Extended Application of All-in-One Protection and Control System for Hydropower System Compliant with Industrial Field Level Network

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Abstract

The Feed-in Tariff (FIT) system for the purpose of promoting renewable energy was introduced. Japan's energy self-sufficiency rate is at a low level, therefore, against the background of the social trend aiming to improve the rate of energy self-sufficiency, the hydropower market is surging. We are working to further popularize hydropower systems, to meet various demands for further expansion by providing new products and optimal systems. In the field of general hydropower, we are responding to many requests for maintenance and labor saving, and a more compact and light mass system design.

For hydropower systems with multiple hydro turbine generators, we additionally offer a common control panel that can control up to four hydro turbines and an all-in-one protection and control system for network-ready hydropower generation. The correlation graph and start/stop measurement graph display functions that contribute to further labor saving in maintenance have also been expanded to the maintenance support device.

1 Preface

While activities aimed at carbon neutrality are being promoted worldwide, Japan also introduced a Feed-in Tariff (FIT) system in July 2012 with the aim of promoting renewable energy resources. Japan's energy self-sufficiency rate, however, is at a low level of 11.2% (FY2020).

Among renewable energies, hydropower is expected to be a highly reliable power source because it can be a more stable supply than solar and wind power. Supported by social trends aimed at improving the rate energy self-sufficiency, the hydropower market is gaining momentum.

In 2011 we developed a maintenance support device that contributes to maintenance labor saving, and in 2015 we developed an all-in-one protection and control system for hydropower system (next-generation control device) compliant with industrial field networks in order to respond to various demands for the spread and expansion of hydropower generation. This paper introduces the new functions of the next-generation control device for multiple hydro turbine units and the associated maintenance support equipment developed to meet the demands of hydropower plants.

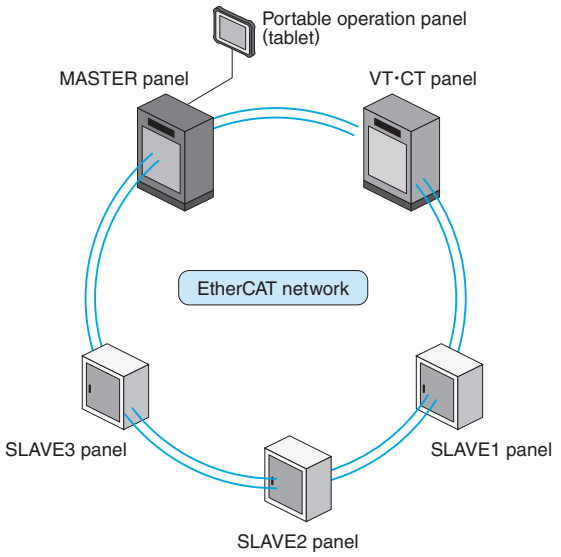
2 Technical Background of Functional Expansion

2.1 Next-Generation Control Device

Fig. 1 shows a configuration of the conventional system. The conventional system was only applicable to power stations with a single hydro turbine generator. To expand the application of next-generation control devices to power stations that have two or more hydro turbine generators, we developed a common control device that realizes common control functions between units, such as water response and automatic load regulation (ALR) control. The device was commercialized in 2019.

2.2 Maintenance Support Device

Many hydropower plants are in mountainous areas, making it difficult to conduct on-site inspections. Demand is increasing for equipment that can easily collect information for maintenance. In addition, for conventional maintenance support func-



・A redundant system is established.
(The system is still available even when the cable is disconnected at a point.)
・If the span between panels exceeds 100 meters, an optical cable can be connected.

MASTER panel	
Power unit	AC/DC redundant input power supply
Controller	Provision of main control block and EtherCAT master
Tablet slave	Tablet communication block
Communication unit	IP-TC slave station, Web monitor unit
VT･CT panel	
VCT slave	VT･CT secondary input, protective relay block
VTT･CTT	Test terminals for protective relays
Tablet slave	Tablet communication block
SLAVE panels	
SLAVE1 panel	
Emergency stop slave	Backup stop circuit block for system errors
EtherCAT slave	I/O block (CB, hydro turbine control panel, etc.)
SLAVE2 panel	
FD slave	Speed input block
EtherCAT slave	I/O block (Inlet valve, brake, aux. machine, etc.)
SLAVE3 panel	
EtherCAT slave	I/O block (GOV panel, thyristor panel, etc.)
Tablet slave	Tablet communication block

※According to the situation at the site, system configuration and internal equipment may differ.

Fig. 1 Configuration of Conventional System

A single hydro turbine generator unit is composed of the MASTER panel, VT･CT panel, and the SLAVE panel.

tions, we increased the display functions of the “correlation graphs” and “startup and stop measurement graphs” that meet the requirements of preventive maintenance by abnormality sign detection and labor-saving facility inspection.

3 Next-Generation Control Devices Applicable to Multiple Machines

3.1 Specifications and External Appearance

Table 1 shows the specifications of the common control panel, and Table 2 shows the external appearance and specifications. This device realizes water level start-stop operation, ALR, and flow rate control for up to four hydro turbine generators. Based on continuing operation even when the common control panel fails, the water control function is implemented in the controller of each unit. The device appearance and the monitoring operation follow the features of a conventional device, such as with a compact size, is light weight, and uses a tablet PC-based monitoring operation. Fig. 2 shows an example of a tablet PC screen.

3.2 System Configuration

Fig. 3 shows an example of a multi-unit system configuration. This system adopts the EtherCAT as the communication system for fast and reliable communication. A ring topology type common EtherCAT network is constructed and connected between the common control controller and each

Table 1 Specifications of Common Control Panel

Supporting high-speed communications and network redundancy, control functions for multiple machines are provided.

Item		Specifications
Panel configuration	Single unit	Redundant power supply, controller, maintenance support device, simplified IP-TC
General specifications	Power supply specifications	Input: Redundant power supply of DC88～DC286 V and AC85～AC253 V
		Output: DC110 V/3 A, DC24 V/6 A
	Temperature and humidity	Temperature: 0～40℃, relative humidity: 5～95% (no dew condensation)
Control functions	Water level start-stop operation control	Startup action at the water level startup operation
		Stop action at the water level stop operation
	ALR control	ALR proportional division
	Flow rate control	Flow rate proportional division
Field level network communication specifications	Communication system	Fixed period communication (4 ms)
	Redundancy	Communication continued by a loop-back function in the case of a network cable disconnection
Telemetry and operation	Portable type	Tablet

unit controller. The data transmission system achieves redundancy, and even if one LAN cable is disconnected, transmission will continue for all units. It's designed so that if the common EtherCAT network is to lose communication or stop functioning, providing that the network of each unit is sound, it will not immediately affect the operation of the control unit.

Table 2 External Appearance and Specifications

It realized the compact and light mass design with the same size and mass of the MASTER panel.

External appearance	
Name	Common control panel
Construction	Self-standing type; front and rear maintenance enabled
External dimensions	W800 × H1050 × D350 mm
Approx. mass	50 kg

The data for each unit is aggregated in a common controller, so that a single maintenance support device can apply information for maintenance and operation for multiple hydro turbine generators.

If there are three or more hydro turbine generators, a star system network can be constructed. **Table 3** shows the advantages and disadvantages of each connection system. It is necessary to consider the connection system after considering the operation system of each hydropower plants.

In addition, one tablet PC can be shared. As a result, even at a power station with four hydro turbine generators, a single tablet PC can be used to

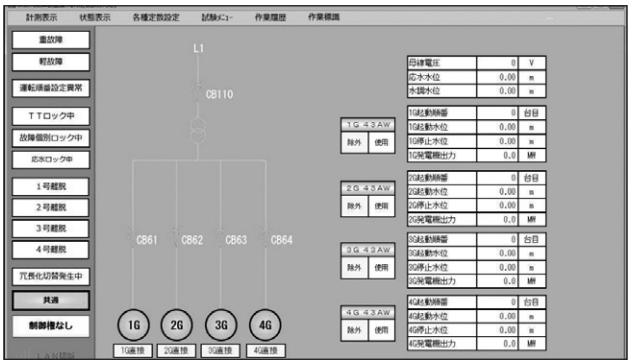


Fig. 2 Example of Tablet PC Screen

A maximum of four units can be monitored.

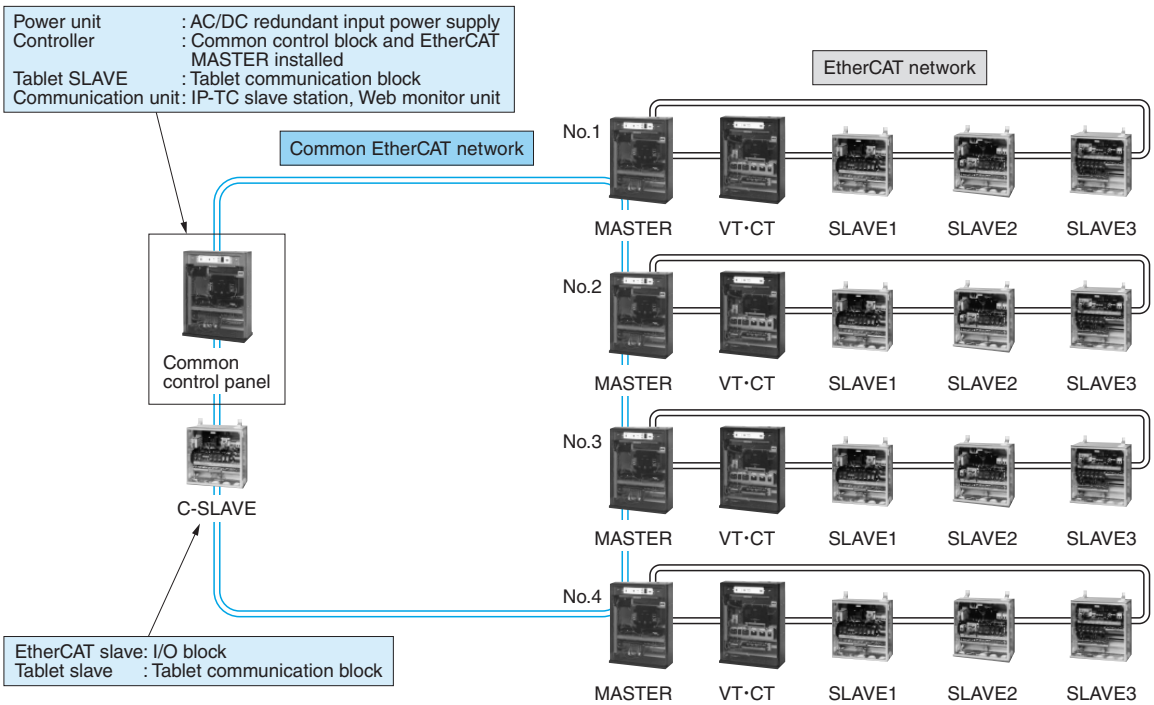


Fig. 3 Example of Multi-Unit System Configuration

The common control panel controller and each MASTER controller are connected through the EtherCAT network so that high-speed communication and reliability can be secured.

Table 3 Advantages and Disadvantages of Each Connection System

According to the connection system, there are advantages and disadvantages. The connection system can be selected based on the quantity of installed machines and the operating system of a power station.

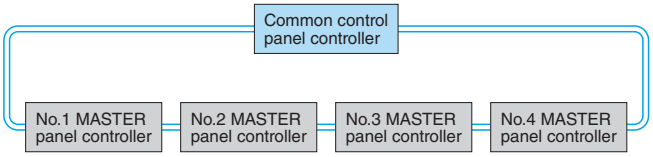
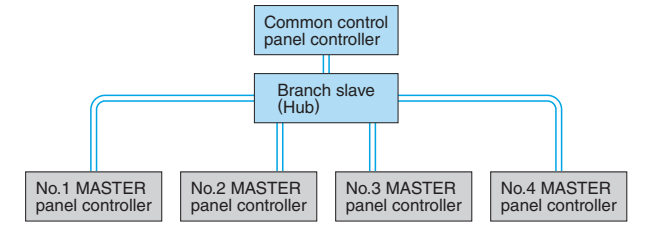
Connection system		Features
Ring topology system		・The common control panel controller and the MASTER panel controller of each generator are serially connected. ・No branch SLAVE is required. ・In the case of a failure in serial machines such as No.1 & 2 MASTER panel controllers, the No.3 & 4 MASTER panel controllers can maintain communication with the common control panel controller.
Star topology system		・The common control panel controller and the MASTER panel controller of each generator are connected in parallel. ・For machines other than the failed machine, communication is possible with the common control panel controller.

Table 4 Specifications of Power Plant

Specifications of Nishi Tenryu Hydropower Plant belonging to the Enterprise Bureau of Nagano Prefecture are shown.

Item	Specifications
Names of water system and river	The Tenryu River of the Tenryu River Water System
Location of power plant	Ozawa, Ina-shi, Nagano Prefecture
Generation system	Channel type
Max. output	3200 kW
Max. water quantity	5.56 m^3/s
Effective head	63.95 m
Hydro turbine	Horizontal Francis
Quantity	2 units

monitor and operate a common control panel and each unit.

3.3 Introduction of Case Studies

A common control panel was delivered to Nishi Tenryu Hydropower Plant that began operation in February 2022. The facility belongs to the Enterprise Bureau of Nagano Prefecture. **Table 4** shows the specifications of this power plant. **Fig. 4** shows the example of installation. The common EtherCAT network is of the ring topology type and the common control panel is provided with functions of a water level start-stop operation.

In addition, the common control panel is provided with water level distribution circuit. Since this circuit is connected to the controllers of the respective generators through hardwires, operation can be continued even when the common control panel should fail.

Fig. 4 Example of Installation

A single common control panel and two each, of a MASTER and VT・CT panels, are installed in the switchgear room.

4 Functional Expansion of Maintenance Support Device

This maintenance support device collects status change data, failure information, and various measurement data input to the for power generation control. Customers can view information from a general-purpose browser. It has multiple functions such as a status change history display, a real-time graph display of measurement data, and a failure analysis graph/data display. **Table 5** shows the functional specifications of the maintenance support device, and **Fig. 5** shows an example of the system configuration. It has newly expanded functions, such as a “correlation graph” and “start meas-

Table 5 Functional Specifications of Maintenance Support Device

For a new functional extension, the functions of correlation and associated graph display, and the startup measurement and stop measurement graph display, are added.

Functional item	Contents
Data gathering points	Analog: 96 values Contacts: 320 points Common + 3 units Max.
Connection-enabled controller	5 models of general-purpose controller
Screen display	Screen display by general-purpose browser (Chrome or Edge)
Status and telemetry display	Periodic display of status and telemetry data (Initial value for 1 second)
Error display	Periodic display of error data (Initial value for 1 second)
Status history display	Display of ON/OFF history regarding status and failures (The latest one is saved in a file.)
Real-time telemetry	Graphic display of present telemetry data
Telemetry trend graph data	Display of telemetry data per minute in a round-the-clock graphic and table style (All items of telemetry data are saved.)
Failure analysis graph and data	10 minutes before and after the occurrence of a failure (0.1-second periodic sampling for 60 seconds before occurrence and 10 after). Graphic and table style data display for 1-second sampling (All items of telemetry, status, and failure data are saved.)
Data storage	Each CSV file of status history, telemetry trend data, and failure analytical data is saved in the PC.
Real-time trend data in CSV	Data of real-time trend graphs in the specified range is saved in the CSV file. During minimum 0.1-second sampling, data can be saved for a maximum of 6 minutes.
Auxiliary machinery operation count	Counting and resetting of pump operation frequency, CB trip frequency, etc.
Computing function	Arbitrary preset operation is performed for a specified period and the result is saved in the output item.
Pre-alarming function of analog items	Uppermost limit, upper limit, lower limit, and lowermost limit are set for history registration in consideration of the case when the preset level is exceeded.
Correlation graphs	Two points of the relationship between field current and generator voltage, for example, are displayed in the plot style based on a graph of y = ax + b.
Startup and stop measurement	Data of startup and stop measurement are displayed in graphs.

urement/stop measurement graph display" functions.

Fig. 6 shows the display screen of the correlation graph. You can select two items from the collected measurement data and check the trends. Furthermore, a range line can be set, and an "abnormality" can be registered in the status change history when the data deviates from the range. (For example, by selecting the generator active power, the guide vane opening, and by checking the correlation, it is possible to detect the output decreasing trend due to factors such as clogging with dust.)

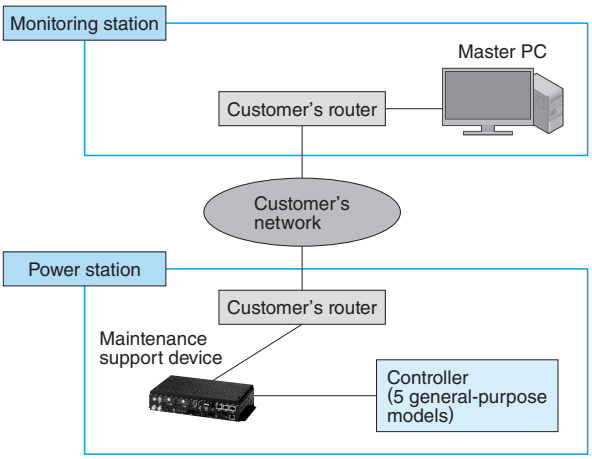


Fig. 5 Example of Maintenance Support System Configuration

Five models of general-purpose controllers including the FA-M3 made by Yokogawa Electric Corporation can be connected.

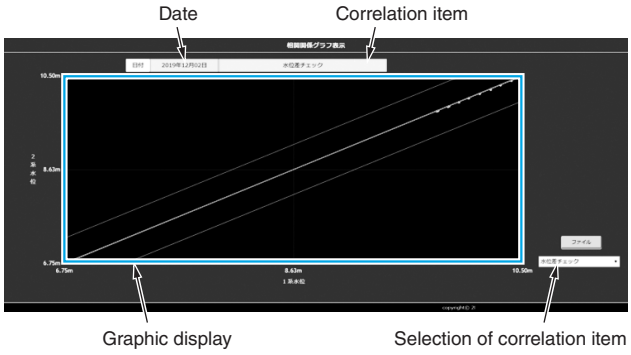


Fig. 6 Display Screen of Correlation Graphs

Correlation of two preset telemetry values can be grasped at a glance.

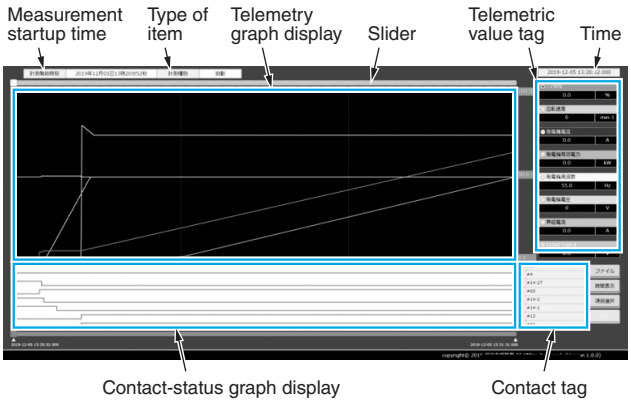


Fig. 7 Display Screen of Startup and Stop Measurement Graphs

Data of startup measurement and stop measurement can be displayed in graphs.

Fig. 7 shows the Display Screen of Startup and Stop Measurement Graphs. The measurement

time can be checked, from the set measurement start state change to the measurement end state change, and each measurement time is calculated automatically. Expanding these functions can contribute to labor-saving work maintenance of the hydropower plant.

5 Postscript

This paper introduced new functions of the maintenance support device and an all-in-one protection and control system compliant with industrial field level network.

This system will be used in hydropower plants as our main product. By the functional expansion of the maintenance support device accompanying this system, new added values will be offered to meet the requirements of maintenance labor-saving.

In the future, we plan to add transmission line monitoring and control functions to the common control panel.

In addition, we plan to add a transformer protection function compatible with this system. As such, we will work on realizing multi-function systems.

Lastly, we would like to express our deepest gratitude to many people for their cooperation for our paper writing.