Nanocoating Testing for High Voltage Transmission Applications

A. Phillips*, A. Gould*, C. Engelbrecht* and D. McGuire**

*Electric Power Research Institute,
Charlotte, NC, USA, aphillips@epri.com
**Southern Company,
Birmingham, AL, USA, dbmcguir@southernco.com

ABSTRACT

This document describes the testing performed to qualify advanced coatins for use in electric power transmission environments. Of particular interest are opportunites to reduce the effects of insulator contamination, conductor and structure icing, and corona performance. Each opportunity will be described. A test methodology is presented that provides the basis for testing coatings in specific and deliberate methods. Finally, the test methods are described. These tests will result in deployed, high-voltage field tests and may lead to functional specifications for future transmission designs.

Keywords: power transmission, high-voltage, coatings

1 INTRODUCTION

New advances in material science have resulted in the development of a family of advanced coatings which can be engineered to provide surfaces with specific desirable properties. These coatings have found application in the aero-space industry to keep surfaces ice free and in architecture to provide self-cleaning properties for windows. Other properties advanced coatings can provide are resistance to scratches, corrosion and chemicals as well as super hydrophobicity.

These coatings can potentially benefit the electric power industry where the self-cleaning and super hydrophobic properties of these materials are particularly attractive for application on insulators in contaminated environments and coatings with ice repelling qualities may reduce the risk for flashovers during winter storms. Icephobic coatings are also of interest for application to conductors and supporting structures in areas where there is a risk for mechanical overload due to ice accretion in winter months. The application of super-hydrophobic coatings to conductors also has the potential to reduce the audible noise, radio interference and corona loss on high voltage transmission lines.

These benefits not only have the potential to increase the reliability of transmission assets, but it may also enable a reduction in the capital cost of new construction. An example would be the ability to reduce the dimensions of a conductor bundle due to the reduction in audible noise under wetting conditions which in-turn would result in smaller structures and foundations.

Before applying this new breed of coatings utilities need to be confident in their performance and life expectancy. Critical factors are that these coatings, when aged, will not result in a reduction in performance below that of uncoated surfaces and that they will not require a high level of maintenance. It is therefore vital to identify suitable test methods to qualify advanced-coatings as part of the procurement process. Furthermore it is also important to consider all aspects of applying and maintaining the coating to ensure that benefits of the coating outweigh the total life cycle costs and that the performance of the power system is not in any way placed at risk.

2 OPPORTUNITIES

The application of super hydrophobic and Ice-phobic coatings offers a number of opportunities to improve performance of the electrical power system. These opportunities will be briefly described.

2.1 Insulator Contamination

The presence of a conducting or partially conducting contamination layer on external insulation surfaces may result in a significant reduction of its power frequency flashover strength. Such a layer is formed during natural wetting conditions if the insulator surface is contaminated by air-borne contaminants. Common contaminants are

- Salt from the ocean
- Pollution from factories or mining activity
- Road salt
- Chemicals used in agricultural activities such as fertilizers

The contamination severity is measured in terms of the amount of contaminants present and their conductivity when dissolved in water.

Room temperature vulcanized (RTV) silicone rubber coatings are nowadays an accepted and widely used remedy to improve the contamination performance of insulators. These coatings provide conventional insulators (i.e. porcelain or glass), with surface hydrophobicity. While advanced coatings have, as yet, not found wide spread use they do have attractive properties which could be used to improve the contamination performance of conventional

CTSI-Cleantech 2014, www.ct-si.org, ISBN 978-1-4822-5819-6

insulators. In this regard coatings that offer super-hydrophobicity or "self-cleaning" are particularly attractive.

2.2 Insulator Icing

In cold climates the performance of insulators in ice and snow conditions is of concern. Service experience indicates that the likelihood of an electrical outage is the greatest if ice or snow accretion is followed by a period of thaw. The likelihood for such events may be further increased if the insulator was already contaminated at the time of the icing event. These flashovers are therefore generally a concern for lines and substations in urban areas with a high road traffic density where roads are regularly salted to ensure ice free roads. Ice flashovers may also occur in areas with a relatively low contamination severity but with high levels of ice accretion. In such cases the ice may bridge all the sheds and, although ice is a relatively good insulator, can result in flashovers when it melts.

The sources of contamination are essentially the same as mentioned in the previous section, but of particular interest is road salt which is normally applied when icing events are expected. Insulators installed close to expressways and through roads may be exposed directly to a salt spray, resulting in a fast buildup of contamination. This is also the case for insulators installed in proximity of cooling towers.

The severity of the ice condition is measured in terms of the weight of ice present and the conductivity of the melt water.

2.3 Conductor and Structure Icing

The accretion and shedding of ice and snow on transmission lines and substation components in combination with the effects of wind, can pose a real threat to its mechanical integrity. Typical ice loads on conductors may be as high as 3 kg/m but under extreme conditions this could be much higher. The increased diameter of conductors and structures because of ice also increases the wind force on the structure. Furthermore, ice accretion on conductors changes the shape of the conductor, which could result in conductor lift in windy conditions. In severe cases this induced movement could result in galloping that subjects the conductors, insulators and supporting structures to heavy dynamic mechanical loads and flashovers if minimum clearances are breached.

The strength of the ice adhesion to the substrate is a key parameter that determines how much ice accumulates on conductors and structures. It also determines how easy it is to remove such ice deposits.

To date, coatings have rarely been considered as a way to reduce the ice loading on transmission conductors and support structures. Rather lines are designed to cope with the expected ice loading or they are fitted with passive devices to prevent or reduce ice buildup. In extreme cases manual labor or mechanical devices have been used to de-ice lines.

2.4 Conductor Corona

One part of the electrical design of transmission lines is to control the electric field around conductors and hardware within acceptable limits as to avoid corona discharges. Corona discharges have a number of undesirable side effects such as audible noise, electromagnetic interference, power loss and the generation of ozone and nitrous oxides. Lines are generally designed to have little to no corona under fair weather conditions. It is however not always economical to dimension the conductors or conductor bundles to be free of corona under all weather conditions. As a consequence there may be some level of corona activity during foul weather when there are water drops, frost or icicles on the conductor surfaces.

Corona on wet conductors is at is most intense if the conductor is hydrophobic. In this condition the water forms in to distinct drops that stick to the surface. Under high electric fields these water drops deforms into a pointed shape which may enhance electric field sufficiently to initiate corona discharges.

It is foreseen that applying a coating with super hydrophobic properties and high water drop mobility would result in less water drops on the conductor surface and thus fewer sources of corona and a lower level of annoyance.

Ice phobic coatings also hold promise for utilities that are interested in reducing winter power losses on transmission lines. Hoarfrost, or wet snow, could give rise to significant power losses; values of up to 22 kW/km have been measured. A conductor coating that would inhibit frost formation or would shed wet snow could result in significantly lower winter corona losses.

3 TEST METHODOLOGY

A difficulty in considering the implementation of a new technology, such as advanced coatings, to power equipment is the lack of standards or accepted or relevant test methods that can be used to qualify the coatings for use. There is thus a need to identify appropriate test methods that can be used to evaluate advanced coatings for use on the electric power system. The experience gained through such testing would also help to identify the opportunities and challenges involved in the application of such coatings.

Basic requirements that test methods should meet to in order to successfully qualify products include representation of service, repeatability, and reproducibility [1]. To meet these requirements, three evaluation tiers were developed:

- Tier 1 – Small Scale Testing on Coated Material Samples, e.g. glass or aluminum
- Tier 2 – Laboratory Testing on Coated Components, e.g. conductors or insulators
- Tier 3 – Field Demonstrations at Utility Sites

4 TEST METHODS

A key requirement for any technology that is applied to the power system is that it should maintain its functional properties for a considerable period of time, normally 20 to 30 years with minimal maintenance. It is expected that the cost of the coating itself is usually minor compared with the total cost of applying the coating. In many cases it may also be difficult to obtain access to the line or substation for maintenance due to restrictions on planned maintenance outages. A series of tests were designed to determine the performance and durability characteristics of the coatings under test [2].

4.1 Categorization of Hydrophobicity

Because hydrophobic insulators may lose their hydrophobicity, it may be necessary to evaluate the condition of an insulator by categorizing its level of hydrophobicity. This may be done using a number of standardized methods described in IEC Technical Specification 62073:

- Measuring the contact angle
- Measuring the surface tension
- Comparison agains a control sample

4.2 Icephobicity

This test measures the force that is needed to break the bond between ice and the substrate, using the result as an indication of the icephobicity of the coating. A small cylinder of ice is frozen onto the substrate which is chilled with a cold plate. The force needed to break the ice cylinder off is then translated into the shear strength of the bond by taking account of the surface contact area.

4.3 Self-Cleaning Ability

For the Tier 1 testing, the self-cleaning ability of coatings is determined by artificially applying a contamination layer to the coating and then to measuring the washing effect by spraying the contaminated sample with a spray bottle.

An additional method is in development. In this method a layer of condensed water on the coating surface captures and binds a dry contamination mix applied by airflow. The initial results show that it was possible to obtain rather uniform contamination coatings on the samples.

4.4 Surface Adhesion

The surface adhesion of the coating is determined using two methods. The first uses a loading dolly fixed to the coating with an adhesive. The separation pressure and failure interface are noted.

The second method is the tape test. This test consists of cutting a pattern into the coating then applying and removing tape on the coating. The amount of coating removed is then classified.

4.5 Dielectric Test

This test is performed on coatings applied to flat aluminum samples. A dielectric tester is connected to the sample with the ground lead connected to the metal substrate and the high voltage probe (via a pointed probe) to and electrode that rests on the surface of the coating. The HV electrode used is as specified in IEC 62217 for the high voltage test on the core material.

The dielectric tester has an automated test sequence which starts at the minimum output voltage and slowly increases the volts until the material breaks down. The test is repeated at various locations on the coating surface to obtain statistical information on the uniformity of the results.

4.6 Ultraviolet Light Test

Two UV tests are performed. The first uses a Xenon bulb in a heated chamber for 2,000 hours. This lamp's spectral output closely matches that of the sun.

The second test exposes the coatings to fluorescent lamps and high humidity for 2,000 hours.

After either test, the coating is visually inspected for signs of deterioration and changes in hydrophobicity.

4.7 Humidity Test

The response of the coating to extended period s of high humidity is determined in the humidity chamber test. This is a non-standard test devised by EPRI. The coated samples are placed on a flat surface with the coating facing upward in an enclosed chamber. Cold humid air supplied by an ultrasonic humidifier is injected into the chamber to keep the relative humidity at 100% for a duration of 100 hours.

4.8 Temperature Cycling

The test samples are subjected to temperature cycles to verify its ability to cope with rapid changes in temperature in accordance to ANSI C29 with modified temperature maximums. Over a 24 hour period the temperature is increased over 4 hours to a temperature of 60oC after which it is soaked for 8 hours, the temperature is then lowered to -20°C over 4 hours and again soaked for 8 hours. The cycle is repeated four times for a total test duration of 96 h.

4.9 Ice Exposure

This is an EPRI devised test to determine the ice phobic properties of the coatings. The coated test samples are mounted in an outdoor test frame during Tier 1 testing

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during subzero outdoor temperatures at EPRI's Lenox high voltage laboratory. A visual inspection is done early in the morning, before the samples were exposed to direct sunlight to determine the degree of ice or frost accretion on the sample surface. The samples are then sprayed with fine water mist to determine if the water droplets freeze onto the coating surface. Photographs are taken as visual record of the extent of ice accretion.

4.10 Inclined Plane Test

The tracking and erosion performance of the coatings when energized is tested with the inclined plane test as described in ASTM D2303. The initial tracking voltage test method is used during which the voltage stress across the sample is increased after one hour and then every 30 minutes. The performance of the coating is measured by the time it takes for tracking or erosion to extend across half the sample length (1 inch).

4.11 Corona Test

In this non-standard test devised by EPRI the coated test samples are continuously irradiated with a strong source of both positive and negative corona. The gap between the energized electrode and the top of the coating surface is 2 mm. The test duration is 1000 h.

4.12 Tracking and Erosion Test

The 1000-hour salt fog test specified by ANSI and IEC is a continuous stress test. Insulators energized to a USCD of 34.6 mm/kV and subjected to a standard salt fog of between 1 to 5 kg/m3 for 1000 hours. The salinity is adjusted to avoid flashovers and to increase the erosion stress. This test is performed to IEC standard 62217.

4.13 Scratch Test

The susceptibility of the coating to scratching, marring and similar physical damage due to handling is evaluated with the Taber Multi-Finger Scratch/Mar Tester according to ASTM D5178.

The test specimen is secured to a pneumatically driven platform underneath five independent spline-shaft fingers, each loaded with a different weight. The interchangeable scratch tips exert a constant, vertical load on the coating while the platform moves to produce scratches of varying depths in the coating surface.

4.14 Abrasion Test

The abrasion resistance of the coating is tested using the Taber Rotary Abraser. During this test, which is described in ASTM D4060, the coated test specimen is mounted onto a rotating turntable, and then subjected to the rub-wear action of two abrasive wheels. Driven by the test sample, the wheels produce abrasion marks that form an abrasion pattern in the shape a circular path. The number of turntable revolutions required to completely remove the coating is noted as the test result.

4.15 Impact Test

The impact resistance of the coatings is tested by the drop test performed on a universal impact tester according to ASTM D2794. During this test a standard weight is dropped onto the test sample. In the standardized test the point at which failure usually occurs can be determined by gradually increasing the distance the weight drops, generally 1 inch (25 mm) at a time. For the tests on the glass substrate the test comprised one drop test from a height of 4 inches above the coating. The coating was visually inspected for damage after the test.

4.16 Gravelometer

The resistance of the coating to chipping caused by impact of gravel and other debris is tested with the Gravelometer as per ASTM D3170. The coated test specimen is mounted in the back of the Gravelometer, and air pressure is used to project 1 pint of gravel at the sample. After the test object is removed and gently wiped with a clean cloth. Adhesive tape is then applied to the entire tested surface and removed to remove any loose fragments of the coating. The appearance of the tested sample is then evaluated against reference pictures to determine the chipping ratings.

5 CONCLUSION

Through testing, it can be seen that advanced coatings have the potential to provide benefits to the electric power industry. While the coatings are in use in some applications, high-voltage environments present unique challenges. The testing described here is proving critical in qualifying the coatings for field use in utility environments.

REFERENCES

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