Cable Testing
Excerpt
From
Prysmian's
WIRE AND CABLE ENGINEERING GUIDE

700 Industrial Drive
Lexington, South Carolina 29072
Phone: 1.800.845.8507
Fax: 1.803.951.1142
www.na.prysmian.com/energy

CABLE TESTING

Testing represents an integral part in the life of a cable. A cable will be subjected to multiple tests in its lifetime including a series of tests beginning at the factory and potentially continuing throughout the lifespan of the cable. Cable testing is performed in different phases including: materials testing, qualification testing, production testing, and field testing (including on-reel, installation, acceptance, and/or maintenance testing). The types of tests performed in the various phases can depend on the environment of the cable as well as the type of cable being tested: low-voltage or medium-voltage, shielded or non-shielded, etc. Various cable testing practices are covered in the following documentation.

It is important to recognize that many factors must be considered to properly characterize the test results obtained from any cable testing program. Many of those factors are controllable as part of material testing, qualification testing, and production testing. Unfortunately, field testing does not allow control over many factors, two of which are temperature and humidity. Keeping track of the various factors that influence cable testing results and accounting for them can be the difference between passing or failing results.

MATERIAL TESTING

In order to provide a quality cable, quality materials must be utilized in the manufacturing processes. To ensure quality materials are used in the production of our cables, Prysmian adheres not only to the requirements of industry standards but also to our own strict internal requirements. Industry standards, such as those from ICEA (Insulated Cable Engineers Association) and ASTM (American Society for Testing and Materials) provide requirements for anything from the conductor to the metallic shields, armoring, and all the extruded materials. The material testing requirements apply to both the physical and the electrical characteristics of the cable, but NOT necessarily to the specific ingredients of the materials. Many of the cable test results are commonly summarized in a Certified Test Report (CTR), which can be used as a means to compare industry standard requirements and/or customer specifications to as tested values.

In recent years, ICEA has been transitioning towards performance-based standards. *After all, while the quality of the materials is indeed important to the cable, even more important is the performance of the finished product.* For this reason, the end user should give greater consideration to the tests performed on the cable as a whole as well as the overall performance of the cable rather than to the individual ingredients of a compound or the compounds themselves.

QUALIFICATION TESTING

Qualification testing, also known as type testing, insures the credibility of the cable's overall design. Qualification testing is performed on a particular cable design and some tests encompass accelerated aging as part of the testing protocol. ICEA S-94-649 and S-97-682 list five main types of qualification tests including:

(1) Core Material Qualification (this includes Conductor-Shield/Insulation Qualification and Insulation/Insulation-Shield Qualification)
(2) Thermomechanical Qualification
(3) Jacket Material Qualification
(4) CV Extrusion Qualification
(5) Other Qualification Tests (this includes Insulation Resistance, Accelerated Water Absorption Tests, etc.).

These qualification tests, especially the Core Material Qualification tests, provide the consumer with a sound and relative means for comparing the *performance* of cables produced by various cable manufacturers. This apples-to-apples comparison is based on industry standard (ICEA) details, which provides the exact method of testing and the procedures to be used as well as the specifics regarding the cable sample: 15 kV, unfilled, 1/0 AWG Al Class B compressed conductor, 100% insulation level, unjacketed cable. Each manufacturer is required to comply with the same set of tests according to the same test parameters.

PRODUCTION TESTING

Production tests are performed on a routine basis on various types of cables during and immediately following the manufacturing process. Production testing insures the continuous quality of the products and the products' compliance with industry standards while also providing a means for evaluating the efficiency of the manufacturing line and/or facility.

Virtually every mechanical and electrical aspect of each element of the cable design is governed by an applicable industry standard as well as Prysmian's internal requirements. These physical and electrical characteristics are then tested for compliance with various industry and internal requirements. While there are many tests, in fact too many to discuss in this forum, following are some of the main production tests worth noting:

1. Elongation and Tensile Strength of the extruded materials.
2. Hot Creep and Hot Set
3. Dimensional Analysis
4. High Voltage AC Withstand (MV Cables)
5. Partial Discharge (MV Cables)
6. Spark Testing

Elongation and Tensile strength tests ensure the materials have been extruded correctly and the required physical properties are as they should be. Hot Creep and Hot Set tests indicate whether the applicable material has been properly cross-linked or thermoset. Dimensional analysis indicates whether the cables comply with the limits set forth in industry requirements for diameters and thicknesses. The High Voltage AC Withstand test ensures the electrical integrity of the insulation system with regards to its dielectric strength while the Partial Discharge test identifies significant voids and possible contaminants with surrounding voids that may be present within the dielectric material. Spark testing is an inline voltage test used for low-voltage insulation and medium-voltage non-conducting jackets. Spark testing continuously inspects for pinholes or other breaches in the outer layer of the cable.

FIELD TESTING

Field testing of cable is commonly employed to determine the as-received condition of the cable, the as installed condition of the cable, and/or the operating condition of the cable. Field testing can be divided into two broad categories: Type 1 - Destructive and Type 2 - Non-Destructive. Both of these categories of tests can be conducted as part of on-reel testing, installation testing, acceptance testing and/or maintenance testing.

Today, there are more field test methods available than ever before. The test method chosen depends on multiple factors, such as what is to be tested and what information is to be obtained (i.e. instant analysis or historical data). Six commonly referenced field tests are listed below.

1) High Potential Testing (Hi-Pot)
2) Very Low Frequency Testing (VLF)
3) Partial Discharge Testing (PD)
4) Dissipation Factor/Tan Delta Testing (Tan δ)
5) Megohmeter Testing of Insulation Resistance (a.k.a. Megger Testing)
6) Time Domain Reflectometry Testing (TDR)

Specific test methods may be more applicable to one category, while some test methods may be applied to both categories. More importantly, the above list of tests is not meant to be a comprehensive list of all field tests available.

<u>Type 1 – Destructive Field Tests</u>[†]

Destructive tests can be categorized as "pass/fail" or "go/no-go" tests. By nature, a withstand test that tries to breakdown a

700 Industrial Drive
Lexington, South Carolina 29072
Phone: 1.800.845.8507
Fax: 1.803.951.1142
www.na.prysmian.com/energy

cable defect during the time of testing is considered a destructive test.

Destructive tests typically consist of applying a high electric stress for a prescribed duration. Three common voltage sources used for withstand testing are DC, power frequency AC, and VLF AC. It is important to recognize that Type 1 field tests may trigger failure mechanisms within a cable that will not show up during the test but may cause subsequent failures in service.

Type 2 – Non-Destructive Field Tests[†]
Non-destructive tests can be categorized as "diagnostic" tests which are used to provide the relative condition of the insulation system by comparison with figures of merit.

Diagnostic testing is typically performed by means of moderately increased voltages applied for relatively short duration or by means of low voltages. Two common types of diagnostic tests are PD Testing and Dissipation Factor/Tan δ testing. It is important to recognize that, in an advanced condition of insulation degradation, Type 2 field tests may aggravate the condition of the cable and cause breakdown before the results can be determined or before the test can be terminated.

High Potential Testing
Hi-Pot testing can be conducted with a DC potential or AC potential and can be applied as a Type 1, withstand test or a Type 2, diagnostic test.

The DC hi-pot withstand test is a Pass/Fail test that has been applied to all types of cable and accessories. The DC hi-pot leakage current technique, sometimes referred to as a Megger Test, involves the measurement of leakage current when a high potential (above nominal) is applied to the conductor while the metallic shield of the cable is grounded. The behavioral characteristics of the leakage current are evaluated to determine the condition of the cable, specifically the insulation.

It is important to recognize that published documentation provides details showing DC hi-pot testing mostly finds conductive type gross workmanship errors in extruded dielectric cable systems[†]. Consequently, the practical use of the DC hi-pot testing is recommended only for paper insulated cable systems and for performing a safety check before switching an extruded cable system into service (to prove that the system is not grounded).

The AC Hi-Pot withstand test is a Pass/Fail test routinely applied by cable manufacturers before the cable leaves the plant. When used in conjunction with PD Testing and/or Tan δ testing, the AC Hi-Pot test can be considered a diagnostic test.

Additional details on DC high potential testing can be found by referencing IEEE 400.1 *IEEE Guide for Field-Testing of Laminated Dielectric, Shielded Power Cable Systems Rated 5kV and Above with High Direct Current Voltage*.

VLF Testing
Very Low Frequency (VLF) testing incorporates the application of an AC voltage at a low frequency in the range of 0.01 to 1.00 Hz. The typical frequency applied is 0.1 Hz. The VLF AC withstand test (Type 1) should not be confused with the non-destructive (Type 2) diagnostic tests which use a VLF voltage source as part of a partial discharge test or a dissipation factor (tan delta) test. When VLF testing is referenced as a stand alone test, it typically refers to VLF AC hi-pot testing.

A very low frequency AC high potential test is a destructive withstand test. It is generally operated at 0.1 Hz or lower, which allows the equipment to be smaller than power frequency voltage sources. The withstand test causes large electrical trees and mechanical defects in the cable to grow towards failure. The recommended test voltage is 2.0 to 3.0 times the cables' normal line to ground voltage ($2.0V_0 – 3.0V_0$); while the recommended test duration is 15 to 60 minutes. The test voltage and time are

700 Industrial Drive
Lexington, South Carolina 29072
Phone: 1.800.845.8507
Fax: 1.803.951.1142
www.na.prysmian.com/energy

dependant on the type of test being performed (i.e. installation, acceptance, or maintenance). A properly implemented VLF test will not cause damage to good insulation†, but will reveal many cable system defects during the test duration.

Additional information on VLF testing can be found by referencing IEEE 400.2 *IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)*.

<u>PD Testing</u>

Partial Discharge (PD) testing is a diagnostic (Type 2) test which analyzes cable systems for voids or contaminants in the conductor shield, insulation, and, insulation shield caused by electrical trees, water trees, cracks, delamination, and/or workmanship error. A partial discharge is a localized dielectric breakdown of a small portion of the electrical insulation system under voltage stress†. PD testing can be implemented online or offline and is the only test that can detect, locate, and characterize defects in cable insulation. Caution should be used when PD testing is performed at elevated voltages on discharge-resistant cables as defined by ICEA S-94-649† due to the fact that it may not be very useful.

Offline PD testing is performed through the application of an elevated AC voltage between the conductor and metallic shield. An oscilloscope and/or proprietary digital signal analysis platform is used to detect transient microvolt or microampere level signals that are generated at the discharge site and travel through the cable to the detection equipment†. PD testing is performed on all medium voltage cables at the factory as a production test and is governed by ICEA T-24-380 which limits the PD limit to 5 picocoulombs or less at a stress of 200V/mil.

Online PD testing typically employs high frequency current transformers (CTs) or capacitively coupled voltage sensors to detect transient signals from discharges. Acoustic PD measurement techniques could potentially be applied to parts of the cable system that allow direct contact†. No external voltage source is needed as the online technique provides testing under normal operating conditions.

Partial discharge threshold levels have been established for factory testing of terminations, joints, connectors and cable. Comparison against these values provides excellent reference for the condition of the cable system.

Additional information on PD testing can be found by referencing IEEE 400.3 *IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment.*

<u>Dissipation Factor/Tan Delta Testing</u>

Tan Delta (Tan δ) testing is a diagnostic test that provides a means of measuring the AC dielectric losses of the insulation and then making a determination of the condition of the cable based on this information. In theory, a medium voltage cable approaches being a perfect capacitor; a dielectric sandwiched between a center conductor and a surrounding metallic conductor. However, since the insulation is not a perfect dielectric, the system is not a perfect capacitor.

The Tan δ test essentially measures the phase shift between the voltage and the current. In an ideal or perfect capacitor, the insulation is free of impurities as well as dielectric losses and the angle between the voltage and current is 90°. Based on the degree of impurities in the insulation, the angle will decrease from 90°. The results of a dissipation factor test are generally grouped into one of three categories: like new, aged, highly aged.

Additional information on dissipation factor/tan δ testing can be found by referencing the National Electric Energy Testing Research and Applications Center (NEETRAC) Project No. 04-211 *Overview of Cable System Diagnostic Technologies and Application Overview.*

Megohmeter Testing of Insulation Resistance

Megger testing can be applied as a destructive (Type 1) test or a diagnostic (Type 2) test depending on factors such as test duration and test voltage. Typical application of a megger test determines the total insulation resistance of each cable. The resistance measurement is used to determine if the circuit will operate without excessive leakage current through the insulation when energized. Measured values can be impacted by certain external factors (temperature, moisture, etc.), which may result in questionable readings, even when evaluated on a satisfactory length of cable.

The megger test is performed by applying an elevated DC voltage to the conductor and measuring the current flow to a ground reference. With the known voltage and measured current, an insulation resistance value can be calculated.

It is important to recognize that megger testing non-shielded cables may produce marginal results due to the inherent lack of a completely encompassing and uniform ground plane over the dielectric of the cable.

Additional information on megohmeter testing of insulation resistance can be found by referencing Megger's "A Stitch in Time" *The Complete Guide to Electrical Insulation Testing*.

Time Domain Reflectometry Testing

Time Domain Reflectometry (TDR) testing, or a RADAR test, by itself does not evaluate the insulation of shielded power cables. Therefore its 'Type' is not classified into destructive or non-destructive. However, when low voltage pulses are used (≤600V), the test can be considered a non-destructive diagnostic test.

The test uses pulse reflection to measure the distance to changes of characteristic impedance in the cable. In theory, a completely uniform cable that is properly terminated will exhibit no characteristic impedance changes and will not reflect a pulse. In reality, interruptions in the cable shield, joints, open circuit faults, terminations, and short circuit faults all produce reflections.

A graphical interface is commonly used to display the original pulse, any reflected pulses, as well as cable data. When fault locating, the TDR response of the cable system will yield a positive polarity reflection at an open circuit and a negative polarity reflection at a short circuit.

Additional information on time domain reflectometry testing can be found by referencing Megger's *Fault Finding Solutions*.

Field Tests

The tests detailed above are six commonly referenced field tests in an industry that has even more options. These tests are referenced to provide a general overview of some of the field tests available today. It is up to the end-user to determine which field test method will provide the most accurate and useful information. One test method cannot completely asses the condition of every cable. To properly determine the condition of a cable, the best test method may be a combination of tests.

On-Reel Testing

On-Reel (field) testing is a rather uncommon practice that allows the end user or installer to test the integrity of the cable on the reel at the time of delivery and prior to installation. On-reel (field) testing is uncommon due to the fact that prior to shipping, the cable undergoes a thorough testing program at the factory. On-reel testing by the end-user insures that the cable has arrived without sustaining any damage while in transit. During shipment the cable may be loaded and unloaded several times after it leaves the manufacturer and before it arrives at its final destination. This extraneous, but sometimes necessary, handling of the cable provides added opportunity for the cable to experience mechanical damage. If the cable is damaged during transit and is not on-reel tested, the cable may then be installed, prepared, and tested only to determine the cable is failing installation test due to damage incurred during shipping.

On-reel testing of cables incorporates different test methods when testing non-shielded vs. shielded cables. On-reel testing of non-shielded cables is a difficult, if not an impossible task. Unless there are multiple cables wound on the same reel or the cable and reel can be submerged in water to afford a continuous ground plane, on-reel testing cannot be successfully performed for non-shielded cables.

A commonly used test method for non-shielded cables is a megger test. Megger testing non-shielded cables typically involves applying a potential to the 'test cable' and grounding the other cables on the same reel, and then measuring the insulation resistance. This test may produce marginal results due to the inherent lack of a completely encompassing ground plane. The insulation resistance of a single non-shielded cable on a reel can be determined if the end-user has the means of submersing the cable and reel while performing a megger test.

On-reel testing of shielded cables involves a slightly different method of verifying the cable integrity. Shielded cables inherently provide a solid ground reference for the test setup by means of the metallic shield. Therefore, it is not necessary to have multiple cables on a reel or have submersion capabilities. DC hi-pot testing has been commonly utilized as an on-reel test of shielded cables. Since partial discharge testing is performed at the plant on these reels, on-reel field testing using a PD test set would provide results that are the most readily comparable to the plants' PD test results, as long as field 'noise' is filtered out of the results.

It is important to note that any intention to on-reel test cables should be pointed out to the manufacturer. In order to facilitate on-reel testing by the end-user, the manufacturer will have to ensure test 'tails' are present on the reel. Test tails will consist of allowing access to appropriate lengths of cable at the drum end of the cable. This will enable the connection of both cable ends to the necessary test equipment. Test tails typically consist of a length of cable at the drum end that is approximately 24 inches long.

Installation Testing

Installation testing is conducted after cable installation but before jointing (splicing) or terminating. The test is intended to detect shipping, storage, or installation damage[†]. *Installation testing of cable offers the best possible assurance that the cable has not been damaged and will perform satisfactorily when energized.*

There are many ways cables can be damaged during installation: pulling through ducts that are in poor condition, improper use of pulling equipment, exceeding minimum bending radii or training radii, or exceeding maximum pulling tensions or maximum sidewall bearing pressures. If damage has occurred during installation, it is important to determine this prior to energizing. Installation testing can prevent a safety hazard or a potential cable or accessory failure during inopportune times. To test the integrity of only the cable, the installation test should be performed. Once the cable tests satisfactorily, the accessories can then be applied and the system can be 'acceptance tested' to ensure the accessories were applied successfully and are of good quality.

Installation testing non-shielded (<5 kV) cables typically involves applying a potential to the 'test cable' and grounding the other cables in the same duct as well as possibly grounding the duct itself, and then measuring the insulation resistance. This test may produce marginal results due to the inherent lack of a completely encompassing and uniform ground plane.

Hi-Pot testing, VLF testing, partial discharge testing, etc. are all types of installation tests that may be used on shielded cables. These tests involve applying a potential to the conductor and grounding the inherent ground plane (the metallic shield).

Acceptance Testing

Acceptance testing is conducted after the cable system installation, including all terminations and joints (splices), but before the cable system is placed into normal service. The test is intended to detect installation damage and to show any gross defects or errors in installation of other system components/accessories†.

Various test methods have been used to acceptance test a cable system, from DC hi-pot testing to PD testing. The test data obtained from these tests typically provides information about the whole cable system being tested. Some acceptance tests may be able to differentiate the results between the cable and any accessories. An acceptance test provides a good starting point for verification of the cable system installation; however, if marginal test results are obtained, further testing should be performed.

As part of an acceptance test, the accessory manufacturer should be contacted for appropriate testing practices. In no case should the testing of the cable exceed the limits of the accessories or cable.

Maintenance Testing

Maintenance testing is conducted during the operating life of a cable system. It is intended to detect deterioration of the system (in cable or accessories) so that suitable maintenance procedures can be initiated†.

While there are multiple maintenance test methods available, DC Hi-Pot Testing is not recommended as a maintenance test for any solid dielectric insulated cable, especially for Cross-Linked Polyethylene (XLPE/TRXLPE) cables and definitely not after five years of in-service life. More information concerning this issue can be found in the Electric Power Research Institute (EPRI) project report TR-101245 "Effect of DC Testing on Extruded Cross-Linked Polyethylene Insulated Cables."

Maintenance testing of cables typically includes all the cable accessories as part of the test results. Consequently, any test result must be interpreted to properly determine if there may be a problem with the cable or an accessory. Maintenance testing of cables can be accomplished through multiple test techniques: AC Hi-Pot testing, Tan Delta testing, PD testing, and/or VLF testing. Each test offers unique advantages as well as disadvantages.

Cable Testing

Multiple testing practices are covered within this document; however, please note that this document is only intended to provide general information about cable testing. For further information about cable testing, please contact Prysmian's Application Engineering department or a reputable cable testing company.

The interpretation of cable testing results is the key to properly assess the characteristics of a cable!

†Documentation references are available upon request.

700 Industrial Drive
Lexington, South Carolina 29072
Phone: 1.800.845.8507
Fax: 1.803.951.1142
www.na.prysmian.com/energy