Corona Rings: Are They Needed?

Modeling predicts corona levels based on configuration, hardware and line voltage.

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Since 2006, some utilities have been experiencing an increased number of polymer insulator failures on their 115-kv and 138-kv transmission lines. Investigations have shown these failures can be attributed to high electric fields (E-fields) occurring close to, or on the high-voltage end fittings of, these insulators. The findings of the investigations suggest that, contrary to conventional wisdom, it might be necessary to consider the application of corona protection on polymer insulators applied below 161 kV.

A 2008 report by the Electric Power Research Institute (EPRI) was conclusive in its findings that there is an issue with polymer insulator degradation on 115-kv and 138-kv lines on certain configurations and specific insulator designs. The polymer insulator failures have raised concerns about the health of the remaining insulators in service, and the EPRI report highlighted the need for utilities to determine appropriate actions they can take to extend the life of their remaining units. Transmission line reliability can be affected if utilities do not have measures in place to minimize the effect of corona discharges on the rubber material and end-fitting seals.

Having seen increased evidence of polymer insulator failures attributed to electrical discharge, a team at Public Service Electric and Gas Co. (PSE&G; Newark, New Jersey, U.S.), a subsidiary of Public Service Enterprise Group, thought it prudent to investigate electrical discharge activity on its recently re-conducted and re-insulated 138-kv lines. The results of the investigation, using a DayCor camera, confirmed there was corona activity. Over at Public Service Company of New Mexico (PNM; Albuquerque, New Mexico, U.S.), the electric utility experienced some of its first failures caused by corona discharges at 115 kV.

Failure Mechanism

High E-fields cause increased corona activity, which in turn causes polymer insulator failure. In dry conditions, high E-fields cause continuous corona activity on the metallic end fittings and nearby insulator surface. This erodes the insulator housing and degrades the end-fitting seal. Over time, this may expose the fiberglass rod to the environment, initiating a failure mode such as a brittle fracture, destruction of the rod by partial-discharge activity or an internal flashover (flashover).

It is also possible for non-uniform wetting of the polymer rubber material to enhance any high E-fields and thus corona activity on the insulator surface. The wetting may be in the form of discrete droplets or water patches, depending on the surface properties of the rubber and whether the wetting is fog, mist or rain. This wetting enhances the local E-field, resulting in increased corona discharge activity, which occurs on most transmission insulators and is acceptable in limited conditions.

Images of the fracture surfaces and one of the failed insulators in situ.
amounts. It is the unanticipated high levels of surface E-field magnitudes and the resultant corona activity that may result in accelerated aging and reduced life expectancy of insulators.

**Investigating Failures**

A research team examined five insulator failures at three different utilities that were recorded between June 2006 and August 2007 on 115-kV and 138-kV lines. All insulators failed mechanically because of stress corrosion cracking (brittle fracture). All failures were on the same insulator design and on units manufactured between 1993 and 1999.

The failure investigations showed all failures could directly be attributed to continuous discharge activity from the end fitting under dry conditions. This corona cracked the rubber sheath and degraded the end-fitting seal, allowing moisture to come into contact with the rod, leading to a brittle fracture of the rod.

**Problem-Solving Approach**

As a consequence of these polymer insulator failures, utilities have been forced to reexamine the use, or lack of use, of corona rings on 115-kV and 138-kV polymer insulators. For instance, PSE&G has more than 5000 polymer insulators in its network, with a majority of them at the 138-kV voltage level. These insulators represent 20% of its entire insulator population. PNM operates 1100 miles (1770 km) of 115-kV line, representing 7000 structures, of which 12% are equipped with polymer insulators. Utilities, in cooperation with EPRI, have initiated a number of specific activities to assess the risk of 115-kV and 138-kV polymer insulators aging prematurely due to high electric fields and determine what actions to take. These activities included the following:

- **Conducting daylight discharge inspections.** These are used to determine how many units in service are being aged prematurely by continuous dry corona activity.
- **Performing E-field calculations.** These are used to determine...
what designs have a high risk of corona activity and whether corona rings are needed.

- Conducting detailed examinations of insulators taken from service. These are used to determine the loss of life and risk posed by units that have been in service for multiple years without corona rings installed.

Daylight Discharge Inspections

Through the research collaboration, several discharge inspections were conducted on 115-kV and 138-kV transmission lines to determine whether continuous discharge activity was occurring from the end fittings under dry conditions. These inspections were primarily directed toward one particular insulator design, but there were also opportunities to inspect a limited number of other insulator designs. The discharge inspections showed the following:

- All of the 115-kV and 138-kV transmission lines inspected had continuous dry corona activity from some of the insulators energized metal end fittings.
- All types of the configurations inspected had corona activity. These included suspension, braced-post and deadend designs.
- On average, 20% of the insulators inspected had corona from the end fittings.
- Deadend units had a higher level of corona activity.
- The level of discharges observed was relatively low but continuous.
- Corona was observed on four different designs of insulators.

E-field Modeling Results

EPRI performed extensive 3-D E-field modeling for four utilities at both 115 kV and 138 kV to address the issue. About 200 individual cases were considered, covering typical configurations and four insulator designs. The aim of these calculations was to determine the following:

- The E-field distribution on the insulator end fittings and on the rubber surfaces
- The E-field distributions of different insulator designs
- The extent to which the inclusion of "hot-line links" influences the E-field magnitude (these links are also called "dog bones")
- Whether corona rings are needed and the required ring size.

The results of the E-field modeling showed that deadend insulators have higher E-field magnitudes than suspension insulators. In particular, single deadend insulators have higher E-field magnitudes than double deadend insulators. Also, the addition of a hot-line link results in a slightly, approximately 3%, higher E-field magnitude on the insulator.

It was noted that there is a significant difference in the E-field levels between different insulator designs. Small and slender end fittings tend to have higher E-fields in the region of the end-fitting seal. The shape of the end fitting dictates where the highest field occurs and, accordingly, whether or not the dry corona, if present, will be in contact with the housing material.

The E-field magnitudes exceed EPRI's recommended...
limits on all designs of 115-kV and 138-kV polymer insulators when installed without corona rings. However, in most cases, the addition of 8-inch (203-mm) corona rings at the live end of the insulator is sufficient to reduce the E-field magnitudes to an acceptable level.

Finally, E-field limits need to be adjusted downward for insulators installed at high altitude (i.e., above 3300 ft [1006 m]). The E-field modeling results together with the daytime discharge inspections confirmed that the failures and observed degradation on 115-kV and 138-kV insulators can be attributed to high E-field levels.

**Insulators Removed from Service**

There were 200 115-kV and 138-kV insulators removed from service for evaluation, of which 74 were subjected to a detailed examination comprised of a visual inspection, hydrophobicity measurement, dye penetration test, dissection and, in some cases, mechanical testing. The remaining units were evaluated only by performing a visual inspection.

In all cases, it was found that the most severe degradation was observed in the same areas where dry corona activity was seen during the daylight discharge inspections. On some units, it was found that the degradation of the sheath and end-fitting seal progressed so far that the rod was exposed to the environment. These latter units are considered high-risk units; failure is considered inevitable.

Mechanical tests were also performed on the majority of units. It was found that the units still retained their mechanical strength. Therefore, the degradation had not progressed so far as to affect their mechanical strength.

The evaluation of the units removed from service showed these findings:

- The degradation observed could be directly attributed to dry corona activity or wetting discharge activity.
- Varying levels of degradation were observed on more than 80% of the units evaluated.
- Degradation varied from initial degradation to severe damage that would result in a high risk of failure of the unit.
- The older the units, the more significant the degradation.
- Severe damage was only observed on units that had been installed more than seven years, with units exceeding 12 years in service having the most significant damage.

**Information into Action**

Based on the approach taken, four recommendations were developed. First, for the insulator designs and configurations evaluated, it was determined that corona rings were needed. Second, before installing a new design, 3-D E-field modeling or full-scale three-phase testing is necessary to determine whether corona rings are needed. Third, units in service need to be retrofitted with a corona ring or replacement units need to be installed with corona rings. And finally, other transmission lines with 115-kV and 138-kV insulators without corona
These examples of 3-D E-field models show a double-circuit structure (left) and an insulator modeled with a corona ring in place (right).

rings need to be evaluated using both discharge inspections and E-field modeling to determine whether accelerated aging is occurring.

As soon as the presence of electrical discharge was verified with the daytime corona camera, EPRI worked closely with PSE&G engineers to develop an approach to assess the level of risk for the installed population of insulators. It also helped formulate a suitable remediation plan and instruct the PSE&G workforce on the condition assessment of field units, which included a customized field guide and training video.

The results from this project allowed the PSE&G re-conductoring project to continue, prevented a greater population of polymer insulators from being installed without corona rings, avoided the need to replace a significant number of in-service polymer insulators and established an approach for future assessments. One negative consequence from a business perspective was the additional time and cost incurred to revisit each structure in order to address the issue.

PNM has replaced all deadend insulators on the 14-mile (23-km) 115-kV transmission line on which the failures occurred. All of its other 115-kV lines have been inspected with daytime corona cameras and units with corona activity were addressed. For new designs, PNM is specifying corona rings for certain applications, including braced-post designs.

**EPIC Software**

To address the application of corona rings on transmission line composite insulators, the Electric Power Research Institute (EPRI) has developed 3-D electric field (E-field) modeling software for use by utilities and manufacturers. The EPRI Polymer Insulator Computation (EPIC) software has been specially designed for composite insulators and calculates the E-field distribution, comparing the results against EPRI or custom threshold levels. This helps the user determine whether a corona ring is necessary or is of the correct dimensions. In order to minimize the effort and expertise required to use the software, it has been designed using a database where structures, conductors, line hardware and insulators are selected from manufacturer or standard databases. It has a graphical interface to make selections easy.

The EPIC software currently models suspension, angle and deadend structures. Post and braced-post configurations are being incorporated into the system in 2010 with initial work on hardware rings for porcelain and glass insulators. The software has been designed with several unique features that users will recognize in functionality and capability:

- Enables utilities to make informed decisions on the application of corona rings
- Enables use by non-experts in CAD and electromagnetic field modeling
- Reduces model creation time due to the use of industry standard databases
- Significantly reduces the time needed to determine 3-D E-field distribution, enabling the evaluation of different scenarios
- Enables a standard modeling approach using data from different manufacturers and utilities
- Allows member utilities to review and adjust models provided by participating manufacturers as part of a procurement process.

The EPIC software was developed by EPRI with the aid of 32 participating utilities and four insulator manufacturers.

**Early Detection**

Deterioration due to corona discharge activity takes time to develop. Condition assessments made on an existing in-service population of polymer insulators are a vital element for utilities to assess the degree of deterioration and their individual levels of risk.

At PSE&G, research findings have underscored the need to ensure polymer insulators at all transmission voltage levels are free of dry weather corona by evaluating the E-fields in the design and procurement process. Having a tool like the EPIC software package allows utilities to assess E-field levels in the design phase. Since many, if not most, of the major polymer manufacturers have supported the development of the EPIC software program, they can also run the analysis for the utility either before or during the insulator procurement process. EPRI criteria for electric field levels on polymer end fittings will be incorporated into polymer specifications.

This also points out the need for utilities to provide polymer manufacturers with specific structure information so they can better assess the need
for corona rings. Findings also support the value of performing as-build benchmarking after any line construction project with a DayCor camera to ensure the line and associated hardware are corona free. Detecting problems early enough enables a less costly intervention and avoids a potential failure of the polymer string.

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Companies mentioned in this article:
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- EPRI www.epri.com
- PNM www.pnm.com
- PSE&G www.pseg.com