Extra-High-Voltage SF_6 Gas-Insulated Switchgear

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1. Introduction

Due to location criteria and toughened restrictions on transportation, it has become increasingly difficult over the past several years to secure sites for substations. Consequently, the development of smaller-sized SF_6 gas-insulated switchgear (GIS) has been eagerly awaited.

In accordance with these needs, Fuji Electric has recently developed a small-size lightweight 245/300kV phase-segregated type GIS (model: SDA530) that can be transported fully assembled. This paper will introduce the construction, special features and test results of this GIS.

2. Details of Development

Figure 1 shows the external view of the SDA530 type GIS. This GIS has a phase-segregated construction in which the busbars are located in front, the line-side equipment of the circuit breaker (CB) is at the back, and the CB is arranged horizontally at the bottom.

Fig.1 An outside view of the 300kV phase-segregated type GIS

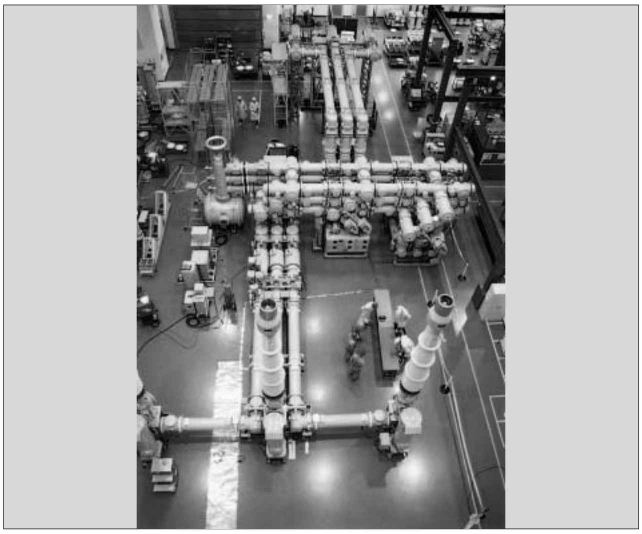
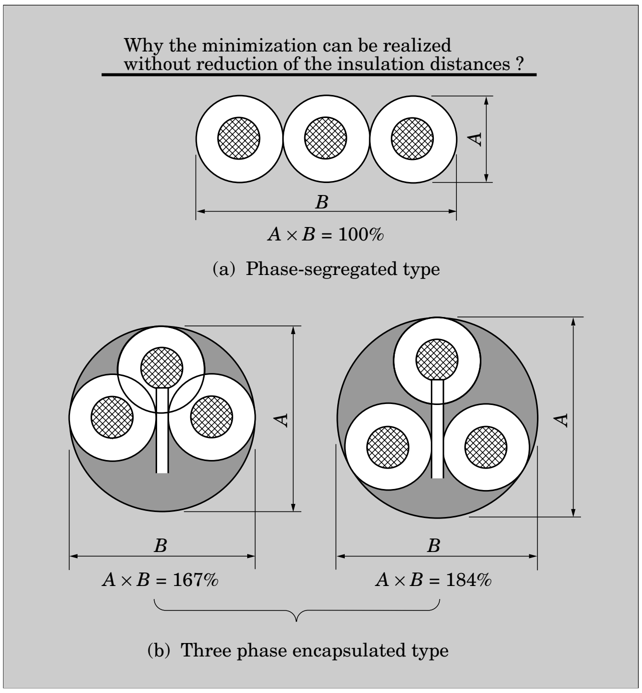


Figure 2 shows a comparison of space factors between a phase-segregated type GIS and a three-phase encapsulated type GIS with the assumption that the busbar diameter and the insulation distance are equal for both of these two types. It is obvious from Fig. 2 that the phase-segregated type has a higher space factor and therefore has greater potential to be made smaller with a new design.

Fuji Electric recognized this point, and in 1989 first developed a small and lightweight 145kV phase-segregated type GIS (model: SDA514) with a new conception. The new 300kV phase-segregated type GIS (model: SDA530) was developed to be transportable after full assembly. The construction of the SDA530 is basically similar to that of the SDA514 type GIS, however by introducing the latest equipment technology, a noticeably smaller size and lighter weight have been realized.

Fig.2 Comparison of the space factors



3. Ratings and Specifications

The major ratings and specifications of the newly developed GIS are listed below.

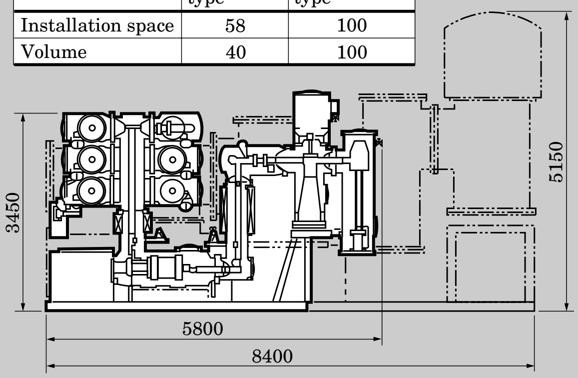
(1) Rated voltage: 245kV, 300kV
(2) Rated normal current: 2,000/3,150/4,000A
(3) Rated short-time withstand current: 31.5/40/50kA
(4) LIWV: 1,050kV
(5) Rated SF_6 gas pressure: 0.6MPa

The design was standardized for the 245kV and 300kV GIS. The rated normal current and the rated short-time withstand current are unified at 4,000A and 50kA respectively, sufficient for almost all of the specified ratings in the marketplace. Consequently, development costs have been reduced and the economics benefits of standardization have been obtained.

Fig.3 Comparison of dimensions

The dimension ratio designed in our company (unit: %)

Item	Phase-segregated type	Three phase encapsulated type
Installation space	58	100
Volume	40	100



4. Special Features

(1) Small size and lightweight

Due to the utilization of such features as phase-segregated construction and aluminum alloy tanks, a remarkably small-size and lightweight has been obtained. Figure 3 shows the comparison of dimensions between the conventional three-phase encapsulated type (Fuji Electric's typical design) and the newly developed phase-segregated type. From this comparison, it can be seen that installation space is decreased to 58%, volume to 40% and weight to 50%.

(2) Improved reliability

Because of the phase-segregated type construction, there is no occurrence of phase-to-phase short-circuits. Assembly is easy and centering is not necessary because of the simple and concentric structure of the conductor. Fully assembled transportation by trailer is possible, and the GIS may be installed in a substation in the same condition as it stood in the factory after assembly and tests. This stabilizes the quality control.

(3) Improved maintenance and on-site inspection

Since the driving mechanism and gauges are all located in either the front or the rear areas, daily inspection and operation are possible from the front or rear spaces.

Fig.4 The sectional view of a GIS and the applied major technology

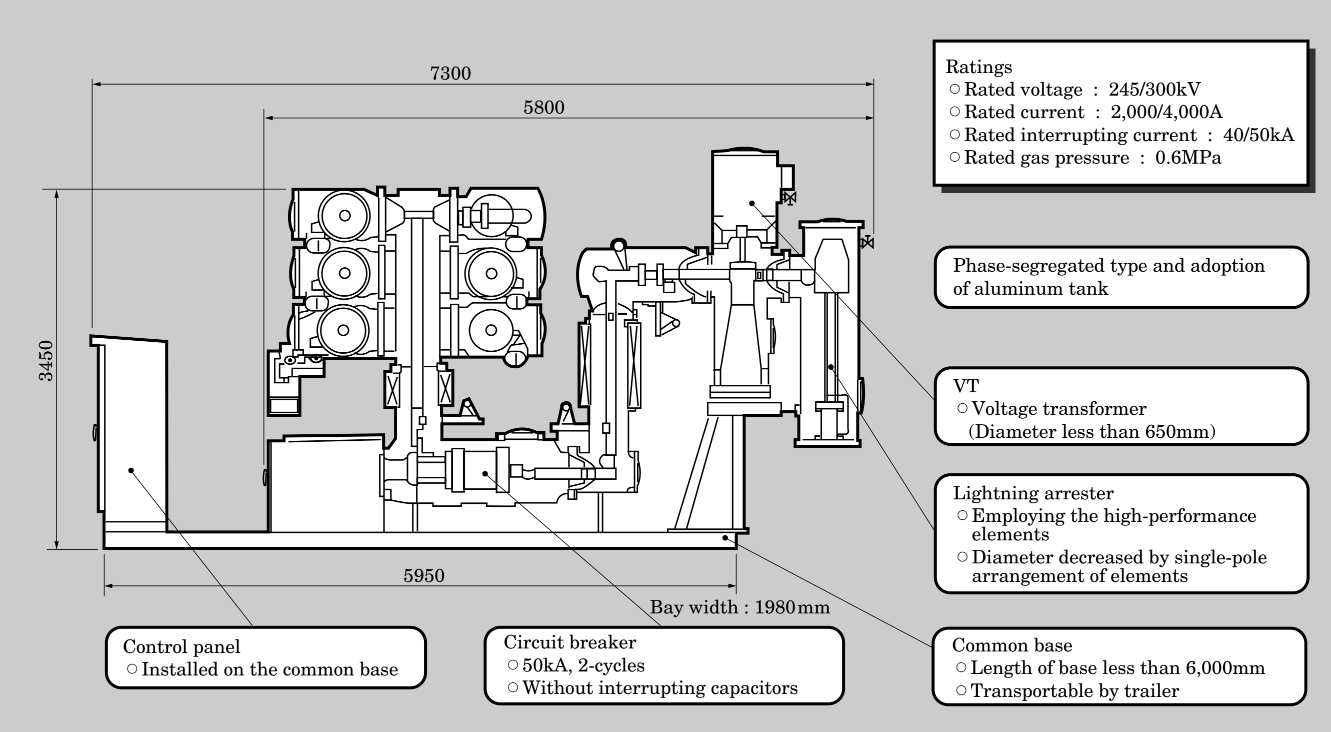


Fig.5 The pressure-rising after the beginning of gas-blast

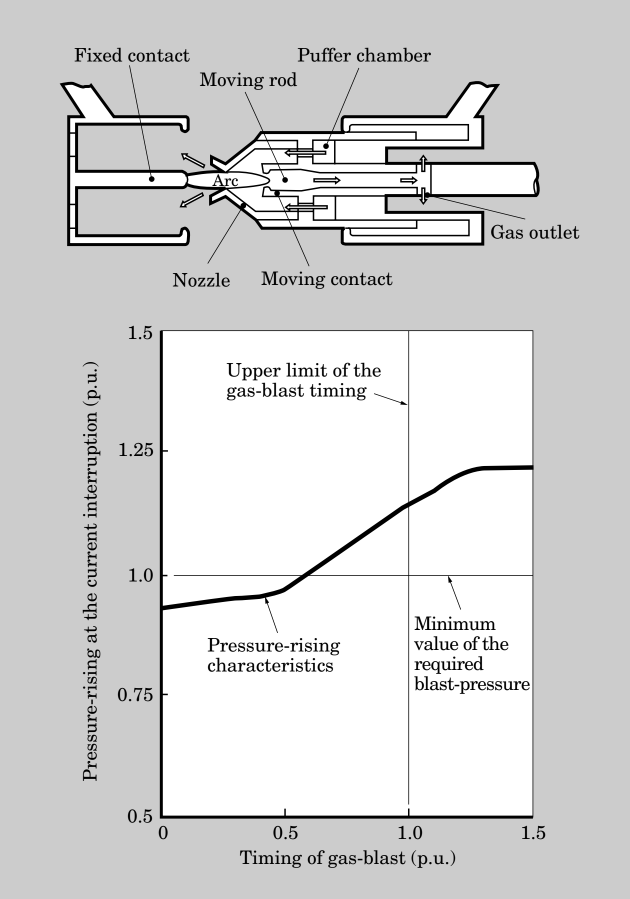
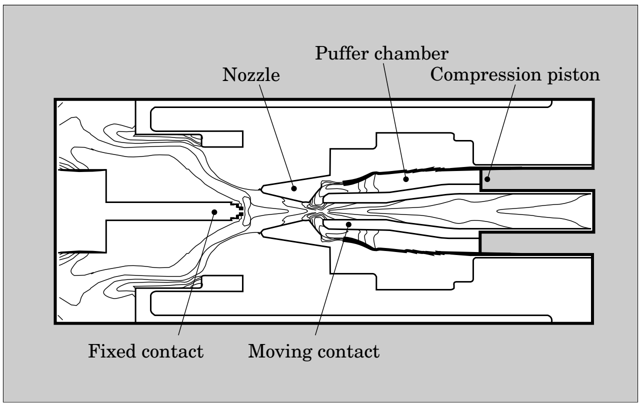


Fig.6 Analysis of the gas density at the moment of 50kA-short current interruption



(4) Easy on-site installation

The foundation work is simplified because of the small size and lightweight of the GIS. Because the GIS is fully assembled prior to transport, on-site connecting work is limited to the connection of busbars and cables. Therefore, the on-site working period can be shortened by 50%. Furthermore, since the control panel is mounted on a common base and then transported, it is unnecessary to connect control cables on-site.

(5) Easy troubleshooting

Because of the phase-segregated type construction, the areas of possible malfunction are limited. The weight of parts, such as the busbar, are light, and may be replaced easily without the need for large cranes.

5. Construction

5.1 Total construction

A cross-sectional view of a typical unit and the major technology applications are shown in Fig. 4. Because the circuit breaker is located at the lowest position horizontally, total height is reduced and consequently, the fully assembled GIS (including the control panel) can be transported at one time. All of the tanks are made of aluminum castings. These aluminum casting tanks are not only beneficial to decreasing the weight, but are also well suited for machining and economical because they do not require welding. The pitch between phases is 650mm, the bay width is 1,980mm and the total weight is approximately 12 tons. Details of each apparatus are described below.

5.2 Circuit breaker

A new type of interrupting chamber has been developed that utilizes effectively the arc-energy generated during the current breaking to raise the interrupting gas pressure. Consequently, the diameter of circuit breaker tank was decreased to 70% compared to our conventional tank, contributing to the minimization of the new GIS. For the driving mechanism of the circuit breaker, a small, powerful, highly reliable hydraulic operating mechanism was utilized, and has yielded good operating results.

5.3 Isolators and earthing switches

To obtain stable operating performance, all of the remotely operated isolators and earthing switches are driven by motor-spring driving mechanisms. A thermal puffer type arc quenching system that efficiently utilized arc-energy is used with the earthing switches to break induced line current.

5.4 Lightning arrester

For the lightning arrester in the GIS, a high performance zinc-oxide device developed by Fuji Electric Co from a mixture of rare earth elements was used. Consequently, the single-pole arrangement of the device could be adapted even for UHV applications and a remarkably smaller size was realized.

5.5 Voltage transformer (VT)

The shape of the high voltage electrode was determined by means of electric field analysis to minimize the tank diameter. The construction was simplified to create VTs that can be arranged linearly with a 650mm pitch between phases.

Fig.7 An example of the 3-D field-analysis for the connection of the conductors between main circuit and circuit breaker

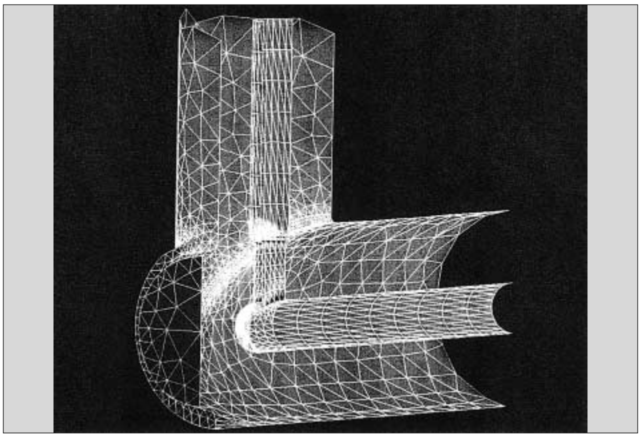


Fig.8 The state of earthquake-proof test

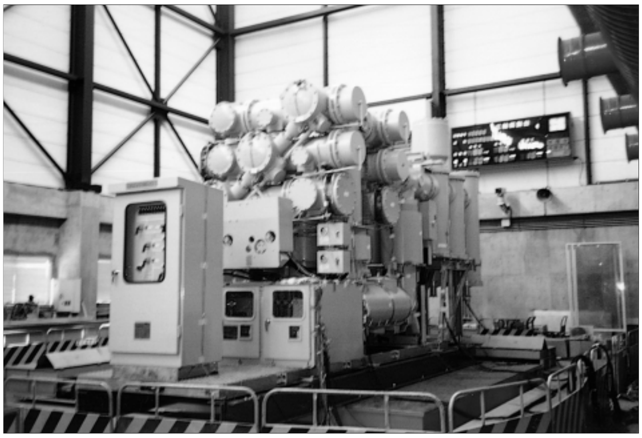


Fig.9 The state of transportation test

5.6 Current transformer (CT)

It was decided that the current transformer would be installed outside of the tank to utilize the characteristics of phase-segregated construction. Consequently, a CT primary current injection test can easily be performed by flowing the test current through the tank. For the purpose of CT testing, terminals for the test current are mounted on the tank.

Fig.10 The state of freeze test

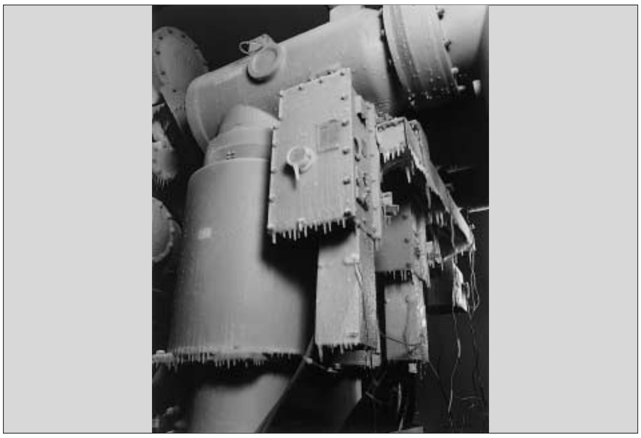


Fig.11 The state of long-term energizing test

6. Main Analysis Technologies

The main analysis technologies used to minimize elements of the GIS are listed below.

6.1 Interrupting pressure rise analysis

In the conventional circuit breaker, capacitors were installed in parallel between the main contacts in order to interrupt the large current easily. The capacitors function to mitigate the rate of rise of transient recovery voltage. However, a goal of this new GIS was to achieve interruption without the use of parallel capacitors. To achieve this goal, we improved the interrupting chamber so that the arc energy generated during the interruption contributes to raising the interrupting gas pressure, and blasting begins at the optimum point of interruption. Figure 5 indicates the results of the analysis.

6.2 Gas flow analysis

Since the hot gas generated by large current interruption is blasted out instantaneously into a metal tank at ground potential, we improved the shape of nozzle and contacts and controlled the blowing direction of the hot gas so that the insulation ability would not decrease. An example analysis of the gas density distribution is shown in Fig. 6.

6.3 Electric field analysis

To analyze the electric field of complex parts such as the bent part of a conductor or the potential sharing on an arrester element with consideration of the back-side of conductors, three-dimensional electric field analysis by the surface-electric-charge method was applied. Figure 7 shows an example of the three-dimensional electric field analysis for the connecting part between a conductor of the main circuit and a circuit breaker.

7. Special Tests

The following special tests were implemented to verify the practical capacity of the GIS device. Sufficient capacity was fully verified.

7.1 Seismic tests

$3m/s^2$ 3-cycle vibration tests on resonant frequency were performed with a tri-axial vibrator and a safety factor of above 2 was verified. Additional seismic tests were performed using the “El-centro” wave, “Hachinohe” wave and “Kobe” wave, and the GIS was verified to be sufficient for earthquake-proof. The seismic testing is shown in Fig. 8.

7.2 Transportation test

The GIS was carried on a low-platform trailer, and tested with a rough road traveling test, a sudden start and stop test, and a test that ran over a square piece of timber. It was verified that there were no problems in any of these tests. The transportation test is shown in Fig. 9.

7.3 Heat cycle and freeze tests

With the GIS fully assembled, a heat cycle test between –35°C and +55°C and a freeze test were performed. It was verified that all of the equipment or devices operate normally under these severe conditions. The freeze test is shown in Fig. 10.

7.4 Long-time energizing test

A long-time energizing test was performed on an outdoor GIS for an interval of 8-months under the conditions of 200kV to earth and 4,000A. During the tests, each piece of equipment was operated intermittently, normal operation was verified, and there were no unusual states such as partial discharge or partial overheating. The long time energizing test is shown in Fig. 11.

8. Conclusion

A summary of the 300kV phase-segregated GIS (model: SDA530) has been presented. Fuji Electric will continue its efforts to minimize, and improve the quality and economy of the GIS.