 2-1000 | 56 | 64 |
| | 1001-3000 | 56 | 64 |
| 15001-25000 | 1-3000 | 80 | 96 |
| 25001-28000 | 1-3000 | 84 | 100 |
| 28001-35000 | 1/0-3000 | 100 | 124 |
| 35001-46000 | 4/0-3000 | 132 | 172 |

DC test voltages are applied to discover gross problems such as improperly installed accessories or mechanical damage. DC testing is not expected to reveal deterioration due to aging in service. Evidence exists that dc testing of aged cables can lead to early cable failure. For alternative testing methods to dc testing, consult IEEE P-400.
The dc voltage proof test shall be made immediately after installation not exceeding the maximum specified value. The voltage shall be applied between the conductor and the metallic shield with the shield and all other metallic components of the cable grounded. The rate of increase from the initially applied voltage to the specified test voltage shall be approximately uniform and shall not be more than 100 percent in 10 seconds nor less than 100 percent in 60 seconds.
The duration of the dc voltage test shall be 15 minutes.

## Time-Leakage Test

For more sophisticated evaluations, it is important to recognize the components of dc "leakage" current. The output current of the test set into the cable is not the true leakage current. The output current is the sum of three currents: geometric capacitance, absorption, and true leakage current. The absolute value of output current is not of primary importance. This value is virtually impossible to predict and is dependent upon the previously mentioned factors, which can affect the resultant output current from a few to hundreds of microamperes.

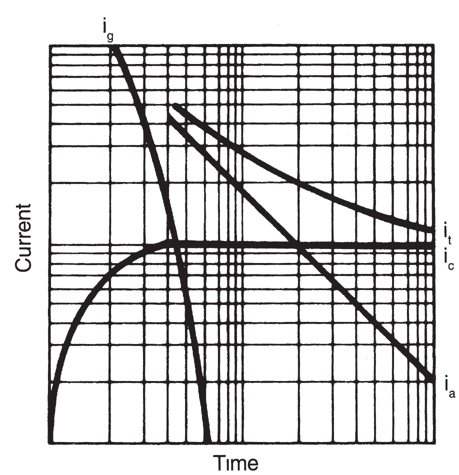


**Figure 9-1**
**Components of DC Test Output Current**

[3] ICEA S-93-639 (NEMA WC 74-2000): "5 - 46 kV Shielded Power Cable for Use in the Transmission & Distribution of Electric Energy."

where: $i_t = i_a + i_g + i_c$

$i_g$ = *geometric capacitance current*

$i_a$ = *absorption current*

$i_c$ = *leakage/conduction current*

$i_t$ = *total current*

The shape of the total current curve (it) with respect to time indicates the condition of the dielectric. A drop-off of current with respect to time is an indication of sound insulation. A distinct or fast rising current is an indication of questionable condition or impending failure. A flat curve is generally a result of test conditions.

The output current variation with respect to time of voltage application is generally considered more indicative than the absolute value. The characteristic shapes of the time-leakage current curve and probable causes are outlined below.

1. A **fast rising leakage curve at a steady voltage** may be indicative of faulty insulation. However, other leakage paths (over porcelain surfaces and through insulating fluids) can contribute to such a result.

2. A **falling leakage curve** is indicative of good insulation characteristics especially if it is at similar levels for all phases.

3. A **flat leakage curve** at low value is generally indicative of acceptable insulation. Flatness may be influenced by circuit length, cable geometry, and possible presence of moisture or contaminants over terminal surfaces.

4. A **flat leakage curve** at high value may indicate any of the following conditions:
   a. presence of moisture
   b. contaminants over terminal surfaces or other creepage surfaces
   c. surface leakage greater than volume leakage
   d. moist laminated insulation
   e. condition of insulating fluids
   f. air ionization losses (corona) from projections

5. **Dissimilar leakage curves** are indicative of non-uniformity of circuit insulation. The characteristic curve of each phase should be analyzed to determine the cause of dissimilarity. Air ionization losses from projections may affect one phase more than the others, dependent upon corona shielding (such as at terminals),temperature and humidity transients, air movement, and the like.

Generally speaking, the increase of current with test voltage is approximately linear for sound insulation. Care should be exercised to prevent terminal corona and minimize terminal surface leakage as these can mask test results.