
Credit: AES

Wind and Solar Underground AC Collection System Cable Testing

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Introduction

Wind and Solar Utility scale projects in North America are typically quite large, with miles of buried cables transmitting energy to and from the substation. Multiple factors can converge to create erratic faults, catastrophic failures, and other maintenance challenges.

The collection system is typically arranged in radial strings of turbines connected to a collection point, typically at a collector substation. The most common collection voltage is 34.5kV, but other voltages may be encountered. These cable systems are commonly aluminum conductors with water tree retardant cross-linked polyethylene (TR-XPLE) solid dielectric insulation, copper concentric (flat or round) wire neutrals, and a protective polyethylene (PE) outer jacket.

Due to the length of some circuits, the cable segments are spliced together in various configurations with pre-molded, heat shrink or cold shrink accessories and directly buried in the earth. Another common solution is to use above ground junction boxes when cables are excessively long or when branches of the circuits are split or combined.

These types of cable systems have proven to be highly effective in providing excellent reliability when inherent defects are removed at commissioning. However, when cable systems exhibit in-service failures, they can adversely affect wind farm operating costs, reliability, revenue, and most importantly, safety.

There are many different types of Cable tests mentioned in the industry literature, but this paper will cover five of the more widely available test methods used in the renewable energy industry to test medium voltage cables.

There are four typical uses for cable testing on an underground collection system:

1. Commissioning new cable systems
2. Proactively investigating reliability issues
3. Safety ground/short checks
4. Locating failures

(**Note:** If the reader would like to know about all type of tests, it is recommended to review the manufacturers' standards IEEE 48, IEEE 386, and 400 series as references.)

There are a variety of test methodologies available to an owner that can be used for each of these scenarios with varying degrees of cost, complexity, accuracy, and effectiveness. The purpose of this paper is to provide an overview of some of the most commonly used test methods for these applications and give the benefits and limitations of each so the owner can select the best test for the job.

How Do Typical Underground Collection System MV Cable Systems Fail?

Modern cables, insulated with plastics, do not fail by the same method as previous generations of cables. Previous generations of cables were insulated with materials that could absorb water or had limited value degradable insulations (Paper, Oil). A common test was therefore to validate whether the insulation was still acceptable through withstand tests or electrical withstand measurement, tests which have less value in modern cable systems.

The insulating plastics in extruded insulated cable systems should maintain their dielectric withstand strength for the life of the cable unless they are degraded. Extruded cables fail due to unmanaged electrical stresses that create partial discharges which can lead to a dielectric failure of the insulation system. Partial Discharges can be identified by three distinct causes: manufacturing created defects, workmanship (handling damage, contaminants, and dimensional issues) created defects, and operating conditions created defects.

Manufacturing defects are rare but can include things such as insulation voids, conductor, and insulation screen defects, and even accessories not meeting manufacturers' specifications.

See figures 1-3 below

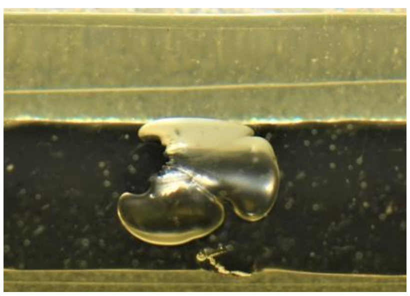

Figure 1 Insulation voids at the conductor screen defect created during manufacturing (image courtesy of IMCORP)

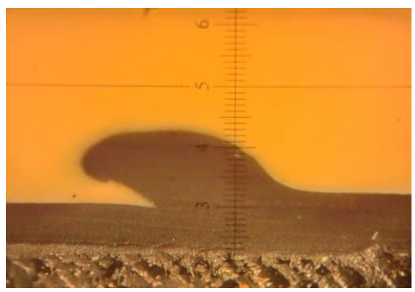

Figure 2 Conductor screen defect created during manufacturing (image courtesy of IMCORP)

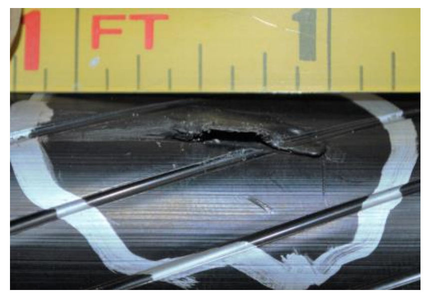

Figure 3 Insulation screen defect created during manufacturing (image courtesy of IMCORP)

Workmanship defects are due to various mistakes made during the design and, more commonly, the assembly and installation processes. Workmanship defects can exist due to inappropriate selection of the accessories, inadequate heat dissipation due to poor design, incorrect backfill or inadequate compaction or, improper installation practices.

See figures 4-6 for examples of workmanship related issues.

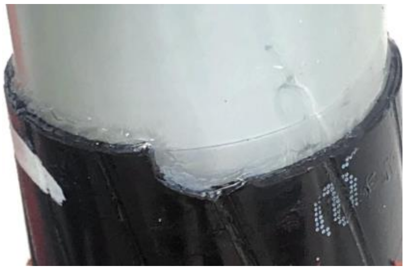

Figure 4 Improper insulation screen cutback and insulation score due to improper tool setup (image courtesy of IMCORP)

Figure 5 Improper accessory alignment. Was in service for 1.25 years before detection (image courtesy of IMCORP)

Figure 6 Improper compaction allows for water infiltration, erosion, and eventual lack of heat conduction potentially causing cables to overheat and fail prematurely

Operational practices create the third origin of failures. Defects which, under normal operating conditions, would be unlikely to ever fail can be exacerbated by transient conditions created throughout the normal operation of a plant as well as by improper protection setpoints. For instance, lightning and grid events can create degrading transient conditions, however more common damaging events are the transients from operations conditions such voltage surges from cap bank operations, or fault locating by excessive "thumping." Depending upon the design impulse, fault locating may be required multiple times on a long circuit for every fault. Setting capacitor banks operation setup points too closely together can mean thousands of unneeded switching transients each year which could result in upwards of 100,000 transients during the life of a plant.

Regardless of the mechanism of failure, identifying these issues before, on a proactive basis, or locating a failure efficiently and confirming effective repairs are critical to the reliable operation of a wind or solar project.

Cable Testing Options

For this paper we are dividing the typical cable test options into two categories, Type 1, Withstand and Type 2, Diagnostic tests.

Type 1 Withstand Tests

Type 1 Withstand Tests are designed to stress the cable system by applying an overvoltage for a prescribed duration of time. Withstand Tests are typically considered a pass/fail test but can also be destructive in nature. The goal of these tests is to accelerate the breakdown of a defect if present, or to show if a failure is currently present. A cable that immediately fails upon, or shortly after energization, has a defect that has now (usually) been explosively or catastrophically, failed. If your cable does not fail during the test, then the cable is presumed to have passed. While it is true that a completely perfect cable should not fail during such a test, without knowing if a defect is present, or what that defect is, then you have no idea of how long it will take at elevated electrical stresses to fail. Withstand tests are effective at eliminating weak spots such that the resulting system is more reliable than one that was not tested. The key is to select the right test voltage-test time recipe. These are provided in IEEE 400 series documents. Typically, MV Cable defects are not instantaneous failures, they take time to develop, erode the insulation, and fail in hours, days, and sometimes years. By using a "withstand test" it is a possible risk that the test was stopped too soon, and the cable may fail quite soon after being put in operation.

By nature, withstand tests do not provide information regarding future reliability or detect defects that did not fail under test, they only indicate if the cable failed during the test. Common Type 1 Withstand Tests applied to wind and solar projects are AC Withstand tests sometimes called VLF (very low frequency, 0.1Hz) test or high potential tests (or HiPot Tests). DC HiPot Withstand tests have long been known to be destructive and should never be used for aged, extruded cable systems.

Type 2 Diagnostic Tests

Type 2 Diagnostic Tests are intended to provide indications of overall health, of specific portions of the cable system, or the cable system as a whole.

Three common off-line diagnostic tests are partial discharge ("PD") where the electrical discharge associated with pre-failure conditions is measured; dissipation factor (also known as tangent delta or tan-delta, (that measures dielectric loss by comparing a measurement relative to an ideal capacitor)), and DC insulation resistance testing (which detects the resistance of insulation by measuring leakage current).

Diagnostic testing can be performed on-line with limited effectiveness. The most common on-line test is a PD test (measures partial discharge at operating voltage and temperature but lacks the ability to elevate voltage).

In the following sections each of these tests will be described and a summary of the benefits and limitations of each.

Type 1 Withstand Testing

As previously stated, the most common withstand tests that may be found in use at wind and solar projects are DC Insulation Resistance and VLF tests.

Very Low Frequency (VLF) High Potential Withstand Testing

An AC withstand test or VLF high potential withstand test includes the application of up to 300% over operating voltage VLF source (alternating polarity typically every 5 seconds or 0.1Hz) for a duration of typically 15, 30 or 60 minutes. If no fault occurs, the cable system is believed to be serviceable. Historically, VLF withstand testing was commonly used as a low-cost commissioning and maintenance test, however, many owners restrict the use of VLF voltage sources to operating voltage level for just a few minutes as a proof test before energizing the circuit.

DC Insulation Resistance Testing

DC Insulation Resistance Tests are typically performed with a megohmmeter. Since the test uses voltages *below the operating voltage* of the cable system it is considered to be a non-destructive test. Typically, 5 or 10kV DC is applied for approximately one minute or until the voltage stabilizes, whichever comes first. For good insulation, the resistance usually reads in at least the megohm, and often in the gig ohms, or higher range. Readings in the ohm range are not acceptable, and readings in the kilo-Ohm range usually indicate an insulation problem. The absolute value of the reading is very subjective and not of significance and since the test cannot detect the vast majority of defects in cables and accessories it is of limited value. It is an effective method of ascertaining that all “Shorts and Grounds” have been removed from the system prior to energization. Comparing phases to determine if one has a significantly lower resistance may be useful for isolating faults.

Type 2 Diagnostic Tests

As previously stated, common diagnostic tests in use on wind and solar projects include offline and online PD, offline tangent delta, and DC insulation resistance testing.

Offline Dissipation Factor/Tangent Delta

Tangent delta (TD) typically uses a VLF voltage source applied at a few voltage levels while measuring any losses in the cable system. The test provides a relative measure of how the cable system compares to a perfect, lossless, capacitor. Since the test is very sensitive to losses associated with conductivity, it may be useful for detecting very specific conditions, especially in older projects. Tangent delta testing can also detect water trees and corroded neutrals in the cable system. If owners are interested in confirming if losses have increased in the cable over time, Tan-Delta gives an average dielectric loss value which can mask discrete defects. Tangent delta testing is of limited value in locating defects and other methods of testing may be needed to identify the precise location of defects. Tan-Delta gives an average capacitive value which can mask discrete defects.

Offline Partial Discharge (PD) Testing

Offline 50/60 Hz partial discharge testing is often specified as a commissioning test for new wind and solar projects however it has been used extensively to test aged cables as well. PD testing is widely used in the wind and solar industry because of its ability to provide a direct comparison to the original factory quality control test and can provide an accurate location of the defect. In Offline PD testing, a power frequency Hipot set is used to briefly energize cables at voltage levels up to two times operating voltage while measuring the cable system's response and measuring PD activity. If PD activity is detected it is investigated and recommendations or repairs are made accordingly. When performed properly, factory levels of detection at sensitive levels as low as 5pC can regularly be achieved in the field.

Some sites utilize VLF PD testing using a 0.1Hz (VLF) voltage source. While this test is less effective than the 50/60Hz voltage source PD test, it may provide some indication in the egregious cases.

Online Partial Discharge (PD) Testing

Online partial discharge testing is the only electrical test which can be performed without taking the cable system out of service. Typically, a high frequency current transformer (HFCT) is used to detect levels of PD activity. The test can be used to detect substandard components which have active PD at operating voltage but cannot identify specific damage and may be inaccurate depending on the number of sensors used. Location detail accuracy is also dependent on the number of sensors and can be affected by devices with inherent PD such as transformers and rotating machines like wind turbine generators. Online may be helpful for operational wind sites which cannot afford to take cable systems out of service.

Conclusion

In conclusion, there are a number of cable system test methods available to wind and solar project owners and operators. It is up to each owner and operator to determine why they are performing testing on their underground collection system and to select the best test method to meet their needs.

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