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HISTORY AND DEVELOPMENT TREND OF FUJI SF_6 GAS INSULATED EQUIPMENT

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1 INTRODUCTION

SF_6 gas circuit breakers and SF_6 gas insulated switchgears (GIS) have various features in their outstanding current breaking performance, insulation, reliability and inspection/maintenance eases, and they have been remarkably developed throughout the world.

When looking back the development during the recent 15 years, for gas circuit breakers, the arc-quenching system has been changed from the double pressure type to single pressure puffer type, the operating mechanism has been changed from the pneumatic type to hydraulic type, and also raising the voltage of one breaking unit from 72.5 kV to 300 kV, simplifying the construction, extending the inspection cycle and reducing the dimensions were made.

Particularly for the single pressure type arc-quenching system, such an initial idea as that, to increase the breaking capacity, the blast gas pressure is increased by increasing the operating force has been gradually changed. The recent arc-quenching system has been so constructed that a high gas blast pressure can be obtained by effectively using the arc energy produced when arc-quenching, and this idea has promoted the greatly reduced dimension of arc-quenching chambers.

On the other hand, for GIS, the initially developed phase segregated type has been improved to three phase encapsulated type, and at present, those of 170 kV or lower are of a three phase encapsulated type. Further, for the busbar, 420 kV three phase encapsulated type is already employed.

The fundamental policies in developing gas insulated equipment by Fuji Electric are:

(1) Improvement of reliability
(2) Improvement of serviceability realized by parts standardization.
(3) Reduction of installation space realized by reducing dimensions of the equipment
(4) The pursuit of maintenance ease.

We are confident that these policies are important not only for the users but also for us, the manufacturer.

Fuji Electric has developed gas insulated equipment and accumulated the technologies and experience based on this idea. Looking back the history of Fuji Electric's gas insulated equipment, this paper introduces the particulars.

2 HISTORY AND DEVELOPMENT TREND OF CIRCUIT BREAKERS

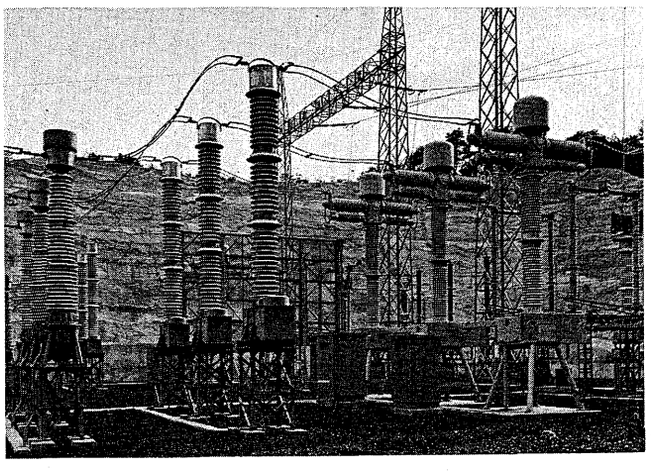
2.1 Double pressure gas circuit breakers (Beginning of gas circuit breakers)

The history of Fuji Electric's gas circuit breakers began with the Model HF904 double pressure gas circuit breaker (300 kV 25 GVA 2000/4000A rating) developed early in 1969. This double pressure gas circuit breaker was of four break type, and was operated by compressed air. Subsequent to this first model, in the summer of the same year, Fuji Electric developed the Model HF902 double pressure gas circuit breaker of two break (168 kV 10 GVA rating), Model HF912 two-break gas circuit breaker of 300 kV 20 GVA rating in 1970, and thus, completed the series of double pressure gas circuit breaker. This Model HF912 was in the largest level at that time in the world for the voltage and capacity per interrupter unit.

As described above, the history of the gas circuit breakers began with the double pressure type, and the reasons were because:

(1) As a principle, operating force could be reduced by the

Fig. 1 240 kV 40 kA double pressure two-break gas circuit breaker



double pressure type, and the operating mechanism which was popular at that time could be used.

(2) The arc-quenching system was separated from the operating system, the arc-quenching phenomenon could be simply devised, and a large breaking capacity could be obtained regardless of the operating energy.

During six years between 1970 and 1976, Fuji Electric delivered 87 units of 72 kV to 240 kV double pressure type gas circuit breaker to the customers. During this period of time, Fuji Electric established the technologies for the decomposed gas resisting materials, gas leaking, countermeasure for intruded moisture, gas monitoring, etc. which are required in manufacturing gas insulated switchgears and gas circuit breakers. These technologies have been thoroughly employed thereafter in making series of single pressure gas circuit breakers.

2.2 Development of single pressure gas circuit breaker

The gas circuit breakers began with the double pressure type had, however, two major problems.

(1) Complicated construction

(2) High cost

For these matters, the single pressure type is better than the double pressure type. Fuji Electric completed a 72.5 kV 3.5 GVA porcelain type single-break single pressure gas circuit breaker in early 1971, and further in 1972, completed the 170 kV two-break type single pressure gas circuit breaker. The single pressure gas circuit breaker used the same 15 kgf/cm^2 compressed air operating mechanism as the double pressure type, and the arc-quenching chamber was of a single flow type with an insulation nozzle. At this time, the single pressure type gas circuit breaker was not large enough for the voltage and capacity to replace double pressure type, and for a while, two series, namely single pressure type circuit breakers for medium capacity series and double pressure type for large capacity series were used.

On the other hand, for 72.5 kV ratings, plug-in type single pressure gas circuit breakers were developed and added to the series. Since the era of low-oil-content circuit breaker (ECB) and air-blast circuit breaker, (ABB) this plug-in type circuit breaker belongs to Fuji Electric's favorite field. The plug-in type gas circuit breakers were recognized to be extremely effective in reducing dimensions of indoor type substations, and a number of plug-in type gas circuit breakers were delivered.

2.3 Hydraulically operated single pressure type gas circuit breakers

Compressed-air operated gas circuit breakers had the following problems to be solved.

(1) The problem of noise was greatly reduced in comparison with the air-blast circuit breaker, however, the noise generated during operations still remained as a problem.

(2) The gas circuit breaker proper was constructed to be a maintenance free. However, the air system which con-

Fig. 2 168/204 kV 31.5 kA pneumatically operated single pressure type gas circuit breaker

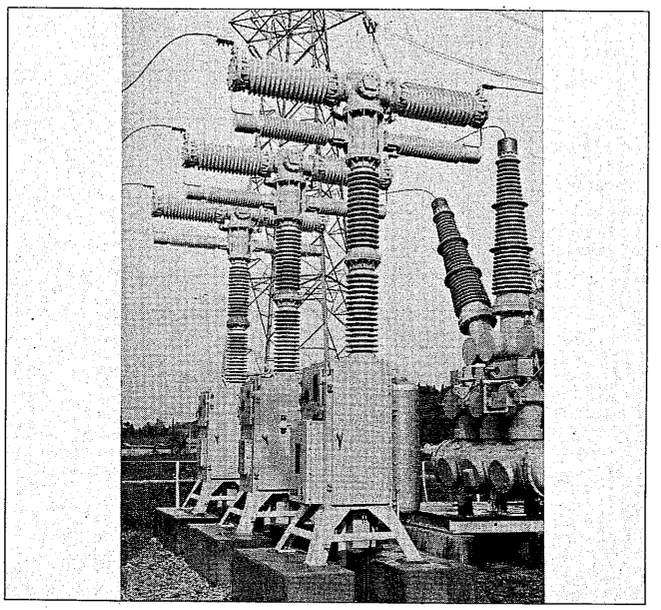


Fig. 3 72.5 kV 25 kA plug-in type gas circuit breaker

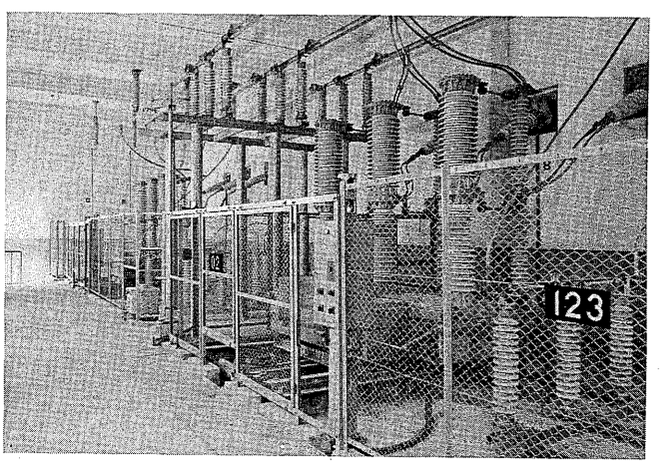
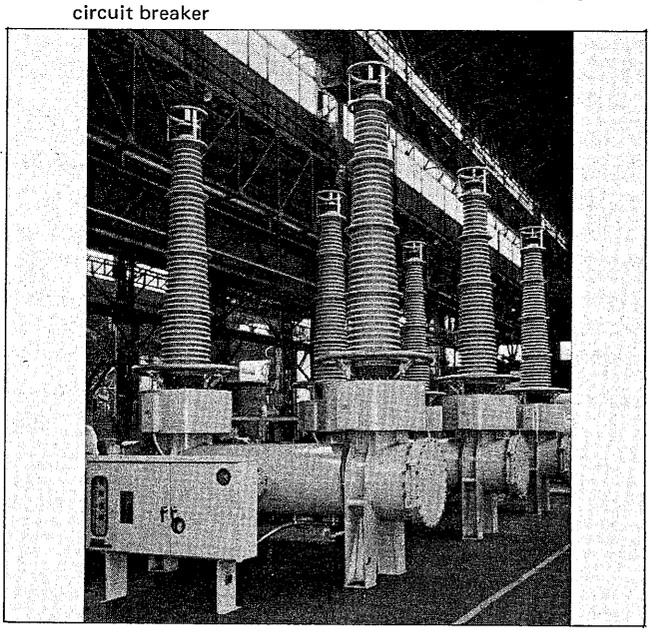


Fig. 4 362 kV 40 kV hydraulically operated dead tank type gas circuit breaker



sisted of an compressed-air operating mechanism and compressor required the conventional maintenance, and therefore the air system was not well matched with the circuit breaker proper.

(3) Even if it was intended to increase operating force for increasing capacity of single pressure type gas circuit breaker, it could not be avoided to increase the total dimensions as long as a compressed air operating mechanism was used.

To solve these problems, Fuji Electric started developments of hydraulic operating mechanisms, and in 1972, Fuji Electric completed the series of 72.5 kV to 300 kV hydraulically operated gas circuit breakers. For the hydraulic operating mechanism, oil leaking from the piping was a typical problem. However, the operating mechanism developed by Fuji Electric was of a block structure from which the piping was greatly reduced, and the reliability against oil leaking was remarkably improved. During recent years, reduction of maintenance cost on substation equipment has been strongly demanded, and the hydraulic operating mechanism has been favourably evaluated to be the optimum operating mechanism. Further, with the hydraulic operating mechanism employed, no air piping is required, making it possible to realize substation having no air piping, and contributing to reductions of construction cost and time.

Including those for GIS, such a large number of Fuji Electric's hydraulically operated gas circuit breakers as 1266 units have been delivered to the customers. It has been over ten years since Fuji Electric delivered the first hydraulic operating mechanism, and recently, it has been evaluated so highly that the hydraulic operating mechanism is the main stream of the operating mechanisms for gas circuit breakers.

2.4 Making series of dead tank type circuit breakers and increasing the capacity

For gas circuit breakers started with the porcelain type, in Japan, the dead tank type was the main stream especially in the high voltage class. The reasons are.

(1) Earth-quake proof
(2) Outstanding feature against pollution
(3) Including CT, space reducing effect can be expected.
(4) Maintenance and inspection of arc-quenching chamber are easy.

Paying attention on these features of dead tank type circuit breakers, Fuji Electric intended to make them in a series, and started the delivery to the customers in 1977. The dead tank type circuit breakers used the hydraulic operating mechanism which was practically used in the porcelain type, and for the arc-quenching chambers, a single flow type of 31.5 kA breaking current and double flow types of 40/50 kA breaking current were used in the series.

Taking an opportunity on the series of this dead tank type gas circuit breaker, capacity of single pressure type gas circuit breakers kept increasing, and capacity of the recent single pressure type has exceeded that of some double pressure types. *Fig. 5* shows the particulars of unit capacity increase of gas circuit breakers. In 1977, Fuji Electric completed the extra high voltage 242 kV circuit breaker with a single interrupter unit, and in 1978, 19 units of this circuit breaker were delivered to National Power Corporation in the Philippines. This dead tank type circuit breaker took the initiative for the extra high voltage single interrupter design. Since then, about 200 units of dead tank type circuit breakers (most of them were extra high voltage 242 kV) have been delivered to the Corporation.

Fig. 5 Trend of unit capacity of gas circuit breakers

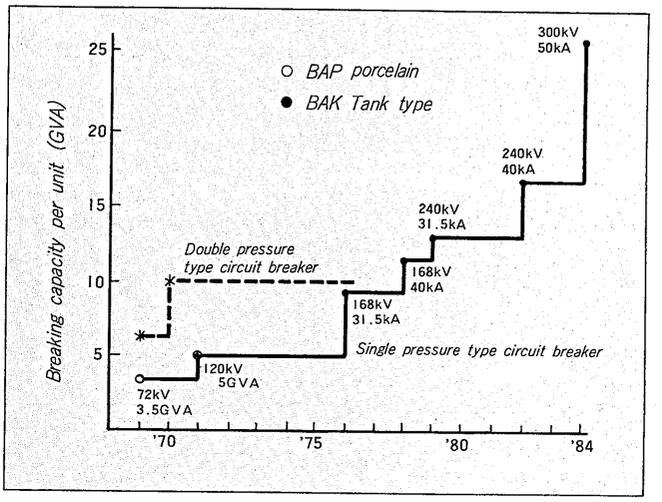
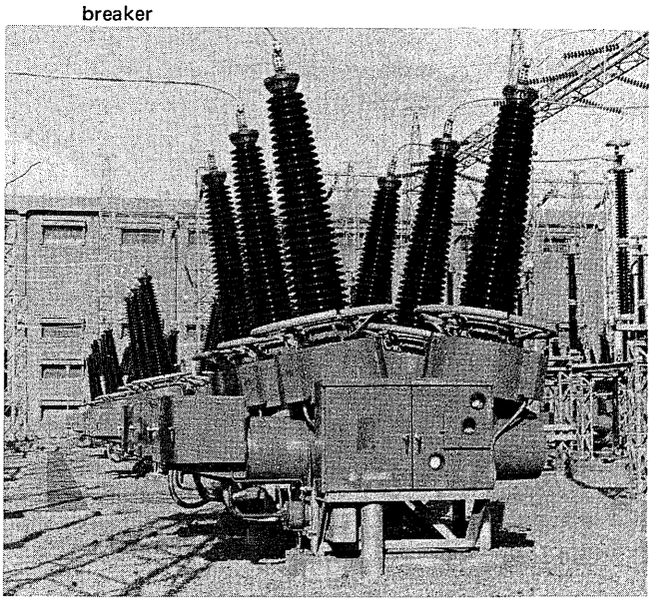


Fig. 6 242 kV 31.5 kA single break dead tank type gas circuit breaker



In 1981, a 300 kV 50 kA 2-cycle circuit breaker and 362 kV 40 kA circuit breaker with a closing resistor were delivered respectively to the Japanese National Railways and Korea Electric Power Corporation.

2.5 Gas circuit breakers delivered to the customers and recent trend of the development

Since Fuji Electric started deliverying the gas circuit breakers to the customers in 1971, including the 24/36 kV class circuit breakers, the following circuit breakers have

been delivered.

24/36 kV:		700 units
72/84 kV:		1314 units
120/145 kV:		352 units
168/204 kV:		188 units
240~362 kV		145 units
	Total:	2699 units

Based on this rich manufacturing experience and by fully utilizing the recent analyzing and measuring techniques, Fuji Electric developed compact and high performance circuit breakers. In the low-oil-content circuit breakers which once made an epoch previously, so called self-actuating type arc-quenching chamber which actively uses the arc-energy generated at the time of a breaking for the arc-quenching act was employed. The arc-quenching of the conventional puffer type gas circuit breakers was made by the gas blast obtained only by the operating mechanism, and to increase the breaking capacity of the conventional puffer type, it was necessary to increase the operating force. The gas circuit breakers which Fuji Electric presently makes available under the standard series are actively using the arc itself for increasing the gas blast pressure as well as the conventional low-oil-content circuit breakers, and equipped with small operating force yet large capacity compact high performance arc-quenching chambers. Moreover, these circuit breakers are using the conventional hydraulic operating mechanisms.

Fuji Electric is manufacturing two main types of circuit breakers, dead tank type and porcelain type which is expected to be mainly exported to the overseas, and to enhance the reliabilities, common use and standardization of parts are made to the extreme limit. For the arc-quenching chamber and hydraulic operating mechanism which are most important circuit breaker components, all ratings are covered by three series; two series from 72.5 kV to 245 kV and one series for 245/300 kV 50 kA 2-cycle single interrupter type, and further, in the indicidual series, the parts are used commonly as much as possible.

3 HISTORY AND DEVELOPMENT TREND OF GIS

3.1 Details of development (Phase segragated type to three-phase encapsulated type)

The history of Fuji Electric's GIS began 1965. Thereafter, in 1969, 72.5 kV to 123 kV GISs were manufactured and exhibited to the public. These GISs had such excellent features as (1) self-supporting type without using frame, (2) earth-quake proof type which arranges the busbar in the bottom, (3) employment of compound composition units and (4) steel used for the capsule mateiral, and these features were used in the standard construction of the GIS thereafter. Initially, the GISs used the three phase encapsulation in the busbar unit only, phase-segregated type was used for other composing units, and for the circuit breakers, compressed-air operated single pressure type was used. The first GIS was delivered to a customer in 1970. Subsequently, Fuji Electric developed a 145/170 phase segregated type GIS equipped with a hydraulically

Fig. 7 72.5 kV phase-segragated type GIS

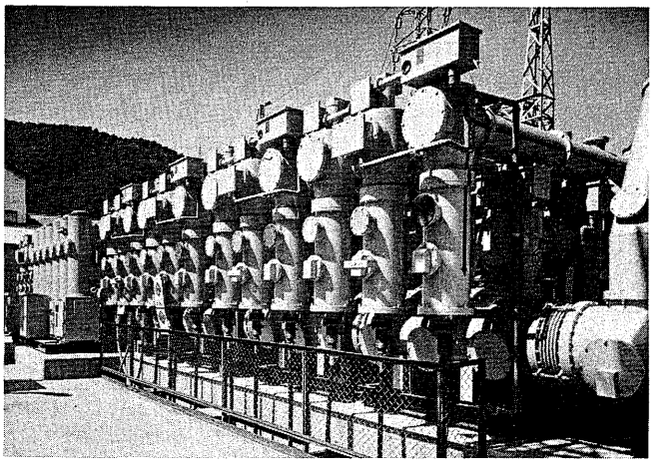
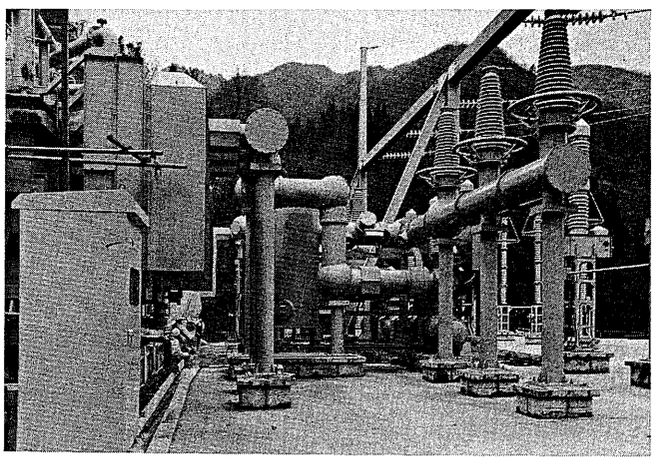


Fig. 8 168 kV three phase encapsulated type GIS



operated double pressure type gas circuit breaker, and since 1973, started deliverying the GISs. The GIS started with the phase-segregated type was further developed, and technical development was proceeded to develop three-phase encapsulated type. The three phase encapsulated type has, in comparison with the phase segregated type, various features such as space saving, transportation and installation eases, advantageous in countermeasure for carrying current, greatly reduced flange length which affects prevention of gas leakage and reduced lengths of gas piping and control cable wiring. Fuji Electric developed the first three-phase encapsulated type GIS for 72.5 kV in 1974, and started deliverying them to the customers next year. Further, also for 145/170 classes, Fuji Electric proceeded the development of three phase encapsulated type, and in 1978, Fuji Electric delivered a 168 kV three phase encapsulated GIS to Electric Power Development Co. in Japan as the first of this kind in the world. Thereafter, in addition to the operating performance and many advantages of the three phase encapsulated type GIS, it was found that the insulator, dust and gas sealing were more important to improve reliability of GIS rather than the matter of phase-segregated type or three phase encapsulated type. Thus, the three phase encapsulated type GISs were rapidly developed and popularized. At present, even a 300 kV class GIS tends

to be three phase encapsulated, and for the busbar, three-phase encapsulation is realized up to 550 kV. Further, in 1983, Fuji Electric developed and started deliverying 72.5 kV calss cubicle type GIS. The circuit breaker unit of the cubicle GIS (C-GIS) is the same as the conventional GIS. However, other units are filled with low pressure SF_6 gas, the enclosure shaped in rectangular, and thus, the dimensions are further reduced. *Figs. 9* and *10* show reactively an example of the 72.5 kV cubicle type GIS for outdoor installation and sectional view of the 72.5 kV cubicle type GIS for indoor installation.

Fig. 11 shows the comparison of the required spaces and cubic volume of the initial phase-segregated type, present standard three-phase encapsulated type and cubicle type, and from this figure, the technical advancement of GIS during the last 15 years can be read out.

Fig. 9 72.5 kV cubicle type GIS for outdoor installation directly coupled with transformer

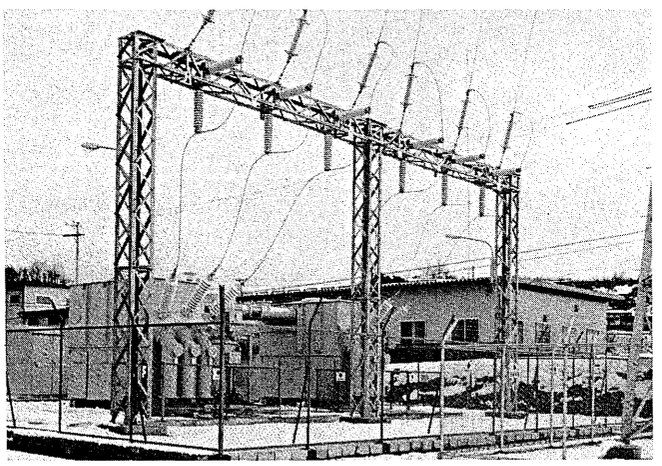
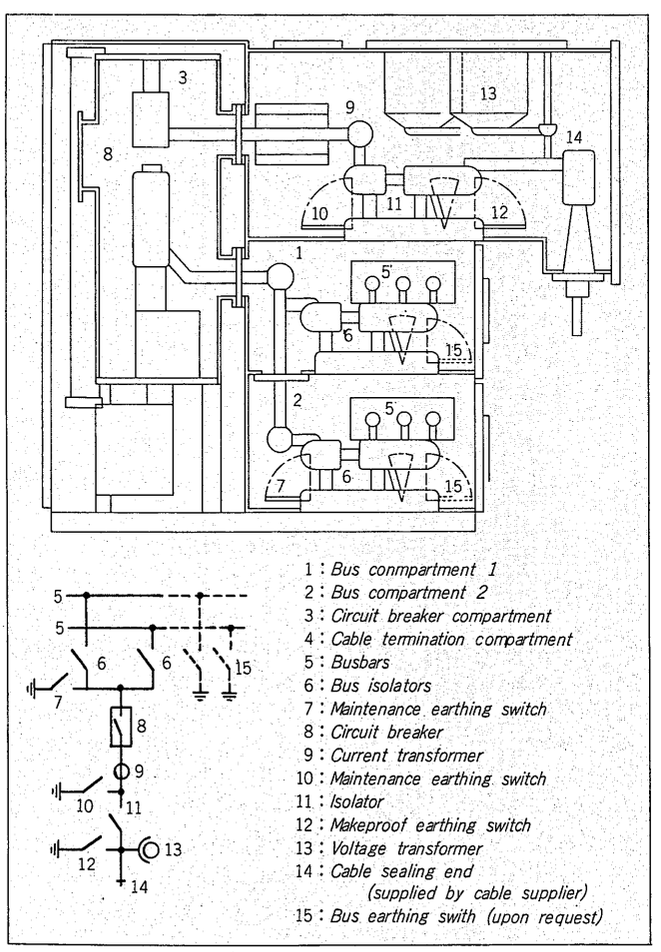


Fig. 10 Sectional view of 72.5 kV cubicle type GIS for indoor installation



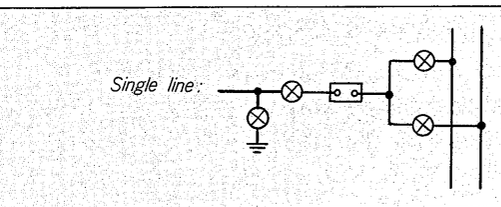
3.2 Features of Fuji GIS

As a switchgear, the GIS has many features such as greatly reduced installation space, high reliability and safety, harmonization with the environment and maintenance and inspection ease. To permit GISs fully displaying these features, Fuji Electric's GISs have been, since the initial period, provided with the following technical remarks.

3.2.1 Ribbed insulator

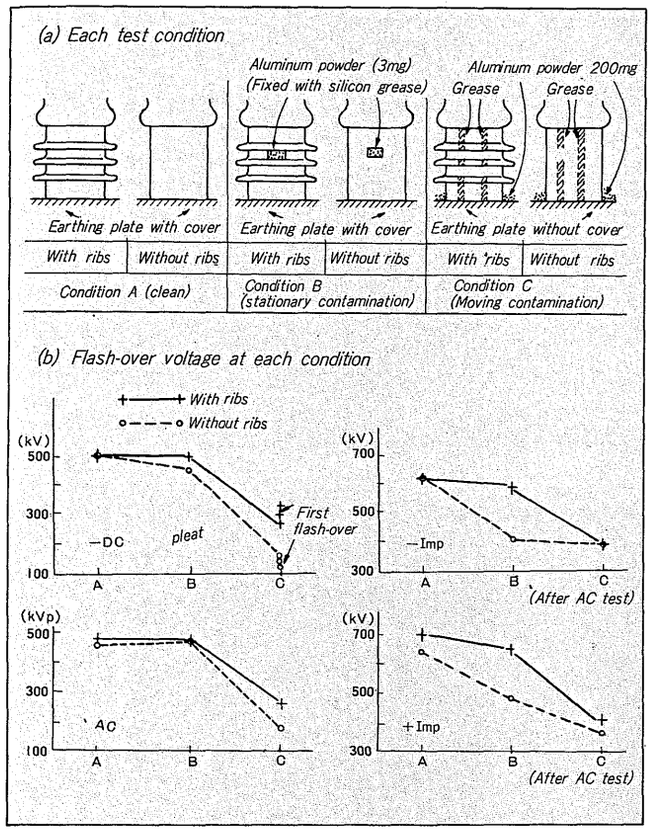
For reliability of a GIS, the cast resin insulator is an extremely important parts. The cast resin insulator must be designed with the serive life taken into considerations. Fuji Electric selects the design value of the internal electric field at a sufficiently low level against the breakdown electric field after an estimated life of the machine. To evaluate the life of insulators correctly, Fuji Electric conducts long duration tests on the actual products, and collects the data. The most typical feature of Fuji Electric's insulator is that the insulator is provided with ribs. Effects of the ribbed insulator have already been well known, but again, it is emphasized that the withstand voltage is outstanding particularly when the insulator is contaminated. *Fig. 12* shows results of an experiment to prove effects of ribs of a post insulator. From this figure, it can be understood that dielectric strength of ribbed insulator is higher than that of a insulator without ribs particularly when metalic dust exists. GISs are assembled carefully in a clean

Fig. 11 Trend of GIS space reduction



		72.5kV 2000A 31.5kA		
		Phase-segregated type	Three-phase encapsulated type	Cubicle type
Dimensions (mm)	Width	2400	1400	1300
	Depth	4700	4300	3400
	Height	3400	2600	2750
Installation space (%)		100	53	39
Cubic volume (%)		100	41	32

Fig. 12 Rib-effects of post insulator



environment so that no dust will enter the GIS. However, still it is necessary to take eventual dust intrusions into considerations. Further, occurrence of metal particle after starting operations (due to loop current switching of the associated disconnecting switch) must also be taken into considerations. Fuji Electric has ribbed insulators throughout the manufacturing since the first GIS was developed.

3.2.2 Fully earthed steel enclosure

Because of (1) better protection against internal arc, (2) machining ease and (3) better gas tightness, Fuji Electric has used steel for the material of enclosures. Further, including insulators, all enclosures covered with metal are completely earthed, featuring that there is no anticipation of electric shock or no flash-over caused by high frequency surge (generated when making earthing switch or during switching of the isolator). Further, the outer circumference of the bushing insulators is covered by metallic flange so that the epoxy portion will not be exposed to the outdoor (insulator flange shown in *Fig. 13*), and the weather resistance is high.

3.2.3 Gas tightness

Reliability against gas leakage is decided by the construction of gas seal at the flange surface, quality of O-ring and countermeasure for corrosion of the flange surface. *Fig. 14* shows the standard construction of the seal on a flange of the GIS for outdoor installation. As seen in this figure, the insulators are carefully constructed so that gas will not leak through the O-ring groove due to occurrence of rust. Fuji Electric has used the sealing construction with a single layer O-ring from the beginning, and GISs have been operated smoothly without any trouble since the deliveries. Further, the shipping release value is less than 0.2% per annum for the gas leakage.

3.2.4 Without using air piping

Fuji Electric's GIS hydraulically operates the associated circuit breakers and operates the isolator and earthing switch with electric motors. Futther, with Fuji Electric's GIS installed in a substation, no air piping is needed, realizing reduction of facility cost. In comparison with the GIS which uses a pneumatically operated circuit breaker, the GIS which uses a hydraulically operated circuit breaker is more advantageous in the minum maintenance and harmonization with environment (low noise).

3.3 Delivery experience

Having the above introduced features, Fuji Electric's

Fig. 13 Construction of bushing insulator

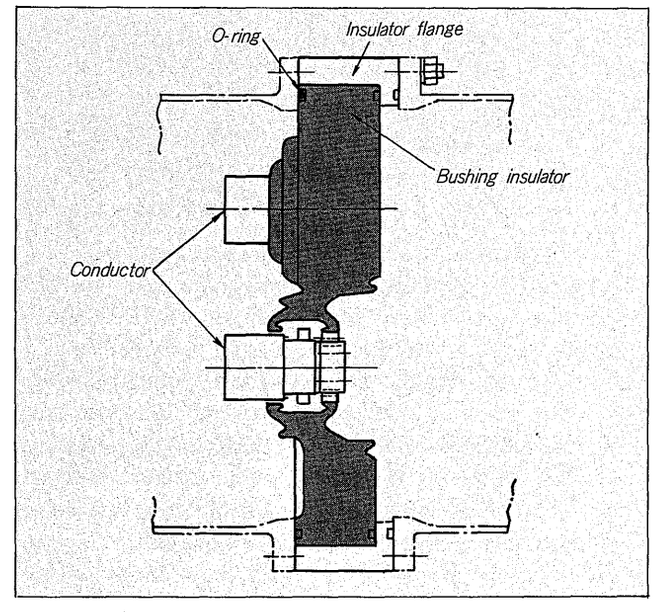


Fig. 14 Gas seal construction at the flange of a GIS for outdoor installation

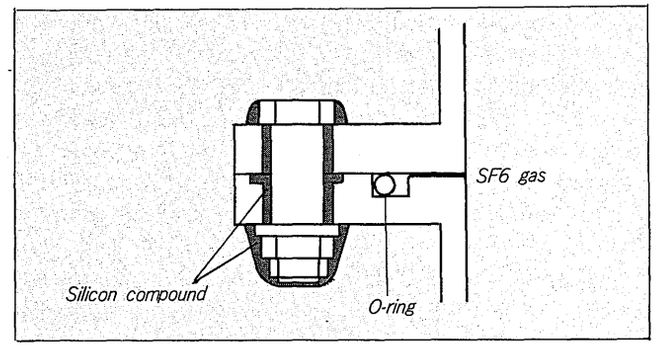
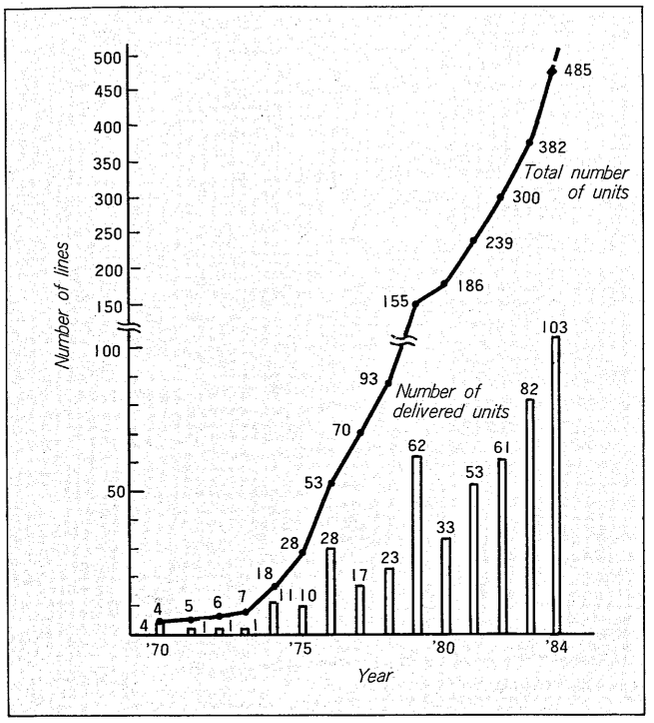


Fig. 15 Accomplishment of GIS delivery



GISs are delivered to the customers more and more steadily, Since the first GIS was delivered to the customer in 1970, including those to be delivered within 1984, the following deliveries have been

72.5 kV class	:	353 bays
123 ~ 170 kV class	:	132 bays
Total	:	485 bays

Fig. 15 shows the particulars by each fiscal year.

As for the places where the GISs have been delivered, domestically, they have been delivered to Hokkaido to Okinawa, and in overseas, they have been delivered to allover, namely, Middle East, Australia, South East Asia, South America, etc. Further, the installed places vary from an indoor substation in the middle of big city to an outdoor substation where the environmental conditions are severe. Typical examples of the GISs for outdoor installation exposed to severe environmental conditions are:

(1) Geothermal power plant which requires gas resisting specifications
(2) Substations in coast where GISs are exposed to salt contaminations
(3) Substations in cold areas where GISs are exposed to freezing and heavy snow

Even in this kind of places, Fuji's GISs have recorded the outstanding performance. Especially, for the GISs installed in a geothermal power station, countermeasures for corrosive gas such as gas sulfide are important, and in this respect, the hydraulic operating mechanism is optimum for the circuit breakers.

Recently, the GIS users tend to replace the already existing conventional type switchgears. The reasons will be

Fig. 16 145 kV GIS to be delivered into Middle East

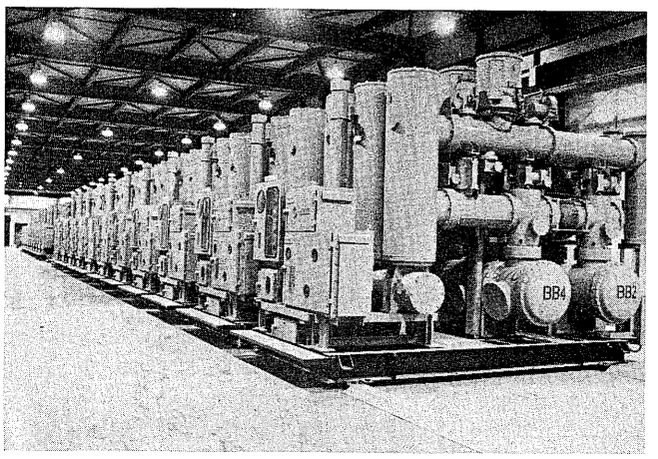
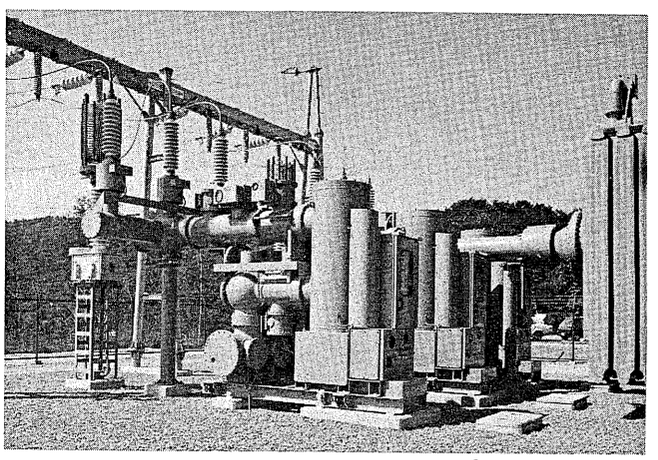


Fig. 17 72.5 kV GIS for geothermal power station



(1) to secure space for additional installation of bays, (2) to improve maintenanceability and reliability of the equipment.

4 POST SCRIPT

Mainly, this paper outlines the foot-marks along which the Fuji Electric's gas circuit breakers and GISs have grown. The matters which must be further developed are:

(1) Practical external diagnosis of GIS
(2) Further improved maintenance-free feature
(3) Improvement of handling ease

However, throughout the entire phases, the most important matter is the reliability improvement, and to achieve this target, we will continuously move forward. To have higher and true supports by the users, Fuji Electric will further concentrate its efforts in adding a higher reliability to the circuit breakers and GIS introduced in a separate article.