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FUJI FULL INSULATED METALCLAD HIGH VOLTAGE SWITCHGEARS

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I. INTRODUCTION

1. Increase in Density of Power Requirements

Power requirements are increasing steadily year by year and the problems in respect to the magnitude of these demands have already changed into problems concerning density. In other words, population increases which are tending to concentrate in large urban centers not only mean a concentration of the means at production in cities but also results in a large expansion of consumer industries in the cities and their suburbs. Because of the distribution of these requirements, the density of power demands increases and this presents an important problem in respect to power supply.

2. Need for More Compact Substations

The need for much more compact substations and easier construction of substations in cities where land space is a problem has become pressing. With the great advances made in technology, the air insulation formerly used can be eliminated and it has become possible both technically and economically to use SF_6 gas insulation. This article will introduce a fully insulated metalclad switchgear which was developed in accordance with social requirements and technical innovations.

The main requirements of the fully insulated metalclad switchgear is that it be compact in order to save space. Much greater reliability is also required in power networks because of the widespread use of camputers, the popularity of electronic medical equipment and the construction of high buildings. Therefore, the second most important requirement is that the substation be fully protected against the influences of salt, dirt, lightning, storms, floods, birds and animals.

Because of manpower shortages due to the shift of the labor population to tertiary industries and the great increases in wages, it is necessary that construction of the substation be simplified in respect to the equipment use, maintenance and checking after construction be easy and the maintenance intervals be as long as possible in order to save labor. The fully insulated switchgear fulfills all three of these requirements.

II. RATINGS AND FEATURES

1. Ratings

The shape and dimensions of the switchgear as shown in *Figs. 1* to *3*. For details of the switching units, refer to section **III**.

The various ratings are as follows.

1) Main ratings of switching unit

Type : VH 930

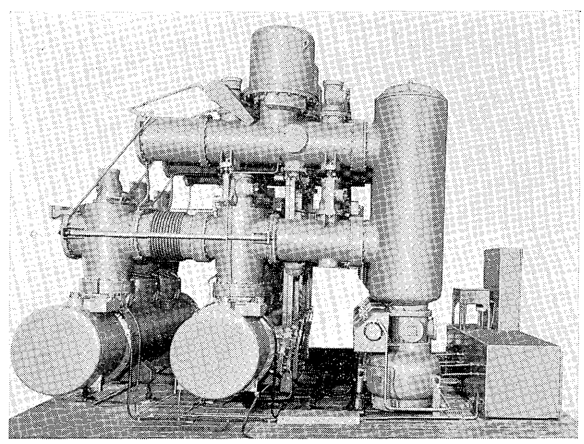

Fig. 1 Fully insulated metalclad high voltage switchgear

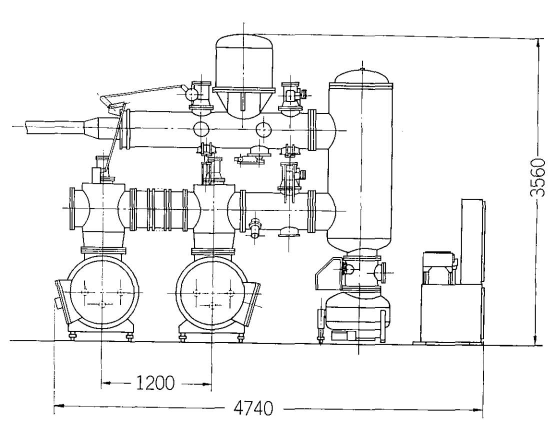

Fig. 2 Outline dimensions

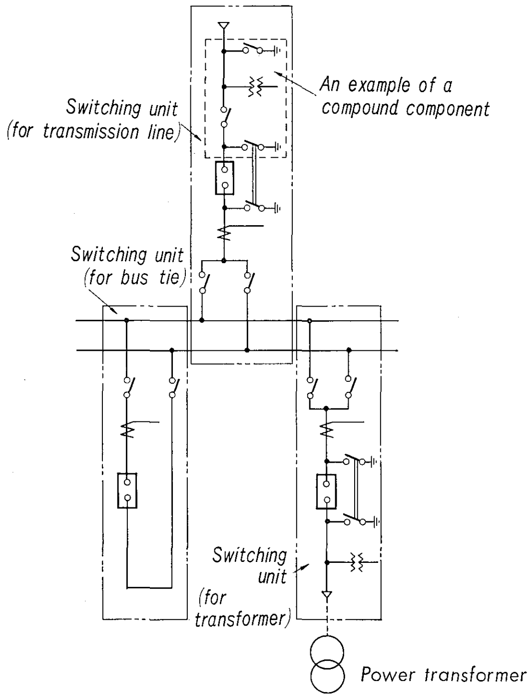

Fig. 3 Skeleton diagram

External dimensions:
 2.4 × 3.5 × 4.5 (m)
Weight: About 12 tons
Nominal voltage: 66/77 kV, 110 kV, 154 kV
Rated current: Bus line 1,600 A/2,500 A
 Others 1,200 A/2,000 A
Interrupting capacity:
 3,500 MVA, 5,000 MVA, 7,5000 MVA
Kind of insulation:
 SF_6 gas pressure 1.3 kg/cm^2·g (20°C) and 3.1 kg/cm^2·g (20°C)

2) Main ratings and numbers of components

(1) Bus capsule
Type: Three conductors in a common steel pipe insulated with SF_6 gas
Number: 2 sets
Rated voltage: 72/84 kV, 120 kV, 168 kV
Insulation class: No. 70, No. 100, No. 140
Rated current: 1,600 A/2,500 A
Rated short time current:
 28.1 kA

(2) Circuit breaker
Type: 3-pole single throw puffer system or double pressure system
Number: One
Rated voltage: 72/84 kV, 120 kV, 160 kV
Insulation class: No. 70, No. 100, No. 140
Rated current: 1,200 A/2,000 A
Rated frequency: 50/60 Hz
Rated interrupting capacity:
 3,500 MVA, 5,000 MVA, 7,500 MVA
Rated short time current:
 28.1 kA
Rated interrupting time:
 5 cycles, 3 cycles
No-load closing time:
 0.15s
Operation system: Compressed air closing, pressurized oil closing and spring trip

(3) Disconnector
Type: 3-pole single-throw SF_6 gas insulation type
Number: 2 of right angle type and 1 of linear type
Rated voltage: 72/84 kV, 120 kV, 168 kV
Insulation class: No. 70, No. 100, No. 140
Rated current: 1,200 A/2,000 A
Rated short time current:
 28.1 kA
Operation system: Motor drive

(4) Current transformer
Type: Toroidal core type insulated with SF_6 gas
Number: 3 units
Current transformation ratio:
 400,200/5 A
Burden: 40 VA
Accuracy class: 1.0 class

(5) Potential transformer
Type: Wound type insulated with epoxy mold and gas
Number 3 units
Rated voltage: 66, 77/3 kV $110/\sqrt{3}$ V
 100/3 kV $110/\sqrt{3}$ V
Burden: 200 VA
Accuracy class: 1.0 class

(6) Working grounding switch
Type: 3-pole single-throw insulated with SF_6 gas
Number: 2 units
Rated voltages: 72/84 kV, 120 kV, 168 kV
Insulation class: No. 70, No. 100, No. 140
Operation system: Motor drive

(7) Grounding switch with making capacity
Tyae: 3-pole single-throw type insuted with SF_6 gas
Number: 3 units
Rated voltage: 72/84 kV, 120 kV, 168 kV
Insulation class: No. 70, No. 100, No. 140
Rated closing current:
 76.5 kA
Operation system: Hand spring operation system

(8) Accessories
External connectors:
 OF cable, CV cable, Overhead wire } can be attached
Separate control box:
 Pressurized oil control, gas

circulation, gas pressure monitoring, interlocking: all in one unit

(9) Lightning arrester
Type: Insulated with SF_6 gas
Nominal discharge current: 10 kA

Spark over voltage \ Rated voltage	84 kV	98 kV	140 kV
AC	126 kV or above	147 kV or above	210 kV or above
Impulse voltage (100%) or less	228 kV or less	266 kV or less	380 kV or less
Impulse voltage (0.5 μs) or less	264 kV or less	308 kV or less	440 kV or less
Switching surge spark over voltage	228 kV or less	266 kV or less	380 kV or less
Residual voltage (10 kA)	228 kV or less	266 kV or less	380 kV or less

2. Features

1) Gas techniques

The same arc extinguishing system as in the well established F-type circuit breaker[3] (SF_6 gas circuit breaker) is used. The techniques for gas insulation and sealing are identical to those used in the F-type circuit breaker. Therefore, the reliability is very high (refer to section **III**).

2) Extremely compact and economical

Because of the new units system and compound components elements as well as a rational distribution of components, it is possible to greatly reduce the area occupied. The area occupied is about 1/15 of that occupied by outdoor type switchgears and the volume occupied is about 1/7 of that occupied by the indoor type (refer to section **IV**).

3) Rational distribution of components

Earthquake resistance and safety are greatly improved because the bus lines and the circuit breakers which are the largest and heaviest components are arranged directly on the foundation part. Since steel supports are not required, the weight is less, it is easier to check and also more attractive (refer to section **III**).

4) Wide adaptability in substations

This equipment can be used with any type of line system including single, double and attendance buses. Because of the uniform design of the switching units which will be described later, it is comparatively easy to increase the number of circuits and banks (refer to section **VI**).

5) Highly practical

This switchgear is completely safe because of the foolproof sealing, grounding switch and gas pressure monitoring system. It also fulfills all of the requirements for new switchgears since it allows for savings in labor, has excellent anti-contamination characteristics and need not be checked for long periods.

III. BASIC ITEMS OF THE NEW EQUIPMENT

1. The Application of SF_6 Gas

SF_6 gas is used in this new equipment as both an insulation and arc extinguishing medium. The electrical excellence of this gas has already been described[1] [2] and will be omitted here. Only two or three simple points will be included.

Previously the main insulation mediums were liquids, especially insulating oil. This has been used successfully for a long time and will continue to be highly effective in devices such as the T-type circuit breaker which uses an extremely small volume of oil. However, in large capacity switching equipment, oil presents problems in respect to handling and fire hazards.

Air has also been used as an insulation medium, especially compressed air, as in the highly succeeful air blast circuit breakers. However, to compress air to the same degree as SF_6, more than ten times the pressure is required and the air must also be completely dry.

The other major type of insulation is solids. At present, cross-linked polyethylene cable of the 60/70 class has come into use and in the future, it should be possible to adopt the solid insulation to the 60/70 class has come into use and in the future, it should be possible to adopt the solid insulation to the 60/70 class switchgear. However at the present, for insulation of class 60 or above, SF_6 gas is considered to be a more effective insulation medium.

2. Distribution of Devices and Construction

1) Switching units

First an investigation was conducted concerning typical substations in Japan. The main methods used for connection are as shown in *Fig. 3* and include the following.

(1) Part for connection with transmission line
(2) Part for connection with power transformer
(3) Part for connection between bus line
(4) Others (connection of bus lines to lightning arrestors, potential transformer etc.)

The individual units are collected together in one device which is known as a switching unit and the various switching units are all uniform.

There are various types of bus lines including the single, double and attendance buses. These switching units have been made so that they can be used with any of these various types of bus lines and therefore they are highly effective.

All of the above points have been considered carefully and the most important points have been chosen in the development of this equipment.

2) Compound elements

Many methods must be considered when designing the switching units. The most extreme example would be where all the switching units were contained in one case. In such a case, the equipment would be very compact but it is necessary to design various types of equipment and there is a basic problem in smoothly adapting all these elements to the substation.

However, each unit can also be designed separately and combined like building blocks to form a unit. With this method, the combination of units is evry versatile but sufficient compactness is not possible and the costs of the substation are higher. In the equipment developed by Fuji Electric, the advantages of both of the above cases can be obtained by using compound component elements which are as in one case as possible for parts between the external connectors, circuit breakers and of bus lines.

3. Construction and Materials

There are two or three very important points which must be considered in the construction of a fully insulated switchgear. For the gas sealing section, the O–ring is the same as in previous models but the O–ring groove has been specially processed. The metal seal (rim joint type, flare system etc.) used previously has been eliminated and the use of a seal washer insures greater gas-tightness than ever before. With this type of sealing, leakage resulting in "a pressure reduction of 3% or less during twelve hours" as stipulated by Japanese power companies can be reduced to an extremely small fraction.

The materials used must naturally be highly resistant to decomposed SF_6 gas and the filler used for the wall bushing, support insulators and disconnector operating rod must not be quartz powder but a special material. Other materials which demand special consideration include the O–ring, high pressure gas tube (insulation tube), circuit breaker operating rod, the breaker arc resistant metal, paint, etc. The bearings are impregnated with a special alloy of lead and tetra-fluroic ethylene with a sintered layer of bronze particles. No lubricating oil is used.

A problem inherent in the fully insulated switchgear is expansion caused by temperature increases. A polygon contact is used in order to avoid symmetrical expansion between the conductor and capsule. To absorb the differences in expansion between the capsules, the base of the capsule is placed on a freely moving roller and a bellow-type flexible tube is placed between the capsules.

4. Control and Protection

1) Grounding switches

Unlike in previous models, conducting parts in this equipment are completely enclosed and therefore it is necessary to include a grounding switch. Because of the residual charge due to electrostatic induction, each of the conducting parts separated by the switch of the main circuits must have one grounding switch. There must be one switch for every bus line capsule without exception even when several are inclosed in one substation.

2) Setting the gas pressure

In order to protect the power lines, switch (excluding the grounding switches but including the breakers and disconnectors) and bus capsule are separated each other by the gas separators. Therefore, the gas system is as shown in *Fig. 4*. Although it is not shown in this diagram, circulation is also possible in order to eliminate moisture in the gas in the bus line and disconnector parts. *Fig. 5* is a pressure setting diagram. The lower limit of the gas pressure is detected by a pressure switch with temperature compensation. In the range from −20°C to +95°C over which the gas temperature can vary, the set value of the pressure switch with temperature

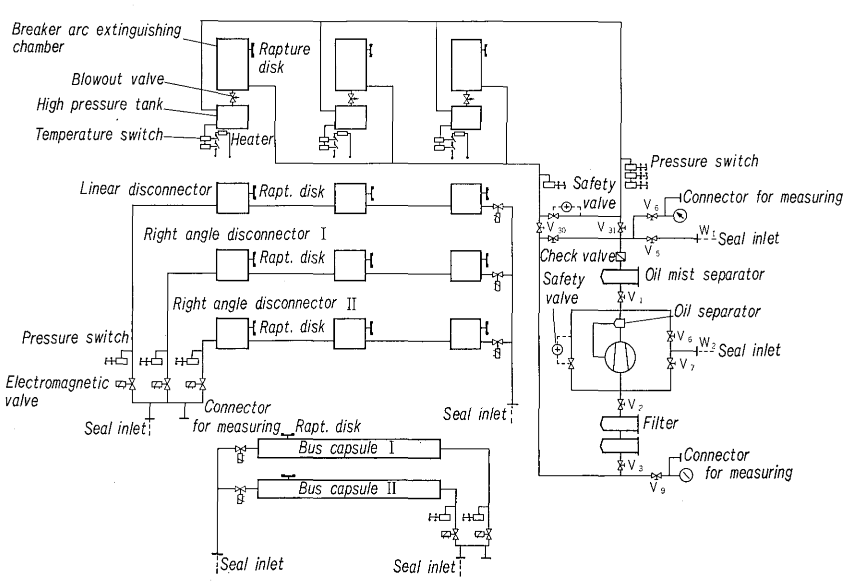

Fig. 4 Gas system diagram

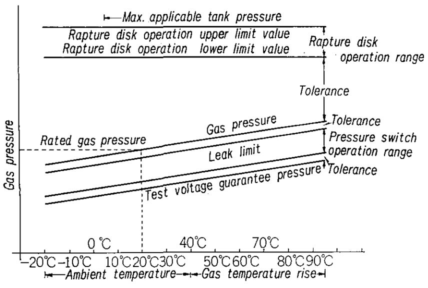

Fig. 5 **Pressure setting diagram**

compensation is determined so that the pressure needed to guarantee the test voltage is exceeded. The gas sealing pressnre is selected to be in excess of the upper limit of the working value of the pressure switch with temperature compensation. The rupture disc protects against abnormally large pressure increases. These pressure switches and rupture discs are arranged in eacg gas section.

3) Operation interlocking

Erroneous operation must not occur in any of the switches including the grounding switches. Therefore, an interlocking mechanism which differs slightly depending on the substation is arranged inside each of the switching units. However, they are all operated electrically and insure safety.

IV. CONSTRUCTION OF EACH PART

1. Bus Capsules

Three conductors are arranged together in one capsule in what is called the " three conductors in a common capsule " bus system. Compared with the system in which the three conductors are separated, the space factor is reduced considerably in this system. Since temperature rises due to iron loss can be avoided, it is not necessary to use expensive non-magnetic materials. However, there are certain disadvantages such as the large electromagnetic forces between the phases due to interrupting current and the ease with which ground faults in the bus capsule develope into interphase short circuits. To prevent the electromagnetic force between the phases, the best distribution is selected so that there is no bending moment in the epoxy resin support insulator. It is also not necessary to worry about flash faults inside the bus capsule or even flash faults between the phases because the flash fault voltage inside the bus capsule is sufficiently high in respect to the BIL. *Fig. 6* is an inner view of the bus capsule.

2. Circuit Breaker

The circutt breaker contains the same arc extinguishing chamber as used in the outdoor type SF_6 gas breaker (F-type circuit breaker). There are two

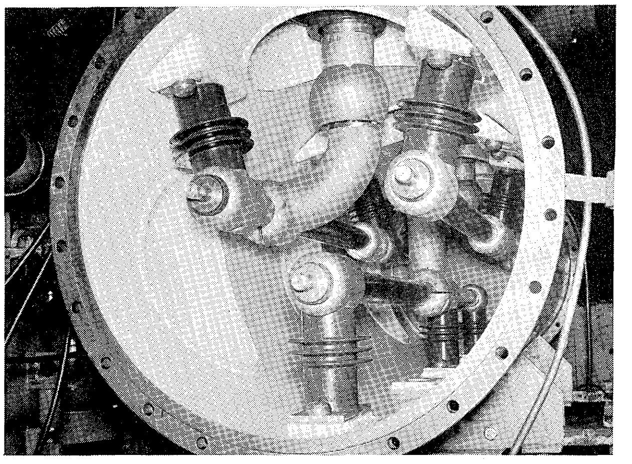

Fig. 6 **Inner view of bus capsule**

types of arc extinguishing chamber : the single pressure or puffer system and the double pressure system. The single pressure puffer system is used in cases when the nominal voltage is from 66 to 110 kV and the double pressure system is employed when there is an especially large breaking capacity between 66 and 110 kV or for nominal voltages of 154 kV. The gas sealing pressure is 5 $kg/cm^2 \cdot g$ (20°C) for the single pressure system and 19 $kg/cm^2 \cdot g$ (20°C) on the high pressure side and 3.1 $kg/cm \cdot g$ (20°C) on the low pressure side in the double pressure system. *Fig. 7* shows a sectional view of a circuit breaker using the double pressure type arc extinguishing chamber. The SF_6 gas which is blasted between the movable and stationany contacts follows a double flow system with part going up and part down. Closing is affected by a pressurized oil operating mechanism and interrupting is performed by a spring.

Two special problems which are peculiar to fully insulated switchgears are (1) it must be easy to check the arc extinguishin chamber and (2) as in the SF_6 gas outdoor type circuit breaker, it is difficult to seal the SF_6 gas which has been decomposed on contact with the arc in the breaker insulation tube and there are discharges within the capsule.

Concerning the first problem, the entire arc extinguishing chamber can be lifted out by removing the cover on the top of the capsule, taking out the one bolt which connects the chamber to the upper wall bushing and removing the pin which connects operating lever and crank via the manhole on the bottom of the capsule as shown in *Fig. 7*. The lower wall bushing is connected to the chamber by pushing the protruding rod into the tulip contact imbedded in the bushing conductor by means of the arc extinguishing chamber attachment. Since the SF_6 gas tube is inserted in its holder only with a packing, it can be removed at the same time as the chamber is lifted out. With this method, it is very easy to inspect the arc extinguishing chamber for short periods.

Concerning the second problem, a high quality

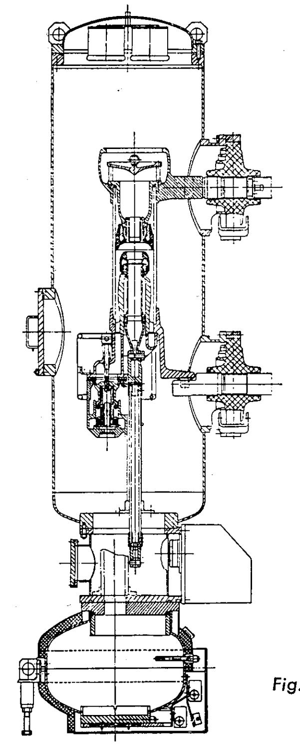

Fig. 7 Sectional view of circuit breaker

filter is arranged in the upper part of the capsule so that even if the decomposed SF_6 gas arises, it can be absorbed in a short time.

The insulation materials (wall bushing, insulation tube, high pressure SF_6 gas tube, nozzle, cap etc.) which would be most influenced by contact with decomposed SF_6 gas were investigated carefully and have been made of epoxy resin with special matetials used for the base or fillers.

Deep heaters are arranged in the wall bushings since they are long. With these countermeasures, there were absolutely no problems when a withstand voltage test was conducted after an interrupting test.

3. Disconnectors

The disconnectors used in this equipment are of two types in respect to shape: the linear type in which the current path is a straight line and the right angle type in which the current path is bent at right angles in the disconnector. In the example shown in *Fig. 2,* the linear type is used in the cable connection parts and the right angle type is used in connecting parts for the bus capsules. The linear type can also be employed in buses with three conductors in a single pipe as a section disconnector for the bus lines.

Both types of disconnector are switched by means of a motor driven operating mechanism. The three phases are connected by a link mechanism and driven by a single motor. The distance between the poles is decided in accordance with the chamber pressures of $1.3\ kg/cm^2 \cdot g$ (20°C) and $3.1\ kg/cm^2 \cdot g$ (20°C). In order to make the electric field as uniform as possible, the poles are shielded with large diameter metal spheres.

4. Transformers (PCT)

There is one grounded potential transformer in each phase of this equipment. In order to make these transformers as small as possible, they were insulated with special epoxy resin for 66/77 kV and 110 kV. Compared with the previous potential transformers and devices, the space required is very small.

The current transformers depend on the rated primary current and a through-type current transformer is installed in the capsule. As in the potential transformers, the core and windings are completely insulated against the SF_6 gas by means of epoxy resins. There is no decomposed SF_6 gas in the places where the current transformers are inserted but in order to insure complete safety, the current trasnformers are also covered with epoxy resin. It is possible to install a cable current transformer in the cable.

5. Grounding Switches

Grounding switches are arranged at both ends of the breaker. These are working switches which are motor driven. There is another type arranged at the inlet (sometimes referred to as the outlet) of the fully insulated switchgear. This type has a making capacity. The grounding switch with making capacity employs the so-called rapid cut-off operating mechanism which utilizes for making the energy of a spring which is manually put under tension during interrupting. This uses reverse switching of the operating mechanisms of former load switches.

6. Separate Control Equipment

There are separate control devices for each component and also on the front surface of the equipment. The equipment is 2,300 mm wide and it was designed so that the devices are placed adjacent their respective switching units. Maintenance, operation and looks have also been considered. The internal devices can be classsified into the following four blocks.

1) Oil pressure control device

Closing of the breaker is performed by pressurized oil. Most of the devices for this are concentrated in this block and are very compact. A schematic of this system is shown in *Fig. 8*. The oil tank is arranged on top of the separate control box and oil is supplied to the oil pressure control device via a filter. When the accumulated pressure is spent in closing the breaker, the oil pressure meter with contacts attached indicates the minimum oil pressure and the motor begins to operate. This causes the direct-coupled rotary pump to operate and the oil is supplied to the accumulator via a check valve. When the oil pressure reaches an absolute minimum, an alarm is sounded and closing can be interlocked.

The accumulator is in the form of a piston cylinder and is divided into an oil pressure chamber and a nitrogen chamber. The standard pressure is

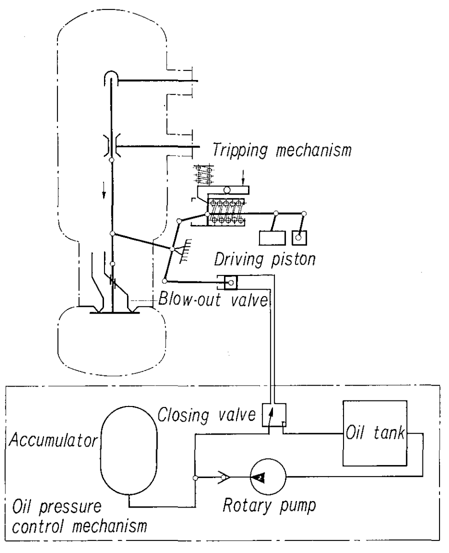

Fig. 8 Schematic diagram of oil system

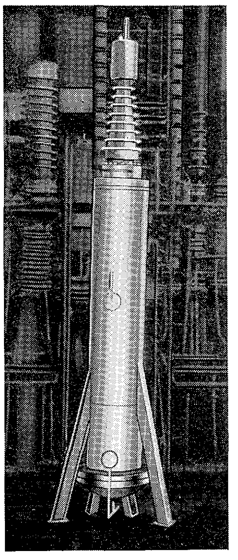

Fig. 9 Lightning arrester

200 kg/cm^2·g and operation is guaranteed in the temperature range from -25°C to $+45$°C.

The closing valve consits of a closing magnet, a retaining valve, a servo valve, a main valve and a flow detector, all of which are assembled in a single block. As a result, the piping which is usually under pressure is connected only to the oil pressure meter and there is no need to worry about oil leaks.

When the cosing signal is received, the servo valve is opened by the closing magnet and the resulting pressurized oil opens the main valve. From the main valve, oil flows to each parts of the breaker and drives the oil pressure piston inside each operating mechanism. When there is no longer any oil flow, this is detected, the pressurized oil between the piston and closing valve is discharged to the oil tank and tripping is possible.

2) Gas circulation device

Fig. 4 shows an outline of the section in which the gas which has been used for breaking is returned to the high pressure gas tank. This part is exactly the same as that in the outdoor type gas circuit breaker.

3) Interlocking mechanism

There is a so-called control box which is arranged on top of the case containing the above three devices. This box is related to the main control panel and can be altered as the customer wishes.

7. Lightning Arrester[5]

This arrester is basically the same as the widely used N_2 gas filled arrester except that it is filled with SF_6 gas. However, with this type of arrester there are certain problems which must be solved such as uniformity of the partial voltages of the series gap due to the influence of the grounding materials (metal capsule) and the penetration of SF_6 gas into the series gaps of the arrester. To cope with these problems, the potential dividing impedance was strengthened and all the gaps were arranged in one place. In order to prevent the SF_6 gas from getting into the gaps, a special type of sealing was used and all the above problems could be solved satisfactorily.

V. TESTS

1. Voltage Wisthstand Test

The voltage withstand test was performed when the equipment was completely assembled. More importahts however is the flash over test which was performed on each part separately. For these tests, the equipment was broken down into the bus lines, right angle type disconnectors, circuit breaker, current transformer, insulated operating rod, support insulator, wall bushings etc.

Fig. 10 shows a curve ih which the minimum voltage withstand values for each part are used. This therefore shows the guaranteed voltage withstand values for the whole equipment for each gas pressure. Sufficient tolerances are shown for the test voltages. It also indicates that the withstand voltage increases

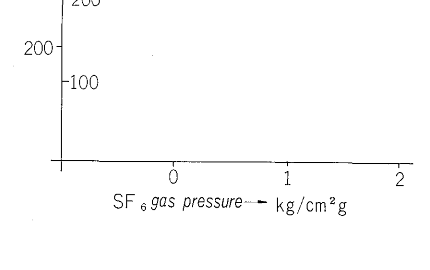

Fig. 10 Withstand voltage diagram of whole equipment

almost linearly with the pressure so that the design is suitable and there are no uneven electric fields.

2. Heat Run Test

Fig. 11 shows the results of the heat run test. When the sealing was air at a pressure of 0 kg/cm²·g, measurements were taken at currents of 600 and 1,200 A. Then the sealing was changed to SF_6 gas at 1 kg/cm²·g (rated pressure: 1.3 kg/cm²·g) and measurements were taken for a current of 1,200 A. From the test results, the places where the temperature rise was largest were the cable head connectors and the movable conductors connected to the two right angle type disconnectors. However, in each case, this rise was less than the specified value of 55°C.

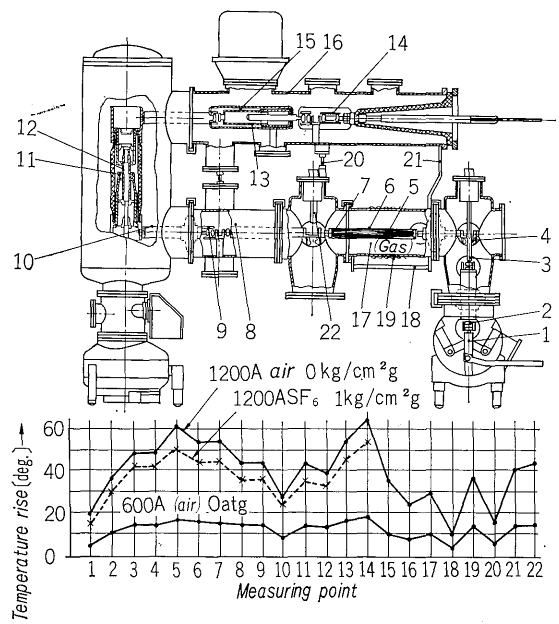

Fig. 11 Heat run test

VI. ADAPTATION TO SUBSTATIONS

1. Space Factor and Economy

The space factor depends greatly on the existing equipment, so can not be generally compared. However, the basic tendencies can be seen from a comparison of the basic skeleton. The following is a comparison of this equipment using a double bus system and previous type equipment.

Outdoor type substation	Previous equipment	This equipment
Width (m)	9.0	2.4
Depth (m)	30.0	7.7
Area (m²)	270.0 (100%)	18.5 (6.9%)
Indoor type substation	**Previous equipment**	**This equipment**
Width (m)	5.5	2.4
Depth (m)	11.0	7.7
Hight (m)	10.1	4.8
Area (m²)	61	18
Volume (m³)	610 (100%)	89 (14.6%)

When considering the economy of this full insulated switchgear, it is naturally essential to compare the land prices and construction costs for the buildings used to house this equipment because of the aims in developing this equipment. Construction costs can not be neglected in cases such as underground substations especially.

2. Adaptation to Various Bus Systems

As was described befare, the components have been so arranged in this equipment that it can be used with any bus system. The results of this feature are evident from *Fig. 12*. This figure contains examples of the most basic switching units for transmission lines but exactly the same construction is

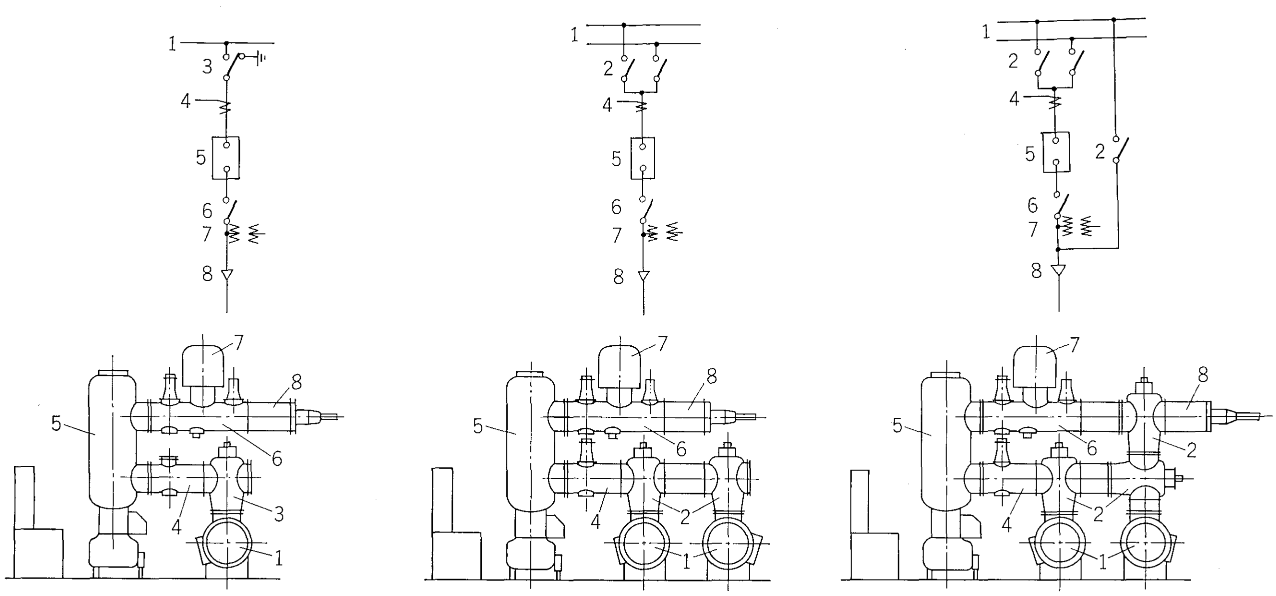

Fig. 12 Application in various bus systems

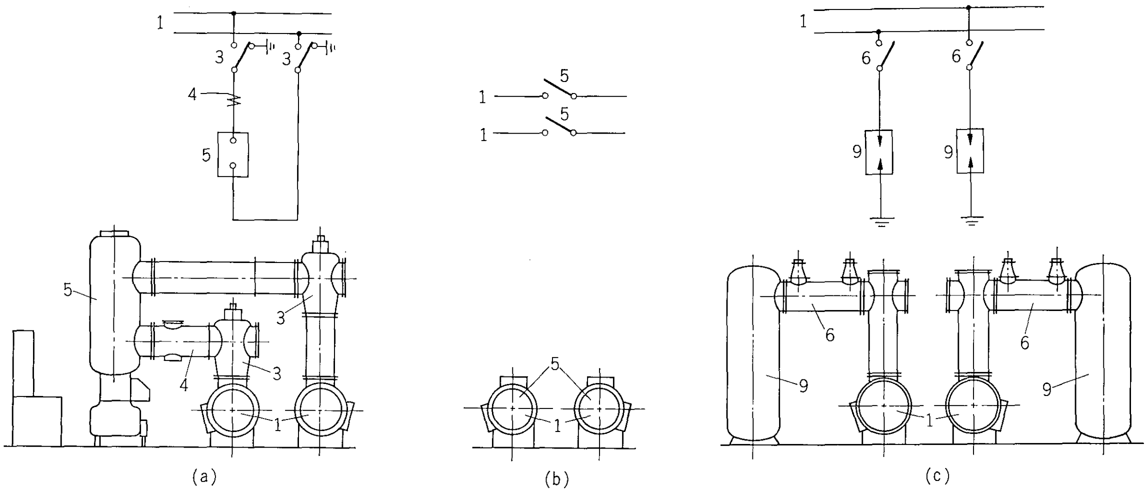

Fig. 13 Some examples of special swichgear units

possible in units for transformer feeders and bus tie. The main parts are all common in such cases.

In addition, other bus line systems such as the attendance bus and ring-shaped bus can be applied. If slight alterations are possible, 1.5 and 2 breaker systems can also be used.

3. Special Switching Units

Until now explanations have centered mainly around the basic switching units for transmission lines. However, two or three other special switching units are required when assembling all of the substation equipment. In principle, exactly the same type of construction can be used for these units.

The switching unit for the transformer can be the same as that for the transmission lines or it can look exactly the same from the outside with only the linear type disconnectors and potential transformer omitted.

The bus line switcning unit can be constructed as in *Fig. 13* (*a*). The external dimensions are exactly the same as the basic type and the positions related to the circuit breaker and bus line are also the same as in the basic type so that maintenance and looks can be improved. The bus line section disconnector can be used inside the bus capsule as shown in *Fig. 13* (*b*).

A typical auxiliary switching unit is like that for the lightning arrester as shown in *Fig. 13* (*c*). The lightning arrester is placed in an SF_6 gas tank which looks just like that used for the circuit breaker. The positions related to the bus capsule resembles that of the circuit breaker. It is also possible to construct units for use with the bus line potential transformer etc.

VII. CONCLUSION

The fully insulated switchgear described above has three main features: it is compact, highly reliable and labor saving. It is clear that these are the switchgears of the future. On the basis of this knowledge, Fuji Electric will continue to endeavor to fulfill customer expectations.

References

(1) Izeki, Ohara: Fuji Electric Journal 42 No. 3 (1969) (In Japanese)
(2) Izeki, Ohara: The Journal of the Institute of Electrical Engineers of Japan 88 1134 (1968)
(3) Saijo, Kokubo, Kawabata: Fuji Electric Journal 42 NO. 3 (1969) (In Japanese)
(4) Saijo, Nishino, Kishida: 1969 Combined Meeting of Four Electrical Societies of Japan 746
(5) Miyagawa: 1969 Meeting of the Tokyo Section of the Institute of the Electrical Engineers of Japan