Diagnostics for Nonceramic Insulators in Harsh Environments

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Diagnostics for Nonceramic Insulators in Harsh Environments

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One of the main reasons for using nonceramic insulators in polluted regions is the reduction of maintenance needed to keep a line in service. Because the useful lifetime of these insulators depends largely on the pollution conditions, it is advisable to inspect the insulators on a regular cycle. The article discusses several diagnostic techniques that can be applied to detect risky conditions before failure.

Introduction: Insulator pollution is one of the main problems with insulators on transmission lines and in substations. Utilities annually budget and allocate considerable resources for preventive and corrective maintenance to minimize system interruptions. Several methods are being used to predict the operative conditions of the insulation, such as the detection of visual corona on insulators, measurements of the equivalent salt deposit density (ESDD), and nonsoluble deposit density (NSDD), and measurement of the electric field along insulators [1]–[4]. In Mexico, because of weak regulations, the pollution level has increased in recent years and the placement of heavy industries close to the overhead power system is a further cause of pollution. The use of nonceramic insulators is preferred by most of the utilities in Mexico; however, manufacturers do not recommend preventive maintenance. Nevertheless, in highly polluted areas utilities must perform preventative maintenance, otherwise system outages will occur. Some nonceramic insulators are being used in highly polluted areas but tracking and erosion on these insulators has limited their use in these regions. Sometimes with a better selection in the characteristics of the insulation, the problem can be successfully overcome; however, there is a risk of insulation over-dimensioning. This reselection is achieved with more leakage or arcing distance, redesigning the profile, and with the use of different matrix insulating material such as silicone rubber. Although nonceramic insulators have better performance than traditional insulators under polluted conditions, their expected life span, and their long term reliability, are still unknown. Nonceramic insulators have been installed since 1995 on transmission lines located in polluted regions along the coast of the Pacific Ocean in the state of Michoacán, México. In addition to marine pollution, this area is home to steel and fertilizer industries. Pollutants from these industries are dispersed to the transmission lines that supply power to them. In these areas, visual inspections of these insulators have been performed periodically during the night for signs of surface discharges. As the determination of the operative condition is difficult to establish based on the presence or absence of surface discharges on the insulators, leakage current monitoring was implemented on two towers. Although the insulators performed well for two years, in 1998, the sensors detected leakage current peak values between 350 to 450 mA on various insulators. These insulators were examined and it was determined that they displayed critical degradation along their surface, consisting of tracking and erosion. The degraded nonceramic insulators were replaced by new ones because they represented a risk of failure of the power line. The newly installed insulators were redesigned by the manufacturer with more weathersheds and leakage distance added. Currently, these insulators continue to operate on the transmission line. Since 2003, visual corona and electric field measurements were added as diagnostics of the insulators in service to identify insulators at risk. Also, ESDD, NSDD, and leakage current measurements continue to be used as diagnostics and this article presents the results of these evaluations.

Table 1. Characteristics of Nonceramic Insulators Installed.

<table>
<thead>
<tr>
<th>Insulator</th>
<th>Housing material</th>
<th>Sheds</th>
<th>Unified specific creepage distance (mm/kVp-p)</th>
<th>Arcing distance (mm)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCI-1</td>
<td>SIR</td>
<td>63</td>
<td>40.0</td>
<td>2234</td>
<td>2591</td>
</tr>
<tr>
<td>NCI-2</td>
<td>SIR</td>
<td>48</td>
<td>28.5</td>
<td>2240</td>
<td>2591</td>
</tr>
<tr>
<td>NCI-3</td>
<td>EPDM/SiR</td>
<td>60</td>
<td>35.8</td>
<td>2310</td>
<td>2591</td>
</tr>
</tbody>
</table>
Pollution Level and Leakage Current

The insulators installed on a 230-kV line in polluted regions along the coast in the state of Michoacán are characterized by the data in Table 1. The line operates at a maximum of 245 kV phase-to-phase and this voltage is used for calculating the unified specific creepage distance (mm/kVp-p) as per IEC 60815 [5]. The housing materials SiR and EPDM/SiR corresponds to silicone and a blend of EPDM and silicone rubbers, respectively. Insulators on two structures in the region of highest pollution level were monitored for leakage current, using custom made monitors installed on the ground side of the insulators [6], in which the number and magnitude of leakage current peaks are logged. After only one year, insulator NCI-1 had ESDD values between 0.91 to 1.82 mg/cm² and a NSDD of 2.56 to 8.05 mg/cm². The ESDD measurements that were done 2 years after the initial installation of the insulators showed pollution levels from 0.45 to 0.55 mg/cm². Correspondingly, the magnitude of the leakage current increased with increasing ESDD level as shown in Figure 1. After 8 years, the pollution level actually decreased to 0.1 mg/cm², which was attributed to reduced production levels from the nearby industries. Salt-fog tests at 14 and 112 kg/m³ and clean fog tests were done on insulators removed after 8, 18, 25, 36 and 45 months of service. These results are shown in Figure 2. From the measurements of ESDD, it was verified that the flashover voltage was lower when the ESDD and the corresponding leakage current measurements were lower.

Corona Inspection

The first corona inspection, which was carried out in 2003, using a DayCor II corona camera [7], showed no corona on any of the transmission line insulators. However, the inspection during 2004 showed corona around the high voltage end. During the inspection of 2004, corona activity was observed around the high voltage end of type NC-2 and NCI-3 insulators as shown in Figure 3. No corona was evident on type NC-1 insulators. In 2006, the inspection identified corona activity on the same insulators, as shown in Figure 4. In addition, corona was detected near the energized side on 12 other insulators, and on at the grounded end on another insulator. These observations could be attributed to either the position or absence of corona rings while in most of the cases, corrosion of the hardware caused displacement of the grading ring. Because damage to the insulator housing is a distinct possibility over the long term, grading rings were either added or replaced.

Figure 1. Leakage current measured on two towers in the most severe area along the 230-kV line.

Figure 2. Flashover of insulators removed from the line after 8, 18, 25, 36 and 45 months and tested in the laboratory using the salt-fog and clean-fog tests.
In-Service Electric Field Measurements

Porcelain material and component manufacturing imperfections including voids can lead to the formation and growth of micro-cracks in the porcelain. Thermal cycling and differential thermal expansion between materials and the applied electrical and mechanical stress grow these cracks, which may develop into carbonised conducting channels between the metal pin and cap. This produces a lower insulation resistance and increased dielectric losses and heating in this disc. Electrical stress is highest near the conductor so it is common for the insulator closest to the conductor to be in a degraded condition. However, degradation also depends strongly on manufacturing imperfections that tend to create stress concentration points, therefore random failures can occur at any position in the string. The composite insulator tester developed by Hydro-Québec [8] was used to measure the field distribution along the insulator - Table 1. Characteristics of Nonceramic Insulators Installed. Insulator Housing material Sheds Unified specific creepage distance (mm/kV p-p) Arcing distance (mm) Length (mm) NCI-1 SiR 63 40.0 2234 2591 NCI-2 SiR 48 28.5 2240 2591 NCI-3 EPDM/SiR 60 35.8 2310 2591 Figure 1. Leakage current measured on two towers in the most severe area along the 230-kV line. Figure 2. Flashover of insulators removed from the line after 8, 18, 25, 36 and 45 months and tested in the laboratory using the salt-fog and clean-fog tests. Authorized licensed use limited to: University of Waterloo. Downloaded on November 22, 2009 at 22:54 from IEEE Xplore. Restrictions apply. 30 IEEE Electrical Insulation Magazine tors. The field probe of this tester is mounted on a carriage which must be slid manually along the insulator by a lineman on the tower. The measured data are stored in the memory of the tester which is later transferred to a computer and according to the shape of the curve it may be determined if the insulator is damaged, because damage is assumed to affect the electric field. An example of electric field measurement is shown in Figure 5.
Insulators Removed for Visual Inspection

In 2003, one of insulators, NCI-2 of phase C, was removed from the transmission line for a close-up inspection of the housing. The selection was based on the time in service of about 8 years, and because it had the highest variation in the electric field measurement. The insulator showed slight erosion on the surface, of about 15 mm in length and 1 mm in depth, and in different regions along the surface, as shown in Figure 6. As the risk of failure was considered to be low, the insulator was put back into service on the same structure. In 2004 the electrical field measurements, Figure 5, showed an increased variation near the tower end of the insulator. The same insulator, NCI-2 of phase C, was removed for close-up inspection. The inspection revealed that the major erosion observed a year earlier had increased from 15 to 20 mm in length and from 1.0 to 1.5 mm in depth. Once again, it was judged that the degradation did not represent a high risk of failure and so the insulator was reinstalled on the same structure. However in 2006, the electric field distributions presented major changes along the entire length.
length of the insulator, when compared to the previously measured field distribution, and as evident for insulator NCI-3 in Figure 5. Three insulators, NCI-2 on phase C and NCI-3 on phase C1 and C2, were removed and showed severe degradation as shown in Figure 7. Insulators NCI-3 on phases C3 and C2 had been in service for 6 years, with degradation exposing the fiberglass rod. Because this condition could quickly lead to a catastrophic failure, these insulators were changed out for new units. Insulator NCI-2 on phase C, with 10 years of service, showed very deep erosion on its sheath near to the energized end of the insulator. As the depth of the erosion was about 2 mm, and approaching the core, this insulator was also changed out with a new unit. In the same year, insulator NCI-1 on phase B was also removed from service to validate the results obtained during the previous two inspections, which indicated that its operational condition was satisfactory. The examination showed only minimal erosion along the length of the insulator and the insulator was re-installed.

Simulation of Electric Field
As a comparison to the in-service electric field measurements, the electric field distribution of the insulators was modeled using COMSOL Multiphysics, without pollution, and with a surface layer of pollutant having a conductivity of $1 \times 10^{-6}$ S/m. Figure 8 shows that the simulated normal component of the electric field on insulator NCI-2, without considering pollution and with line end corona ring, is quite low over most of the insulator, increasing slightly near to the tower end of the insulator, but increasing exponentially between the first shed and the end fitting at the line end. However, the normal component of the electric field at the line end hardware seal is only 1.8 kV/cm, which is considerably lower than the 4.5 kV/cm maximum electric field for non-ceramic insulators that has been suggested in an IEEE Committee paper by Phillips et al. [9]. Pollution is simulated by including a uniform and continuous layer of conductivity of $1 \times 10^{-6}$ S/m over the surface of the insulator. This simulation, shown in Figure 9, indicates that the normal component of the electric field follows the simulated result without pollution; the maximum electric field is somewhat higher at 3.9 kV/cm, but is still lower than the suggested maximum. However, with this electric field strength, slight degradation can take place on the insulator surface. This simulated electric field value suggests that as the pollution conductivity increases, the degradation will also increase.

Conclusions
Based on periodic inspections that were made in this project, degradation of nonceramic insulators may be detected using a combination of techniques such as measurement of ESDD and leakage current, corona observations, and measurement of the electric field. Corona was evident on insulators that either did not have a corona ring or had a ring that was not in the correct position, and in this project, corona became evident on corona rings that had shifted because of corrosion of the mounting hardware. In addition, it is possible to establish degradation of an insulator by measurement of the electric field. Simulation of the electric field on the insulators that were used in this project suggests that the current suggested maximum electric field on insulators, 4.5 kV/cm, may still be too high; however, it is still too early to say definitively that this level should be lower. The results of this project indicate that the useful life of nonceramic insulators installed
in polluted regions depends largely on the actual conditions of pollution. From earlier experience on this transmission line, some insulators showed severe degradation in less than one year, while others have endured 4 years and still others have been operating for 10 years without any problems. One of the main reasons for using nonceramic insulators in polluted regions is the reduction of maintenance that otherwise would be necessary to keep a line in service. Because the useful lifetime of these insulators depends largely on the pollution conditions where the insulators are operating, it is advised to inspect the insulators on a regular cycle. These inspections will help detect insulators at risk of failing and help maintain the reliability of an overhead line.

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References

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