7.2 kV SF_6 Gas-Insulated Switchgear

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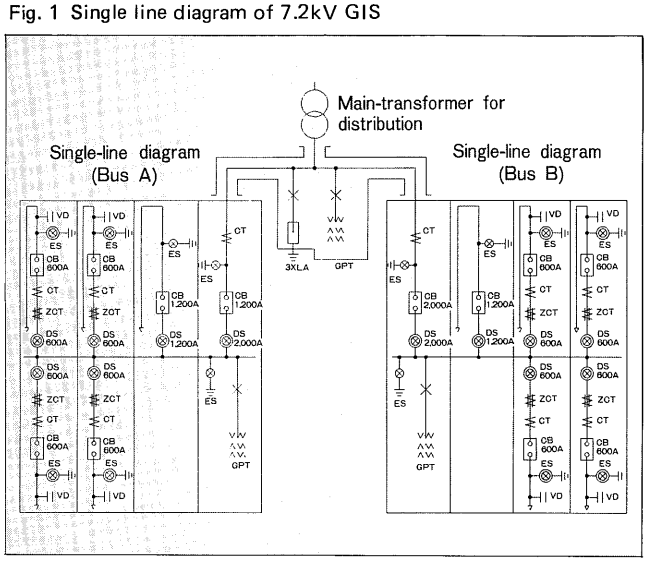
1. Introduction

Air is the main insulation medium for medium-voltage switchgear (3.6 to 36 kV) from the economical and construction point of view. However, an SF_6 insulation medium is more reliable and SF_6 gas-insulated switchgear is smaller and easier to maintain than comparable air-insulated switchgear. These advantages of SF_6 gas-insulated switchgear can meet the recent demand for reliability improvement, manpower saving for maintenance and inspection and reduction in substation areas due to difficulty in substation site acquisition.

Therefore, Fuji Electric is developing SF_6 gas-insulated switchgear as medium voltage switchgear. We have recently developed 7.2 kV gas-insulated switchgear (GIS) in cooperation with Chubu Electric Power Co., Inc. This equipment aims to prevent decreases in insulation resistance due to moisture and dust which are harmful to air insulation systems. It also aims to prevent faults caused by small animals. The technologies used to develop this new, compact equipment allow manpower to be reduced during maintenance and inspection work, and reliability to be improved. The 7.2 kV GIS is introduced below.

Fig. 1 Single line diagram of 7.2kV GIS



2. Outline of Gas-Insulated Switchgear and Control Unit

The ratings of the newly developed 7.2 kV GIS are shown in **Table 1**. The single line diagram and layout drawing (plan) are shown in **Fig. 1** and **Fig. 3**, respectively.

2.1 Features

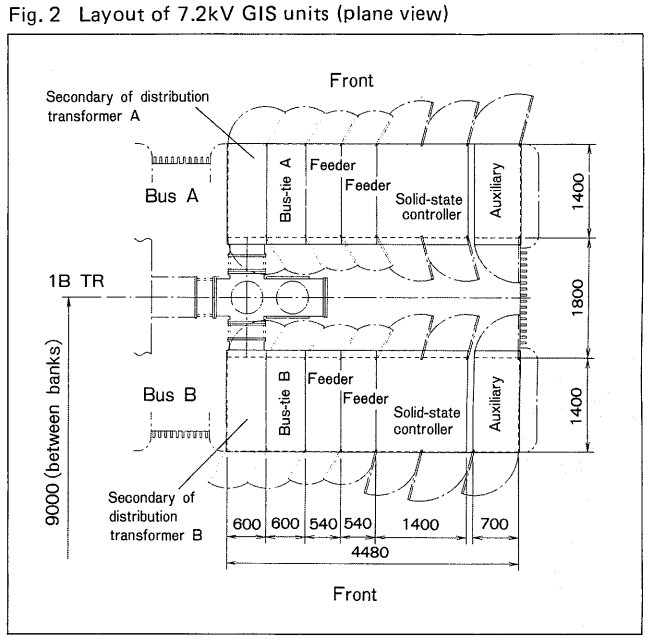
The features of the equipment are as follows.

(1) Manpower saving during maintenance and inspection work

Table 1 Ratings of the 7.2kV GIS

Rated voltage		7.2kV
Rated insulation level		6A
Rated frequency		60Hz
Rated current	Main-bus	2,000A
	Branch-bus	600/1,200/2,000A
Rated short time withstanding current		12.5kA, 2s
Rated SF_6 gas pressure		0.05MPa (20°C)

Fig. 2 Layout of 7.2kV GIS units (plane view)



Greasless, oiling-free and completely solid-state control circuits are used. Further, a trend monitoring system for gas pressures and operation frequencies, and self-monitoring functions which monitor circuit disconnections and equipment malfunction are provided in the equipment. Therefore, significant manpower saving during maintenance and inspection.

(2) Reduced dimensions and construction time

The dimensions of the switchgear can be reduced by about 50% (compared with those of conventional switchgear) by adopting a gas-insulated system and a two-tiered structure for circuit breakers. This equipment can be directly connected with a transformer. Therefore, substation buildings sizes, construction periods, and costs can be reduced because the new, compact switchgear units are designed to be connected together to form switchgear assemblies, which can be easily transported and installed.

(3) Improvement in reliability

Equipment reliability is improved by simplifying the circuit breaker operating mechanism and eliminating parts requiring grease. The circuit breaker (CB), disconnecting switch (DS) and earthing switch (ES) are designed as modules, which can be easily removed from switchgear. CB-ES modules are independent gas vessels. Therefore, repair time can be shortened during accidents and emergencies.

(4) Improvement in reliability of the power supply

When transformers fail, loads can be evenly distributed to banks because banks are star-connected through bus-tie CB units. Furthermore, fault locators are provided so that, when internal faults occur, they can be located quickly and operations resumed promptly. Thus, the reliability of the power supply is enhanced.

2.2 Configuration

Every bank is equipped with one fault locator and one auxiliary unit. Every half bank consists of one incomer, one bus-tie, one solid-state controller and two feeder units. A maximum of three banks can be connected to each other with cables through their bus-tie units.

3. Gas-Insulated Switchgears (GIS)

Besides air insulation systems, gas-insulated systems, solid insulation systems, and semi-solid insulation systems are possible. Among these, gas-insulated systems have been adopted because they excel in withstanding environmental conditions, fault location and preventive maintenance, and also because gas is used for all substation equipment. New technologies developed during the manufacture of GIS were used to develop to improve the reliability of CB-ES and DS modules.

3.1 Construction outline

The 7.2 kV GIS is shown in **Fig. 3**, and the cross section of a representative feeder unit is shown in **Fig. 4**. The operating mechanisms are arranged on the front and the cable connectors on the rear. The main circuit within

Fig. 3 Internal view (front view) of 7.2kV GIS units

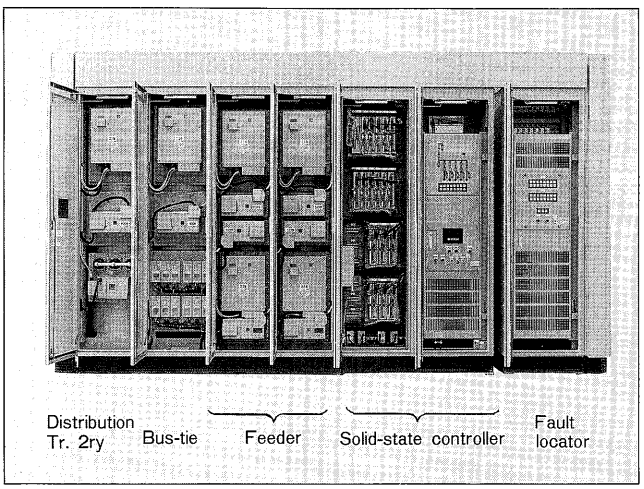


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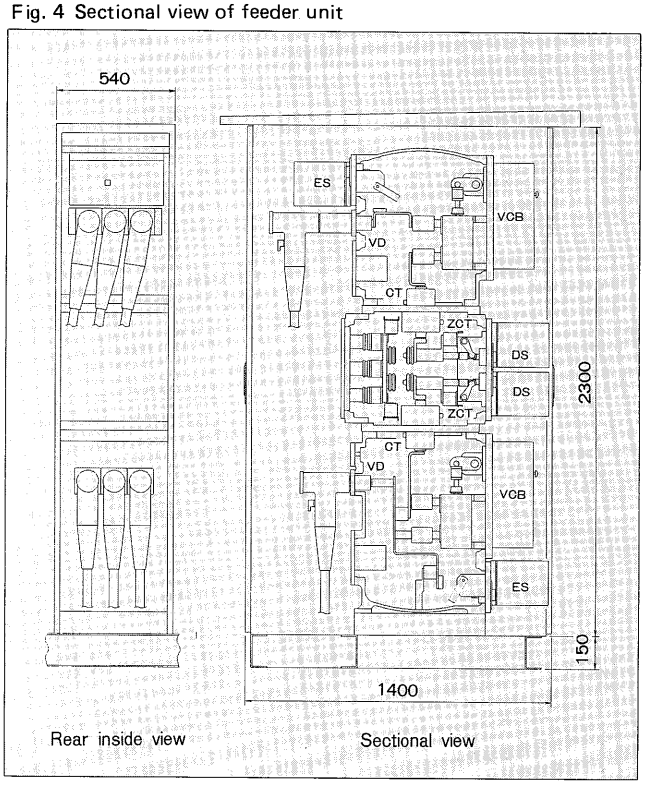
Fig. 4 Sectional view of feeder unit



the gas vesseles of each GIS bank is isolated from the outside.

(1) Main apparatuses

Vacuum circuit breakers are adopted because they do not allow a gas pressure to rise or SF_6 decomposed gas to be generated by an arc when circuit breakers open or close. They are very safe.

An electromagnetic operation system is adopted for operating CBs, to simplify their mechanism and reduce the number of parts. A DS is a finger-contact type which prevents generation of metal power in the gas, thereby, the reliability of the equipment is improved. An ES has rotating blades. these apparatuses (CB, DS and ES) form modules, in which the main circuit parts are sealed in gas. Their

operating mechanisms are externally installed and can be easily detached. Epoxy instrument transformers (GPT, CT and ZCT) are adopted because they are compact. They are also sealed in gas.

(2) Cable connectors

Cable connectors form stress cones made of ethylene-polyropylene rubber and consist of slip-on cable connectors. Therefore, live parts are not exposed. In order to allow test bushings for testing power cables to be easily attached, cable connectors are T shaped. The surface of cable connectors forms a grounded layer and therefore it is very safe.

(3) Vessels

Feeder units are of two-tiered construction with each CB-ES module positioned above and below a common busbar-DS module. CB-ES modules are independent gas vessels. Therefore, the whole CB-ES can be replaced. Vessels are made of aluminium casting and, therefore, they are light and easy to machine. Vessels are designed to withstand increases in pressure caused by an internal short circuit fault until a back-up circuit operates. However, considering the possibility that a back-up circuit breaker does not operate, gas relief vents are provided to allow pressure to be released to the DS-busbar module.

3.2 Advanced functions

SF_6 gas-insulation systems not only allow the equipment to withstand environments but also reduce its dimensions. In addition to these advantages, the following advanced functions are provided.

(1) Greaseless and lubrication-free operating mechanisms

To insure smooth operation of the operating mechanism by preventing malfunction caused by yawning and grease hardening and minimizing troubles, the operating mechanism of the circuit breaker is simplified by eliminating a trip free mechanism. The reliability of the operating mechanism is also enhanced by applying an optimum surface treatment to the mechanism so that it does not require greasing.

Moreover, motor operated, greaseless mechanisms except for speed reduction mechanisms for the DS and ES are applied with a new surface treatment (such as compound plating) which allows them to resist abrasion and be more reliably lubricated. Thus, the amount of maintenance work is reduced by improving operation reliability, reducing trouble and greasing.

(2) Automatic monitoring functions

The following automatic monitoring functions have been added to this equipment.

(a) Monitoring of apparatuses (DS and ES) to detect jamming and non-operation
(b) Constant monitoring of the number of operations
(c) Detection of leakage from vacuum interrupters by using voltage detectors which monitor voltages on three phases
(d) Monitoring of operation and interlock magnet coils

(3) Optical switches

Optical limit switches are adopted as auxiliary switches in the operation mechanism and position sensing limit switches. They reduce the possibility of problems caused by imcomplete contact making and entry of noise into the control circuit.

(4) Remote control

Remote control by motor operating mechanisms is possible. Therefore, a visit to a substation is not required for operating DS and line ES.

4. Solid-State Controller

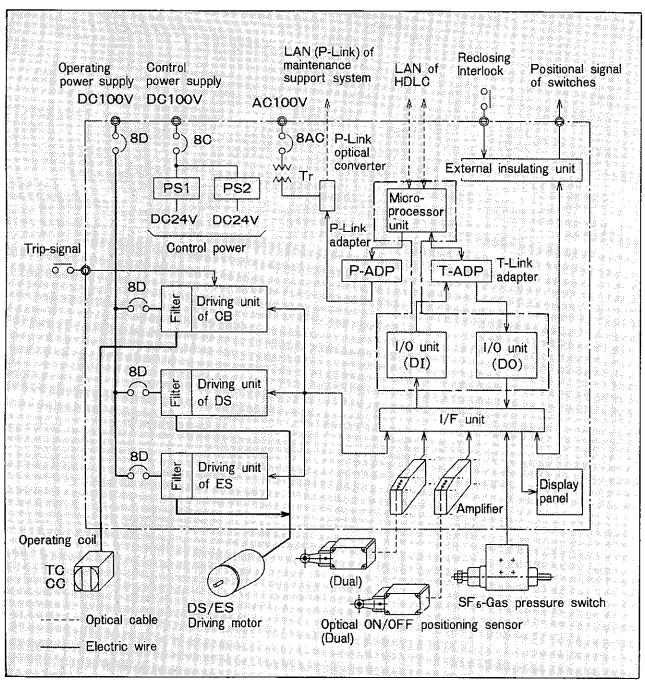
This equipment was put into use as a controller for 7.2 kV GIS based on the results of research and develop-

Table 2 Brief description of functions of solid-state controller

Item	Content
Switchgear control	(1) Selective control to prevent multiple selection of operations (2) Judgement of interlock conditions (3) Locking of control based on various kinds of fault information (4) Switchgear operation control
Automatic monitoring	(1) Constant monitoring –Monitoring of open-close positions of circuit breakers and switches –Self diagnosis of open-close position sensors, Mutual diagnosis –Voltage detection based on VD information and monitoring of leakage from vacuum circuit breakers –Monitoring of alarms such as gas leakage and MCCB tripping –Monitoring of wire disconnections in switch-gear control circuits and short circuiting in driving unit circuits –Checking of input information by detecting discrepancies in dual DI information –Recording of fault information
Maintenance support	(1) Accumulation of number of switching operations (2) Monitoring of switching characteristics (tripping and closing times)
Display	(1) Display of statuses of circuit breakers and switches (30S) Statuses are displayed on mimic buses (2) Fault indication (30F) Displayed by grouped fault indicators and 7-segment fault indicators
Interface with other equipment	(1) Connection through optical systems –Upper control units: Optical RS-232C/HDLC system (9,600 bps) –Maintenance supporting unit: Fuji's optical P-Links (5 Mbps) (2) Connection through contacts –Protective devices: Trip, Auto-reclosing, Pallet signals –Between banks: Conditions for interlocking with other GIS

ment on contactless controllers for GIS which have been conducted by Fuji Electric in cooperation with Chubu Electric Power Co., Inc. Contactless controllers not only improve reliability of contact making but also provide highly reliable performance and advanced functions because automatic monitoring and display functions and a LAN coupling interface can be provided. The functions are shown in **Table 2**.

Fig. 5 System composition of the solid-state controller



4.1 System configuration

Figure 5 shows the system configuration. The hardware unit consists of a programmable controller (PC) for processing, controlling equipment comprizing driving units for operating circuit breakers and switches, open-close position sensors and power supply units, and monitor displays (30F and 30S). By adding external isolation units, isolation transformers and filter units to the above hardware units, the insulation capability and noise resisting capability of this system are enhanced. Solid-state circuits are used in all circuits except for input-output isolation units. Therefore, this system has much higher contact making reliability than the conventional counterpart.

4.2 Fail-safe operation

In the switchgear control, prevention of misoperation output and mis- or non-operation against trip commands is extremely important. The equipment has the following fail-safe operation.

(1) Operation and driving circuits are dual and connected in series.

(2) Tasks of software are separated and memory areas are divided in accordance with the hardware units connected in series.
Even if misoperation or damage occurs in one of the systems, the other system works as a stopper and prevents misoperation as long as it is healthy.

(3) Trip signals are directly input to the trip circuit of the driving unit without allowing it to pass the PC

Table 3 Items for insuring high reliability

Measures taken	Applied system	Remarks
Driving unit	Dual and parallel systems	Prevention of mis- or non-operation, applied to trip circuits
	Dual and series systems	Series connection of logic circuits and elements in output units
	Constant monitoring	Monitoring of short circuit faults in elements in output units
	Automatic inspection	Checking of operation of elements in output units by giving inspection commands (simulation)
Switchgear operation circuit	Constant monitoring	Monitoring of trip coils, closing coils & wire disconnections in operating motors
Position sensors for circuit breakers and switches	Optical systems	Improvement of contact making reliability and noise withstanding capability
	Self diagnosis	Constant monitoring of discrepancies between main output and monitor output
	Mutual diagnosis	Sensors for closing and opening are independently provided. Monitoring of discrepancies of output between sensors
	Dual circuits (CB)	Corresponding to dual and parallel tripping circuits
Inter lock signals Auto reclosing signals	Dual DI systems	Constant monitoring of discrepancies of dual signals
	Separation of DI boards	Fail safe detection of discrepancies in printed circuit board abnormalities and damage
Input signals	Repeated reading of DI	Improvement of noise withstanding capability
DO for driving unit	Separation of DO boards	Separation of DO boards for operation commands corresponding to driving circuits connected in series
PC	Separation of tasks and memories	Separation of software corresponding to driving circuits connected in series and separation of DC boards
	RAS function	Self diagnosis of PC
	Watch dog timer for external hardware	Monitoring of pulses externally by giving DO output of cyclic pulses. Diagnosis of PC

(4) Trip circuits are dual and parallel including separation and dual trip circuits are provided so that mis- or non-operation may not be caused by trip commands when the PC fails.

The entire system of the equipment has been made highly reliable by applying reliability improving techniques employed in digital protective devices as shown in **Table 3**. Automatic monitoring functions include constant monitoring, automatic inspection, self diagnosis and mutual diagnosis.

4.3 Dielectric strength and resistance against noise

The driving unit itself can withstand a lightning impulse voltage of 4.5 kV, and resist a rectangular pulse noise of 1 kV and attenuated oscillation wave noise of 3 kV. Furthermore, the combination of external isolators, isolation transformers and filter units provides the equipment with an impulse voltage capability of 7 kV and the same level of noise resistance against rectangular waves and attenuated oscillation waves that protective relays have.

4.4 Advanced functions

(1) Automatic monitoring functions insure high reliability of the equipment and can take the place of maintenance personnel who inspect and monitor the control unit. Labor saving for maintenance and inspection of the control unit can be achieved.

Remote monitoring is possible by sending information to the maintenance support terminal unit through a LAN when an abnormality occurs.

(2) 7-segment fault indicators can display the details of 231 items of faults for the one half bank by coding the details of faults. A retrieval function is also provided so that the history of 16 faults can be retrieved. Detailed information regarding inital judgements and actions to be taken can be offered.

4.5 Components of the system

(1) Digital controller

The HDC-500, a higher level controller in the MICREX-F series, is used as a digital controller. The advanced functions of the HDC-500 can achieve rapid processing and perform as an interface for LAN coupling required for task separation and switchgear control.

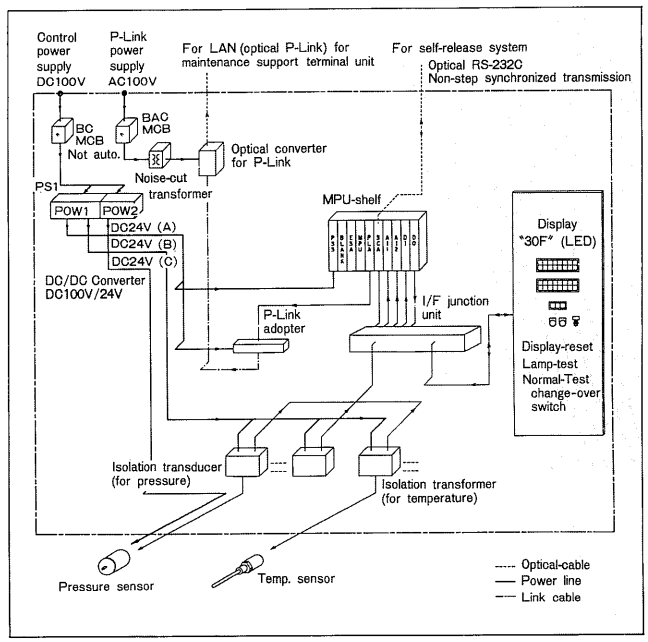
(2) Driving units

The series connection of driving units insures fail safe operation. Moreover, their automatic inspection functions can detect short circuit faults and wire disconnections which may occur in not only the logic circuits but also the other circuits. The output unit consists of pulse transformers and power MOSFETs which simplify insulation between the power supply and signal circuits and the circuits.

(3) Open-close position sensors

Optical limit switches, which can insure excellent contact making and resist noise, are used. They are provided with not only a main output but also an output for monitoring which enable self diagnosis of them by comparing both outputs.

Fig. 6 System configuration of the fault locator



(4) Power supply unit

The power supply unit can tolerate an input variation corresponding to the circuit breaker trip circuit voltage fluctuation range of DC 65 to 125V. It has the same dielectric strength and resistance against noise as protective devices.

(5) LAN

The HDLC system, which is expected to be used for power plants and substations in future, is used for connecting the equipment with the upper controller. P-Link systems, which can transmit a large amount of data at a high speed, are used for connecting the equipment with the maintenance support unit. In both systems, optical transmission systems with excellent noise resistance are employed.

4.6 Controller unit

This controller unit is an outdoor panel connected to switchgear units to form a switchboard. This unit employs a natural cooling system because cooling equipment may fail. The arrangement of components is designed so that air can constantly flow inside it. Sun shades are provided to its door and top roof to reduce the effect of sunlight and limit the temperature rise inside it.

Moreover, components are arranged in accordance with voltage circuits to protect them against surges caused during circuit breaker and disconnecting switch opening and closing, and noise from outside. Wiring routes are separated, mounting fixtures of components are insulated, metal ducts are used to prevent the entry and transmission of noise and surges.

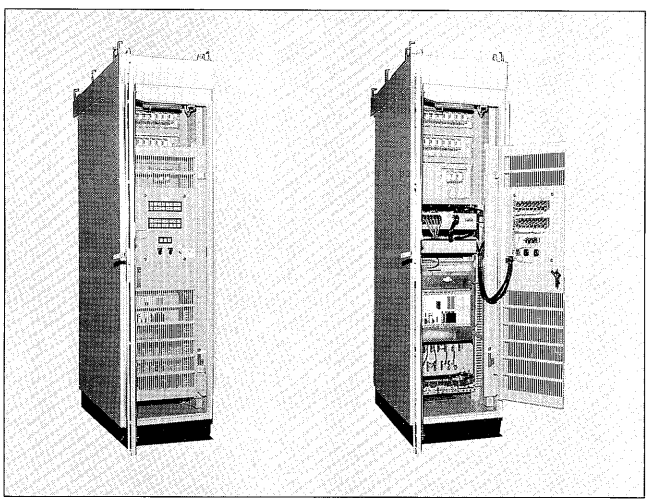
5. Fault Locator

In order to enhance the reliability of power supply, prompt resumption is required to shorten an outage period

Table 4 Brief description of fault locator

Item	Outline of function
Fault locating	–15 gas filled conpartments searched for short circuit faults –Detection and location of fault points with gas sensors sensing pressure increases caused by short circuit faults –Minimum gas pressure detected by a sensor is determined by the minimum short circuit current and fault duration
Detection of pressure relief vent operation	Detection of pressure relief vent operation by monitoring the gas pressure increases in the gas filled compartments adjacent to the compartment where a short circuit fault has caused a pressure relief vent to operate.
Monitoring of gas pressure	Gas monitoring by detecting abnormal gas pressure increases caused by temperature rise and gas pressure decreases by gas leakage –abnormal gas pressure increase: Detection of a gas pressure higher than the gas pressure at the highest permissible gas temperature –abnormal gas pressure decrease: Detection of a gas pressure lower than a set alarm pressure caused by gas leakage –slow leakage: Detection of a gas pressure decrease trend and a leakage rate greater than a set value –sudden gas pressure decrease: Detection of a gas pressure when a gas pressure decreases beyond a set value within a few minutes
Fault indication Data transmission to higher level system	–Gas pressure values (corrected by temperature) and vessel temperature values are transmitted to the maintenance support terminal unit. –Besides displaying faults (30F) on site, the contents of abnormalities are transmitted to higher level units when abnormalities are detected.

Fig. 7 External view of the fault locator



if a fault should occur. Therefore, early detection and location of faults is important. The fault locator detects faults such as short circuiting and operation of pressure relief vents and locate them based on the information given by gas pressure sensors. One fault controller is provided for one bank.

5.1 Components of this system

Figure 6 shows the system configuration. Signals from temperature sensors attached to the gas vessel of CB-ES modules and pressure sensors (strain gauge type) attached to each gas filled compartment are sent through a converter to the digital controller which monitors gas density by correcting gas pressures based on temperatures. Various logical judgements are conducted to detect faults. Fault detection information and data on gas pressures are sent to higher level unit (automatic resuming unit and maintenance support terminal unit) by optic signals.

5.2 Functions and construction

The functions of the locator are briefly given in **Table 4**. The appearance is shown in **Fig. 7**. Because the locator is installed outdoors, sunshades and heat insulating material are used to limit temperature rises. Like the solid-state controller, the locations of de-humidifiers and power units (heat source) are carefully determined. The arrangement of each component, wiring routes and grounding methods, protection against entry of noise from external cables are also carefully considered.

6. Conclusion

In this paper, the construction and function of the 7.2 kV GIS already delivered to our customer were introduced. This equipment is designed to meet the demand for highly reliable, maintenance and inspection free, and compact equipment and expected to be widely used. We at Fuji Electric will continue to make efforts to apply new technologies to produce the equipment with more advanced functions.

Finally, we thank Chubu Electric Power Company. Inc. and all people concerned for their assistance without which this equipment could not have been realized.