〈Case Study〉

Substation and Power Distribution Equipment and Electric Railway Facilities Supplied for Tohoku and Kyushu Shinkansen Lines

Projected Shinkansen Line Plan, Power feed control, Power distribution control, Global environment

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Abstract

With the opening of links between Hachinohe and Shin-Aomori stations on December 4, 2010, the Tohoku Shinkansen line entered full service. On March 12, 2011, a section between Hakata and Shin-Yatsushiro stations of the Kyushu Shinkansen line also opened, which represented the opening of the entire Kyushu Shinkansen line. The opening of both Shinkansen lines means that the distance between Shin-Aomori and Kagoshima-Chuo stations along the Japanese islands is connected by the Shinkansen system.

For the Shinkansen lines, Meidensha Corporation supplied the following major electrical equipment: feeder substation equipment, electrical room facility at the station, power distribution system, and disaster prevention equipment.

For the Tohoku Shinkansen line, Meidensha Corporation supplied equipment for five feeder substation facilities, three distribution facilities, and a complete set of electric installations. For the Kyushu Shinkansen line, the Company supplied five traction substation facilities and two distribution facilities.

1. Preface

With the completion of the extension line work, both the Tohoku and Kyushu Shinkansen lines entered full service, and two Shinkansen lines under the Projected Shinkansen Line Plan were completed.

This paper introduces the feeder substation system, the distribution substation system, and the electric railways installations for these extended sections, which were manufactured and supplied by our company.

Fig. 1 shows locations of substations and power-feeding stations for the Tohoku Shinkansen line, and Fig. 2 shows the locations of substations and feeding stations for the Kyushu Shinkansen line.

The principal features of our supplied items are 168kV Vacuum Circuit-Breakers (VCBs), SF_6 gas-free VCBs, and roof-delta connection transformers.

2. Feeding Equipment

Meidensha Corporation supplied equipment to five locations for the Tohoku Shinkansen line: Shin-Aomori Substation (SS), Shin-Sokota Sectioning Post (SP), Shin-Shimoorigami Sub-sectioning Post (SSP), Shin-Otsubo SSP, and Shin-Nitta Auto Transformer Post (ATP). For the Kyushu Shinkansen line, we supplied facilities to five locations: Shin-Gyokuto SS, Kumamoto General Rail Yard SS, Shin-Shiranui SSP, Shin-Tomiai SSP, and Shin-Hikawa SSP.

Shin-Aomori SS receives two 154kV power lines from Tohoku Electric Power Co. Then, it is stepped down by the 50MVA Scott-connection transformers, and Shin-Gyokuto SS receives two 220kV power lines from Kyushu Electric Power Co. The power is stepped down by 70MVA roof-delta connection transformers. The voltage is stepped down to 60kV at both the transformers, and the power is fed to the trains after stepping down to single phase 30kV by the autotransformers. Fig. 3 is a single-line connection diagram of Shin-Aomori SS.

At the Kumamoto General Rail Yard SS, two 66kV power lines come from from Kyushu Electric Power Co. The power is stepped down to 30kV by 20MVA scalene Scott transformers and supplied to trains within the train yard.

2.1 Power Receiving Circuit-Breaker

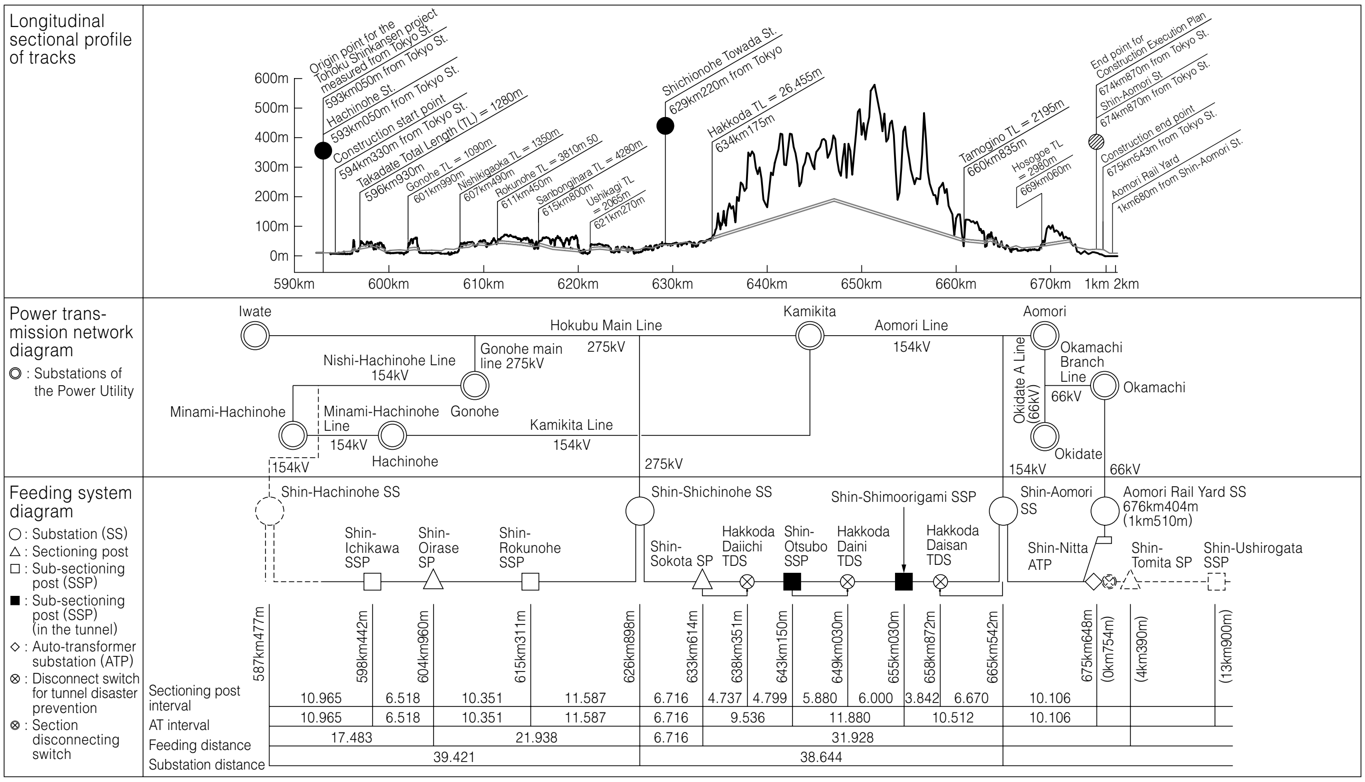
We supplied 168kV VCBs to Shin-Aomori SS and a 240kV gas circuit-breaker to Shin-Gyokuto SS. Improvement in breaking performance and a reduction in SF_6 gas were realized using the vacuum interrupter in the VCB.

A simplified operating mechanism and a considerably compact design were realized using a conical spring operating mechanism in the gas circuit-breaker.

Table 1 shows the ratings of the circuit-breakers, Fig. 4 shows an external view of the 168kV VCB, and Fig. 5 shows the 240kV gas circuit-breaker.

2.2 Feeder Transformer

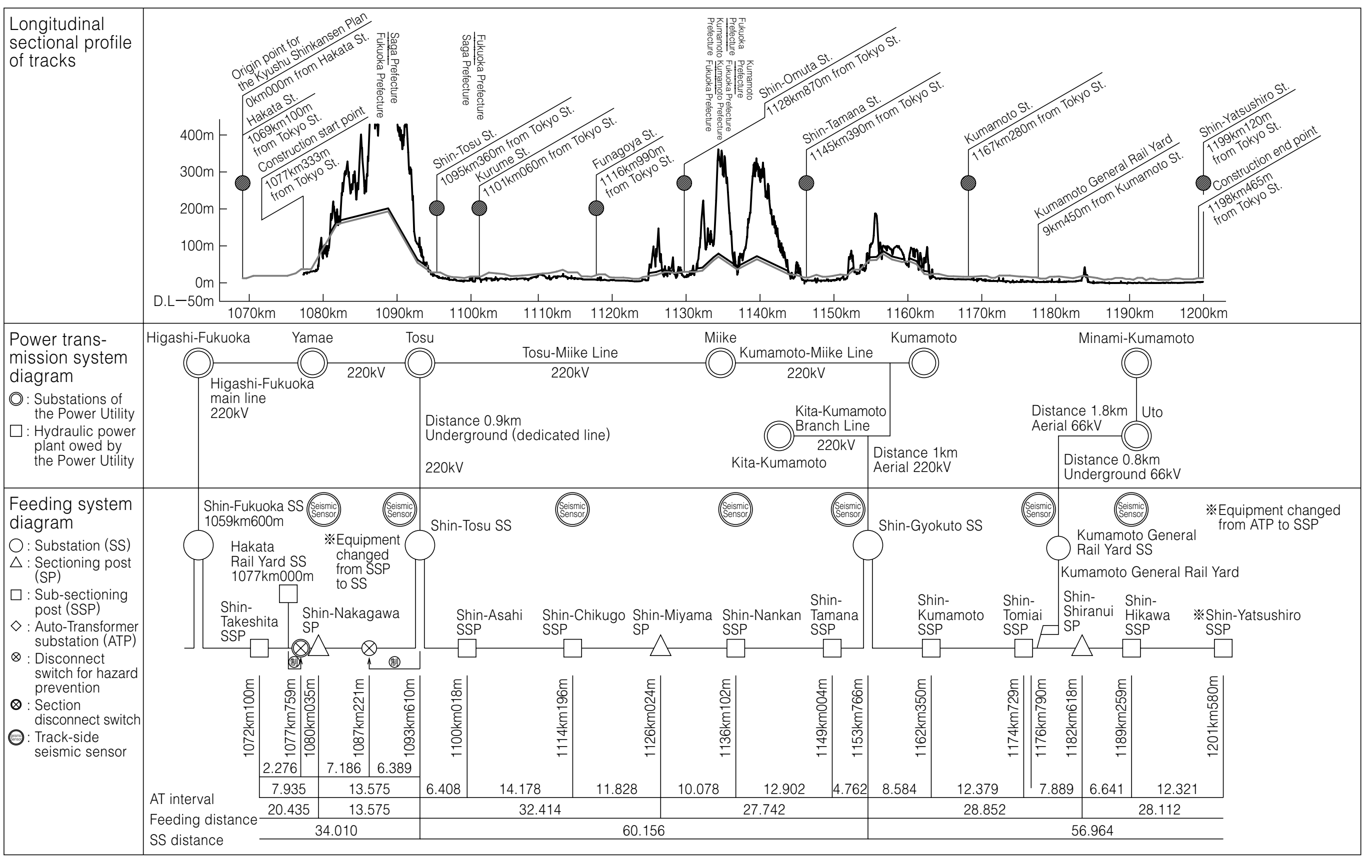
We supplied 50MVA Scott-connection transformers



Source: Courtesy of Japan Railway Construction, Transport and Technology Agency

Fig. 1 Positions of Substation/Feeder Station of Tohoku Shinkansen Line

This figure shows the power transmission and feeding system diagrams for construction of the Tohoku Shinkansen line and its extension line. We supplied equipment to Shin-Aomori SS, Shin-Sokota SP, Shin-Otsubo SSP, and Shin- Shimoorigami SSP.



Source: Courtesy of Japan Railway Construction, Transport and Technology Agency

Fig. 2 Positions of Substation/Feeder Station of Kyushu Shinkansen Line

The chart shows the power transmission and feeding system diagrams for the Kyushu Shinkansen line and its extension line. We supplied equipment to Shin-Gyokuto SS, Kumamoto General Rail yard SS, Shin-Shiranui SP, Shin-Tomiai SSP, and Shin-Hikawa SSP.

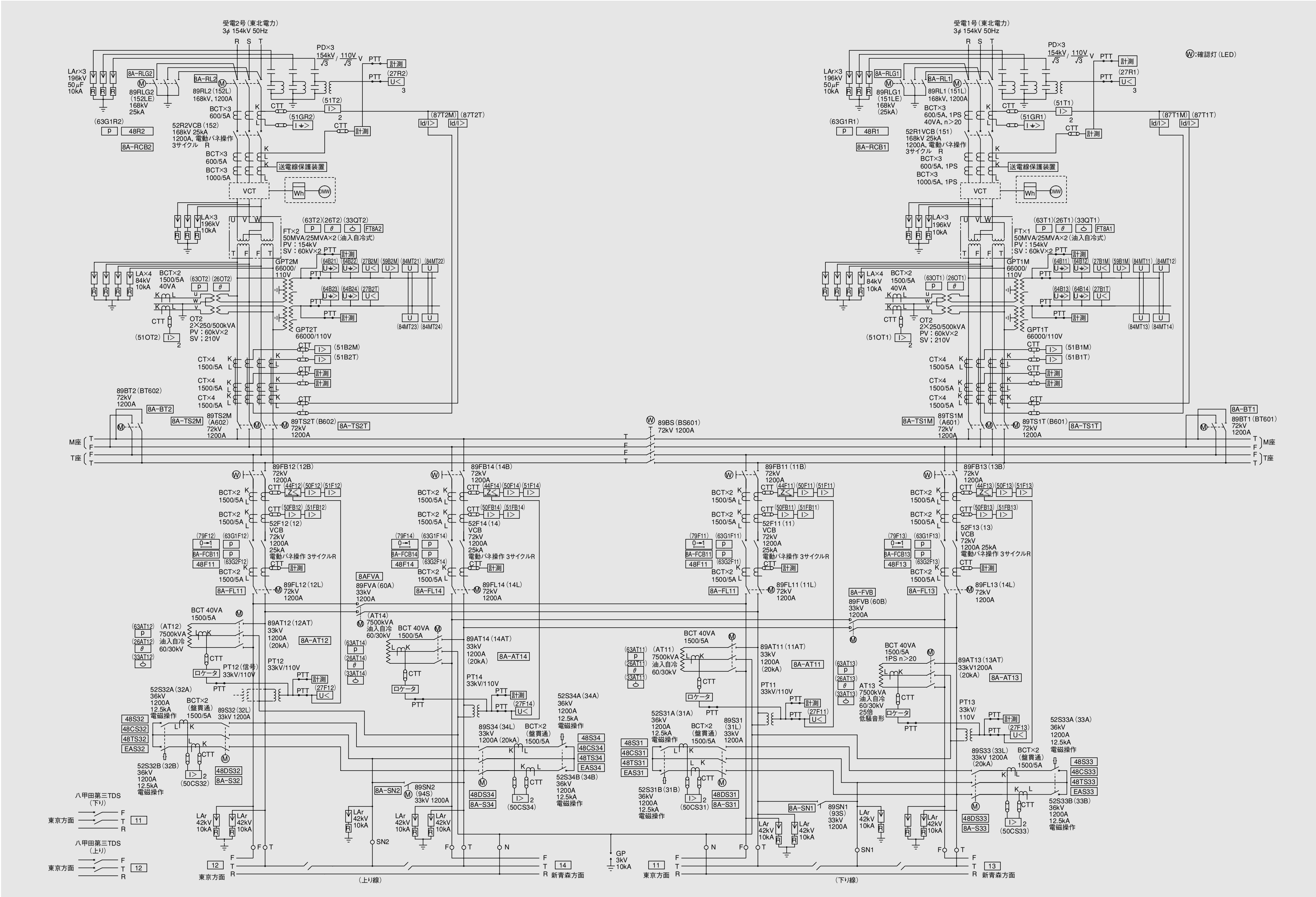


Fig. 3 Shin-Aomori SS Single-Line and Inter-Connection Diagram
This figure shows the main circuit configuration for Shin-Aomori SS. Scott-connection transformers are used and receive 154kV.

to Shin-Aomori SS, 70MVA roof-delta connection transformers to Shin-Gyokuto SS, and 20MVA scalene Scott-connection transformers to Kumamoto General Rail Yard. Principal features of the equipment are as follows:

(1) In the conventional method, a building was required to reduce the noise from the transformer. However, it became unnecessary by making the transformer less noisy. This simplified the construction and installation work.

(2) The compact design of the equipment was made possible by the advancement of our field intensity analysis technology.

Table 1 Ratings of Power Receiving Breakers

The following table shows a comparison of the ratings of the power receiving breakers installed on the Tohoku and Kyushu Shinkansen lines. A significant difference in the specifications can be seen in the voltage, insulation medium, and breaking time.

Line	Tohoku Shinkansen line	Kyushu Shinkansen line
Type	VCB	Gas-filled circuit-breaker
Isolation medium	Vacuum SF_6 gas	SF_6 gas
Number of units	2	2
Rated voltage (kV)	168	240
Rated current (A)	1200	2000
Rated breaking current (kA)	25	31.5
Rated breaking time (cycle)	3	2
Standard operating duty	R	
Operating method	Spring operated	
Operating shaft	3-phase common	
Gross mass (kg)	9900	10,300

Fig. 4 168kV VCB

This figure shows an external view of the 168kV VCB. Three-phase integrated type and the breaking performance part use vacuum insulation.

(3) The surge arrester on the M-point was eliminated by provision of full insulation at the neutral point of the Scott-connection and scalene Scott-connection transformers.

(4) For the roof-delta transformer, the compact size design of the transformers and radiators was realized because the number of windings was reduced, and the total loss was small compared with the conventional modified Woodbridge connection.

Table 2 shows the ratings, and Fig. 6 shows an outside view of the 50MVA Scott-connection trans-

Fig. 5 240kV Gas Circuit-Breaker

This figure shows an outside view of the 240kV gas-filled circuit-breaker. Three-phase common operation and gas-filled insulation are used for the breaking section.

Table 2 Ratings of Feeder Transformers

The following table shows a comparison of the ratings of the feeding transformers installed on the Tohoku and Kyushu Shinkansen lines. For Scott and roof-delta connection type transformers, radiators are separate, and for scalene Scott connection type transformers, radiators are integral.

Line	Tohoku Shinkansen line	Kyushu Shinkansen line	
Connection method	Scott connection	Roof-delta connection	Scalene Scott connection
Type	Outdoors, oil-filled, self-cooling		
Number of units	2	2	2
Rated capacity (MVA)	50	70	20
Rating type	Continuous (300% for 2 minutes)		
Number of phases	3/2		3/1
Rated primary voltage	F168-R154-F147kV (7 taps)	F255-R220-F215kV (9 taps)	F72-R66-F63kV (7 taps)
Rated secondary voltage	60kV × 2		30kV
Net mass (kg)	112,500	159,500	48,500

Fig. 6 50MVA Scott-Connection Transformer
This figure shows an external view of the 50MVA Scott-connection transformer. The primary side is 154kV and the secondary side is 60kV × 2 lines.

Fig. 7 70MVA Roof-Delta Connection Transformer
This figure shows an outside view of the 70MVA roof-delta connection transformer. The primary side is 220kV and the secondary side is 60kV × 2 lines.

former, Fig. 7 shows the 70MVA roof-delta-connection transformer, and Fig. 8 shows the 20MVA scalene Scott-connection transformer.

2.3 Feeder Circuit-Breaker

The operating mechanism of our conventional type VCB uses SF_6 gas for insulation. However, for the Tohoku and Kyshu Shinkansen lines, we introduced eco-friendly tank-type circuit-breakers that use dry air for insulation. Such a design greatly contributes to climate control.

Table 3 shows the ratings, and Fig. 9 shows an outside view of the 72kV SF_6 gas-free VCB.

2.4 Changeover Switch

The changeover switch with low operation current was developed. We improved solenoid-operated changeover switches already in use for the Tohoku Shinkansen line by optimizing the closing coil. This design realized a reduction in the DC power supply capacity and a reduction in the control cable size.

Fig. 8 20MVA Scalene Scott-Connection Transformer
This figure shows an outside view of the 20MVA scalene Scott-connection transformer. The primary side is 66kV and the secondary side is 30kV.

Table 3 Ratings of Feeder Circuit-Breakers
The following table shows a comparison of the ratings of the feeder breakers installed on the Tohoku and Kyushu Shinkansen lines. While the specifications are the same, the number of units is different.

Line	Tohoku Shinkansen line	Kyushu Shinkansen line
Type	VCB	
Insulation medium	Dry air	
Number of unit	6	8
Rated voltage (kV)	72/36	
Rated current (A)	1200	
Rated breaking current (kA)	25	
Rated breaking time (cycle)	3 cycles	
Standard operating duty	R	
Operating method	Spring operated	
Gross mass (kg)	2300 (representative)	1800 (representative)

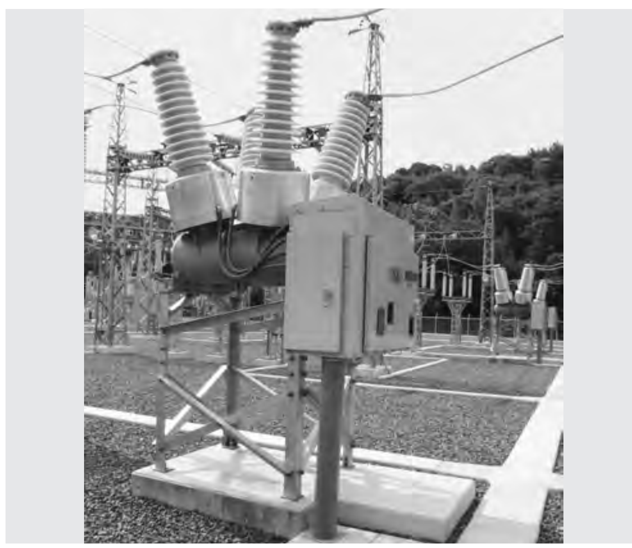


Fig. 9 72kV SF_6 Gasless VCB
This figure shows an outside view of the VCB used on the Kyushu Shinkansen line. SF_6 gas-free design is used.

Table 4 shows the ratings, and Fig. 10 shows an outside view of the 36kV changeover switchgear.

2.5 Gas Insulated Switchgear (GIS) System

We supplied the GIS to Kumamoto General Rail Yard. This GIS realized a compact size and reduced maintenance. A smaller footprint was realized by installing the power receiving system outdoors and by installing the feeder system in the same building where the switchgear room was located.

As this system is critical equipment for feeding power to the rail yard around the clock, these features contribute to a reduction in maintenance.

Table 5 shows the ratings, Fig. 11 shows an outside view of the outdoor type 72kV C-GIS, and Fig. 12 shows an outside view of the indoor 36kV C-GIS.

2.6 Switchgear for Railways

At each post, function-integrated switchgears for railways are installed. Fig. 13 shows the schematic system diagram for Shin-Gyokuto SS, and Fig. 14 shows an outside view of the monitoring and control panel. The principal features of the switchgear are as follows:

(1) High speed operation was realized using the large capacity, high speed Programmable Logic Controller (PLC) and by constructing a stored programmed logic

Table 4 Ratings of Changeover Switch

The following table shows a comparison of the ratings of the changeover switch installed on the Tohoku and Kyushu Shinkansen lines. While the specifications are the same, the number of units is different.

Line	Tohoku Shinkansen lien	Kyushu Shinkansen line
Type	Vacuum switchgear	
Number of units	16	24
Rated voltage (kV)	36	
Insulation voltage between poles (kV)	42	
Rated current (A)	1200	
Rated short-time current (kA)	12.5	
Rated breaking time (cycle)	5	
Operating method	Electromagnetic operation	
Gross mass (kg)	270	

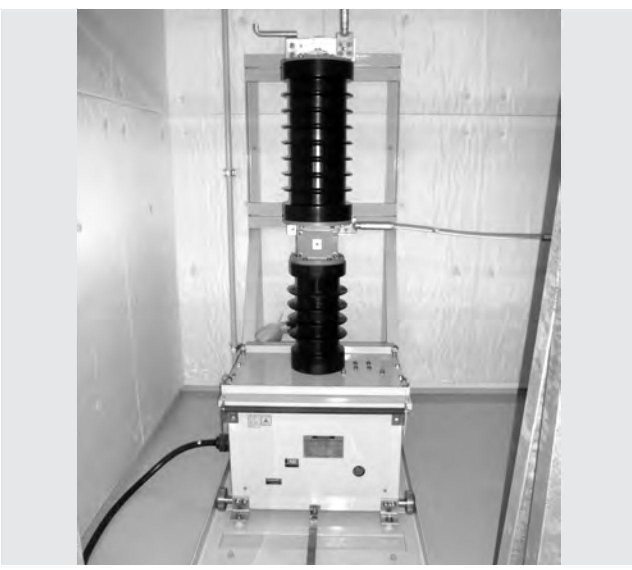


Fig. 10 36kV Changeover Switch

This figure shows an outside view of the 36kV changeover switch. Common equipment is used for both the Tohoku and Kyushu Shinkansen lines. Low operating current type is used, which contributes to equipment cost saving.

Table 5 Ratings of C-GIS

The following table shows a comparison of the ratings of the C-GIS for power receiving installed at Kumamoto General Rail Yard and the C-GIS for feeding. The differences are the voltage and the place of installation.

Line	Kyushu Shinkansen line Kumamoto General Rail Yard SS	
Place of installation	Outdoors	Indoors
Rated voltage (kV)	72	36
Rated current (A)	800	1200
Rated breaking current (kA)	25	
Rated breaking time (cycle)	5	3
Standard operating duty	A	R
Number of panels	8	12

Fig. 11 72kV Outdoor Type C-GIS

This figure shows an outside view of the 72kV outdoor type C-GIS, which receives power from two lines and the 2-VCT type.

Fig. 12 36kV Indoor Type C-GIS

This figure shows an outside view of the 36kV indoor type C-GIS. A complicated single phase feeding system is housed in a compact space.

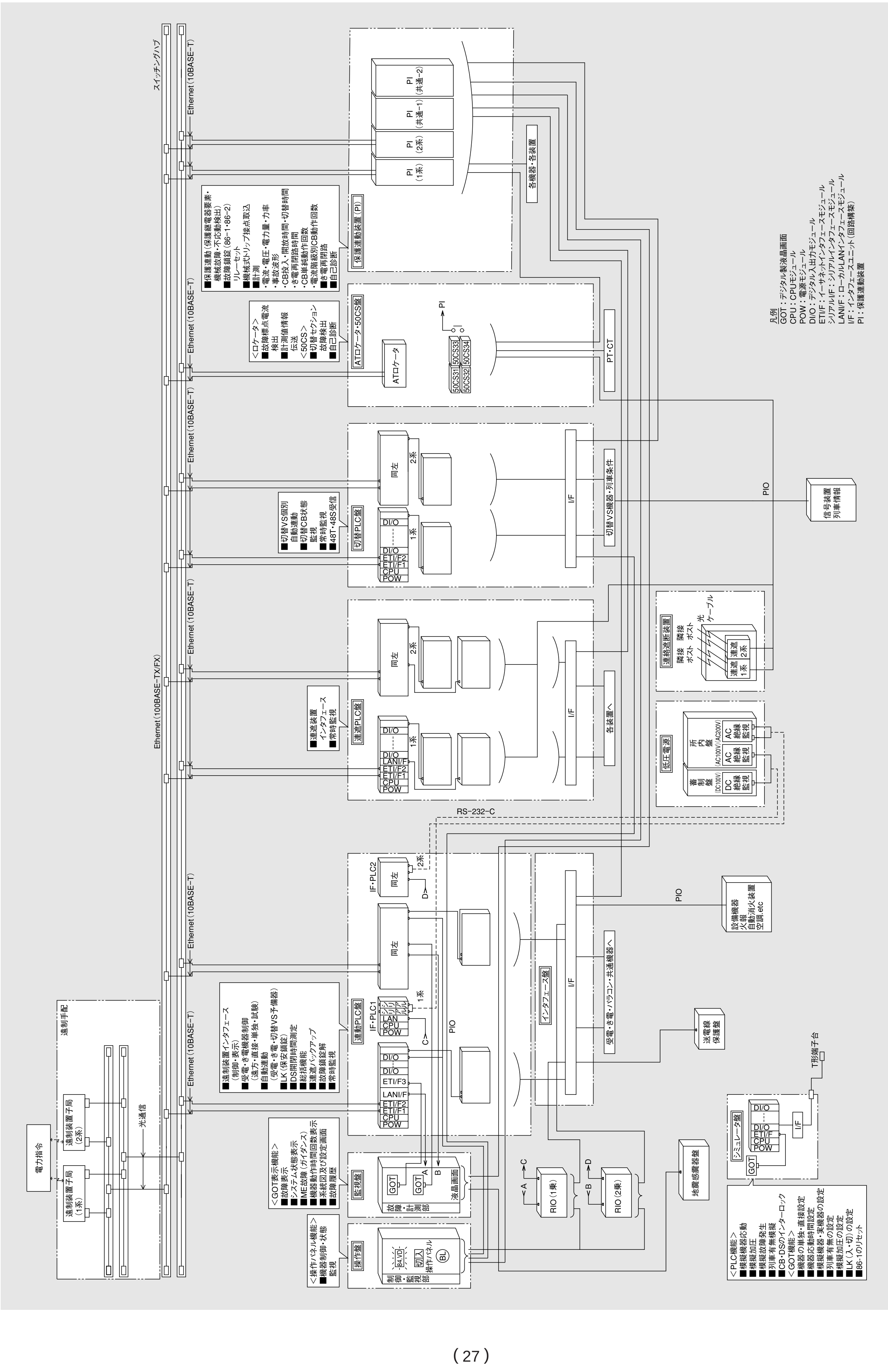


Fig. 13 Shin-Gyokuto SS Schematic System Diagram
A schematic system diagram of the control panel at Shin-Gyokuto SS. A centralized dual system configuration by functions is employed to realize large capacity and high-speed processing.

Fig. 14 Monitoring and Control Panel at Shin-Gyokuto SS

This figure shows an outside view of the monitoring and control panel at Shingyokuto SS. It consists of the operation panel, monitoring panel, respective PLC panels, protection interlock devices, inter-trip devices, and measuring devices.

interlock control. Reliability was also enhanced by using a dual system configuration.

(2) A highly functional, high performance system was established by use of next generation centralized digital relays. Additionally, reliability was enhanced by a fully redundant system configuration.

(3) The equipment was connected by Ethernet LAN, which makes connections with the other units by different supplies easy.

(4) We supplied the simulator panel for the on-site interlocking test after installation in order to reduce the operating frequency of the circuit-breakers and considering improvement of efficiency in central interlock checks.

(5) The optical fiber cable was used for the inter-trip line and for the simplified telemetry line to avoid effect of the noise and to enhance reliability.

(6) The insulation monitoring system of hot lines was provided for the station low-voltage panel and the battery control panel to realize reduced maintenance work.

(7) Separate measuring devices were provided and a summarization function for inspection was added to the current value indication and daily/monthly summarization functions in order to improve the efficiency of maintenance work and on-site inspections.

(8) The principal automatic functions of the SS control panel are as follows:

(a) Receiving circuit automatic changeover and re-closing

(b) Reconfiguration of the feeding circuit, feeding circuit re-closing, and automatic disconnection

(c) Individual automatic function of the changeover switchgear and automatic changeover to the standby unit in case of failure of the changeover switchgear

(d) 89AT automatic disconnection in case of 63AT

3. Power Distribution Station Electrical System

We supplied the power distribution station electrical system to three locations of the Tohoku Shinkansen line at Kanahama Distribution station (DP), Komagome DP, and Toriyabe DP.

For the Kyushu Shinkansen line, we supplied to two locations at Shin-Omuta DP and Chikugo-Funagoya DP.

The power distribution station electrical system is a facility that receives one 6.6kV power line from the power utility and continues to feed power even in a blackout with the emergency generator (Kyushu Shinkansen line only). The power distribution system distributes high voltage to the distribution lines along the track and supplies power to the lighting facilities of the stations, disaster prevention equipment, machinery, and the signaling and communication equipment after stepping down to low voltage. Fig. 15 shows a single-line connection diagram of Shin-Omuta DP.

3.1 High Voltage Switchgear

Devices like circuit-breakers and disconnecting switches were installed in metal-clad enclosures. Electromagnetically operated circuit-breakers were used, which enabled the compact size and reduced capacity of the control power supply. Molded case transformers were also used to enhance inflammable resistance.

Dry air insulation enclosed panels were used for the Tohoku Shinkansen line for ease of maintenance. Fig. 16 shows the high voltage control panel at Shin-Omuta DP and Fig. 17 shows the dry air insulation switchgear at Kanahama DP.

3.2 System Configuration of Power Distribution Station

Large capacity high-speed PLC in redundant systems was used to perform automatic sequential operation during power outage/restoration to enhance reliability. In addition, distributed digital relays combined for respective lines were used to ensure reliability. Fig. 18 shows the schematic system diagram of Chikugo-Funagoya DP and Fig. 19 shows an external view of the monitoring and control panel at Shin-Omuta DP.

3.3 Automatic Periodic Testing Function

The equipment has the automatic testing function of the power system operation in outage/restoration, including verification of integrity of the device control circuits. After establishment of predetermined conditions, power outage linked control is executed by transmission of the simulated power outage signal from the monitoring and control panel, and the power supply is

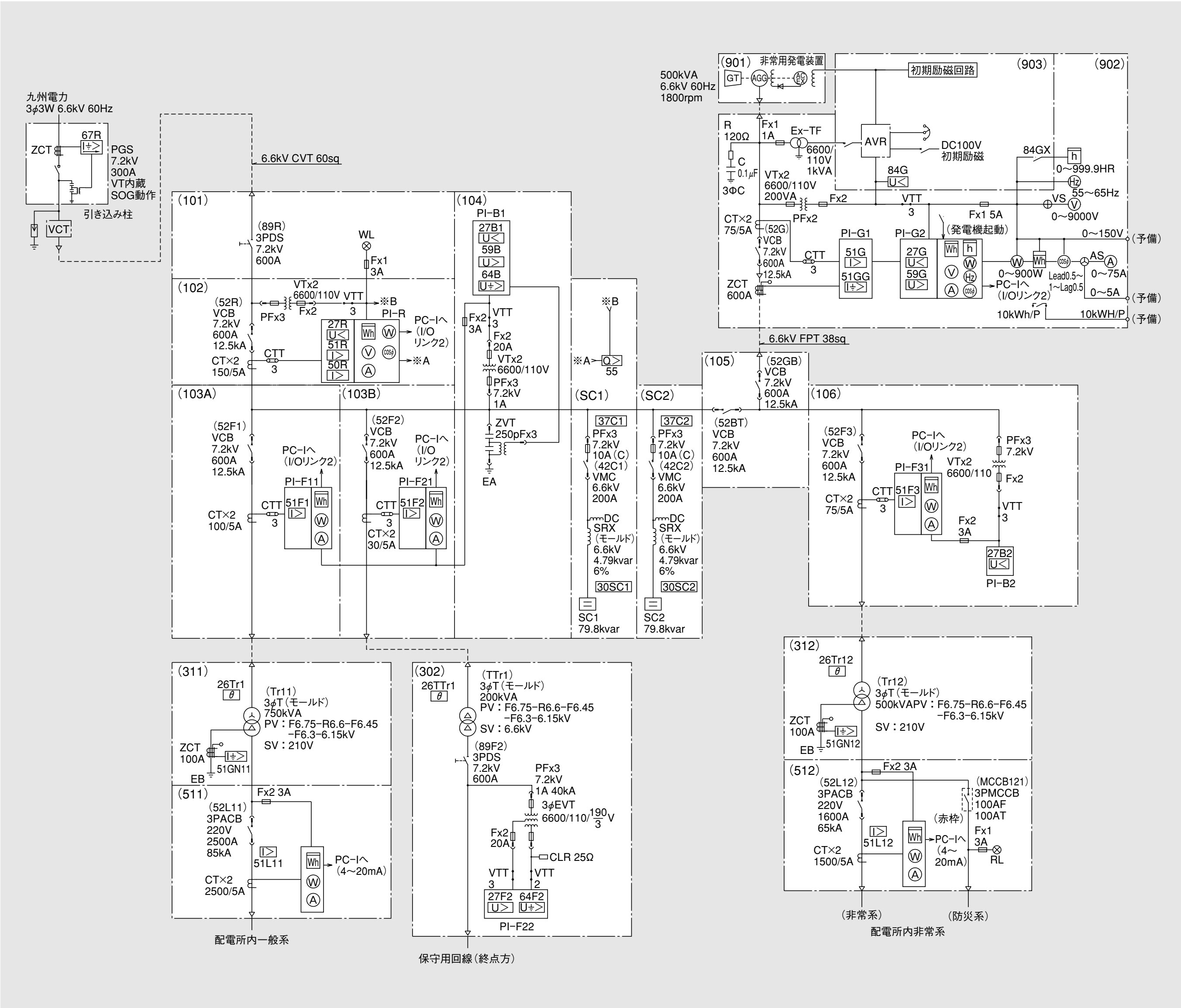


Fig. 15 Single-Line Connection Diagram of Shin-Omuta DP

This figure shows a schematic diagram of the main circuit of Shin-Omuta DP. It has one 6.6kV receiving line and an emergency generator.

Fig. 16 High Voltage Control Panel of Shin-Omuta DP

This figure shows an outside view of the high voltage control panel of Shin-Omuta DP. Cost reduction by use of air insulation and self-cooling method is realized.

Fig. 17 Dry Air Circuit-Breaker of Kanahama DP

This figure shows an outside view of the high voltage control panel of Kanahama DP. Dry air insulation is employed, which affects the environment less, and maintenance is easy.

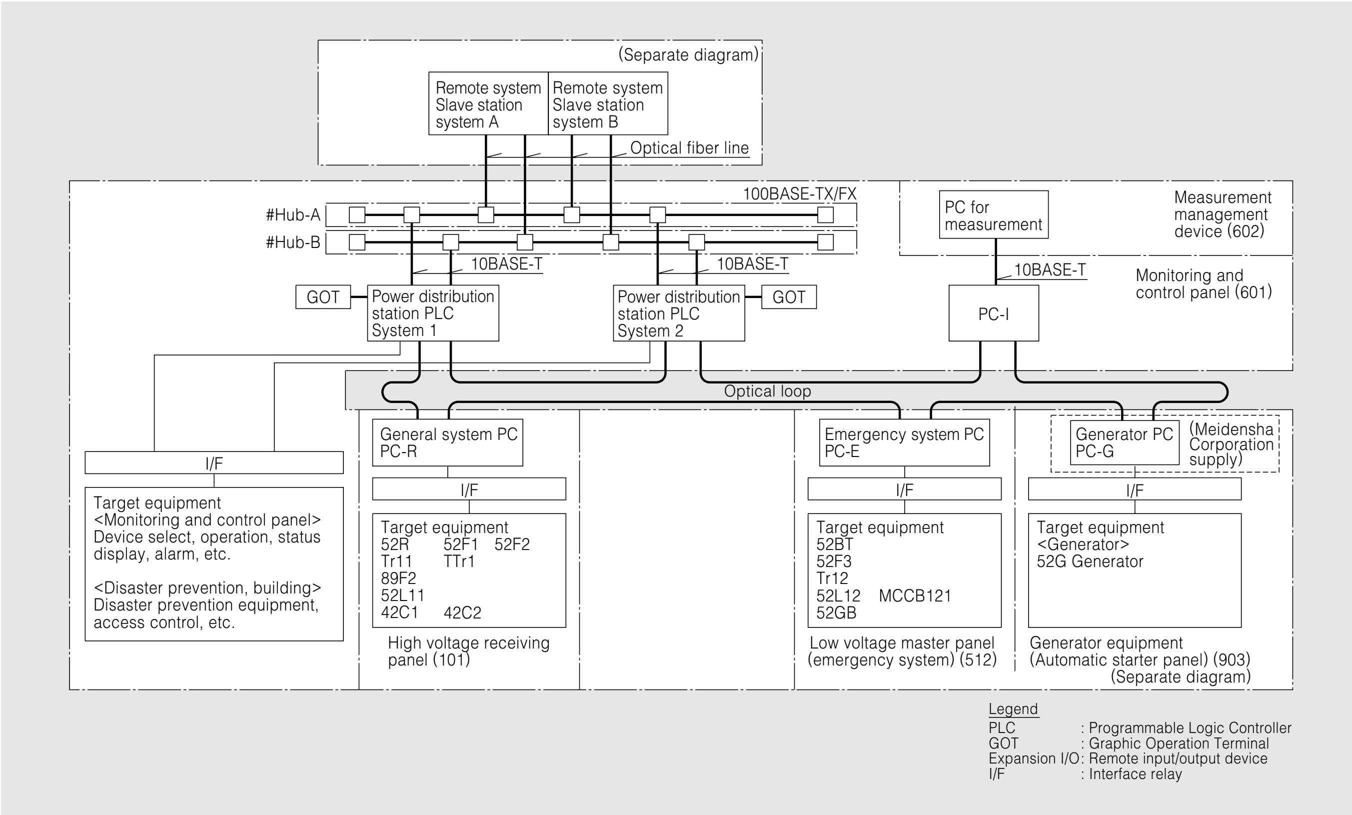


Fig. 18 Schematic System Diagram of Chikugo-Funagoya DP

This figure shows a schematic system diagram of Chikugo-Funagoya DP. The system is connected to PCs by optical loops, and even in the event of a power blackout interruption, monitoring and control are possible using the loop in the reverse direction.

Fig. 19 Monitoring and Control Panel of Shin-Omuta DP

This figure shows an outside view of the monitoring and control panel of Shin-Omuta DP. A centralized dual system configuration is employed to enhance reliability.

switched over to the generator. After certain period of time, the simulated power outage signal is cancelled to execute the power restoration linked operation. Through this function, a reduction in maintenance was realized.

3.4 Measuring Devices

Separate measuring devices were installed to provide current value indication and summarization of daily and monthly data to improve efficiency during maintenance.

Table 6 Ratings of Disconnect Switch for Tunnel Disaster Prevention

Ratings of the disconnect switch for the tunnel disaster prevention are shown. Gas insulation system is used.

Line	Tohoku Shinkansen TDS
Place of installation	Outdoors (in the tunnel)
Rated voltage (kV)	36
Rated current (A)	1200
Rated short-time current	12.5kA-2s
Number of panels	6

4. Electric Railway Facility

For the Tohoku Shinkansen line, we supplied the disconnecting switches for Tunnel Disaster prevention (TDS) in three locations: the Hakkoda-Daiichi Tunnel, Hakkoda-Daini Tunnel, and Hakkoda-Daisan Tunnel. TDS is mission-critical equipment to enable operation of the train within the 7km tunnel so as to reach a safe place in the event of an accident in the catenary system or fire by isolating the facility section and by maintaining the power supply.

4.1 Disconnect Switch for TDS

GIS was employed considering the installation environment within the tunnel. Table 6 shows the ratings.

4.2 Monitoring and Control

Monitoring and control were provided for the TDS by a simplified remote system from nearby substations. Control power was supplied by the battery control panel installed in the TDS location.

5. Postscript

The feeder substation system, power distribution station electrical system, and electric railway installations are all mission-critical equipment necessary for the operation of trains, passenger services, and safety. The functions of each system work fine and contribute to safe, speedy Shinkansen operations.

In closing, we would like to express special thanks to all project members who provided useful advice and support in the supply of these systems as explained in the Shinkansen projects.