Improvement of Insulation Performance of a Porcelain Long-Rod Insulator under Contaminated Conditions

Kazuma Yamada Student Member (Chubu University)
Chiharu Saka Student Member (Chubu University)
Basanta Kumar Gautam Student Member (Chubu University)
Kenji Sakanishi Non-member (Chubu University)
Shin-ichi Sumi Member (Chubu University)
Ryosuke Matsuoka Member (Chubu University)

Keywords: porcelain long-rod insulator, silicone rubber coating, hydrophobicity, salt fog test, contamination flashover voltage

The higher contamination flashover voltage performance of a transmission line polymer insulator has been shown to be attributable largely to its configuration\(^1\). A larger ratio in the shed to core diameter of the transmission line polymer insulator brings about higher surface resistances in its individual trunks, and therefore the voltage applied to the entire insulator can be divided and allotted to these trunks, resulting in a higher flashover voltage. We had expected a similar effect by applying a silicone rubber coating having hydrophobicity only to all the trunk surfaces of a porcelain long-rod insulator. Due to the hydrophobicity, the surface resistances of these trunks could be very high, even under contaminated and wet conditions, and then the voltage applied to this insulator could be divided and allotted to the individual trunks, resulting in a higher flashover voltage. We had tested by the clean fog method and confirmed only about a 10% improvement\(^2\). In this paper, the same such effect was evaluated by the salt fog test method.

In our investigation, tests were conducted fundamentally by the standard salt fog test procedure specified in IEC Pub. 60507, except for the salt fog flow rate which was reduced to half of the specified value, taking into account the recommendation based on the correlation between the laboratory and the field test results of hydrophobic polymer insulators\(^3\)\(^4\). A vertically installed specimen insulator was energized with a test voltage and salt fog was sprayed towards it from two sides. Flashover or withstand within 60 minutes was confirmed. 50% flashover voltage was determined by the up and down method.

Flashover voltages for the porcelain long-rod insulator with silicone rubber coating on its trunks is significantly higher than those for the same insulator without coating, as shown in Fig. 1. Due to hydrophobicity, surface resistances on the trunks of the silicone rubber coated specimen are high enough for the voltage applied to the entire insulator to be divided and allotted to these individual trunks, resulting in the higher flashover voltage.

Its flashover voltage performance is even comparable to that for the transmission line polymer insulator with the same leakage distance, as shown in Fig. 1(b).

Silicone rubber coating on all the trunk surfaces of a porcelain long-rod insulator can be adopted as a very effective anti-contamination measure in the regions with rapid insulator contamination conditions like typhoons or strong seasonal sea winds.

References

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Ryosuke Matsuoka\textsuperscript{*} Member

The higher contamination flashover voltage performance of a transmission line polymer insulator has been shown to be attributable not only to its surface hydrophobicity but also to its configuration. A larger ratio in the shed to core diameter of the transmission line polymer insulator brings about higher surface resistances in its individual trunks, and therefore the voltage applied to the entire insulator can be divided and allotted to these trunks, resulting in a higher flashover voltage. We expected a similar effect by applying a silicone rubber coating having hydrophobicity only to all the trunk surfaces of a porcelain long-rod insulator. We tested by the clean fog method and confirmed only about a 10\% improvement. In this paper, the same such effect was evaluated by the salt fog test method, which confirmed a significant improvement. The detailed investigation results are presented.

\textbf{Keywords:} porcelain long-rod insulator, silicone rubber coating, hydrophobicity, salt fog test, contamination flashover voltage

1. Introduction

Investigations of the contamination flashover voltage characteristics of hydrophobic polymer insulators have found that transmission line polymer insulators have 30 \~ 50\% higher contamination flashover voltages compared with station insulators and bushing shells despite having the same housing material and the same shed configuration\textsuperscript{10}. The much better performance of transmission line polymer insulators was shown to be attributed to a large ratio, such as 4 or 5, in the shed diameter to the core diameter. Due to a large difference in the diameter, the current density in the trunks is 4 or 5 times higher than that in the shed tips, resulting in extremely high surface resistances for these trunks. Under such circumstances, the voltage applied to the entire insulator is divided and allotted to these individual trunks. A better voltage distribution along the transmission line polymer insulators results in higher contamination flashover voltages. Although porcelain long-rod insulators were developed by the same philosophy\textsuperscript{3}, the ratio of shed diameter to core diameter is usually 2 \~ 3 and then the difference in surface resistance between the shed and trunk portions is not so significant and may be masked by other factors such as difference in upper and under shed surfaces, different distribution of fog density along the insulator. So, such a superior contamination flashover voltage performance of transmission line polymer insulators has not been obtained with porcelain long-rod insulators.

Considering such a favorable mechanism for improving the contamination flashover voltage performance of the polymer insulators for transmission lines, we expected a similar effect for a porcelain long-rod insulator by applying a hydrophobic silicone rubber coating only to all the core surfaces (excluding the shed surfaces). Due to the hydrophobicity, the surface resistances of these trunks could be very high, even under contaminated and wet conditions, and then the voltage applied to the entire insulator could be divided and allotted to the individual trunks, resulting in a higher flashover voltage.

The contamination flashover voltage performance of a porcelain long-rod insulator with hydrophobic silicone rubber coating on its trunks was evaluated by the clean fog test method. The hydrophobic trunk surfaces were preconditioned in order to get a uniform contaminant layer\textsuperscript{20}. We could confirm only an approximately 10\% improvement in the contamination flashover voltage compared with the same long-rod insulator without any coating on its trunks\textsuperscript{20}. The improvement in the flashover voltage was not significant even after providing one week of rest time expecting for the transfer of hydrophobicity to the contaminated trunk surfaces.

A significant improvement of about 30\% was obtained in contamination flashover voltage when the specimen was contaminated and tested without preconditioning the silicone rubber coated trunks. Although this is not a realistic condition since continuous contaminant layer cannot be obtained on the trunk surfaces, which is quite different from the uniform contaminant deposit conditions in actual fields, this suggests that if very high surface resistances can be maintained on the silicone rubber coated trunk surfaces, a significant improvement in the contamination flashover voltage may be expected.

\textsuperscript{*} Department of Electrical Engineering, Chubu University
1200, Matsumoto-cho, Kasugai 487-8501

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The insulator contaminant deposit mechanism in regions where insulators are contaminated rapidly by typhoons, seasonal strong sea winds, and other conditions is quite different from that occurring in long-term accumulation conditions. The contamination flashover voltage performance of a long-rod porcelain insulator with silicone rubber coating on its trunks was evaluated by the salt fog test method, which simulated such rapid contamination conditions. Much greater improvement in the contamination flashover voltage may be expected by the salt fog test compared with the clean fog test since at the start of this test the preconditioning is not conducted and, therefore, the trunk surfaces are fully hydrophobic.

In this paper, we present the investigation results from the salt fog test of the contamination flashover voltage performance of a porcelain long-rod insulator with silicone rubber coating on its trunks.

2. Specimen

We prepared a porcelain long-rod insulator coated with Room Temperature Vulcanized (RTV) silicone rubber on all its trunks and the same porcelain long-rod insulator without any coating. Dimensional particulars of the specimens are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Specimen dimensional particulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Silicone Rubber Coating</td>
</tr>
<tr>
<td>Porcelain</td>
</tr>
<tr>
<td>40 mm</td>
</tr>
<tr>
<td>40 mm</td>
</tr>
<tr>
<td>Leakage Distance, mm</td>
</tr>
<tr>
<td>Core Diameter, mm</td>
</tr>
<tr>
<td>Shed Diameter, mm</td>
</tr>
</tbody>
</table>

3. Test Method

Contamination flashover voltage performances of the two specimen insulators were evaluated fundamentally by the standard salt fog test procedure specified in IEC Pub. 60507, except for the flow rate of salt fog. Flow rate was reduced to half of the specified value (500 ml/min/nozzle) as shown in Table 2, taking into account the recommendation based on the correlation between the laboratory and the field test results of hydrophobic polymer insulators. In addition, the preconditioning described in the IEC Standard for the salt fog test of conventional porcelain and glass insulators was not performed since it could destroy the hydrophobicity of the silicone rubber coating on the trunks. Only the bare porcelain surfaces of the specimens were washed thoroughly with detergent before individual tests.

The test procedure and the test arrangement are shown in Figs. 1 and 2, respectively. A specimen was installed vertically in the test chamber and energized with a test voltage. Salt fog was then directly sprayed over the specimen insulator from both sides, as shown in Fig. 2. Flashover or withstand within one hour was confirmed. The test was then repeated on another clean specimen, applying a voltage one
step lower or higher depending on the previous test results. The 50% flashover voltage was determined by the up-and-down method after obtaining 10 or more effective data.

The power source used in this investigation was stiff enough for evaluating insulator contamination flashover voltages even under heavy contamination conditions (8).

4. Test Results and Discussions

4.1 Trunk Surface Resistance

Surface resistances were measured on the individual trunks along the specimen insulators with and without silicone rubber coating after energization for 15, 30 and 60 minutes under salt fog spraying conditions. The results are shown in Fig. 3.

As expected, in the case of 15 minutes after the start of the salt fog spraying, surface resistances on the trunks of the silicone rubber coated specimen were much higher than on the specimen without coating, showing there was high hydrophobicity on the silicone rubber coated trunks. With the silicone rubber coated specimen, surface resistances decreased as the test duration increased for the salinities of both 5 and 20 g/l, possibly due to a reduction in surface hydrophobicity. By contrast on some trunks of the specimen without silicone rubber coating, increased surface resistances were observed as the test duration increased, possibly due to the formation of dry bands on these portions.

4.2 Leakage Current

Typical examples of time variation in leakage current on the two types of specimens for the cases of both withstand and flashover are shown in Table 3. Leakage current started to increase very soon after the start of salt fog spraying irrespective of the types of specimens, and pulsive currents were measured intermittently. Larger and faster growing pulses were measured on the specimen without silicone rubber coating on the trunks. In the case of withstand, for the specimen with silicone rubber coating on its trunks, leakage current continued to increase even after 60 minutes. The individual test duration in our investigation was 60 minutes, but to examine the trend of an increasing leakage current after this period and the tendency of a reduction in the trunk surface resistance (as observed in Fig. 3), it may be better to extend the test duration to longer than 60 minutes. We will conduct such an investigation in the future.

Typical discharge activity for both types of specimens is shown in Fig. 4. We observed arcs on almost all the trunk portions between the consecutive sheds on the specimen with silicone rubber coating but only on some limited portions on the specimen without coating.

4.3 Times to Flashover

Times to flashover after the start of salt fog spraying were compared between the specimens with and without silicone rubber coating on the trunks, as shown in Fig. 5. As can be seen from Fig. 5(a), times to
Table 3. Time variation in leakage current

<table>
<thead>
<tr>
<th>Salinity: 5 g/l</th>
<th>Salinity: 20 g/l</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without Silicone Rubber Coating</strong></td>
<td><strong>With Silicone Rubber Coating</strong></td>
</tr>
<tr>
<td><strong>Withstand</strong></td>
<td><strong>Flashover</strong></td>
</tr>
<tr>
<td>Applied Voltage</td>
<td>Leakage Current, mA</td>
</tr>
<tr>
<td>130 kV</td>
<td>500 min.</td>
</tr>
<tr>
<td>50 kV</td>
<td>20 min.</td>
</tr>
<tr>
<td>100 kV</td>
<td>15 min.</td>
</tr>
</tbody>
</table>

Table 4. Discharge activity

Fig. 4. Discharge activity

Flashovers of the specimen without silicone rubber coating on the trunks occurred within 10–20 minutes after the start of salt fog spraying. Under this higher salinity, salt accumulation more quickly reaches the critical value for the formation of dry bands, leading to flashover. For the specimen with silicone rubber coating on the trunks, however, times to flashover were longer than when the salinity was 5 g/l. This may be explained as follows. Due to the higher salinity, applied voltages are lower than in the case of 5 g/l salinity, and therefore flashovers are not caused by the bridging of the shed tips by arcs, but by the formation of dry bands after a critical amount of salt has accumulated on the specimen surface, combined with the reduction in hydrophobicity on the trunk surfaces.

4.4 50% Flashover Voltage

Fifty percent flashover voltages for both types of specimens are shown in Fig. 6 at both salinities. Although improvement of flashover voltage by silicone rubber coating is not significant by clean fog tests, flashover voltages for the specimen with silicone rubber coating on the trunks are significantly higher than those for the specimen without silicone rubber coating by the salt fog tests. The reason for such a small improvement by clean fog tests may be explained by the following. Although silicone oil
diffuses from the bulk of the coated silicone rubber to the surface of the contaminant layer and covers this layer, resulting in a hydrophobic trunk surface, such a thin silicone oil film on the contaminant surface may be washed away under such severe wetting conditions as heavy fog. Actually, the surface resistances on the trunks were not high enough to divide and allot the voltage applied to the entire insulator to these trunks. On the contrary to the clean fog test results, in the case of salt fog tests, surface resistances on the trunks of the specimen with silicone rubber coating are high enough for the voltage applied to the entire insulator to be divided and allotted to these individual trunks, resulting in the higher flashover voltage.

The results at the salinity of 20 g/l are also compared with the results of a transmission line polymer insulator having the same leakage distance 2170 mm at the same salinity as shown in Fig. 6(b). 50% flashover voltage of the transmission line polymer insulator and the porcelain long-rod insulator with silicone rubber coating on the trunks are comparable. It can be said that if trunk surface resistances can be maintained high, higher contamination flashover voltages can be expected even with porcelain insulators. Silicone rubber coating on all the trunk surfaces of a porcelain long-rod insulator can be adopted as a very effective anti-contamination measure in the regions where rapid insulator contamination like typhoons or strong seasonal sea winds are encountered.

5. Conclusions

A porcelain long-rod insulator was coated with silicone rubber on its all the trunk surfaces, and its contamination flashover voltage was evaluated by the salt fog test, simulating the rapid contamination conditions near sea coasts. Contamination flashover voltages were significantly higher than those for the same porcelain long-rod insulator without any coating. Due to hydrophobicity, trunk surface resistances are high enough for the voltage applied to the entire insulator to be divided and allotted to these trunks, resulting in higher flashover voltages even under severe contamination conditions.

Considering the superior contamination flashover voltage performance by salt fog tests, coating all the trunk surfaces of a porcelain long-rod insulator with silicone rubber may be a very effective anti-contamination measure in the regions with rapid contamination conditions like typhoons or strong seasonal sea winds.

Although the improvement of contamination flashover voltage of a porcelain long rod insulator by applying silicone rubber coating only to its all the trunk surfaces was only about 10% when evaluated by the clean fog tests, such an improvement may be higher in actual fields considering the significantly reduced hydrophobicity on the artificially contaminated insulator surface caused by the preconditioning and the much more improved surface hydrophobicity in actual fields. Higher hydrophobicity is usually observed on silicone rubber polymer insulator surface, even on its contaminated surface in actual fields owing to the migration of low molecular silicone. On the other hand, under severe wet or contamination conditions, hydrophobicity may be reduced or lost temporarily. So of course, it is necessary to confirm its performance in actual fields, under various wet and contamination conditions including rapid and long-term contaminant accumulation conditions.

Renewing of silicone rubber coating may be necessary for long-term application due to gradual reduction in hydrophobicity with age.

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References

Kazuma Yamada (Student Member) was born in Tokyo prefecture, Japan in 1985. He received his B.Sc. in Electrical Engineering from Chubu University, Kasugai, Aichi Prefecture, Japan in 2007. He is currently studying for his M.Sc degree in Chubu University.

Chiharu Saka (Student Member) was born in Mie prefecture, Japan in 1983. He received his B.Sc. in Electrical Engineering from Chubu University, Kasugai, Aichi Prefecture, Japan in 2006. He is currently studying for his M.Sc degree in Chubu University.

Basanta Kumar Gautam (Student Member) was born in Kathmandu, Nepal, in 1971. He received his B.Eng. in Electrical Engineering from Southern Yangtze University, Wuxi, Jiangsu Province, People's Republic of China in 1996. Since 1997, he has been with Institute of Engineering, Tribhuvan University, Nepal. In 2007, he received Ph.D. degree from Chubu University, Kasugai, Aichi prefecture, Japan. His main areas of interest are electrical performance of outdoor insulators. Mr. Gautam is a student member of the IEEE.

Kenji Sakanishi (Non-member) was born in Aichi Prefecture, Japan, in 1943. He was graduated from Gifu Technical High School, in 1962. In 1962 he joined NGK Insulators, Ltd. He was a Supervisor of NGK High Voltage Laboratory, Power Business Group. Since 2003, he has been a researcher of the Frontier Research Project at Chubu University.

Shin-ichi Sumi (Member) was born in Tokushima, Japan, in 1950. He received the B.E. and M.E. degrees in electrical engineering from Chubu Institute of Technology, Aichi, Japan, in 1972 and 1974, respectively, and the Dr.E. degree in electrical engineering from Chubu University in 1986. He has been with Department of electrical engineering, Chubu University (Chubu Institute of Technology) since 1974, where he is currently Professor. He has worked on the experiment of artificial triggered lightning with rocket in Japan. Prof. Sumi is a member of the Institute of Electrical Installation Engineers of Japan, and a member of the Society of Atmospheric Electricity of Japan.

Ryosuke Matsuoka (Member) was born in Gifu Prefecture, Japan, in 1941. He received his BS, MS and Ph.D. degrees, all in electrical engineering from Nagoya University in 1964, 1966 and 1994, respectively. He joined NGK Insulators, Ltd. in 1966. He served as the General Manager of NGK High Voltage Laboratory. He also served as the Manager of Insulator Engineering, at Locke Insulators Inc. from 1981–1986. He retired from NGK and joined the Department of Electrical Engineering of Chubu University as a full-time professor in 1998. Prof. Matsuoka is a Fellow of the IEEE and a member of CIGRE.