News From Japan

Yoshimichi Ohki

Development of Gas-Insulated Polymeric Bushings for 550-kV Gas-Insulated Switchgear and Transformers

Compared with conventional porcelain bushings, polymeric ones are light and therefore possess improved seismic performance. They are also explosion proof with no scattering when broken and are highly stain resistant. In particular, the polymeric bushings coated with silicone rubber show good voltage resistance performance, even when covered with salt deposits. That is, by covering the surface with silicone rubber, the hydrophobic nature of the polymer bushing becomes excellent. This reduces the risk of the occurrence of surface arc discharges and flashovers. Therefore, as shown in Figure 1, the length of a typical polymer bushing insulated with pressurized SF6 can be reduced significantly compared with a conventional porcelain bushing insulated with oil-impregnated paper (OIP) of the same voltage class. The weight can be reduced drastically as well.

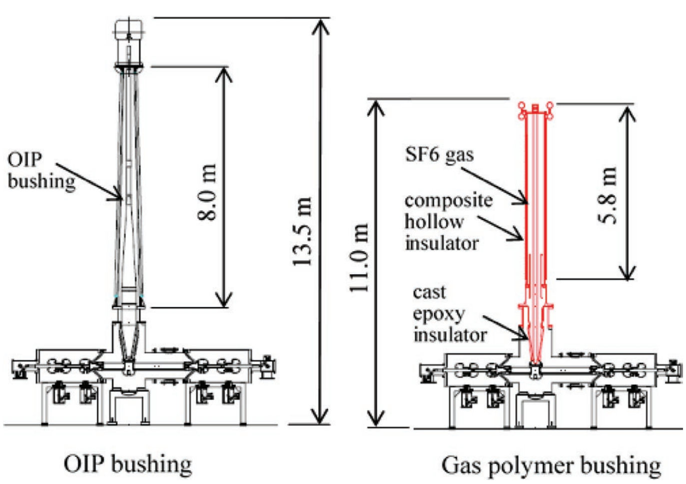

Figure 1. Comparison of structures between the conventional porcelain bushing with oil-impregnated paper (OIP) insulation and the developed polymer bushing with pressurized SF6 insulation.

Although the application of polymeric bushings was expanded in Europe and the United States from the early 1990s, the installation of polymeric bushings was delayed in Japan. Several power apparatus manufacturers in Japan were conducting field tests and evaluation of surface degradation status to develop polymer bushings jointly with electric power utility companies since the 1990s. After such research activities, Mitsubishi Electric began the sale of polymeric bushings toward 500-kV switching devices in the mid-2000s, first in domestic market. Concerning overseas markets, the company claims that it had installed more than 50,000 polymeric bushings in US gas circuit breakers from 1997 up to 2019.

Although the speed of the installation of polymeric bushings in Japan was slow at first, application rapidly expanded, especially after the 2011 Great East Japan Earthquake, due to the necessity of improving earthquake resistance and economic efficiency. Japan is a hot and humid country and has many earthquakes. To install polymer bushings widely in Japan, we needed to enact better anti-stain design standards and test methods due to the climatic conditions and environments peculiar to Japan. A related investigation committee was inaugurated in 2013 with members from universities, research institutes, power utilities, and manufacturing companies. The committee published its report in January 2017 [1]. Based on this report and other knowledge, various related industrial standards were created or revised. One of such standards, JEC-5202 "Bushings," was revised in 2019. Here, JEC is the official abbreviation of the Japanese Electrotechnical Committee, a standardization body inside the Institute of Electrical Engineers of Japan. Table 1 lists the ratings and basic specifications of the gas-insulated polymeric bushings for 550-kV gas-insulated switchgear (GIS) with the rated electric currents of 4,000 and 8,000 A, determined according to JEC-5202: 2019.

Table 1. Ratings and basic specifications of the gas-insulated polymeric bushings for 550-kV gas-insulated switchgear with the rated electric currents of 4,000 and 8,000 A

Rated voltage (kV)	550	
Rated current (A)	4,000, 8,000	
Rated short-time withstand current (kA)	50/63	
Rated gas pressure (MPa-G)	0.5 (rating), 0.45 (minimum)	
Dry lightning impulse withstand voltage (kV)	1,800	
Equivalent salt deposit density (mg/cm^2)	0.01/0.03	0.06
Anti-pollution withstand voltage (kV)	381	
Dimensions of the composite hollow insulator		
Overall length (mm)	5,035	5,800
Creepage distance (mm)	17,426	20,258

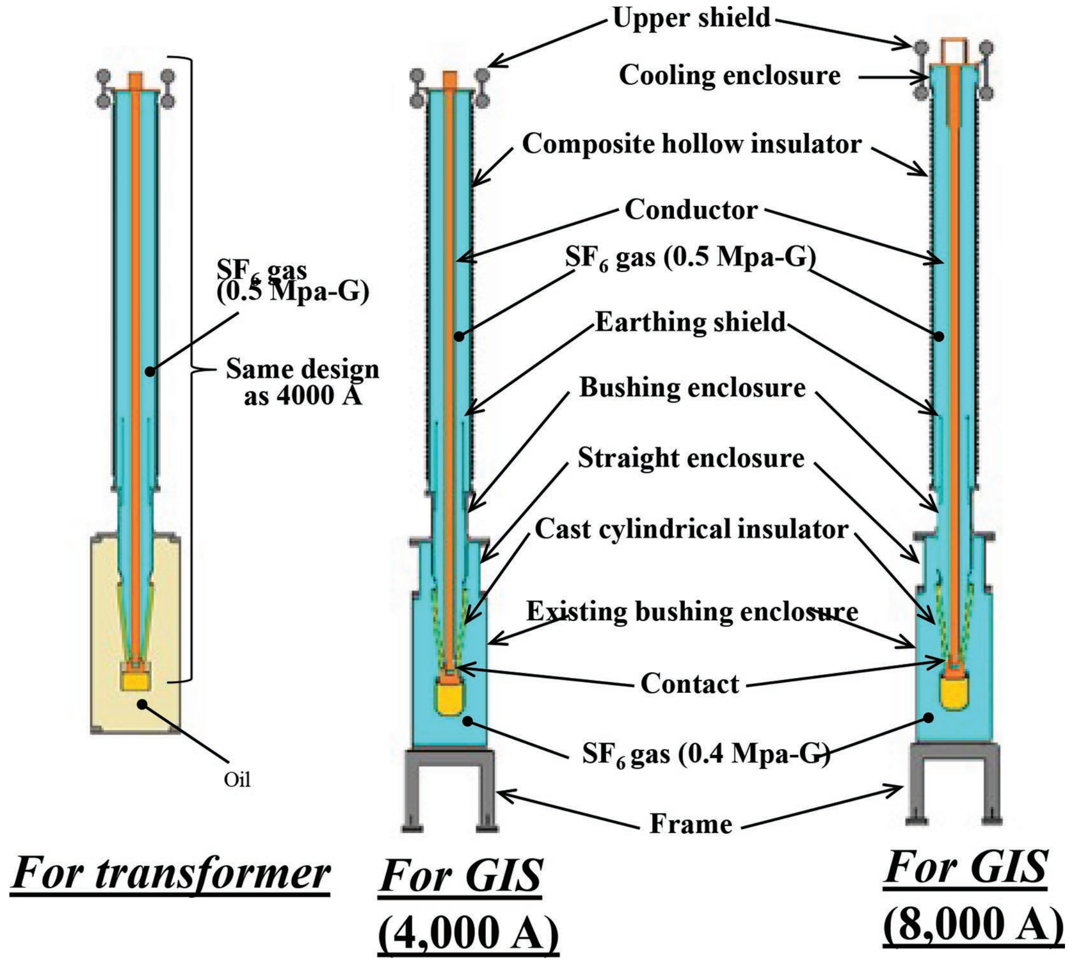

Figure 2. Comparison of cross-sectional views among two polymeric bushings for 550-kV gas-insulated switchgear (GIS) with different current ratings and the one for transformers, showing their internal structures.

Mitsubishi Electric installed many bushings insulated with OIP to transformers and GIS for many years. The OIP-insulated bushing consists of a porcelain tube, a capacitor core, and insulating oil. It is heavy and requires a long manufacturing period. It may also have problems such as the leakage of insulating oil when it ages. For this reason, the company has developed and commercialized the industry's first polymer gas bushing compatible with the OIP bushing and is expanding its installation to replace the existing aged OIP bushing [2], [3].

Although Mitsubishi Electric claims that it has developed polymeric bushings rated for 72- to 800-kV power apparatus, a brief introduction of the one for 550-kV GIS is reported in this short article. Figure 2 shows cross-sectional views and internal structures of two polymeric bushings for 550-kV GIS having different current ratings and those of a polymeric bushing for a transformer. The gas-insulated polymeric bushing has the following features and advantages:

(1) For electrical insulation, SF6 gas is used instead of oil. The new bushing has a cast cylindrical insulator made of epoxy resin, which separates the SF6 gas for the electrical insulation inside the bushing and the GIS. In transformers, the cylindrical insulator separates SF6 gas for the bushing and insulating oil for the transformer.
(2) By adopting the gas-insulated structure, the structure can be lighter and simplified. This in turn realizes higher reliability and better anti-seismic performance and reduces the risk of fire. Furthermore, these features contribute to economic benefits such decreased inspection and maintenance work. The rated SF6 gas pressure is 0.5 MPa-G, meaning that the pressure is higher than the outside ambiance by 0.5 MPa. The company has many experiences dealing with such highly pressurized SF6 gas.
(3) The whole cylindrical structure is mechanically robust and sealed. Therefore, we can conduct the transportation and on-site installation of bushings with the filled low-pressure SF6 gas inside. Future replacement with the polymeric insulator would also be done without removing the gas from GIS with a large amount of gas. Since SF6 gas can be handled with little risk of releasing it, there is a benefit from a global warming point of view.
(4) The bushing of the rated current of 8,000 A has an aluminum cooling enclosure on the top, as shown in Figure 2,

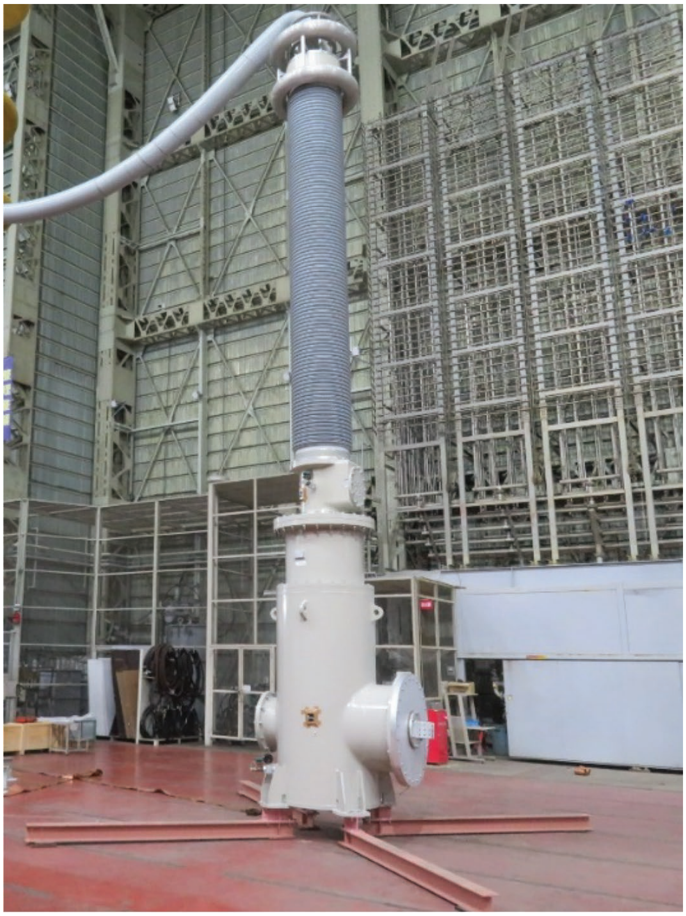

Figure 3. Equipment arrangement used for the voltage withstand tests against lightning impulse, switching impulse, and AC voltages. The respective power sources are not shown.

Figure 4. Equipment arrangement used for the temperature-increase test.

for cooling the insulator and for improving the current-passing ability.

Mitsubishi conducted various tests to verify the performance of the new bushings. Figure 3 shows a scene during a voltage withstand test. The new bushings passed the lightning impulse voltage test, the switching impulse voltage test, and the AC voltage test defined by JEC-5202.

In addition, the temperature rise of the bushing was tested while the rated current was being passed using the test arrangement shown in Figure 4. The increase in temperature was found to be below the criteria determined by JEC-5202 for both the bushings with the rated currents of 4,000 and 8,000 A.

The company also confirmed that the bushings passed the equivalent clean fog test determined according to JEC-5202. In this test, voltages are applied repeatedly until we measure at least 10 flashover voltages. The 5% flashover voltage of the new bushing was found to be higher than the target voltage of 381 kV, which is 1.2 times the normal phase-to-earth voltage. Note that this criterion required by JEC-5202 is more severe than the corresponding IEC standard [4], which employs the normal phase-to-earth voltage as its target [5]. Figure 5 is a

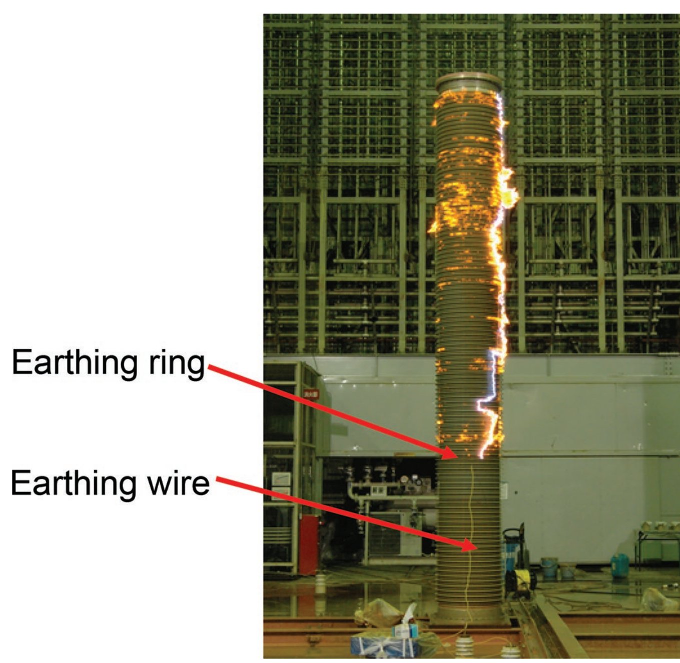

Figure 5. Surface flashover during an equivalent clean fog test.

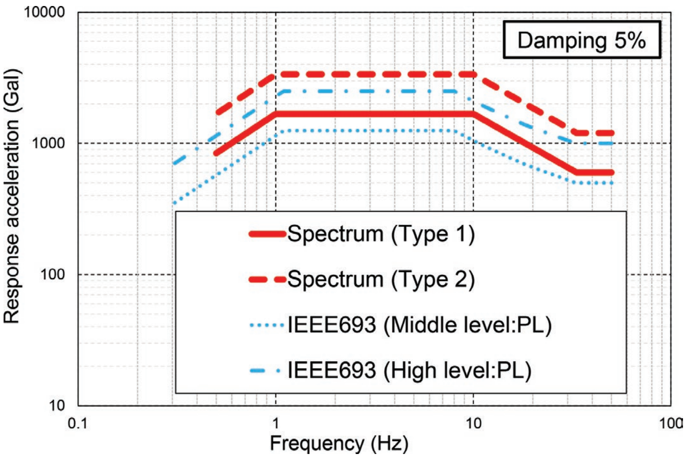

Figure 6. Comparison of the response acceleration spectra for a simulated earthquake between IEEE 693 and JEAG 5003.

photo of an example of the flashovers that occurred during the test.

Because Japan is a country with many earthquakes, the response of the bushing during an earthquake is critical. Regarding this, a Japanese standard, Seismic Design Guideline JEAG 5003 (2019), was recently revised by the Japanese Electric Association that reflects the knowledge and information of the 2011 Great East Japan Earthquake. All the stresses calculated for the new bushing under the maximum seismic force designated by JEAG 5003 are lower than the durable level. Therefore, the bushing can withstand the massive earthquakes designated by JEAG 5003. Note that the response accelerations designed in JEAG 5003 are about 1.3 times those of IEEE 693, as shown in Figure 6 [6], which compares the response acceleration spectra determined in IEEE 693 and JEAG 5003. The maximum seismic force of the spectrum Type 2 designed by JEAG 5003 is also greater than the "high level" designed by IEEE 693 [6].

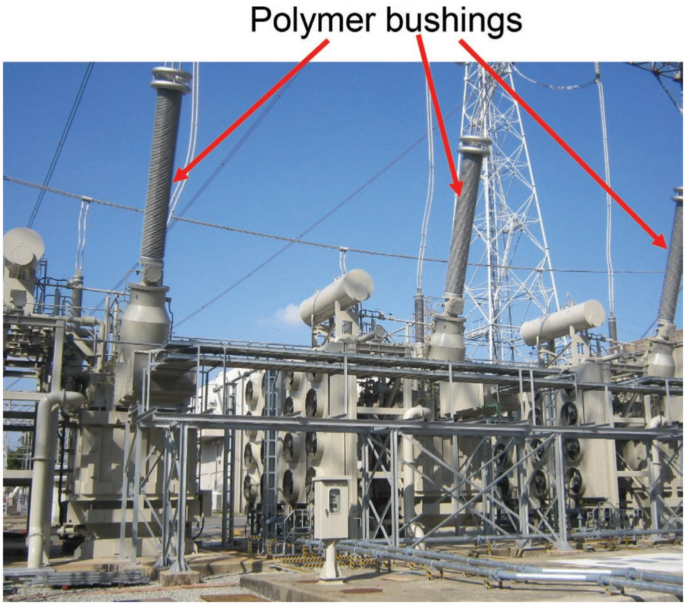

Figure 7. Photo of the polymer bushings retrofitted to a three-phase 500-kV transformer in the Shigi Substation of Kansai Transmission and Distribution.

The developed polymer bushings are retrofittable to existing GIS and transformers. Figures 7 and 8 are photos of the polymer bushings retrofitted to a three-phase 500-kV transformer and 550-kV GIS in the Shigi Substation and the Kinokawa Substation of Kansai Transmission and Distribution, respectively.

Mitsubishi expects utilities to replace of aged porcelain OIP bushings with the developed polymer bushings. More information on the bushings can be found in the literature [7].

This article was completed in cooperation with Kenji Sasamori of Mitsubishi Electric Corporation.

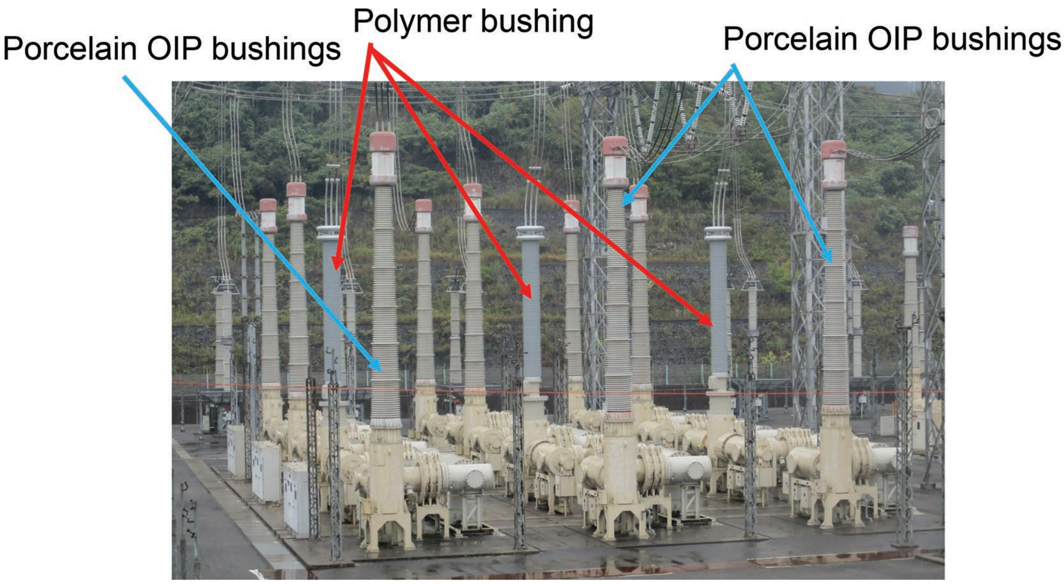

Figure 8. Photo of the polymer bushing retrofitted to 550-kV gas-insulated switchgear in the Kinokawa Substation of Kansai Transmission and Distribution. OIP = oil-impregnated paper.

References

[1] *Standardization of Design and Testing Method of Hollow Polymer Insulators*, Electric Technology Research Association, No.72-4, 2017.

[2] T. Kobayashi, H. Kagawa, M. Ueda, K. Konishi, H. Kajino, K. Sasamori, O. Kisanuki, and Y. Nakashima, “Development and application of polymeric gas bushing for transformer to improve the reliability, seismic performance and maintainability,” presented at the CIGRE SC A2 Colloquium, Cracow, Oct. 2017.

[3] S. Tsukao, A. Tagei, S. Iwasaki, M. Nakai, M. Katsumata, T. Goto, K. Ito, and K. Sasamori, “Application of polymeric gas bushing for transformer to improve the reliability, safety and maintainability in substation,” presented at the CIGRE-IEC Conference on UHV and EHV (AC & DC), Hakodate, Hokkaido, Japan, Apr. 23–26, 2019.

[4] *Selection and Dimensioning of High-Voltage Insulators Intended for Use in Polluted Conditions—Part 1: Definitions, Information and General Principles*, IEC TS 60815-1:2008.

[5] *Insulated Bushings for Alternating Voltages Above 1000 V*, IEC 60137:2017.

[6] *Seismic Design Optimization of Transformation Equipment*, Electric Technology Research Association, No.74-2, 2018.

[7] K. Taketa, Y. Hashiba, M. Miyamoto, K. Ito, Y. Tsukao, and K. Sasamori, “Renovation of the bushing for 550 kV GIS to improve reliability and maintainability of substation,” presented at the CIGRE International Symposium, Ljubljana, Nov. 2021.