New 550-kV Gas-insulated Switchgear

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OVERVIEW: Hitachi has developed smaller and more reliable gas-insulated switchgear (GIS) in response to demands for lower costs and stable power supplies. Reliability of this GIS was improved and the enclosure diameter was reduced in order to minimize the installation space by using new analysis techniques and rationalization in insulation design and in temperature rise criteria. Furthermore, the use of vertical, single-break circuit breakers and a three-phase common GIB (gas-insulated bus) reduced the substation area to 46% of its original size. A reliability test for the GIS was conducted in consideration of the service condition. The test included a limit-performance check test, a type test under hard operating conditions, a temperature-rise test at the site and factory, as well as other tests. The reliability of the GIS was improved by applying new structural design and manufacturing technologies. For example, high-precision parts and a GIS-specific assembling device were used. Large all-weather assembly houses were also used at the site and the assembly process was improved.

INTRODUCTION

THE first generation of gas-insulated switchgear (GIS) that Hitachi developed was 550 kV. Developed in 1978, this GIS used 4-break circuit breakers and all of its phases were of the separated-phase type. Later, circuit breakers were changed to the 2-break type.

In 1989, the LIWV (lightning impulse withstand voltage) was lowered by using a high-performance metal oxide surge arrester, which lowers residual voltage. As a result, a large-radius, 3-phase common spacer was developed and a 3-phase common enclosure was incorporated into a more compact main bus. This was the second generation of GIS. The third-generation GIS was further reduced in size; The tank was reduced to less than 85% of its original size and the installation area was reduced to 46% of its original size. Reliability of the GIS was proven by checking both limit and practical performances. The third-generation GIS, featuring the latest technology, is currently in operation at the Higashi-Gunma

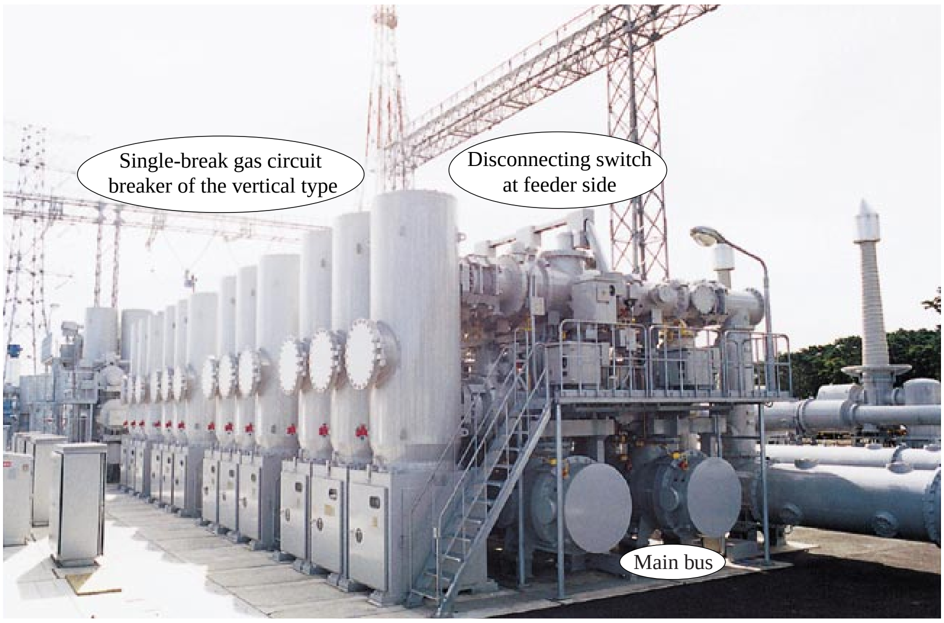


Fig. 1—Installation and Tests of the New 550-kV GIS (TEPCO's Higashi-Gunma Substation) Were Finished.
The new 550-kV uses a single-break gas circuit breaker, and the main bus is attached to the lower part and components located at the feeder side are attached to the upper part of the GIS.

Substation of the Tokyo Electric Power Co. (TEPCO) (Fig. 1).

SIZE REDUCTION

Design Rationalization by Reviewing Specifications

The specifications and structure of transmission line circuits in the new 550-kV GIS[1] are shown in Fig. 2. The factors that determine the size of the tank are the designed gas pressure and the allowable particle length for dielectric characteristics, and the temperature-rise specifications for the current-carrying performance.

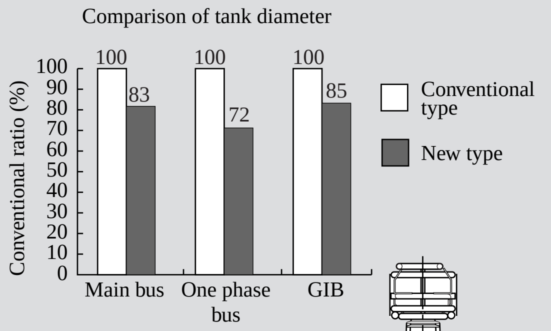
The designed gas pressure of the new GIS was increased to 0.35 MPa, which is 0.05 MPa higher than that of the original. Electric field was designed by analyzing the electric field in consideration with the electrode area effect.

The allowable particle length was changed from 5 mm to 3 mm, because a mechanical operation test showed that no particles of harmful length appeared. A simulation of three-dimensional particle movement was carried out to determine a structure in which floating particles do not reach electrodes and do not affect the dielectric performance.

Based on an evaluation of the thermal characteristics of the material used for the GIS, the temperature-rise specifications of the contact parts of the silver-silver contact conductor in SF_6 was raised from 65 K to 75 K. The temperature-rise of the tank surface, with which maintenance crews might come in direct contact, was raised from 30 K to 40 K. The conductors at the removable joints had the highest temperature-rise, but every part was below the allowable value. The tank flange O-ring where the heat resistance was potentially low was less than 30 K, as indicated by the temperature-rise test, and the average O-ring temperature at an average ambient temperature of 20°C was 50°C. This result is lower than the temperature (60°C) that would ensure a service life of 50 years, so there is no problem.

Specifications

Rated voltage	550 kV	
Rated current	2,000/4,000/6,000/8,000 A	
Rated short-time withstand current	63 kA (2 s)	
LIWV	1,425/1,550 kV	
AC withstand voltage	475 kV-635 kV-475 kV	
Rated pressure	0.6 MPa (GCB) 0.4 MPa (except GCB)	
Operating method	CB	Hydraulic
	DS	Motor wounded spring
	ES	Motor wounded spring (for line) Motor (for main bus) Manual (for maintenance)



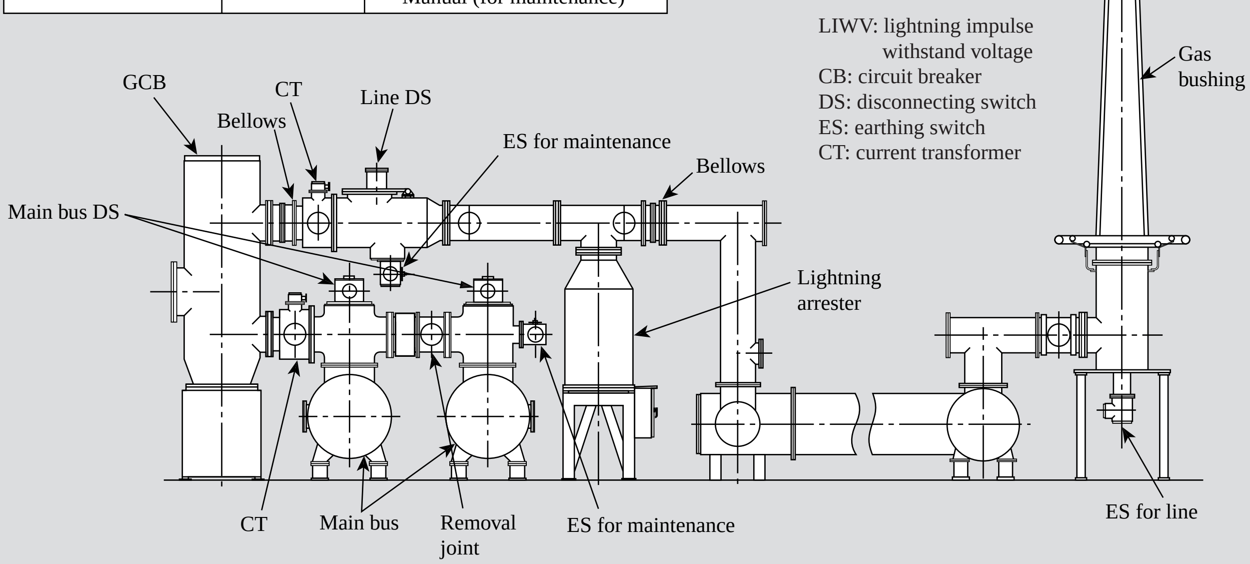
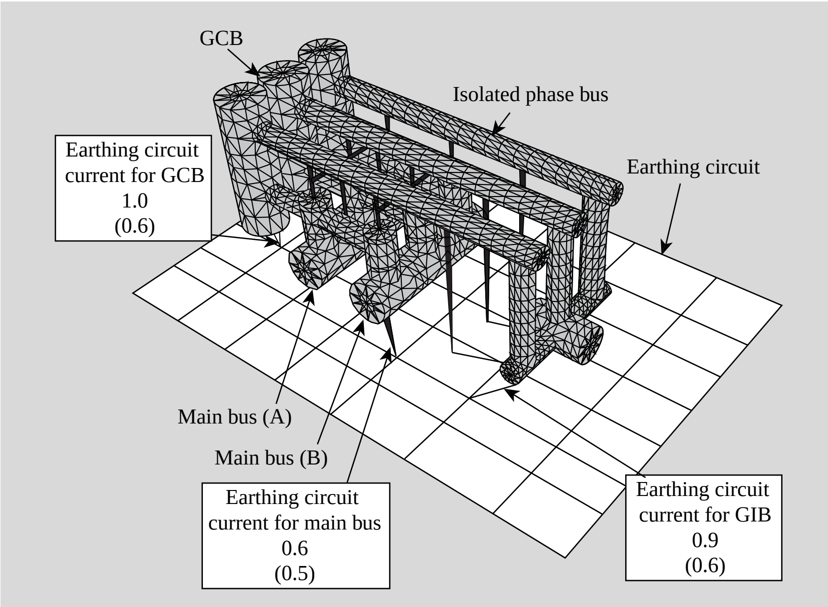


Fig. 2— Specifications and Structure of Line Circuit of New 550-kV GIS.
Tank was reduced to about 85% of its conventional size.



GCB: gas circuit breaker

Fig. 3— Comparison of 3-dimensional Analysis Results and Measured Values for the Earthing Circuit Current.
The analysis results agreed with the measured values.
(1) The value shows the earthing circuit current in case the main circuit current is 100.
(2) The upper values are the analysis results. The figures in parentheses show the value measured by the carrying-current test at the site.

Application of High Accuracy Analysis Technology

Simulation of three-dimensional particle movement

A simulation of three-dimensional particle movement was used to evaluate the dielectric performance when particles were contained in the tank. It was found that the electric field strength in the tank near the particle trap was decreased, due to the fact that particle did not move forward where electric field strength in the tank was low. The GIB structure was able to depress the electric field in the tank without having to enlarge the tank diameter. According to the above, the conductor's shape was modified.

Three-dimensional magnetic field analysis

A three-dimensional magnetic field analysis[2] was conducted for a multi-earthing-point style GIS on an earthing circuit to obtain the sheath current and earthing circuit current. We observed that the temperature-rise of the earthing circuit at the edge of GIS was less than the allowable value, although current might concentrate there. That is, the temperature of the concrete around the earthing circuit was kept to a harmless level, as verified by measuring the current of the earthing circuit at the GIS side. Analyzed and measured values are compared in Fig. 3. The force acting on the conductor and the tank of the three-phase common devices (three-phase main bus and GIB) during short-circuiting and current-carrying in service condition was calculated by the three-dimensional magnetic field analysis. The electromagnetic force acting on the conductor during a short circuit was reduced more than a case of not considering the current that was inducted to the tank.[3] In this way, the number of support insulators could be reduced.

IMPROVED RELIABILITY

Confirmation of Limit Performance

We carried out the flashover test to confirm the tolerance of dielectric characteristics. The flashover voltage became higher in order of components located at the feeder side (i.e. line-disconnector, earthing switch, bushing), the main bus and the circuit breakers. Even devices at the line side showed a tolerance of more than 50% against the LIWV and the result agreed well with the destruction voltage obtained by the analysis. Regarding the current-carrying performance, the rated current, 8,000 A, was carried and the overload current, 110%, was carried after saturated. Then, it took 2.5 hours to reach the temperature-rise. This means that there is sufficient tolerance. A high- and low-temperature test of the mechanical operation revealed that the device was operable at -30°C, lower than the low-temperature specification of -20°C.

Evaluation of Performance Under Practical Operating Conditions

On the subjects of (1) mechanical life, (2) investigation of the particle appearance by operation, and (3) dielectric characteristics after current interrupting, the tests were carried out under the condition that might cause failure. For example, operating speed, eccentricity, contact damage were set up as test parameters. The results were good. The

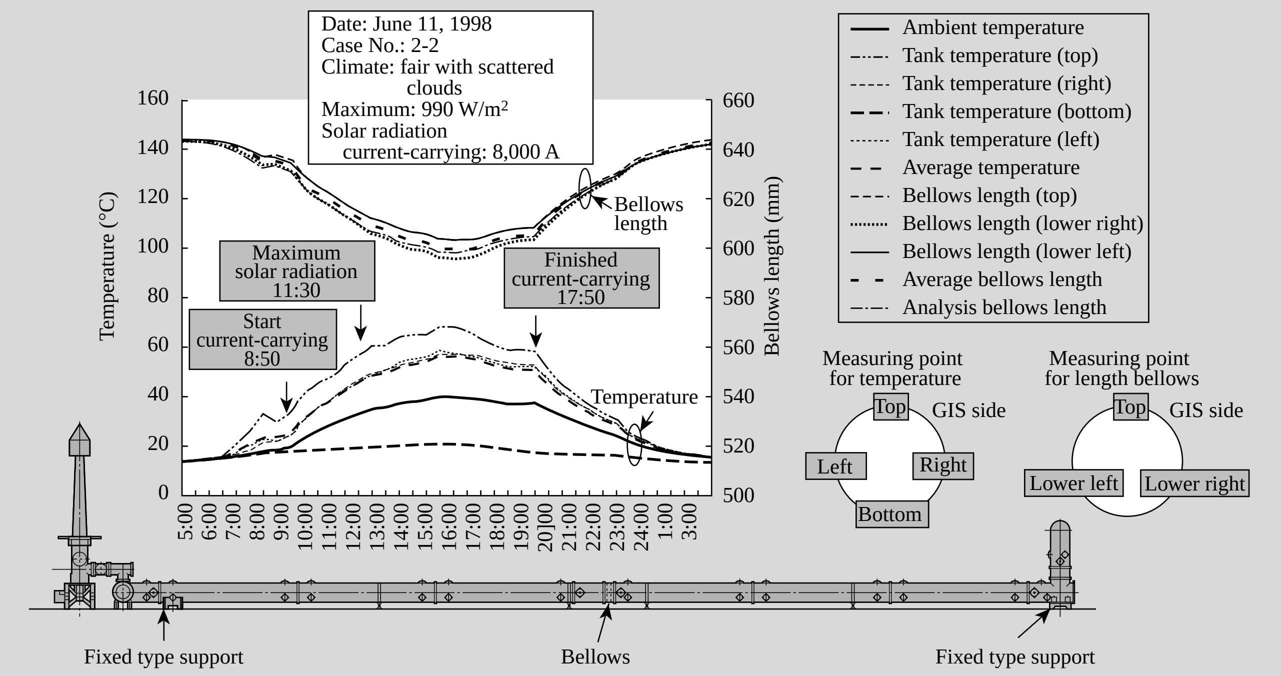


Fig. 4—The Displacement of the Bellows Type Expansion and the Analysis Result for Long GIB During a Current-carrying Test at the Site.
We confirmed that bellows displacement depended on tank temperature. The displacement that we obtained by analyzing measurements of temperature agreed well with the displacement measurements.

dielectric characteristics across open switching device and phase to earth withstood the DC voltage applied during normal operating conditions.

Temperature-rise Test at Site

After installation, a temperature-rise test at the site was carried out on all of the GIS circuits. The results were good; the tanks, support structure and exterior equipment did not generate local heat. Moreover, followings were observed.

(1) The temperature-rise, displacement, and stress of a tank and the expansion of bellows were found to depend on the levels of solar radiation and ambient temperature.

(2) Especially, the surface temperature and the displacement of tanks are changed by solar radiation without a time difference.

(3) Even if the solar radiation rises temperature partially, the displacement does not occur partially and changes as the tank average temperature rises.

Fig. 4 shows a comparison of the measured and analyzed tank temperature-rise and the bellows expansion during the temperature-rise test.

The displacement of the analysis by the finite element method in the three-dimensional shell model in consideration of the circumferential temperature distribution of a tank (difference in temperature between the upper part and the lower part of a tank) agreed well with the results of the temperature-rise test. The validity of the analysis was proven even for three-dimensional movement. The displacement of the insertion dimension at the current collector was measured by X-ray before and after the temperature-rise test. The displacement of the insertion dimension followed the tank displacement due to the temperature-rise of a tank. It was proven that contact parts of the main circuit were successfully improved for the structural and manufacturing quality control.

Improved Reliability by Applying Latest Manufacturing Technology

The following improvements were made in the manufacturing process of GIS. At the same time, size reduction and reliability were accomplished.

(1) The structure was improved by unifying and using high-precision parts. Assembly work was simplified. For instance, the number of connections was reduced and complicated adjustment work during assembly was eliminated.

(2) The assembly work was improved by using GIS-specific assembling tools and jigs. Consequently, the work in a tank decreased substantially and the potential

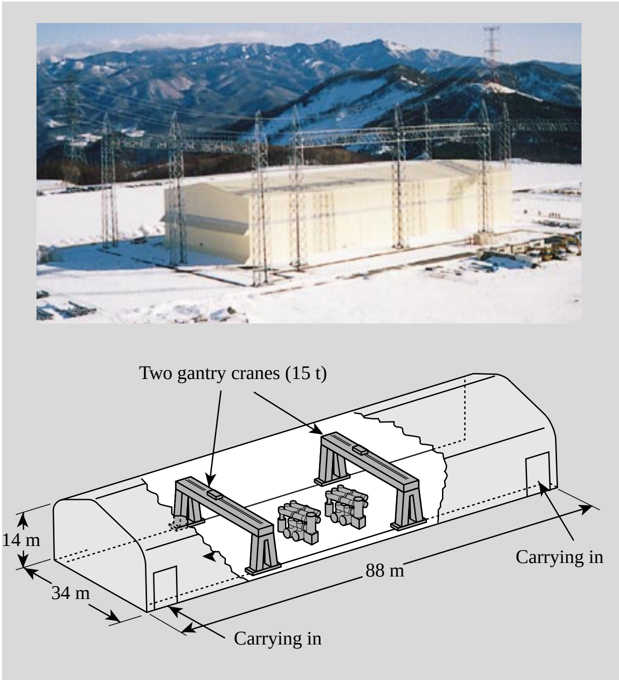


Fig. 5—Large Assembly House at Site.
Up to 12 circuits can be contained in the assembly house. The house is equipped with two gantry cranes (15 t).

trouble from foreign particles was eliminated.

Improvements were also made to the site installation process.

(1) Large all-weather assembly houses (Fig. 5) were established to enable installation work to be carried out even in severe cold period and bad weather. They also help shorten and ensure the quality of the installation work.

(2) Employing a high-precision laser to control the dimensions improves the precision of portions assembled at the site.

(3) We used a QFD (quality function deployment) method to clarify the relation between each work step and trouble potential. This method uses a quality control sheet that incorporates preventive measures to help improve the quality control level.

CONCLUSIONS

Technologies useful for developing the new 550-kV GIS were described above. Using these technologies, we will be able to decrease the size of third-generation 550-kV GIS without lessening its reliability. We intend to develop all other rated-voltage classes of GIS by using the same techniques and basic ideas.

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