STUDY FOR THE INTRODUCTION OF DIGITAL COMMUNICATION USING OPTICAL FIBRE CABLES BETWEEN CONTROL ROOMS AND SWITCHYARD

DAISUKE TAKAISHI[1], HIDEKI NAKAZAWA[1], TAKUYA TAKEMATSU[1], NAOKI YAMANAKA[1], HIDEYUKI YOSHIOKA[2], YOSHITAKA TAKEMOTO[2] & TAKAMICHI ENDO[2]
[1]East Japan Railway Company, Japan
[2]Hitachi Ltd., Japan

ABSTRACT
Many copper cables for supervision, trip, measurements and control commands are laid between the switchyard equipment and the control room in the conventional substation. Therefore, it is difficult to remove the existing cables when the equipment is renewed, and to arrange the cable pits when the equipment is newly installed. In addition, since a large number of cables are connected, there is a problem that the construction period becomes longer. Therefore, to update the equipment easily, we studied the system configuration and information exchange method by digital communication technology reducing the number of cables between the switchyard equipment and the control room. We developed a prototype system, and field tests were conducted for the practical application of inter-equipment optical digital communication in a substation of the East Japan Railway Company. In the field test, we evaluated the prototype system compared to the conventional system not only by the performance test such as operation and transmission, but also by noise resistance performance test, workability check, and weather resistance check. We applied optical fibre cables to connect among the developed protection relay unit and field unit, instead of copper cables. In the substation, we evaluated abnormalities in power supply voltage, transmission line, CPU, etc. in outdoor environment. Also, we confirmed that trip signals and VT information are properly acquired by simulating relay operation, and we evaluated the redundancy in system configuration and protection performance. In conclusion, by using optical fibre cables for control cables except power supplies such as equipment and lighting, we confirmed that it is possible to significantly reduce the number of cables, and that work would become more efficient. We also confirmed that there were no problems about noise resistance, redundancy, and weather resistance.
Keywords: optical fibre cable, protection relay unit, field unit.

1 INTRODUCTION

Many copper cables for supervision, trip, measurements and control commands are laid throughout the substation between the switchyard equipment at the substation and the switchboard, and when updating the equipment. It is difficult to remove the existing cables or arrange the cable pits at the time of new installation. In addition, since a large number of cables are connected, there is a problem that the construction period becomes longer. Therefore, we decided to proceed with the development of a system configuration and transmission method in consideration of the ease of equipment update by digitally transmitting information technology for the purpose of reducing the number of cables between field equipment and switchboards.

A prototype was manufactured and field tests were conducted at the substation for the practical application of inter-equipment optical digital at the substation. In the field test, in addition to the operation test and transmission test for evaluating the performance of the prototype, the noise resistance performance, workability and weather resistance from the existing equipment were tested, and the conventional system configuration and the developed system configuration were evaluated. The equipment configuration was such that the developed protection relay unit and field unit were replaced with optical fibre cables via

WIT Transactions on The Built Environment, Vol 213, © 2022 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/CR220171

L2SW from multiple metal cables. For Musashisakai substation of bulk power supply substation in the East Japan Railway Company (Fig. 1), check for abnormalities in power supply voltage, transmission line, CPU, etc. in outdoor environment, acquire trip information and VT information from existing equipment by simulating relay operation, and system configuration Issues were extracted from the confirmation of redundancy and protection performance.

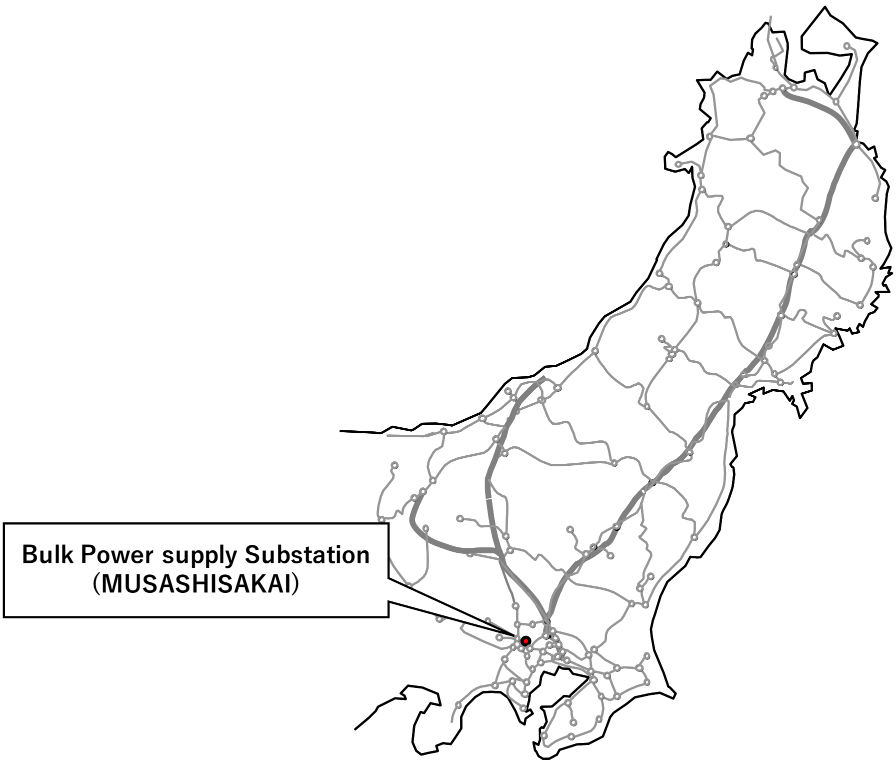


Figure 1: Location of the Musashisakai substation.

2 COMPARISON WITH THE CURRENT SYSTEM CONFIGURATION

2.1 Current system configuration

There are many cables between the field equipment and the switchboard, and there are a lot of issues such as electric shock risk due to incorrect wiring, cost increase due to the use of the switchboard, long construction period, noise intrusion into the control circuit due to opening/closing surge and lightning damage (Fig. 2).

2.2 Optical digital system configuration

Digital transmission is used between the field unit and the switchboard. This enables multiplex transmission, so the number of wires can be significantly reduced. Furthermore,

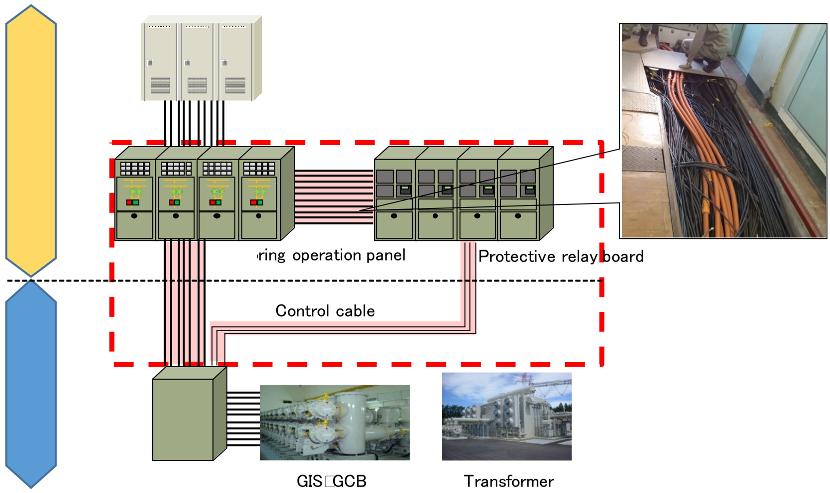


Figure 2: Current system configuration.

by insulating with optical fibre cables, there are many things compared to the current system configuration, such as reduction of electric shock risk, cost reduction due to reduction of the number of control cables, shortening of construction period, reduction of influence of opening/closing surge, securing of renewal space, etc. Therefore, this system is competent. In addition, the PRP (parallel redundancy protocol) method compliant with IEC62439-3 was adopted as the communication method to ensure the redundancy of the transmission line [1]–[3] (Figs 3 and 4).

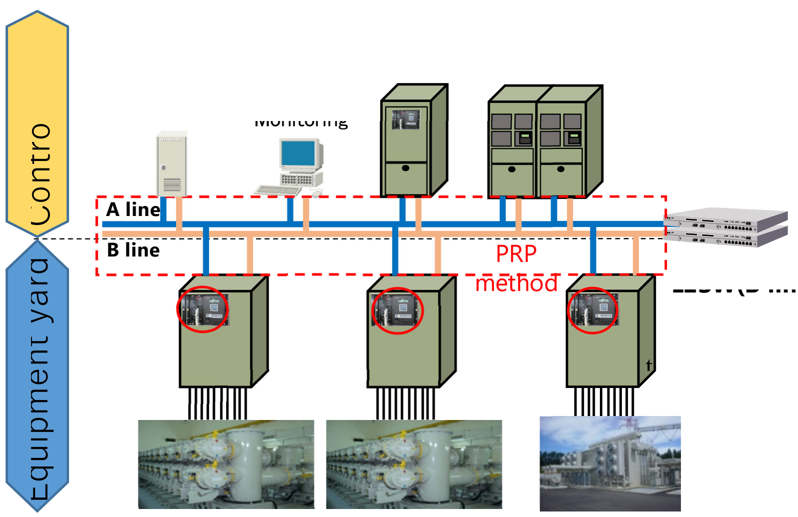


Figure 3: Optical digital system overview.

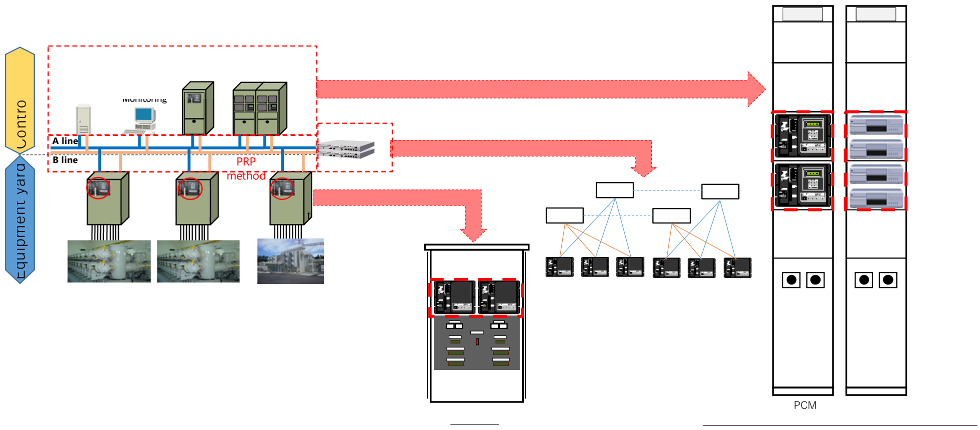


Figure 4: Optical digital system configuration.

3 FIELD TEST CONFIGURATION

The field test was conducted at the Musashisakai Substation. As a test configuration, a protection relay unit and a master clock were installed in the optical digital transmission switchboard. An optical digital transmission site unit was installed at the site, and L2SW was connected between by the PRP method, and various tests were conducted. The master clock is installed to time synchronization between distributed field units. As PRP communication path monitoring (transmission route monitoring), monitoring packets are sent from the master clock to all field units and protection relay units for each route A and B, and the reply is monitored to identify the location of the failure. In addition to the optical fibre cable, each unit is also duplicated to ensure redundancy (Fig. 5).

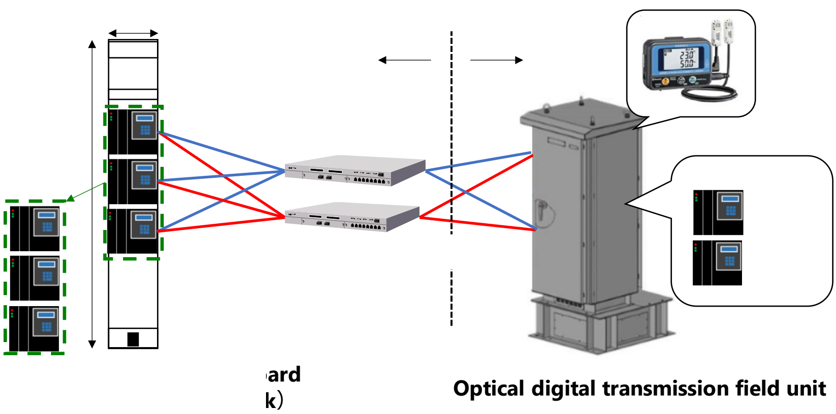


Figure 5: Field test configuration.

4 FIELD TEST CONTENT

4.1 Transmission abnormality test

In order to ensure redundancy, the transmission line is always a dual system, and it was confirmed that the protection function can be continued in the event of an abnormality in the single system transmission line. Specifically, the optical fibre cables from ① to ⑩ in Fig. 6 were connected and disconnected to simulate transmission abnormalities. As a result, the test results of ① to ④, ⑨ and ⑩ were able to get good results. However, after disconnecting the optical fibre cable from ⑤ to ⑧ (between the field unit and L2SW) and confirming that the protection is continued, when the optical fibre cable is reconnected to L2SW, the transmission error item GOOSE (generic object oriented substation events) on the field unit side. The reception error has occurred. GOOSE indicates a general-purpose object-oriented substation event defined in IEC61850 [4], and is a high-speed and highly reliable message. It is mainly used for information transmission such as circuit breaker cut-off command, operation command, field equipment status, and failure information. In order to identify the cause of the GOOSE reception abnormality, the same transmission abnormality simulation pattern was carried out, and the detailed monitoring items on the site unit side were directly confirmed on the debug PC. In order to check the soundness of the sender, we used a LAN monitor to check whether the GOOSE transmission operation was normal. We also confirmed whether there was any influence on the L2SW side. As a result, the GOOSE reception error detection process was operating normally, but in the software process on the site unit side linked to the master clock transmission route monitoring function, a transmission error was detected when the optical fibre cable was repeatedly inserted and removed in a short time. It turned out that the software processing continues abnormally. In the factory, when we simulated the abnormal mode when inserting and removing the optical fibre cable that occurred in the field, we confirmed that the transmission abnormality continued in the same way as in the field, and repaired the software.

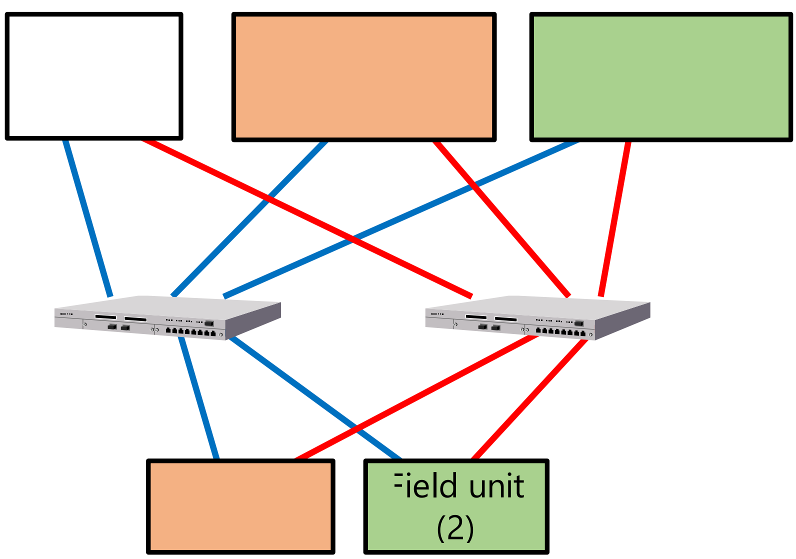


Figure 6: Transmission abnormality test contents.

When analysing the cause of this event, by implementing a memory dump function that captures the memory contents at the time of occurrence in an external file, it became possible to identify the cause of the abnormality and shorten the response time. In addition, it is effective to visualize the software operation so that debugging and software operation confirmation can be confirmed more easily and quickly.

4.2 Circuit breaker open/close surge test

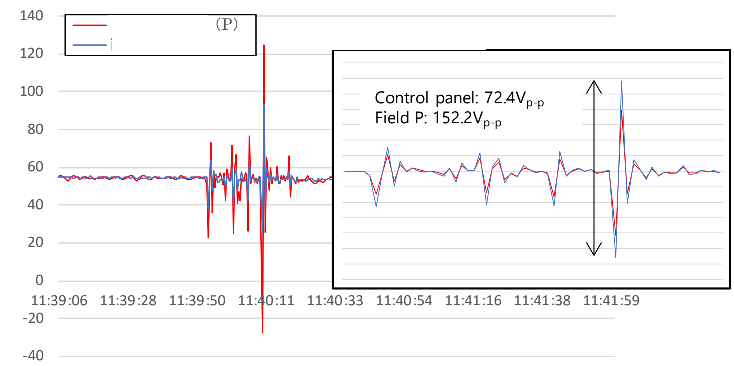
In the past, a substation in the JR East had an event that affected the equipment due to noise caused by an opening/closing surge of the circuit breaker. The opening of circuit breaker operation was performed, and the presence or absence of system failure and the surge voltage were measured. The measurements sampling was set to 5 μs. For the measurement points, total of four items were measured: field unit power supply-reference ground, field unit-reference ground, switchboard power supply-reference ground, and switchboard-reference ground. As a test procedure, the circuit breaker of the 22 kV line was repeatedly turned on and off three times. As a result, the surge was larger on the field unit side than on the switchboard side because it was closer to the circuit breaker (Table 1). The potential difference of about 80 V was generated between the field unit and the switchboard side (Fig. 7), Fibre optic cables do not affect transmission information. It was also confirmed that the switchyard unit responded normally before and after the opening/closing surge test. For the protection of field unit electronic components, it is necessary to reduce the ground impedance and consider installing in a place away from GIS equipment.

Table 1: Circuit breaker open/close surge test results.

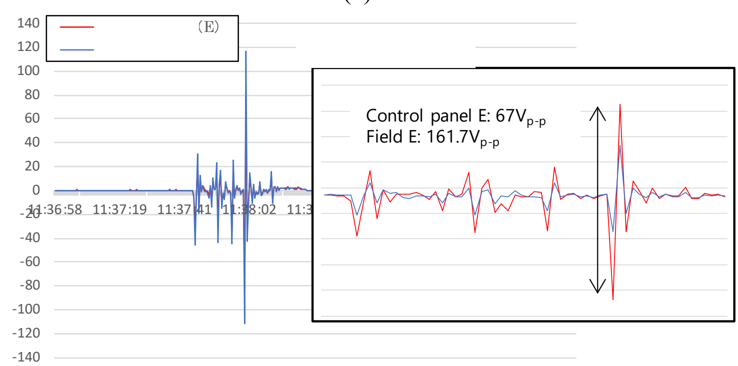
	Field unit power supply-reference ground			Field unit-reference ground			Switchboard power supply-reference ground			Switchboard-reference ground		
	Min	Max	P-P	Min	Max	P-P	Min	Max	P-P	Min	Max	P-P
CB close 1st	–50.8V	124.8V	175.6V	–99.9V	89.5V	189.4V	18.3V	89.6V	71.3V	–34.7V	34.4V	69.1V
CB close 2nd	–4.3V	106.3V	110.6V	–57.0V	48.7V	105.7V	32.9V	76.3V	43.4V	–20.8V	22.4V	43.2V
CB close 3rd	–27.4V	124.8V	152.2V	–83.2V	78.5V	161.7V	25.6V	98.0V	72.4V	–28.4V	38.6V	67.0V
Average	–82.5V	63.6V	146.1V	–80.0V	72.2V	152.3V	–29.4V	33.0V	62.4V	–28.0V	31.8V	59.8V

4.3 TCB on/off test

In order to operate the keep relay (TCB) that imitates the circuit breaker once every 10 days, the circuit breaker on/off command is transmitted from the protection relay unit to the site unit, the TCB is operated, and the TCB on/off information is transmitted to the protection relay unit. By transmitting to the side, it was confirmed that there was no abnormality in the entire system including the trip circuit. As a result, it was confirmed that there was no abnormality due to TCB operation.



(a)



(b)

Figure 7: Circuit breaker open/close surge test waveform. (a) Field unit-reference grounding; and (b) Switchboard-reference ground.

4.4 Input electric energy test

The single-phase 100V AC voltage (device power supply) was taken into the field unit and sampled, and it was confirmed that the input electricity amount was always displayed correctly in the digital transmission and protection relay unit. As a result, it was confirmed that the AC voltage can be input normally (Fig. 8).

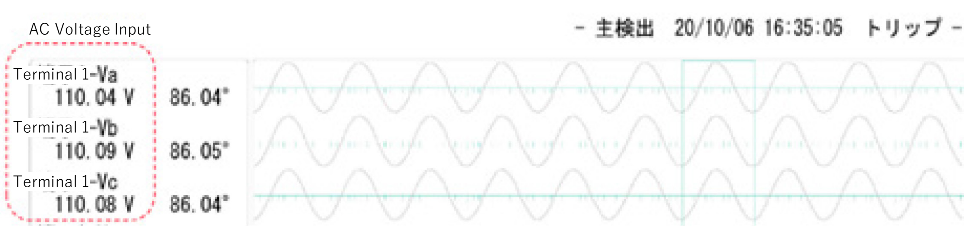


Figure 8: Input electric energy test result.

WIT Transactions on The Built Environment, Vol 213, © 2022 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)

4.5 Bypass circuit test

As a system configuration, all units are duplicated, the protection relay operating conditions are transmitted from the protection unit to the site unit, the conditions of the site unit 1 system and 2 system are configured by the hard circuit, and the AND condition is output. It was configured. In addition, the circuit configuration is also equipped with a function (bypass circuit) for bypassing the faulty system break circuit in the event of a single system failure among the field unit or protection unit. This time, we simulated the power failure of one system of the protection relay unit, and confirmed that the bypass circuit was established by the operation of the security lock (86) of the same system, and the final output was normally performed only by the cut-off command of the sound system (Fig. 9).

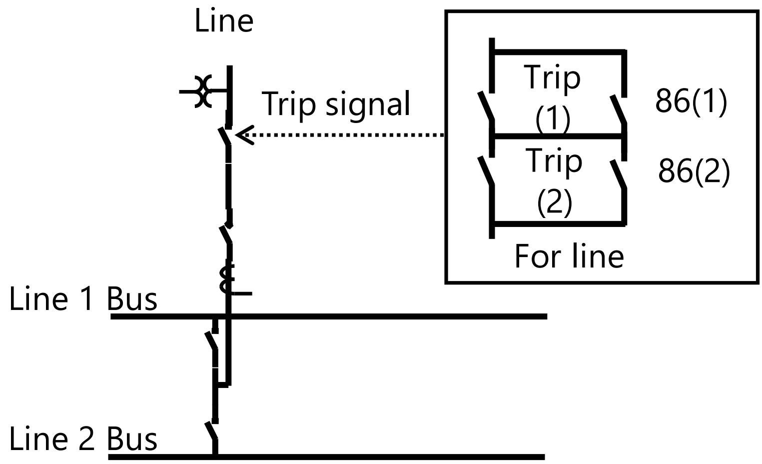


Figure 9: Operation/trip circuit.

4.6 Temperature/humidity environment evaluation test

For the cubicle equipped with the switchyard unit, the temperature rise was calculated based on the outside air temperature, the exhaust heat of the unit, the shape of the cubicle, etc. The specifications were set to be within the upper limit of the temperature specifications (Table 2). As a result, the maximum temperature inside the cubicle was 49.2°C, which did not reach the unit operating temperature upper limit of +50°C. This is because in the heat calculation at the design stage, the maximum power consumption of the unit was taken into consideration, and the light-shielding plate was attached so that the temperature did not exceed +50°C, and the width and position of the vents were designed (Table 3).

Table 2: Temperature and humidity performance.

Performance temperature	0 to + 40°C
Operating temperature	–10 to +50°C
Restoration temperature	–20 to + 60°C
Humidity	30 to 80% (however, does not condense)

Table 3: Temperature and humidity measurement results.

	Maximum		Minimum	
	Temperature (°C)	Daily average relative humidity (%)	Temperature (°C)	Daily average relative humidity (%)
Cubicle	49.2	76.5	1.2	22.8
Outside	44.2	100.0	–2.5	34.1
Difference	5.0	–23.4	3.7	–11.3

4.7 Consideration for accidental failure

By detecting a system abnormality (serious failure) during the field test, the failure history was confirmed on the board of the field unit and the protection relay unit. The log of each unit was acquired, and it was confirmed that the cause of the failure was a transmission error between field unit and the protection relay unit. When checking the equipment operation records at the Musashisakai Substation, it was found that the equipment supplying power to the substation premises was stopped at the same time as the failure occurred. The power supply in the substation is a dual system. This time, the regular power supply system was stopped. Therefore, it was found that the cause was a momentary power outage when switching from the regular system to the standby system. Specifically, since the L2SW power supply used in the field test was 100V AC, the L2SW power supply was temporarily lost due to a momentary power failure of the power supply in the substation, and communication became impossible, resulting in a transmission error in field unit and the protection relay unit. As a finding obtained from this event, the L2SW and the power supply for the master clock, which are the common parts of the substation system, are DC with the backup of the storage battery and the power cable is duplicated to ensure sufficient reliability as in the transmission part.

5 CONCLUSIONS

With the aim of reducing cables between switchyard equipment and switchboards. We produced prototypes of system configurations and transmission methods that take into consideration the ease of equipment update by digitally transmitting information. We conducted field tests at the Musashisakai Substation. From the results, it was possible to significantly reduce the number of cables by using optical fibre cables for control cables other than power supplies such as equipment and lighting, and it was confirmed that workability was improved. It was also confirmed that there were no problems with noise resistance, redundancy, and weather resistance. Since the prototype equipment is a part of the equipment required for the substation configuration, we will continue to develop and verify it for practical use. In addition, the transmission method conforms to international standards to ensure the redundancy of the transmission line, which is a shared part, and the unit redundancy ensures high reliability in the system, so that various power systems can be used. It is expected to be introduced in. In the future, based on the results of this research, specifications will be formulated with an eye on the realization of digitalization of the entire control and protection system of the substation.

REFERENCES

[1] IEC 62439-3, Industrial communication networks: High availability automation networks – Part 3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR), 2016.
[2] Ueraku, Y., Nishizawa, K., Tanaka, Y., Endo, T. & Yoshioka, H., Development of transmission line protection relay device using PRP redundant communication. PRP-17-013, 2017.
[3] IEC 61850-9-2 Ed.2.0, Communication networks and systems for power utility automation: Part 9-2: Specific communication service mapping (SCSM) – Sampled values over ISO/IEC8802-3, 2011.
[4] IEC 61850-8-1 Ed.2.1, Communication networks and systems for power utility automation: Part 8-1: Specific communication service mapping (SCSM) – Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3, 2020.