Introduction of Substation and Power Distribution Facilities and Electrical Train Line Facility for Hokuriku Shinkansen (Between Nagano Station and Kanazawa Station)

Noriyuki Eto,
Keisuke Morito

Keywords Construction project, Feeder control, Power distribution control, Global environment, Different frequency power supplies

Abstract

Hokuriku Shinkansen for linking Kanazawa Station with Tokyo Station is a projected Shinkansen Line Plan.

Part of the route between Tokyo Station and Nagano Station already began commercial operation in 1997 by the name of Nagano Shinkansen. The section between Nagano Station and Kanazawa Station is an extended part of the overall section.

Hokuriku Shinkansen (between Nagano Station and Kanazawa Station) was inaugurated in the spring of 2015. As a result, the required time to travel between Tokyo Station and Kanazawa Station is reduced from 4 hours to 2.5 hours. The section between Kanazawa Station and Tsuruga Station is scheduled to be inaugurated in an estimated 10 years from now.

Major electrical facilities we delivered involve substations for feeders and railway track facilities.

1 Preface

The length of the construction site for Hokuriku Shinkansen (between Nagano Station and Kanazawa Station) is about 228km in track length. For this construction project, we manufactured and delivered substation facilities for feeder systems, power distribution facilities, electrical train line facilities, and associated equipment.

Fig. 1 shows the location of power transmission and distribution substation facilities for Hokuriku Shinkansen. In the feeder substation facilities, there is a boundary section where two different frequencies of 50Hz and 60Hz are used in power supplies. It was a big challenge to solve the frequency difference of the facilities and build a unique system. This paper introduces how we face such challenges and provides the outline of the supplied facilities.

2 Feeder Substation Facilities

The project sites are at four posts: the Shin-Kurobe Substation (SS), Shin-Takada Sectioning Post (SP), Shin-Kuwadori Sub-Sectioning Post (SSP), and the Shin-Nou SSP.

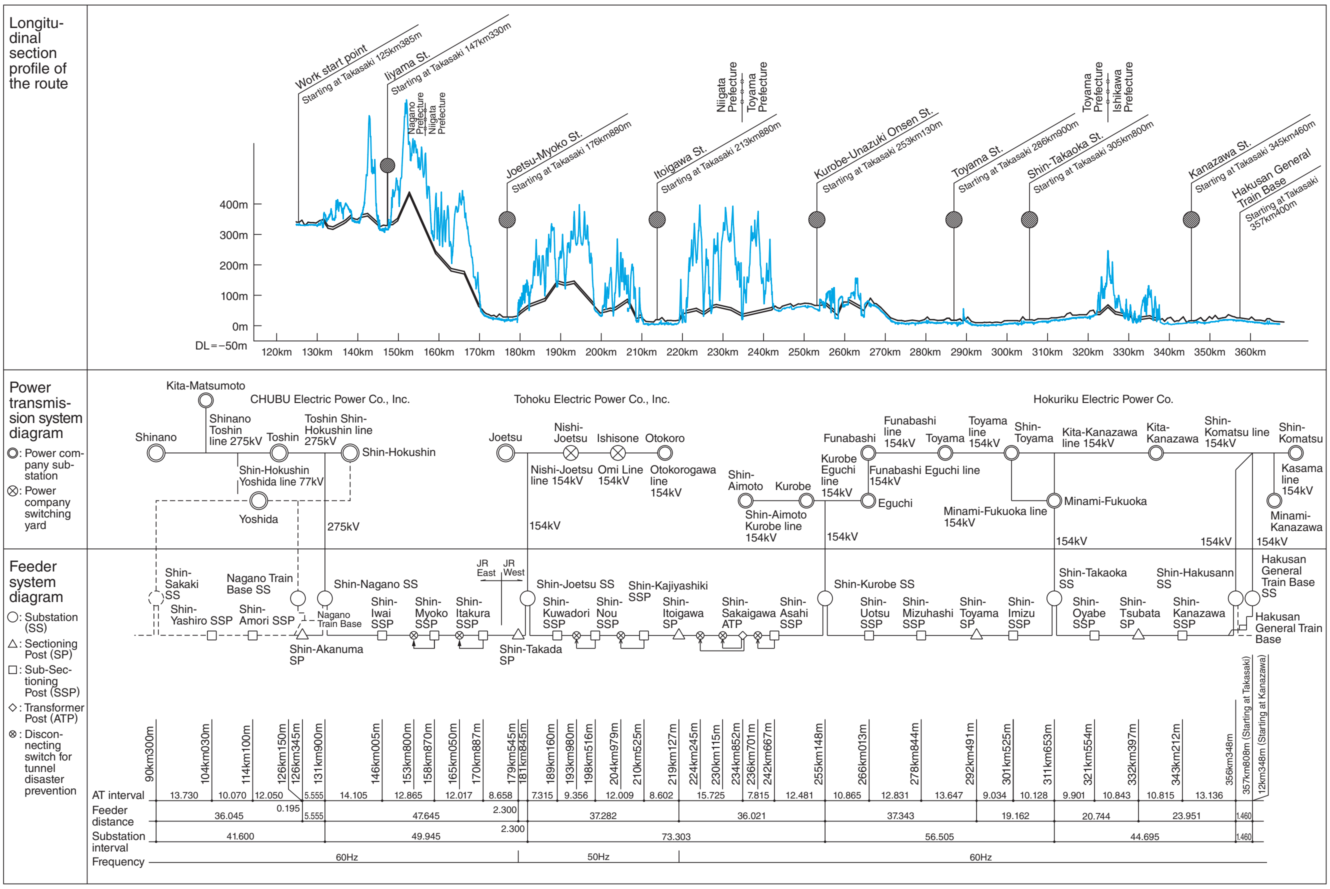
The Shin-Kurobe SS receives utility power through a 2-circuit 154kV transmission line from Hokuriku Electric Power Company and the received power is stepped down to single-phase 2-circuit 60kV by a Scott-connection transformer. The 60kV single-phase power is converted into single-phase 30kV through an auto-transformer. The resultant power is fed to commercial train cars in operation. Fig. 2 shows a main-circuit connection diagram for the Shin-Kurobe SS.

2.1 Power Receiving Circuit-Breaker (CB)

We delivered a 168kV Gas-insulated Circuit-Breaker (GCB) to the Shin-Kurobe SS. Since the GCB is adopted, features of compactness and lightness can be attained. Table 1 shows the ratings and Fig. 3 shows an external appearance of a 168kV GCB.

2.2 Feeder Transformer

A 70MVA Scott-connection transformer was delivered to the Shin-Kurobe SS. The major features



Source: Japan Railway Construction, Transport and Technology Agency (JRTT)

Fig. 1 Location of Power Transmission and Distribution Substation Facilities for Hokuriku Shinkansen

Power transmission system diagram and feeder system diagram are shown for Hokuriku Shinkansen (between Nagano Station and Kanazawa Station). Our supplied posts are the Shin-Kurobe SS, the Shin-Takada SP, the Shin-Kuwadori SSP, and the Shin-Nou SSP.

of this transformer are described below.

(1) Since the transformer main body was designed for a low-noise configuration, it does not require a building for its transformer noise. As a result, site construction work was very simple.

(2) Thanks to the progress of analytical technologies for electrical field intensity measurements, it was possible to substantially attain compactness.

(3) Since the neutral point of the Scott-connection transformer was fully insulated, it was possible to omit the Point-M surge arresters.

Table 2 shows the ratings and **Fig. 4** shows an external appearance of the 70MVA Scott-connection transformer.

2.3 Feeder CB

An ecological tank-type Vacuum Circuit-Breaker (VCB) has been introduced. This type is eco-friendly because dry air is used as the insulation medium. Since this is SF_6 gas-free, it contributes to Climate Control.

In addition, since there is no need for the recovery of gas and maintenance for current breaking parts, the life cycle cost is also reduced. **Table 3** shows the ratings and **Fig. 5** shows an external appearance of the 72/36kV eco-tank type VCB.

2.4 Changeover Switch

A solenoid-operated changeover switch of the low operating current type was delivered. A high withstand voltage type was delivered to the post where the different-frequency boundary section is situated. This program applies to the posts where the Shin-Takada SP and the Shin-Itoigawa SP are located. **Table 4** shows the ratings and **Fig. 6** shows the 36kV changeover switch.

2.5 Track Feeder Control Switchgear

For each post, we installed a functionally packaged control switchgear for the railway. **Fig. 7** shows the monitoring and control panel and **Fig. 8** shows the system configuration diagram of the Shin-Kurobe SS. The major features of the switchgear are specified below.

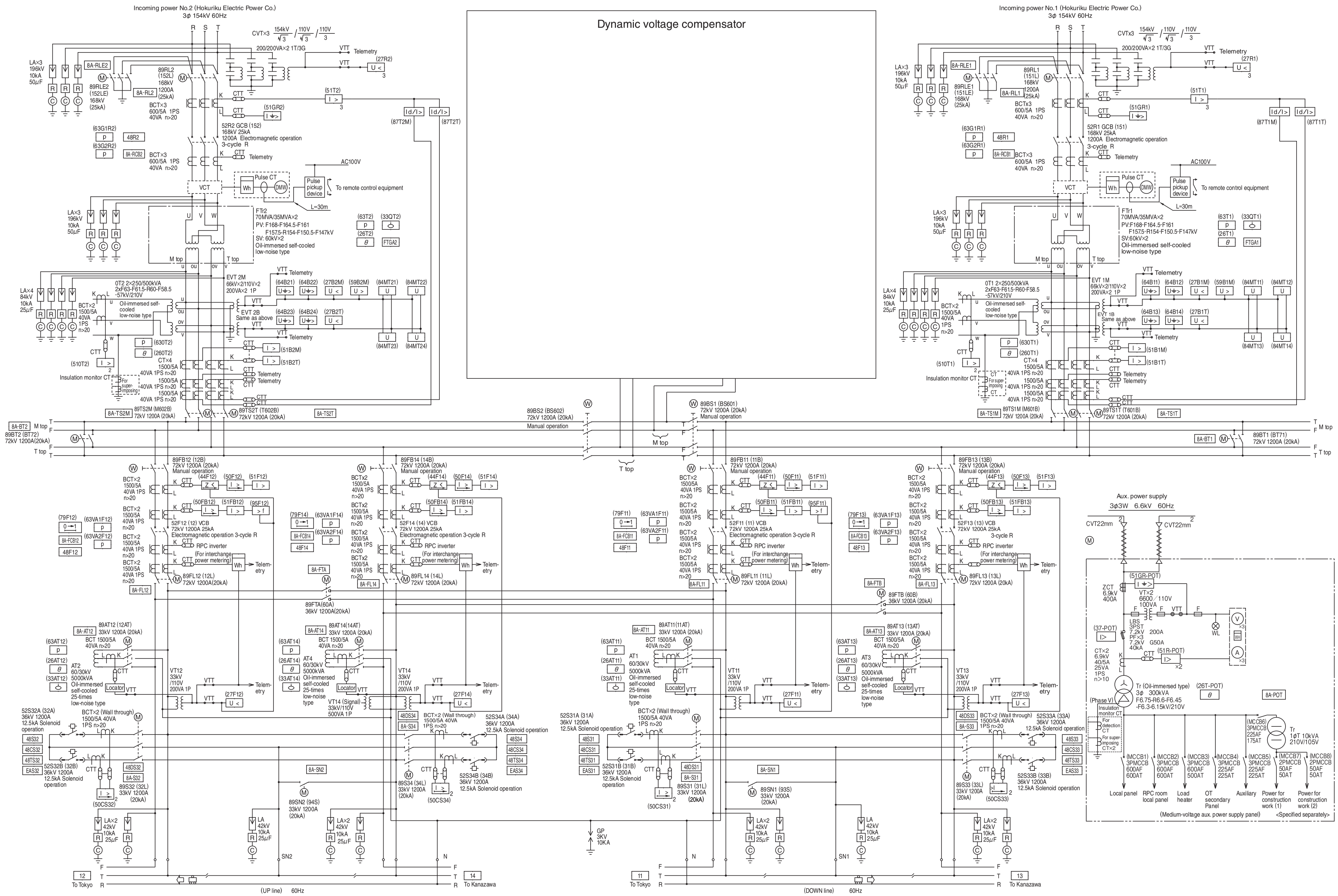


Fig. 2 Main-Circuit Connection Diagram for the Shin-Kurobe SS

The main-circuit configuration of the Shin-Kurobe SS is shown. The incoming power is received at 154kV and Scott-connection transformers are installed.

Table 1 **Ratings of the Power Receiving CB**

Ratings of the power receiving CB delivered to the Shin-Kurobe SS are specified.

Item	Ratings
Type	Gas-insulated CB
Insulation medium	SF_6 gas
Quantity	2 units
Rated voltage	168kV
Rated current	1200A
Rated breaking current	25kA
Rated breaking time	3 cycles
Standard operation duty	Class R
Operating system	Electromagnetic operation
Operation axis	3-phase integrated type
Total mass	6600kg

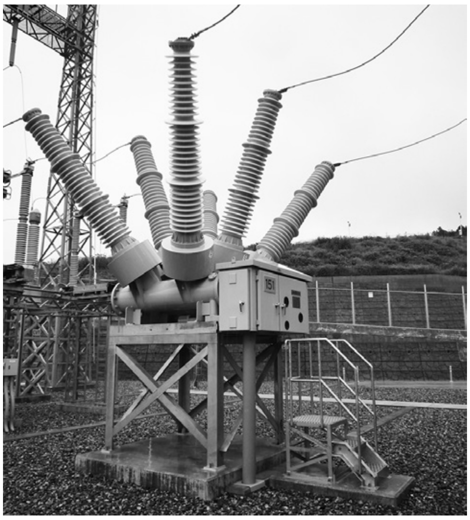


Fig. 3 **168kV GCB**

An external appearance of 168kV GCB is shown. It is of the 3-phase integrated type and current interrupters and mechanisms are insulated by SF_6 gas.

Table 2 **Ratings of the Feeder Transformer**

Ratings of the feeder transformers delivered to the Shin-Kurobe SS are specified. Each transformer is fabricated in T-connections and the incoming voltage is stepped down to 60kV × 2 circuits.

Item	Ratings
Connection system	Scott connection
Type	Outdoor oil-immersed self-cooled type
Quantity	2 units
Rated capacity	70MVA
Type of rating	Continuous (300% for 2 minutes)
No. of phases	3/2
Rated primary voltage	F168～R154～F147kV (7 taps)
Rated secondary voltage	60kV × 2
Total mass	135,000kg

Fig. 4 **70MVA Scott-Connection Transformer**

An external appearance of 70MVA Scott-connection transformer is shown. The transformer comes in a configuration of primary voltage 154kV and secondary voltage 60kV × 2 circuits.

Table 3 **Ratings of the Feeder CB**

Ratings of the feeder CB are specified. The insulation medium is dry air that contributes to the prevention of climate change.

Delivery post	Shin-Kurobe SS	Shin-Takada SP
Type	VCB	
Insulation medium	Dry air	
Quantity (units)	4	2
No. of poles (P)	2	
Rated voltage (kV)	72	36
Rated current (A)	1200	
Rated breaking current (kA)	25	
Rated breaking time (cycles)	3	
Standard operation duty	Class R	
Operating system	Electromagnetic operation	
Total mass (kg)	1800	1700

Fig. 5 **72/36kV Eco-Tank Type VCB**

An external appearance of the 72/36kV eco-tank type VCB is shown. The mechanical section is insulated by dry air and current interrupters are vacuum-insulated. Such an insulation configuration is completely free from SF_6 gas.

Table 4 Ratings of the Changeover Switch

Ratings of the changeover switch are specified. Items delivered to the Shin-Takada SP are specified for a high withstand voltage and only the section between contact points is specified for a withstand voltage of 60kV.

Supplied posts	Shin-Kurobe SS	Shin-Takada SP (high withstand voltage)
Type	Vacuum switch	
Quantity (units)	8	8
Place of use	Indoors	
No. of poles	Single pole	
Application	For changeover	
Operating system	Solenoid operation system	
Rated voltage (kV)	36	
Contact gap insulation voltage (kV)	42	60
Rated frequency (Hz)	60	50/60
Rated current (A)	1200	
Rated closing current (kA)	31.5	
Rated short-time current (kA)	12.5 (2s)	
Rated contact opening time (s)	Up to 0.05	
Power frequency contact gap withstand voltage (kV)	100	140
Power frequency line-to-ground withstand voltage (kV)	70	
Contact gap impulse withstand voltage (kV)	250	350
Line-to-ground impulse withstand voltage (kV)	200	
Operation duty	O−(1s)−C, C−(1s)−O	
Total mass (kg)	270	

(1) A large-capacity and high-speed Programmable Logic Controller (PLC) is adopted. This equipment makes it possible to take high-speed actions for the interlocked operation. High reliability is assured due to the redundant configuration.
(2) By adopting the integrated type next-generation digital relays, it realized a high-function and high-performance system. High reliability is assured due to the redundant equipment configuration.
(3) Units are mutually connected through Ethernet Local Area Network (LAN). Such an approach is effective in building a system where the system is comprised of some units and equipment by other corporations.
(4) In consideration of reduction of CB operating frequencies at the time of field interlock testing, a simulator panel was introduced.
(5) In order to improve system reliability, optical cables are used for bus tie breaking circuits and simplified remote control circuits because the optical cables are less influenced by noise.
(6) A live line insulation monitor unit is provided for the local low-voltage and battery control panels in order to realize labor-saving maintenance.

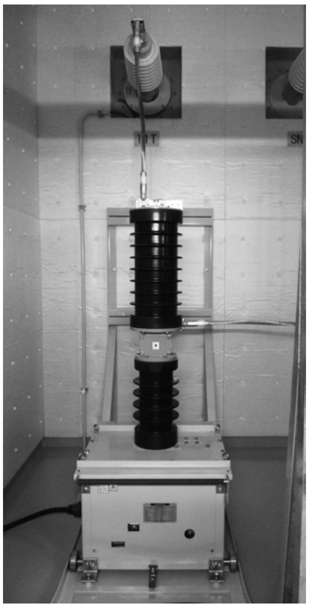


Fig. 6 36kV Changeover Switch

An external appearance of 36kV changeover switch is shown. The low operating current type was adopted. A high withstand voltage type was also delivered.

Fig. 7 Monitoring and Control Panel for the Shin-Kurobe SS

An external appearance of a monitoring and control panel for the Shin-Kurobe SS is shown. The overall configuration involves the operator panels, monitor panels, respective PLC panels, protective interlock equipment, interlocked breaking equipment, and telemetry equipment.

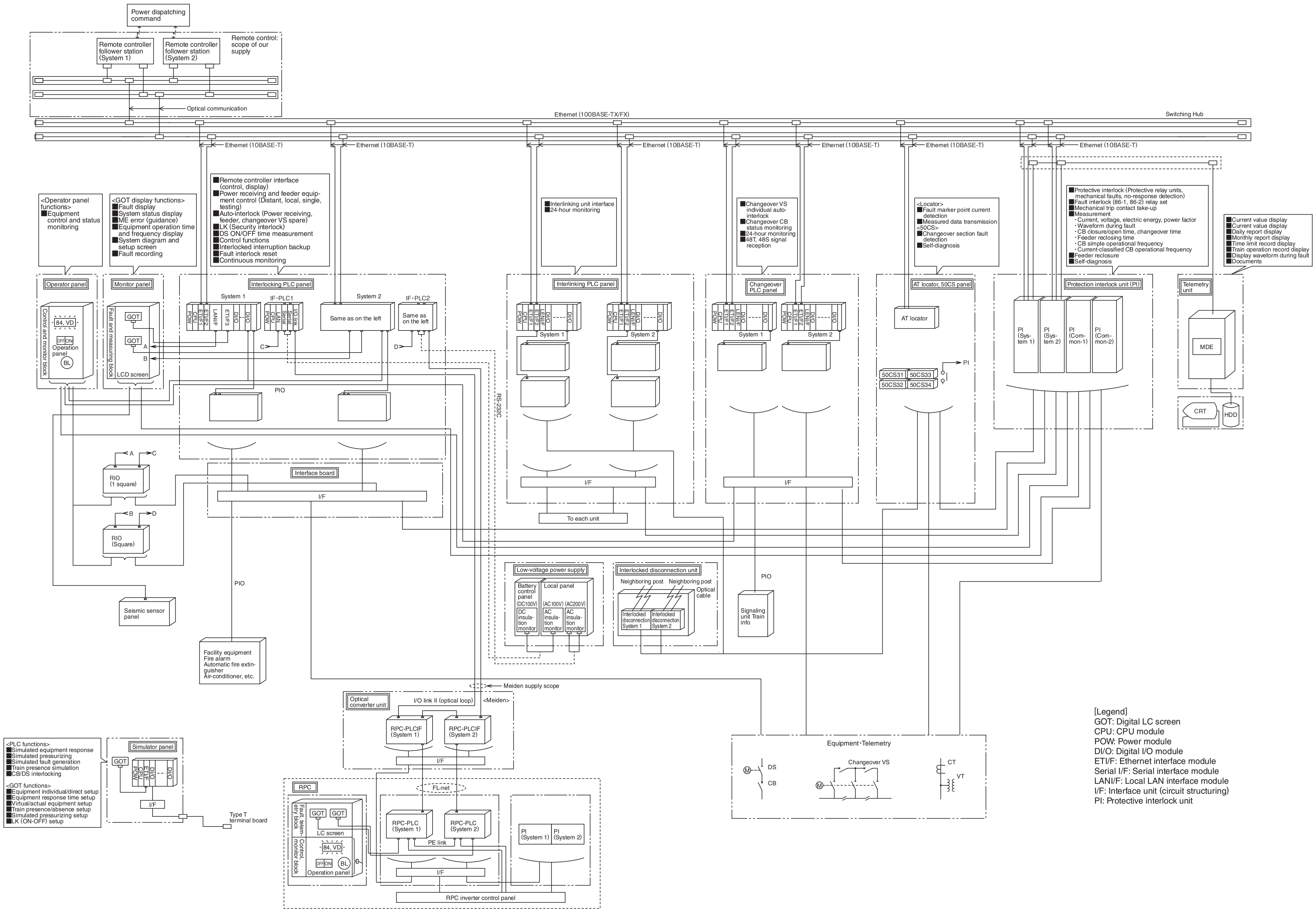


Fig. 8 System Configuration Diagram of the Shin-Kurobe SS

The switchgear system configuration diagram of the Shin-Kurobe SS is shown. A functionally separated concentrated redundancy configuration is adopted that is suitable for large-capacity processing and high-speed operation.

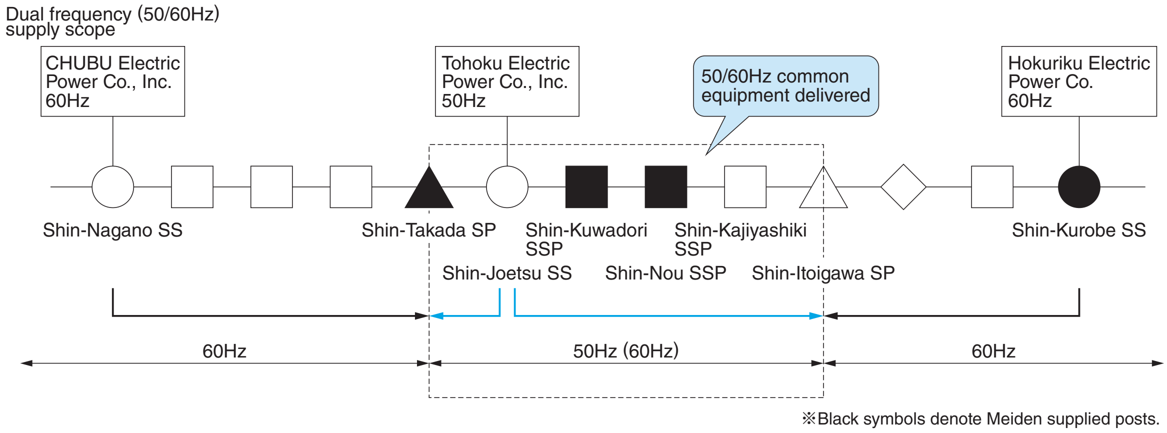


Fig. 9 Different-Frequency Boundary Section and Common Equipment Supply Scope

Dual frequency (50/60Hz) equipment has been delivered to the section between the Shin-Takada SP and the Shin-Itoigawa SP.

(7) An instrumentation unit is installed separately for data logging. This unit displays the presently measured values and shows daily and monthly reports. It is in charge of maintenance work and improvement of system efficiency.

(8) Major auto-functions of power distribution panels for substation are as follows:

(a) Automatic changeover for power receiving and reclosing circuit for power receiving

(b) Power feeding reconstruction, feeder reclosing circuit, and automatic feeder opening

(c) Individual automatic interlocking of changeover and automatic standby unit changeover in case of changeover switch malfunction

(d) Automatic 89AT opening in the case of 63AT in operation

2.6 Measures against a Different Frequency

The section between Shin-Takada SP and Shin-Itoigawa SP is operated at 50Hz. The two sections neighboring both sides of this section are operated at 60Hz. In consideration of any adverse influence upon facilities due to the different frequencies, measures as described below were taken. In principle, any 50Hz power supply is not extended to the section of 60Hz because such an extension results in damage of equipment.

(1) Common use of dual frequency equipment

In the section between Shin-Takada SP and Shin-Itoigawa SP, ratings of winding coil equipment are specified as both 50/60Hz frequency. **Fig. 9** shows the different-frequency boundary section and the scope of dual frequency equipment production range. The applicable posts are the Shin-Takada SP, Shin-Kuwadori SSP, and Shin-Nou SSP.

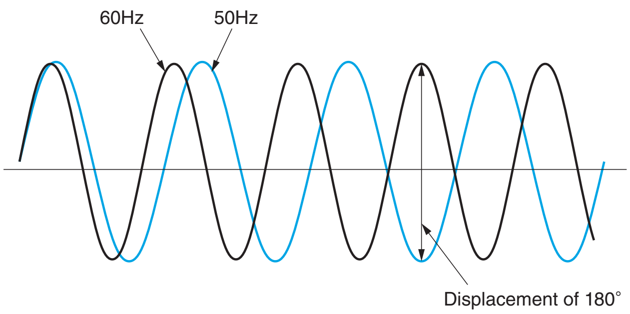


Fig. 10 Phase Displacement in a Different-Frequency Boundary Section

In an area where 50Hz and 60Hz frequency are met, a phase displacement of 180° appears periodically. In this case, a voltage twice the regular level is generated.

(2) Measures against asynchronism

(a) Measures against extension of gap voltage

In a 50/60Hz boundary section, a phase displacement of 180° can occur at the largest. **Fig. 10** shows a phase displacement in a different-frequency boundary section. If a phase displacement of 180° arises in a feeder voltage of 30kV, the resultant gap voltage may rise up to 60kV. For this reason, the delivered changeover switch is designed to have a gap voltage of 60kV so that it can withstand such a high voltage. The objective post is the Shin-Takada SP.

(b) Measures against stray currents on the railway train line and signaling system

In consideration of the effect of stray currents at a different frequency to signaling facilities, the following measures were taken. The applicable post is the Shin-Takada SP.

(i) Insulation area is provided to rails so it gives resistivity to any different frequency power flowing. As a result of taking such a measure, arcs are generated by the effect of a feeble potential difference when train cars pass through this section. As a countermeasure, a rail insulation short-circuiting device is installed so that the rail insulation can be short-circuited when train car passes by.

(ii) A Booster Transformer (BT) is installed in the mid-section so that stray currents can be returned to their own post.

(iii) In order to minimize the effect of different frequency, coaxial cables are adopted for external cables.

(3) Protection against an accident from different-frequency contact

When a 50Hz power supply comes in contact with a 60Hz power supply, a beat-state fault current appears at a period of 0.1 seconds and a frequency of 55Hz. Fig. 11 shows a current waveform in case of a different-frequency contact. In such a case, a normal Relay 44F and Relay 50F may fail to detect or detect incorrectly. In order to avoid such a failure, different-frequency contact relays are separately adopted. Features of these relays are specified below.

(a) 95F

This relay is a device to detect a 55Hz signal component in the case of a different-frequency contact.

(b) 68F

This relay is a device to detect a frequency component level and a contact ratio of the opposite substation.

The applicable posts are the Shin-Kurobe SS and the Shin-Takada SP.

(4) Measure against sampling frequency changeover

Protective relays used in the 50Hz section are set to make sampling at 50Hz in order to detect the occurrence of a fault. If a 60Hz power supply should

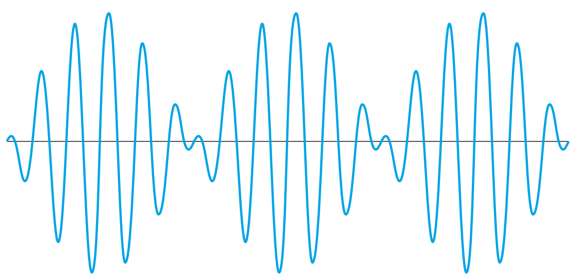


Fig. 11 Current Waveform in Case of Different Frequency Contact

When mutually different frequencies of 50Hz and 60Hz are combined, the resultant voltage waveform appears at a frequency of 55Hz, repeating a strong phase and a weak phase in a period of 0.1 seconds.

intrude into this 50Hz section, normal fault detection cannot occur due to inconsistency in sampling. In order to solve this problem, we have adopted a system where a 60Hz changeover signal is propagated shortly before the intrusion of a 60Hz source. The protective relays are designed to have a function so that the setting can be changed over between 50Hz and 60Hz when this signal input is entered in the relay.

The applicable posts are the Shin-Takada SP, the Shin-Kuwadori SSP, and the Shin-Nou SSP.

3 Local Substation Facilities

Our supplied posts for Hokuriku Shinkansen are the Nishi Kasahara power Distribution Post (DP), the Itoigawa DP, and the Shin-Kurobe DP, totaling 3 posts. The electrical facilities for power distribution posts receive power from the power company through a 6.6kV single- or double-circuit line. Emergency power generating equipment is also installed so that electric power can be kept supplied even though the incoming utility power line experiences a power outage. The power distribution system also supplies power to stations along the railway line. It feeds the power for station building lighting, disaster prevention facility, machinery facilities, and signaling and communication facility. Fig. 12 shows a single-line connection diagram of the Shin-Kurobe DP.

3.1 High-Voltage Switchgear

CB, disconnecting switches, and other essential devices are accommodated in an enclosed switchgear. CBs are of the solenoid operation type. The designing policy has focused on compact design and reduction of control power capacity. In order to emphasize non-flammability, mold type transformers are adopted.

At the Nishi-Kasahara DP, a dry-air insulation switchgear is adopted. Since the main circuit is put in an enclosed tank, this equipment is not influenced by installation conditions and assures freedom from electric shocks. In addition, long service life is assured and maintenance is easy. Fig. 13 shows a medium-voltage switchgear at the Nishi-Kasahara DP. Fig. 14 shows a medium-voltage switchgear at the Itoigawa DP.

Each power distribution post is a facility to receive power from the electric company and system impedance is generally large. The effect of volt-

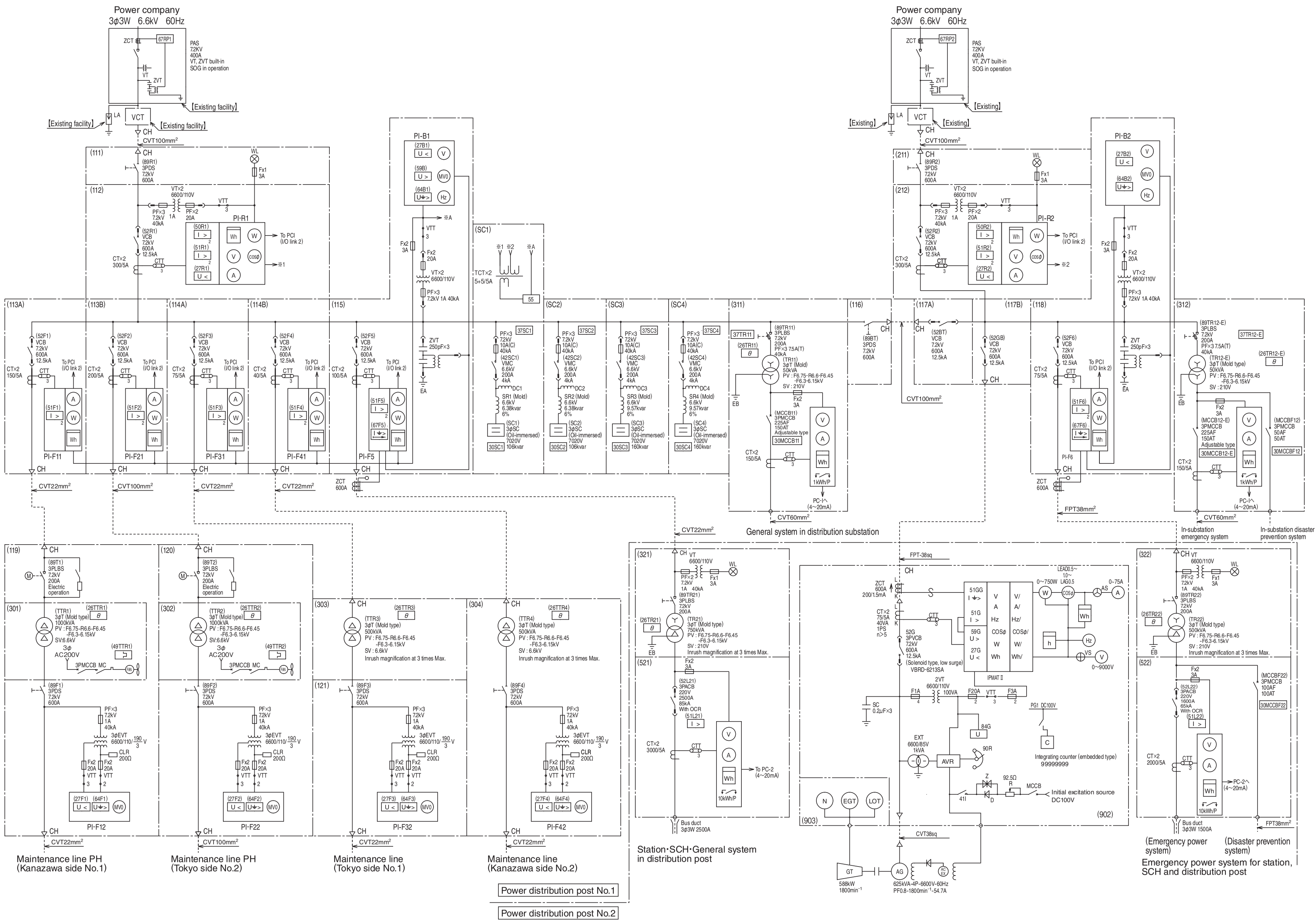


Fig. 12 Single-Line Connection Diagram of the Shin-Kurobe DP

A main circuit configuration of the Shin-Kurobe DP is shown. Utility power is received at 6.6kV through two circuits. An emergency power generating facility is installed.

Fig. 13 Medium-Voltage Switchgear at the Nishi-Kasahara DP

An external appearance of a medium-voltage switchgear delivered to the Nishi-Kasahara DP is shown. A dry air insulation system is adopted. It is less influenced by environmental conditions and easy maintenance is assured.

Fig. 14 Medium-Voltage Switchgear at the Itoigawa DP

An external appearance of a medium-voltage switchgear delivered to the Itoigawa DP is shown.

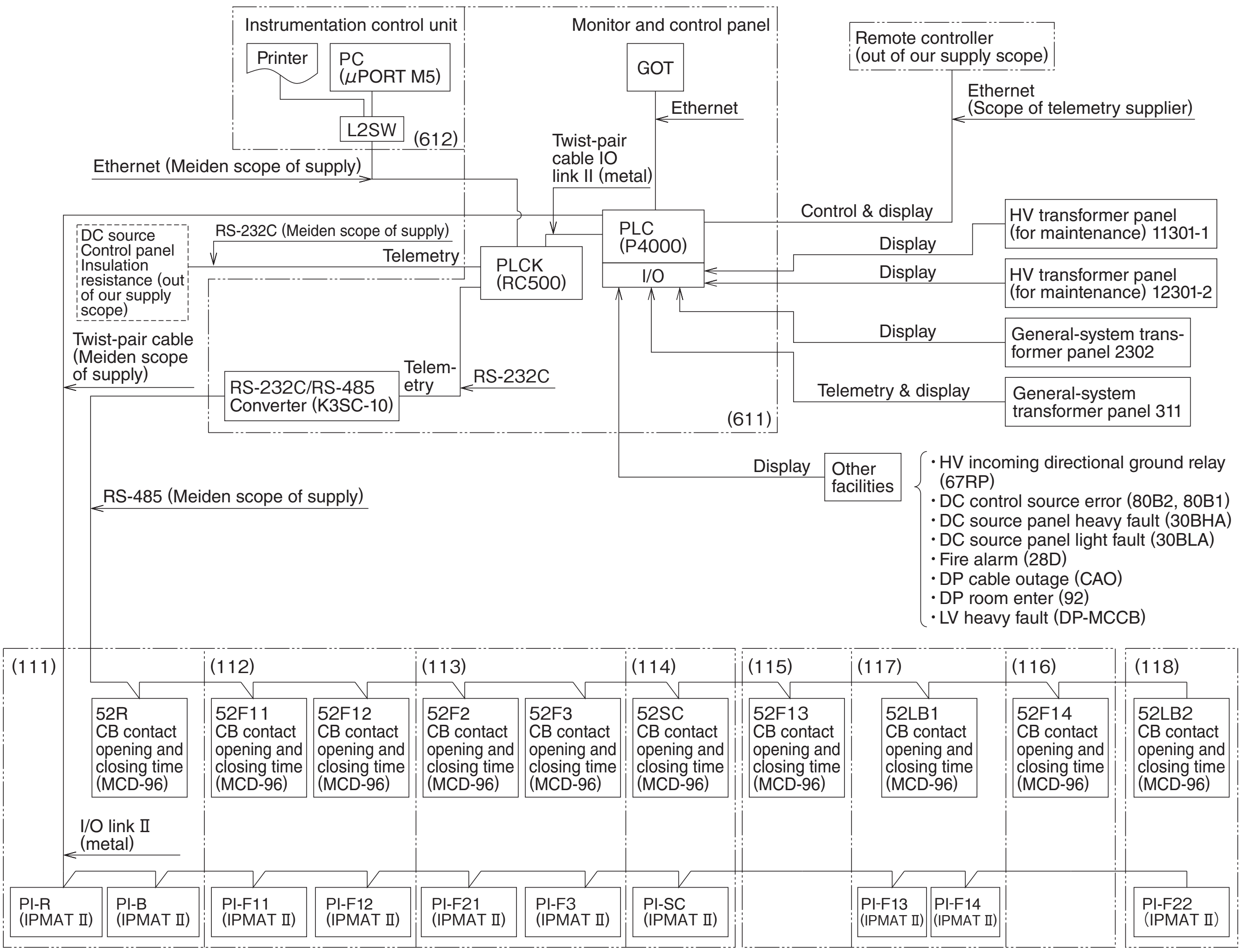
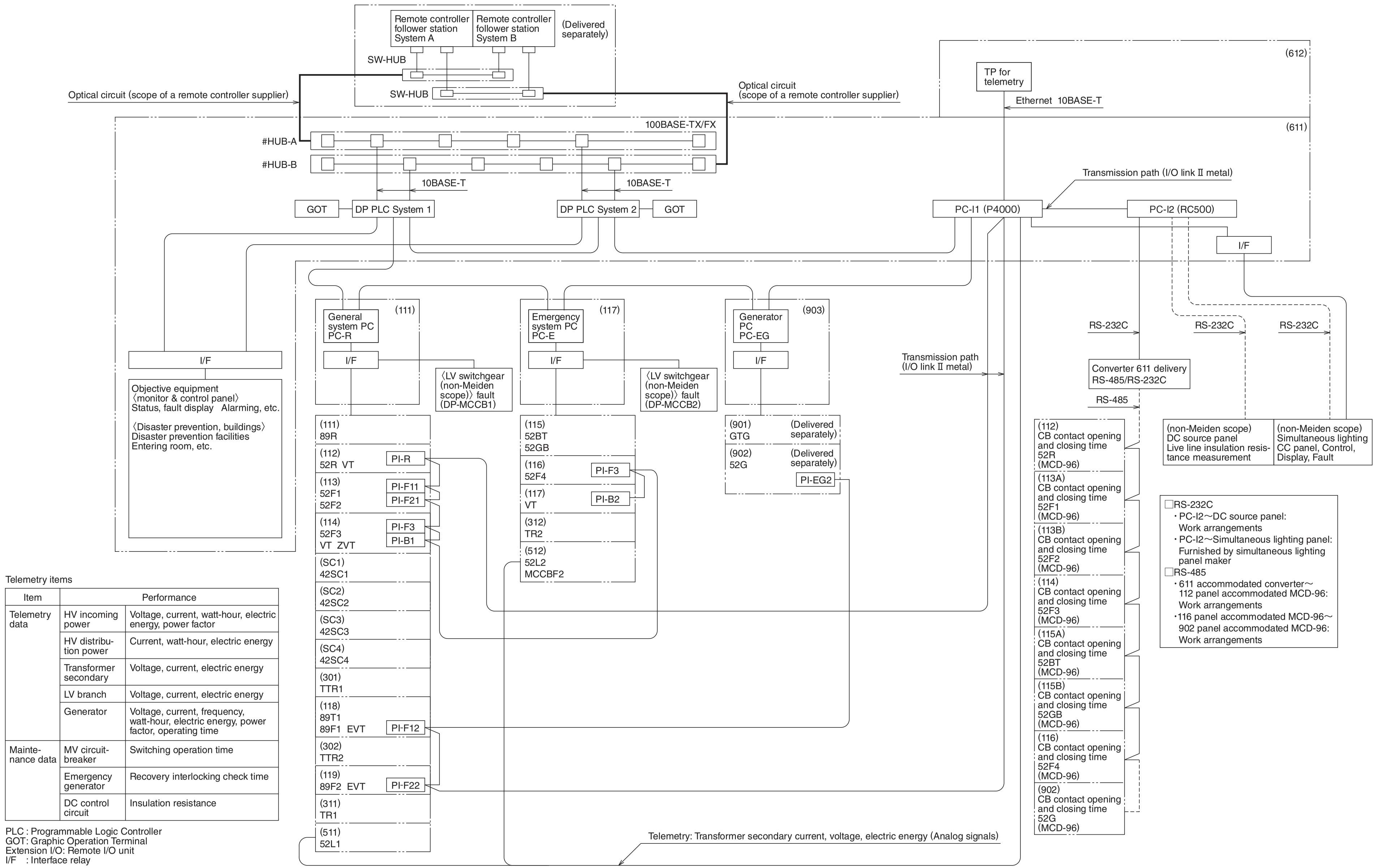


Fig. 15 System Configuration of the Nishi-Kasahara DP

A switchgear system configuration of the Nishi-Kasahara DP is shown. PLC of the DP comes in the simplex system configuration. The switchgear interlock system is composed of hardware circuits.



Telemetry items

Item		Performance
Telemetry data	HV incoming power	Voltage, current, watt-hour, electric energy, power factor
	HV distribution power	Current, watt-hour, electric energy
	Transformer secondary	Voltage, current, electric energy
	LV branch	Voltage, current, electric energy
	Generator	Voltage, current, frequency, watt-hour, electric energy, power factor, operating time
Maintenance data	MV circuit-breaker	Switching operation time
	Emergency generator	Recovery interlocking check time
	DC control circuit	Insulation resistance

PLC : Programmable Logic Controller
GOT: Graphic Operation Terminal
Extension I/O: Remote I/O unit
I/F : Interface relay

Fig. 16 System Configuration of the Itoigawa DP

A switchgear system configuration diagram of the Itoigawa DP is shown. The respective PCs are connected through an optical loop. Even though a circuit is disconnected, monitoring and control can be carried out by reverse looping.

age drop due to inrush current of transformer core excitation therefore becomes an issue. To solve this issue, medium-voltage load break switches with an inrush current restraint function are used. In addition, transformers are adopted to restrain the excitation inrush current within less than three times.

3.2 Power Distribution System Configuration

The Nishi-Kasahara DP employs the large-capacity high-speed PLC and the interlinking of each piece of equipment is configured with hardware circuitry.

At the Itoigawa DP and the Shin-Kurobe DP, automatic interlocking treatments are carried out for power outage and restoration. A redundant configuration is therefore adopted for the large-capacity high-speed PLC to improve reliability. Digital relays are assembled in each circuitry unit to establish an attributed configuration. Fig. 15 shows a system configuration of the Nishi-Kasahara DP and Fig. 16 shows that of the Itoigawa DP.

3.3 Auto-Periodic Inspection Function

The Itoigawa DP and the Shin-Kurobe DP are provided with an automatic checking function for interlocking with power outage and restoration. At the time of maintenance service, this function makes it possible to change operation from grid power to stand-alone generator operation by giving a mimic power outage signal from the monitoring and control panel so that interlocked power outage sequence can be executed. After the specified period of time, the mimic power cut signal is reset in order to execute the power restoration sequence for recovery from a service interruption. This function allows for effective maintenance work.

3.4 Measuring Equipment

Measuring equipment is installed to collect data for the current value display and daily/monthly report logging. For medium-voltage CBs, contact opening and closing time is measured to identify the adequacy of CB operation. By this measurement, it is possible to discover any faulty CB operation resulting from aging deterioration developed in each medium-voltage CB. By virtue of these functions, we designed effective maintenance work.

4 Railway Train Line Facilities

Tunnel disaster prevention Disconnecting Switches (TDS) are installed in seven delivery posts. When a fire breaks out inside the tunnel, the TDS sections the accident spot and makes it possible to feed power to sound circuits. This facility is important because it has a role to take train cars out of the tunnel.

4.1 TDS

Since these disconnecting switches are installed inside the tunnel, the enclosed type GIS was adopted in consideration of environmental conditions. Table 5 shows its ratings.

Table 5 Ratings of TDS

Ratings of TDS are specified. This switch is used when power source separation is needed in case a disaster occurs inside the tunnel.

Item	Ratings
Installation place	Outdoors (inside the tunnel)
Rated voltage	36kV
Rated current	1200A
Rated short-time current	12.5kA-2s
No. of panels	14 panels (2 panels/post)

4.2 Monitor Control

For the control of TDS, monitor control is carried out from a nearby substation post in simplified remote control mode. Control power is fed from the battery control panel installed on the site.

5 Postscript

According to the projected Shinkansen Line Plant, Hokuriku Shinkansen will be extended as far as Osaka via Tsuruga.

Various facilities delivered from us will contribute to safe and fast operations of Shinkansen. We expect that this Shinkansen will be an important means of transportation for the people traveling between Tokyo and Hokuriku Area.

Lastly, we express our deepest gratitude to all individuals who provided us valuable suggestions and cooperation relating to the supply of these facilities.