Passenger needs have become more sophisticated and diversified in the past few years. Particularly, more flexible transport services have come into demand such as shorter travel time, increase of train runs and extension of through services, all while providing safe and precise transport. Improvement of the signal control system is indispensable, however, if we are to provide these services. We have accordingly made continuous improvement of that system. But the current system does not necessarily have a system architecture where we can flexibly carry out installation and improvement due to the constraints in assuring high safety and reliability.

We are thus addressing the development of a new signal control system (network-based signal control system (NW signaling system)). The aim of that is improvement of ease of work in signal installation, that is, shortening work time while improving quality. The new system will achieve simplification of the system architecture and improvement of flexibility in change by unifying and standardizing signal house logic controllers and computerizing and networking control platform of actual signals (1)(2). In this article, we will introduce the development history of the NW signaling systems and the development of the signaling logic controller that conducts centralized control of in-station signals. More specifically, we will cover the development concept of the network-based signal control system in the second section, the basic concept of that system in the third section and the development of the signaling logic controller for station yards in the fourth section. We give an overall summary in the fifth section.

Keywords: Network-based signal control system, Signaling logic controller for station yards, Interlocking, ATS, In-yard crossing

1 Introduction

More flexible transport services are in demand with recent sophistication and diversification of passenger needs. In fulfilling such needs, it is necessary to innovate signaling systems to those that are easy to improve, while maintaining current or higher safety and reliability. In light of that, we have been proceeding with gradual development of a network-based signal control system. In this system, logic controllers in the signal house of the station and the field signaling facilities are connected via an optical network, and control is done by digital data instead of by conventional electric control. In this article, we will explain the development concept of the network-based signal control system and the basic technologies of that. We will also report on the development of the signaling logic controller for station yards that is the final form of network-based signal control system for station yards and the status of field tests of that controller.

2 Development Concept of the Network-based Signal Control System

2.1 Issues with the Signal Control System

Fig. 1 shows the configuration of the current signal control system. A signal control system is divided into two major parts, namely a logic controller and field facilities controller. Issues related to the individual controllers are shown as follows.

1) Issues with the Logic Controller Part

We have systematized logic controllers by the control functions such as interlocking, Automatic Train Protection (ATS) and level crossing. But the architecture of these controllers is not unified, and the information transmission method between devices varies from relay connection to Ethernet. Because of this system architecture, the following issues are present.

a) Partial function changes broadly affect the total system.
b) It is difficult to identify the area affected by the change.

2) Issues with the Field Facilities Controller Part

Equipment directly controlled by sending electricity down the individual copper wires. A huge volume of manual cabling work is thus required, and the following issues exist.

a) There are many items to check, and such checking takes a long time.
b) There is a possibility of transport disruptions occurring due to human error.

2.2 Development Steps of the Network-based Signal Control System

As an approach to solve the aforementioned issues, we are taking the following four steps in system development and introducing the system for practical use (Fig. 2).

1) STEP 1: Network-based Signal Control System for Station Yards

Fig. 1 Configuration and Issues of a Signal Control System
We have developed a system that controls field facilities via the network under the control of the current electronic interlocking equipment with a main purpose of solving the issues with the field facilities controller. That system has been put into practical use at Ichikawa-Ono station on the Musashino line. Furthermore, we have established the basic technologies of NW signaling systems overall such as ensuring safety of signal control via a general purpose IP network.

(2) STEP 2: Network-based Signal Control System for Automatic Block Signals (between stations)

The technologies established in step 1 are applied to control signals between stations in this system. Its purpose is to further improve availability and reliability of such signals.

(3) STEP 3: Logic Controller for Station Yards

We are now addressing integration and standardization of the mechanical aspect of logic controllers and integration of signal control logics. The main purpose of that is to solve issues with logic controllers. We are carrying out field tests of the interlocking control functions and the crossing control function of those.

(4) STEP 4: Level Crossing Control (between stations)

The purpose of the level crossing network between stations is to set more appropriate alarm timing and improve maintainability of crossings. This is done by controlling crossings between stations via the network-based signal control system for automatic block signals. This development is still at the planning stage.

3 Basic Concept of the Network-based Signal Control System

3.1 System Configuration

Fig. 3 illustrates the configuration of the network-based signal control system for station yards as an example of the configuration of NW signaling systems. NW signaling systems mainly consist of a logic controller, field controller, optical network and a remote monitoring system. The roles of individual components are as follows.

(1) Logic Controller (LC)

LC is the collective name of the devices that make centralized processing of control logic of signals and transmit control conditions to and from signals via a network. In NW signaling systems, logic by wire connection is eliminated and basically all signals are controlled by software from the perspective of workability improvement. For the logic description method, we have chosen the built-in control diagram type adopted for and proven in equipment such as current electronic interlocking equipment. That is done under the perspective of being able to deploy to all sorts of locations simply through quality improvement by software standardization and by data change. We are developing three types of LCs. Those are Field object Controlled Processor (FCP) that is regarded as the electronic terminal compatible to the network control under the 301-type electronic interlocking equipment, LC for automatic block signals that controls signals between stations and LC for station yards that controls in-station signals including interlocking equipment and in-yard crossings.

(2) Field Controller (FC)

A FC is a fail-safe terminal that makes electric control of functions such as turning on signal lights and operating switches based on control data from the LC. Because of the advantages in simplified installation work and in measures against lightning surge, we have decided to incorporate a FC in the signal casing and thus developed and introduced downsizing and power-saving technologies such as a fail-safe micro computer in a chip (FS-LSI), high-efficiency power supply (a Tesla converter), a power-saving LED lamp and so on. Fig. 4 shows an example of such a small control terminal built in to the signal casing.

(3) Optical Network

As the optical network system, we have adopted E-PON (Ethernet Passive Optical Network), a general purpose IP network method...
proven in FTTH (Fiber to the Home). In order to ensure high safety in transmission over a general-purpose network, we have also developed the safety-related transmission technology to be explained later.

(4) Remote Monitoring System
In an NW Signaling system, operation conditions and control current values of all devices and signals can be monitored. That information is centralized in database servers installed in individual signal houses. Condition change and excess of threshold values are monitored real time, and a warning is transmitted in case of abnormalities. Since all of accumulated information can be accessed with monitoring terminals such as signal dispatcher’s terminals connected via an Intranet, it is easy to identify the point of failure and analyze the failure cause. The system also has a remote resetting function of temporary failures of electronic devices to enable swift recovery from those failures.

3.2 Basic Technologies for NW Signaling System
Now we explain the basic technologies for the NW signaling system along with data control of signaling facilities and safety-related transmission between LC and FC.

3.2.1 Data Control of Signals
Transformation from control of signals by voltage control to data control allows us to add the following characteristics to the control conditions with no increase of number of core wires of the transmission line. That will contribute to safety improvement and achieving different control functions.¹⁰

(1) Higher Reliability
By adding redundant code, data reliability is improved, and thus system safety is enhanced.

(2) Abstraction
We can send abstract control commands such as “proceed” and “stop” to the FC. The FC decodes that information and makes electric control of signals according to the shape of each facility. That allows flexible signal control even in change of signals.

(3) Diversification
By adding system operation information such as “maintenance” and “test” to the control information, operations related to system maintenance can be supported by the system.

3.2.2 Safety-Related Transmission Technology
Detecting any and every error that might occur on the transmission line using fail-safe devices at both ends of that transmission line to make immediate safety control is the foundation of ensuring the safety of signal control in transmission. Detailed safety requirements for that are determined in IEC-62280-1 (safety-related communication in closed transmission systems).¹⁰ Since this system uses general-purpose network products, we have had to establish a transmission error detection method that is not dependent on transmission protocols, media and facility models. FTA (Fault Tree Analysis) has proved that possible errors are categorized into the following three types, and we have established a method of sure detection of each type of errors by adding appropriate error detection information to the transmission data.¹⁰¹⁰¹

a) Information error: Error where part of the data is missing or replaced. That is detectable by CRC (cyclic redundancy check) and reversed sign check.

b) Delivery error: Error where the data is misdelivered to a device other than that specified. That is detectable by checking IDs in the code that are unique to each device.

c) Time error: Error where arrival of the data is delayed or the delivery order is inverted. That is detectable by serial number check and time-out check.

4 Development of the Signaling Logic Controller for Station Yards

4.1 Overview of the development
The development and start of practical use of the station yard network signal control system (Step 1) has brought about some effects in workability improvement and test simplification. On the other hand, there still remain many facilities that are out of network control such as ATS-P balise and track circuits. Furthermore, the logic controller has a patchy system configuration because of its history where systematization per function has been performed such as systematization of interlocking equipment or of ATS-P. Consequently, we cannot say that we have achieved satisfactory workability improvement of the system. In order to solve this issue, we are now developing a signaling logic controller for station yards as the third step of the network-based signal control system. The objectives of that include simplification of the system configuration by integrating logic controllers that are currently separated by function in the signal house and extension of the network control scope (Fig. 5).¹¹ The development items of the signaling logic controller for station yards are as follows. Fig. 6 shows the development schedule of that.

(1) Integration and Standardization of the System Configuration
We are going to integrate conventional logic controllers separated by function into a piece of hardware with high reliability and high performance. That will reduce the number of interfaces between devices that are the bottleneck in securing reliability. It will also allow simplification of the function of configuration control between multiplex devices, and thus allow us to overcome failures related to configuration control, which are difficult to completely eliminate. Those approaches will improve reliability of the system as a whole.

(2) Restructuring of Control Logic
We will restructure on a common platform control logic that was conventionally built separately such as logic for interlocking

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¹⁰ Proof of concept for this method.
¹¹ Proof of concept for this method.
equipment, ATS and crossings. Shifting those into a software structure that can localize and identify the area affected by improvement of data or function will enable easier improvement.

(3) Unification of Design
By unifying design of control logic, network and monitoring constants based on the common data, we will reduce design work and also improve design quality.

4.2 Integration and Standardization of System Configuration

4.2.1 Concept of System Configuration

Fig. 7 illustrates the total system configuration of the NW signaling system with logic controller for station yards including peripheral devices. This system can be divided into four major segments: the LC for station yard segment, the field controller segment, the remote monitoring segment and the other-system interface segment. The connection interface between segments and connection interface between devices in each segment are unified in an Ethernet interface (IP connection). Allocating different network segments to each segment achieves control where unnecessary data is not transmitted between segments. The configuration of the individual segments is as follows.

(1) LC for Station Yards Segment
This segment consists of a fixed part (always-connected, duplex) and a mobile part (connected as needed, single) of the LC for station yards, and makes batch processing of all control logic within the station yard.

(2) Field Controller Segment
The segment consists of a PON network that transmits control/feedback data between LC and FC and monitoring data between FC and the remote monitoring segment along with FCs that are built in to the signal cases and make control of signals based on the control data from LC.

(3) Remote Monitoring Segment
This is a remote monitoring system that integrates this system and the remote monitoring and maintenance function of NW signaling system for station yards and NW signaling system for automatic block signals that have been developed so far. This segment consists of a remote monitoring server that accumulates operation data such as for the system, a remote control server that processes remote maintenance requests to system devices and a remote monitoring terminal that is a man-machine interface.

(4) Other System Interface Segment
This segment provides interfaces to other network-based signal control systems such as the NW signaling system for automatic block signal and with other systems such as a TC type train approach warning devices. Interfaces are unified to Ethernet interface. To connect conventional systems without Ethernet interface, we will separately develop interface conversion adaptors for individual systems.

4.3 Restructuring of Control Logic

In the operation of the current signal control system, in-station improvement work and other system changes require stopping total system operation, not just train operation, for safety reasons. It is thus very difficult to secure work time. Further, system improvement has much overhead and requires much time such as system change time from the existing to the improved system and check time after testing and returning to the existing system. For those reasons, improvement work of signal systems takes much time. One of the reasons securing safety is difficult when continuing train operation in system change is that the area affected by that change is broad and not clear. Since electronic control systems have software control logic like a black box, it is an important issue to identify the area affected by the test carried out in the factory at system change. The reason why that area is wide and not clear is a structural problem whereby a variety of interfaces are used to transmit control conditions to link different signals.

With the signaling logic controller for station yards, we thus work to minimize and clarify the area affected in the system change by solving the above-mentioned problem. As a method to conduct such minimization and clarification, we have advanced the concept of track circuit reservation of current electronic interlocking equipment and proposed a concept of subroutes to unify interfaces to interlock between signals. Now we are addressing actual development. The concepts for individual control logic are as follows.

4.3.1 Interlocking Logic

Functions of an interlocking equipment can be divided into two. One is a static function of controlling locking of signaling facilities to each other, and the other is a dynamic function of locking/unlocking of switches and controlling aspects of signals on the route as a train moves. By specifying the former (a track circuit reservation function), and the latter (the track circuit tracing function), we have tried to unify interfaces with the current electronic interlocking equipment to transmit control conditions to the track circuit. Still, some exceptions such as conflict check of switches remain, so a totally unified interface have not been achieved.

For the signaling logic controller for station yards, we have suggested a concept of subroutes as the interface. In addition to the above-mentioned reservation and tracing functions, that...
interface makes total control of all signal control conditions, such as route clearing of switches and aspects of signals, and makes unified interlocking to and from signals (Fig. 8).

A signaling logic controller for station yards makes reservation of subroutes included in the track circuit, and makes conflict checks of each subroute. This is done similarly to how a current electronic interlocking equipment makes reservation of track circuits. Since subroutes include clearing of switches, conflict checks of switches are also made at the same time. Furthermore, the unit can make completely reserved conflict checks, while current electronic interlocking equipment have to make exceptional processing because they cannot make reservation of some subroutes included in circuits such as at the starting point and at the destination point.

4.3.2 ATS Control Logic

In principle, control of ATS balise gives warning at the “stop” aspect and cancels warning at the “proceed” aspect according to the aspect of the main signal. There are, however, some control patterns called “special conditions”, where control not under that principle is done due to topographic constraints such as an installation point of a balise and operational constraints of trains and cars. For the conventional signal system, the designer has to extract such special conditions and note those in the control diagrams. That increases the work and burden of the designer, and might cause transport disruption due to design errors.

The signaling logic controller for station yards achieves simplification of control logic design and error prevention by a newly developed method where an algorithm determines applicable type of special conditions based on the reservation of the subroute where balise are installed. More specifically, the design data specifies the subroutes to which balise belong, main signals and whether any special condition is applied or not. The signaling logic controller for station yards picks out the set reservations on such subroutes, determines appropriate special conditions to those reservations, and makes control of ATS balise (giving/canceling warning) using corresponding control sequences (state transition patterns). Fig. 9 shows an example of a case where delaying is specified as a special condition.

4.3.3 Crossing Control Logic

In order to control in-station crossings, diversified control sequences have to be achieved to meet topographic conditions such as track layout and signal layout and operational conditions such as coupling/decoupling and shunting within the station. Control sequences for crossings are defined per warning route. Since there is an extremely large number of many types of control conditions related to a single warning route in the yard of a large-sized station in particular, designing and testing requires much labor at present. Above all, testing to verify that crossings work safely even when the order of conditions coming into effect is wrong is essential, but the increase in conditions directly results in explosive increase of test cases. It is a serious problem for us that checking all conditions is very difficult.

In light of that, we have proposed a new control method of dividing a warning route into subroutes (“warning subroute”) and consolidating the determination results of warning status of each warning subroute in the warning route (Fig. 10). In this method, the number of cases to be verified will not increase much since the system does not need to consider the order of conditions coming into effect per warning subroute, and there are only a few conditions in a single warning subroute. Consequently, we will be able to reduce total testing work.

4.4 Centralization of Designing

When building a signal control system, designers prepare control diagrams per function such as interlocking, crossing and ATS, and each component of the logic controller is produced based on those diagrams. Since those are wide-ranged and preparing them those requires much knowledge about train operation rules and details of diagram drawing rules, we currently rely on the human experience and attention in checking consistency between the drawn diagrams. This leads to much time being required for the work of drawing and consistency checking of control diagrams of the signal control system, and it might end up being a cause of transport disruption due to errors in diagram preparation.

In light of the circumstances, we are addressing development to make centralized design data at each designing stage and make
automatic checking of consistency between those. This eases the burden in designing the signal control system.

Designers interactively input the data necessary in designing to the signal control system using design support tools at each designing stage. The system automatically checks the consistency between the input data, and it outputs that as data under centralized control. The system accumulates the data as design proceeds, and the tools cover all design data necessary for a signal control system when design is complete.

The data necessary for the LC, FC, network devices and monitoring devices are automatically extracted from that centralized design data. In this way, we are developing design support functions, consistency check functions and the automatic data extraction functions for the signal control system with an aim of simplifying designing and improving design quality. We are also studying a function where the check functions and the automatic data extraction functions for devices are automatically extracted from that centralized design data.

The system automatically checks the consistency between the input data and outputs that as data under centralized control. The system prepares based on the centralized design data diagrams that designers now draw using CAD (Fig. 11).

4.5 Field Tests

We have introduced to control logic of the signaling logic controller for station yards new concepts such as subroutes. For that reason, we have carried out field tests to verify the validity of the developed control logic by comparing control timing between the existing interlocking equipment and the signaling logic controller for station yards.

4.5.1 Verification Method in the Field Tests

When selecting the stations where to carry out the field tests, we chose the stations that meet the following conditions, provided that the station uses a relay interlocking system that allows us to easy obtain control conditions for comparison.

a) Many types of signaling facilities
b) In-yard crossings present
c) Frequent in-yard shunting
d) Mid-sized station with approx. 100 routes

We selected Minami-Matsumoto station on the Shinonoi line and Iwanuma station on the Tohoku main line as stations that meet those conditions. As an example, Table 1 shows the facilities of Minami-Matsumoto station tested in the field tests.

We conducted the verification only of interlocking equipment at the start of the field test. Later, we gradually added the function of signals, ATS and crossings to the control function verification. We will further add other facilities.

In order to make route setting and signal control by the signaling logic controller for station yards, the relay interlocking equipment must transmit the route setting conditions and track occupation information to the signaling logic controller for station yards. And, in order to compare the control timing of the relay interlocking equipment to that of the signaling logic controller for station yards, the control results of the relay interlocking equipment on the signals, ATS and crossings must be obtained. In the field test this time, those conditions were obtained using relay contact points (or current sensors where there were no excess contact points) (Table 2).

For the verification in that field test, we assimilated the control results of the control logic developed for the signaling logic controller for station yards and the results of the relay interlocking equipment separately into the comparison device. Verification was thus accomplished by comparing the time when the control output was changed (Figs. 12 and 13).
The developed control logic makes simulated control of basic facilities—the route setting requests and the task occupation information—based on the route setting information.

The interlocking terminal (left) and comparison device (right)

Signal crossing, ATS control output (by signaling logic controller for station yards)

The developed control logic makes simulated control of basic facilities—the route setting requests and the task occupation information—based on the route setting information.

4.5.2 Status of the Field Tests

We have been carrying out field tests since June 2008. Fig. 14 summarizes problems that occurred at Minami-Matsumoto station from the start of the tests to June 2009. Some failures occurred at the beginning, but no new failures have been found after countermeasures were taken. However, there are some differences between the operation of the relay interlocking equipment and of the signaling logic controller for station yards. This is because the signaling logic controller for station yards works based on specifications of an electronic interlocking equipment that basically makes automatic route control, while the relay interlocking equipment compared in the field tests has control functions manually operated by the signal operator. Which operation to specify as the standard for the signaling logic controller for station yards is an issue that will be studied in the future.

Fig. 12 Concept of the Field Tests

Fig. 13 System Components of the Field Test

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5 Conclusion

In this article, we have covered the gradual development of the network signal system to achieve greater workability and achieve greater flexibility in station improvement work while maintaining safety and reliability at levels higher than before. We have also covered the objectives and details of the development of the signaling logic controller for station yards, the final form of the station yard network-based signal control system. The goal of all that development is early achievement of better customer services.

The signaling logic controller for station yards is now under development. At present, we are carrying out field tests on the interlocking, signal control, ATS control and crossing control functions. Since the prototype functions have demonstrated favorable test results, we are planning to undertake development for practical use based on the field test results. We are also planning to conduct development of design centralization for practical use.

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