Investigation into alternative solutions for HVDC station post insulators

Dong Wu*  
Swedish Transmission Research Institute

Urban Åström  Bengt Almgren  Svante Söderholm  
ABB Power Systems
SE-771 80 Ludvika, Sweden

ABB Corporate Research

Abstract: In the design of HVDC stations, it is often necessary to look into possible alternative solutions for HVDC outdoor insulation which can lead to a reduction in the required insulator length and, at the same time, provide reliable pollution performance. Some laboratory investigations related to this subject are presented in this paper. Four well designed insulator shed profiles were tested. The effectiveness of booster sheds was tested under fog conditions. The insulator with its semiconducting glaze was tested in cold fog. The performances of the silicone grease and RTV coatings were compared under rain conditions.

Keywords: HVDC System, External insulation, Station insulation, Flashovers, Insulator coatings, Booster sheds, Shed profiles, Semiconducting glaze.

I. INTRODUCTION

Outdoor insulators operating under DC voltage are more susceptible to pollution problems than under AC voltage. This is because, first, more pollution may be accumulated on insulators under DC voltage, and secondly, discharges under DC voltage are more stable and ready to propagate. To achieve a reliable performance, a longer creepage distance and total insulator length are often required for HVDC insulators compared with HVAC insulators. As a result, the insulator length for application in highly polluted areas and/or for ultra-high DC voltage levels can become so long that it is impractical from the mechanical design point of view; this especially being the case for station insulators which have a relatively large diameter. It is, therefore, necessary to look into possible solutions which can lead to a reduction in the required insulator length and, at the same time, provide reliable pollution performance.

The various possible solutions could include: selecting a better insulator shed profile, installing extra parts on the insulators (e.g. booster sheds or creepage extenders), using insulators with a hydrophobic surface or applying hydrophobic coatings (e.g. silicone grease or RTV) on porcelain insulators, using insulators with a semiconducting glaze, using insulators with a smaller diameter, cleaning the insulators, moving the station to a location of a lower pollution level, building an indoor station, and reducing the numbers of the insulators needed. Each of these solutions has its merits and drawbacks. A particular solution may work well at one place but not at others. It is necessary to understand the efficacy of these solutions. In this paper, some of our studies in this direction are presented.

II. SUITABLE SHED PROFILE

For given site conditions, the criteria for ranking various insulator shed profiles are the amount of pollution they may collect and the dielectric strength they may have with this pollution level. The amount of pollution accumulated on an insulator is determined by the aerodynamic and the self-cleaning properties of the shed profile. Examination of these properties has to be made through operational experience or testing in natural pollution test stations. The dielectric strength of an insulator is determined, at a given pollution level, by the ability of the shed profile to prevent wetting of the pollution and the effectiveness of the creepage distance on the sheds. The dielectric strength of insulators with various shed profiles is often determined by laboratory tests.

The rankings for various insulators, resulting from different investigations and using different test methods, are often not the same and even contradict each other. However, it is evident that, at a given pollution level, the dielectric strength of different shed profiles can differ by 30–40% [1] [2]. Insulators with a larger shed spacing give a better performance than insulators with a smaller shed spacing. Based on this understanding, a further investigation was performed on insulators with four different shed profiles [3]. The test results are summarized in Table 1.

At this pollution level, the difference in dielectric strength between these shed profiles is less than 9%. Considering the uncertainties involved in the test method, this difference is not significant. With the same creepage distance (differing only by a few per cent), all these shed profiles have a relative large shed spacing, which makes it difficult for the discharge activity to bridge the sheds. This is probably the main reason for the small difference between them. As indicated by the test results, a well designed alternating shed profile can have the same dielectric strength as a deep-underrib shed profile. The final choice between them should be based on the site conditions.

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III. BOOSTER SHEDS

Booster sheds were initially invented to prevent flashovers caused by heavy wetting, e.g. during live-line washing [4]. The further major application is to prevent flashovers on HVDC wall bushings caused by uneven wetting. Booster sheds have now been widely used in many countries in both AC and DC stations [5][6].

The effectiveness of booster sheds during fog conditions on vertically installed DC station post insulators was also investigated through laboratory pollution tests [3]. The test results are summarized in Table 2. The improvement in withstand voltage was about 30% when 20 booster sheds were installed as shown in Fig 1.

The improvement in the withstand voltage resulting from the installation of booster sheds is significant, even for fog conditions and for vertically installed insulators. The function of a booster shed is not only as a rain shield, it also acts as a barrier to the propagation of the discharges. It may also be expected that the pollution under a booster shed cannot be wetted as much as the pollution on other parts of an insulator. These dry areas under each booster shed may provide a higher resistance to the leakage current. Apart from its well proven performance in rain, the booster shed seems to be a good solution to the flashover problem.

IV. INSULATORS WITH SEMICONDUCTING GLAZE

In the literature, information on the application of insulators with a semiconducting glaze (referred to as SG insulators in the following text) in DC systems is sparse. The principal issues concerning the application of the SG insulator are: the dielectric strength of this type of insulator under different working conditions, and, more important, their lifetime. In one laboratory study under DC voltage, the SG insulator showed superior pollution performance in comparison with conventional porcelain insulators [7]. The corrosion problem of the semiconductive glaze under DC voltage was also addressed in another study [8]. No information on the long-term performance of the SG insulators under DC voltage in actual working conditions are to be found in the literature.

Our investigation into this subject comprises a survey of the knowledge existing in literature of the performance of SG insulators, some laboratory dielectric strength tests, and aging tests on the insulators obtained from several manufacturers, as well as long-term field tests.

To investigate the pollution performance of the SG insulator under DC voltage, a test in cold fog was performed. Since the SG insulator has the ability to reduce condensation through having a higher surface temperature than that of the ambient air, it is of interest to investigate the situation when cold water may wet the pollution by direct impact (spray) on the surface, e.g. in light rain. The SG insulator tested has exactly the same shed profile and parameters as the insulator type A in Table 1. It has a relatively high glaze resistance of 100 MW/m of creepage distance at 20°C. The insulator is pre-contam-

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**Table 1. Parameters of Tested Insulators and Test Results: All the Insulators Have the Same Construction Height of 2.19 M and a Core Diameter of 0.22 M.**

<table>
<thead>
<tr>
<th>Insulator</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profile</td>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
<td><img src="image3.png" alt="Diagram" /></td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Parameters (mm)</td>
<td>S1=95</td>
<td>S2=35</td>
<td>P1=73</td>
<td>S1=130</td>
</tr>
<tr>
<td>Creepage (mm)</td>
<td>6950</td>
<td>7200</td>
<td>7300</td>
<td>6850</td>
</tr>
</tbody>
</table>

**Table 2. Test Results with Booster Sheds: Solid Layer Method with SDD=0.02 mg/cm²; The Height of the Insulator Stack is 8.8 M; The Test Procedure Used Was Three Withstands out of Four Voltage Applications**

<table>
<thead>
<tr>
<th>Test Objects</th>
<th>Number of Booster Shed</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulator Profile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type A in Table 1</td>
<td>0</td>
<td>3 withstands at -630 kV</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>3 withstands at -680 kV</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>3 withstands at -800 kV</td>
</tr>
<tr>
<td>Type B in Table 1</td>
<td>12</td>
<td>1 flashover, 3 withstands at -680 kV</td>
</tr>
</tbody>
</table>

**Fig. 1. The improvement in dielectric strength in percentage as a function of the number of booster sheds.**
inated to a high SDD level of 0.18 mg/cm² (NSDD=0.04 mg/cm²). The pollution was dry before the test started. The cold fog was generated by two salt fog ramps located on each side of the tested insulator, as shown in Fig. 2. Each salt fog ramp consists of 8 salt fog nozzles. Tap water of 16°C and 250 mS/cm conductivity was sprayed toward the SG insulator with a water flow of 15 litres/hour and a air pressure of 7 bar for each nozzle.

Fig. 2. Photo of the test set-up.

The insulator was energized by a voltage of -150 kV for one hour before the start of the spray. The test voltage was increased to -250 kV at the same moment as the spray started. As soon as the cold fog started, at -250 kV, strong discharge activities were observed. The leakage current pulses soon reached the level of 100 mA. The leakage current declined to a lower level, about 30-40 mA after about 20-30 minutes since the pollution was washed off from the insulator. In these circumstances, the SG insulator is considered as withstanding the pollution level, SDD=0.18 mg/cm². The difference in dielectric strength between the four test-objects was 250 kV for the pollution level, SDD=0.18 mg/cm², has confirmed the excellent pollution performance of SG insulators.

To carrying out a laboratory ageing test, the first question one should consider is the choice of test method. There is no established ageing test method for SG insulators. Our investigation into this subject is still in progress.

V. SILICONE GREASES AND RTV COATINGS

Various types of silicone greases and RTV coatings have been widely used as countermeasures for pollution flashover problems in AC and DC stations. They have also been used on HVDC wall bushings to prevent flashovers caused by uneven wetting. Operational experience of the silicone greases and RTV coatings in HVDC stations has been continuously followed by ABB and STRI [9]. Some laboratory tests have also been performed. In this investigation, the performance of a silicone grease and an RTV coating in rain conditions was studied through laboratory testing.

The test objects were three identical porcelain long-rod insulators with a length of 1.28 m and having flat regular sheds. One of the insulators was coated with an RTV coating. This RTV coating has been on this insulator for about two years and the insulator was kept inside the laboratory. Another insulator was newly coated with a thin layer of silicone grease. The grease was simply applied by hand with a piece of cloth. The third insulator, without any coating, was used as a reference. The hydrophobicity of the RTV coating was about HC=3-4 according to STRI’s hydrophobicity classification (HC=1: totally hydrophobic, HC=7: totally hydrophilic). This insulator was treated by cleaning and drying it in 50°C ambient air until it reached HC=1. Such treatment was applied before each test to ensure the HC=1 condition of the RTV. The insulator coated with grease had HC=1.

Three tests were performed: light rain (0.2 mm/min. for 60 min.), heavy rain (20 mm/min. for 30 min.), and rain on pre-polluted insulators (3 mm/min. for 60 min.). During the tests, the axes of the insulators were tilted several degrees from the horizontal plane (similar to the installation angle of many HVDC wall bushings). The rain ramp was located over the insulator and spray was applied vertically to the insulator. For the rain test with pollution, the dry pollution was applied by spraying on the insulators. The pollution level was SDD=0.2 mg/cm² and NSDD=1.0 mg/cm². After the application of pollution, the insulators were stored in the drying room at 50°C for 24 hours before the test. The tests were performed under positive DC voltage. The hydrophobicity of the insulators before and after each test was measured. The leakage current was measured during the tests. The test results are summarized in Table 3.

In both the light and the heavy rain test, the silicone grease coated insulator had the lowest leakage current. The RTV coating became slightly hydrophilic after the heavy rain test. In the test with pollution, the RTV totally lost its hydrophobicity and become hydrophilic, while the silicone grease kept the hydrophobic property.

VI. DISCUSSION AND CONCLUSIONS

The difference in dielectric strength between the four tested insulators in our investigation, with alternating and deep-underrib profiles, is not significant. They are all well designed shed profiles. This is not to say that selection of the insulator shed profile is not important. A poorly designed profile with close shed spacing should be avoided.

Booster sheds are effective in increasing dielectric strength in both rain and fog, for both vertically and horizontally installed insulators.

The pollution performance of the insulator with semiconducting glaze is superior in comparison with conventional porcelain insulators. It is its lifetime under DC voltage that will determine whether or not it will turn out to be a good solution for the HVDC station post insulators.

Both silicone grease and RTV coated insulators perform much better than uncoated porcelain insulators. However, the loss of hydrophobicity of RTV coated insulators in the situation of pre-pollution under rain must be considered.
TABLE 3. SUMMARY OF TEST RESULTS.

(A) Light rain (0.2 mm/min, 60 min, 150 kV)

<table>
<thead>
<tr>
<th>Test objects</th>
<th>$I_{\text{max}}$ (mA)</th>
<th>HC: before/after test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porcelain</td>
<td>0.7</td>
<td>7/7</td>
</tr>
<tr>
<td>with RTV</td>
<td>0.02</td>
<td>1/2</td>
</tr>
<tr>
<td>with grease</td>
<td>0.001</td>
<td>1/1</td>
</tr>
</tbody>
</table>

(B) Heavy rain (20 mm/min, 10 min, 300 kV)

<table>
<thead>
<tr>
<th>Test objects</th>
<th>$I_{\text{max}}$ (mA)</th>
<th>HC: before/after test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porcelain</td>
<td>flashover</td>
<td>7/7</td>
</tr>
<tr>
<td>with RTV</td>
<td>12</td>
<td>1/3</td>
</tr>
<tr>
<td>with grease</td>
<td>0.21</td>
<td>1/1</td>
</tr>
</tbody>
</table>

(C) Rain with pre-pollution (3 mm/min, SDD = 0.2 mg/m$^2$, NSDD = 1.0 mg/cm$^2$, 200 kV)

<table>
<thead>
<tr>
<th>Test objects</th>
<th>$I_{\text{max}}$ (mA)</th>
<th>HC: before/after test</th>
</tr>
</thead>
<tbody>
<tr>
<td>with RTV</td>
<td>10</td>
<td>1*/7</td>
</tr>
<tr>
<td>with grease</td>
<td>0.09</td>
<td>1*/1</td>
</tr>
</tbody>
</table>

* the measurement of HC levels on pollution layer may not be accurate

VII. REFERENCES


VIII. BIOGRAPHIES

Dong Wu was born in Beijing, China in 1952. He graduated from Xian Jiaotong University, received his M.Sc. degree from the Graduate School of EPRI of China, and gained his Ph.D. from the Royal Institute of Technology of Sweden, in 1977, 1982, and 1988 respectively, all in electrical engineering. From 1982 to 1985, and from 1988 to 1992, he worked as a Senior Research Engineer at EPRI of China. In 1992, he joined a research group as Project Leader in the Dept. of Electrical Plant Engineering at the Royal Institute of Technology in Sweden. In the period 1992 to 1997, he worked as a Project Manager at the High Voltage Research in the Swedish Transmission Research Institute (STRI). Since January 1998, he has been with ABB Power Systems, working in the Converter Valve Development department. He has worked in the field of power electronics and high-voltage engineering. He is active in CIGRE and IEC task forces for outdoor insulation.

Urban Åström was born in Njurunda, Sweden in 1946. He received his M.Sc. degree in physical engineering and B.Sc. degree in astronomy from the University of Uppsala, Sweden in 1973. In 1974 he joined ASEA AB’s HVDC department and worked with design and development of control equipment, thyristor valves and valve cooling. In 1978 he joined the transformer department and worked with design of converter transformers for HVDC. In 1986 he joined the HQ/NEH HVDC project team, being responsible for converter equipment. From 1989 to 1995 he was manager of the HVDC Project Engineering Development department, and since 1995 he has managed the Converter Valve Development department.

Bengt Almgren was born in Gävle, Sweden in 1939. He graduated at Gävle Technical College in 1961. In 1964 he joined the ASEA Central Laboratory in Västerås, working with development design and marketing of electro-hydraulic equipment. In 1972 he joined ASEA AB’s HVDC department and worked with dimensioning of new HVDC converter stations, and research, all with regard to external insulation. In 1997 he was appointed as Company Specialist in the ‘External insulation of HVDC transmissions’ area.

Svante Söderholm was born in Åbo, Finland in 1958. He received an M.Sc. in Engineering Physics in 1982 and a Ph.D. in Solid State Electron Physics in 1987 from the Royal Institute of Technology, Sweden. From 1987 to 1991 he held various positions at the Department of Materials Physics, Royal Institute of Technology, nearly two years of this period being spent at Universität Stuttgart, Germany. He was assistant professor at the Department of Materials Physics from 1991 to 1995. During this period his main research fields were high temperature superconductors and transition metal oxides. In Nov. 1995 he joined ABB Corporate Research, Department of Materials and Chemical Engineering, as a scientist. At present he mainly works with long-term properties of materials, mostly polymers, and magnetic materials.