The Latest Control and Protection Systems for Hydraulic Power Plants

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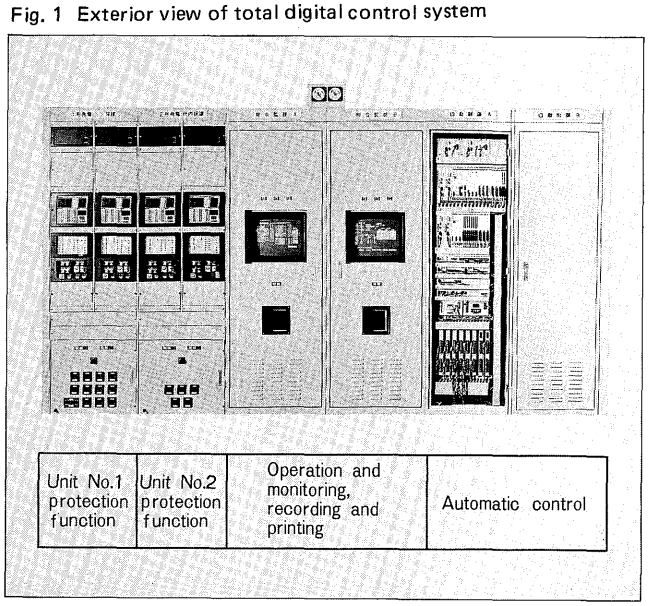
1. Introduction

The application of the programmable controller (PC) for hydraulic power stations has been increasingly popular and indispensable as the essential unit of the control equipment. The application range of the PC has also expanded to include not only the functions of sequence control and simple regulation, but also the functions of the automatic voltage regulator (AVR), speed governor, automatic synchronizing, telemetering/telecontrol and monitoring systems. Further, the PC has been developed as a "total digital control system" which is combined with a digital protection relay unit and a cathode ray tube (CRT) monitoring system. The newest digital control systems for hydraulic power stations will be introduced in this paper.

2. Outline of Total Digital Control System

The control, protection and monitoring functions for a hydraulic power station are operated and processed entirely by the PC, and the functions are connected by various data paths. **Figure 1** shows the exterior view of the total digital control system supplied to Electric Power Development Co., Ltd.'s Akiba No. 3 Power Station.

Fig. 1 Exterior view of total digital control system



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2.1 System composition

Table 1 shows the reference list of the delivered systems. Each system is classified as a "distributed type" or a "unitized type."

2.1.1 Distributed type system

Under this system, the functions described below are operated and processed by the independent PC, whose devices are located near the controlled machine. Each PC is connected by dataways or an I/O unit. This system is suited for cases in which on site test operation, maintenance and operability are important and/or the modification of each of the functions is annually scheduled.

The functions are as follows:

(1) Sequence control, which performs start/stop of water turbine and generator, and the feedback control, which adjusts dam water level, etc.
(2) Sequence monitor
(3) Automatic voltage control
(4) Speed governor
(5) Automatic synchronization
(6) Telemetering/telecontrol
(7) Data logger
(8) Operation and monitoring function
(9) Protection relay function

2.1.2 Unitized type system

Under this system, functions (1) to (6) mentioned above are operated and processed by one set of PC. Since function interface was conventionally performed by the I/O unit and relay, and since its construction is now based on PC memory, the number of I/O units as well as the installation space can be substantially reduced. Further, the man-hours for cable laying can be reduced, because operation and processing are performed by one set of PC, and some of the I/O units are placed near each machine.

2.2 Hardware composition

Generally, the "single system" hardware composition of the control equipment is used, but the "duplex system" is utilized when high reliability is required, depending upon such factors as the power plant's scale and importance.

Table 1 Delivery of digital systems

Customer	No. of systems	Generator output (kVA)	Computing and processing function							PLC for fault monitoring	PLC for control and monitoring	Digital protective relay	Operation start
			Sequence	Simple regulation	Monitoring	AVR	Governor	Synchronization	Telemetering/control				
Kyushu Electric Power Co., Inc.	1	1,230	○	○	○	○	○						'88-07
Electric Power Development Co., Ltd.	2	27,000	○	○	○					○			'89-03
Kyushu Electric Power Co., Inc.	1	3,510	○	○	○	○	○			○			'89-06
Nihonkai Hatsuden Co., Co., Ltd.	1	5,300	○	○	○	○	○						'89-10
Tohoku Electric Power Co., Inc.	1	83,400	◎	◎	◎	○	○		○	○			'90-06
Kyushu Electric Power Co., Inc.	1	4,300	○	○	○	○	○			○			'90-08
Kyushu Electric Power Co., Inc.	1	6,350	○	○	○	○	○			○			'90-10
The Hokkaido Electric Power Co., Inc.	1	52,000	◎	◎	◎	○	○			○			'90-11
Ishikawa Prefecture	1	9,340	○	○	○	○	○						'90-11
The Kansai Electric Power Co., Inc.	1	72,000	○	○	○			○					'91-02
The Hokkaido Electric Power Co., Inc.	1	21,000	○	○	○	○	○	○					'91-03
Tohoku Electric Power Co., Inc.	1	12,200	○	○	○	○	○	○	○	○			'91-05
The Hokkaido Electric Power Co., Inc.	1	4,450	○	○	○	○	○	○					'91-05
Electric Power Development Co., Ltd.	1	47,600	◎	◎	◎	◎	◎	●	○	○	◎	●	'91-10
	1	1,700											
Chubu Electric Power Co., Inc.	1	25,500	◎	◎	◎	◎	◎			◎			'91-10
The Hokuriku Electric Power Co., Inc.	1	2,350	○	○		○	○		○				'92-05
The Hokuriku Electric Power Co., Inc.	1	1,440	○	○		○	○		○				'92-05
Tohoku Electric Power Co., Inc.	1	23,700	○	○	○	○	○	○	○	○			'92-06
Kyushu Electric Power Co., Inc.	1	2,140	○	○	○	○	○	○					'92-07

(Note) ○: Single ◎: Duplex ●: Dual-duplex mixed system

3. Control, Protection and Monitoring Functions

3.1 Sequential logic control functions

Digital sequence controllers have been available for some time now. Recently, a technique is used in which compact I/O units which accommodate 16 or even 32 I/O signals are placed near the controlled machine. In this way, a reduction in cable installation costs can be achieved. Thus, this system has come to be used for small scale logic control as well.

(1) Start/stop sequence

Executes sequence control according to each mode of power generation, pumping, condenser, trial power transmission, etc.

(2) Pattern running sequence

Executes start, stop and load regulation of the main machine according to the predetermined operating pattern.

(3) Transmission line self-recovery sequence

After recovery from a transmission line fault is detected, transmission line breakers are reset, and generator operation is resumed.

(4) Station service automatic switching sequence

Executes automatic switching between the working and reserve systems of the station service power supply or automatically transmits to another power plant.

(5) Auxiliary automatic running sequence

Executes automatic start/stop of the auxiliaries according to the conditions of the power plant, and executes automatic switching between working and reserve auxilia-

ries.

3.2 Sequence monitoring function

This function indicates the progress of the sequence as well as abnormal conditions, to promote improved maintenance. **Figure 2** shows the external appearance of the display unit.

(1) Sequence progress monitoring function

The start/stop sequence of each function is monitored and the progress of each step (on/off of all conditions) is indicated.

(2) Main machine start/stop sequence failure monitoring function

When a sequence failure occurs, the monitor screen ceases updating, and the causes of the errors are indicated.

(3) Operating monitoring function of the auxiliaries

The operating continuation time, operating interval and number of operations of each auxiliary are monitored. In case of an error, the auxiliary name and error information are indicated.

(4) Failure indication

When failure of the automatic voltage regulating function and speed governor function is detected, detailed causes of the failure are indicated.

3.3 Automatic voltage regulating function

While the PC processes high-level functions and performs high-speed computation, system responsiveness requirements and stability are satisfied. Also, the system incorporates the following features:

(1) Electrical quantity detection

Because generator voltage and power are measured by the directly connected digital computer using the output of the auxiliary PT/CT units, a converter is not needed.

(2) Voltage soft start

During the transition from initial excitation to AVR function or during voltage matching, the generator voltage is controlled by an exponential function. The established value can be reached in a short time, without fear of overshooting.

(3) Automatic adjustment of proportional gain

Since the apparent gain fluctuation of the exciter system is automatically compensated, stable control is always maintained.

(4) Field current and reactive power limiting

This operation is performed based on an approximation corresponding to the characteristics of the generator. The exact limitation can be achieved without sacrificing control.

(5) Automatic follow-up

Data is exchanged by the automatic mode (AVR) and manual mode (ACR) memory. This mode change can be performed smoothly and at will.

3.4 Speed governing function

Figure 3 shows the results of the full load rejection test. This function has the following features:

(1) Frequency detection

The signals of the proximity switch (PMG or PT) are input with 2 systems, and monitoring of the rate of change and input conditions are performed with high accuracy and reliability.

(2) Frequency soft start

During runner start and speed matching, frequency (rotating speed) is controlled by an exponential function, and the established value can be reached in a short time, without overshooting.

(3) Compensation of the control valve's non-linear characteristics

The gain of the computing device for regulation of the valve opening is automatically compensated based on the data from the control valve's non-linear characteristics. The servomotor is controlled smoothly and accurately.

(4) Automatic follow-up

Since the load setter and the load limiter have an automatic follow-up function which corresponds to the operation mode, automatic follow-up is possible arbitrarily.

3.5 Automatic synchronizing function

By applying the voltage data from the automatic voltage regulating function and the frequency data from the speed governing function, the circuit breaker closes the circuit at the point where the voltage phases of the transmission line and the generator are equal. In order to calculate this point, voltage differences of 3 identical phases are computed. Also, the mean square value of this results

Fig. 2 External view of display unit

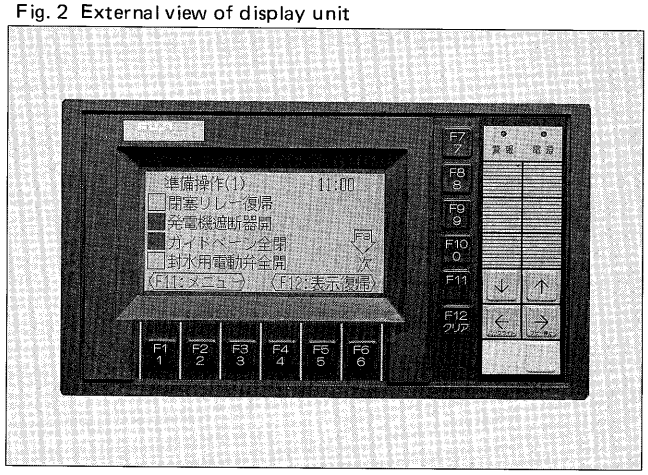

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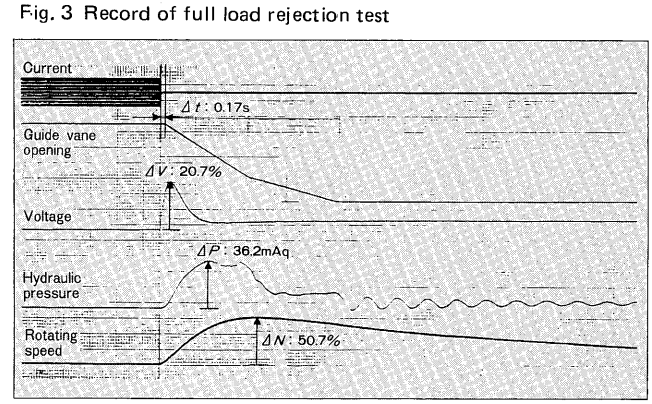
Fig. 3 Record of full load rejection test



are calculated. Based on the differences in the effective voltage value and the frequency, compensation is performed. Accordingly, when the automatic voltage regulating function and the speed governing function are provided, additional hardware is not required. **Figure 4** shows the results of the automatic synchronization test.

3.6 Telecontrol/Telemeter function

Most hydraulic power plants are recently unmanned; thus, the telecontrol system is indispensable. Formerly, the telecontrol system and the control equipment of the machines were installed separately and their I/O connected using cables. However, the advent of an advanced function PC and the integration of the telecontrol system's transmission functions into a card unit have made it possible to utilize this card for the main machine controller's PC. It is also possible to use the control PC for data processing and editing, in the case of small and medium sized hydraulic power plants, where the transmitted data volume is relatively small. **Figure 5** shows the configuration of the integrated telecontrol system.

3.7 Automatic monitoring, data logging and printing function

These functions achieve maintenance and improvement of the reliability of the plant with early detection of water turbine and generator failures, the prevention of failures and the high efficiency of the inspection.

(1) Failure monitoring function

The revision of calculations of the directly and indirectly detected data is computed, taking into account environment conditions. Usually, the plant is continuously monitored under the same conditions. When an error is detected, relative data before and after the error are either indicated or printed out. Useful data for investigating the cause of the error and subsequent processing is supplied. Further, when a transmission function is additionally installed, the conditions of the power plant can be monitored from the control center and technical office.

(2) Inspection data printing

The inspection route and items of the inspection rounds can be stored in the handy terminal, as inspection data can be entered at each inspection point. Subsequently, the inspection data sheet is printed out. **Figure 6** shows the external view of the handy terminal.

(3) Daily, monthly and annual report printing

The collected data will be printed in the predetermined format.

3.8 Operation and monitoring function

Recently, the adoption of the CRT-based system and the mini-desk system has been gaining popularity, as it improves operation efficiency and cuts down on space.

3.8.1 Operation and monitoring by CRT-based system

The features of the CRT-based system follow.

(1) Operation

Operation reliability is improved by the adoption of both the touch-key system (by touching a symbol on the monitor screen) and the master switch system.

(2) Monitoring

Monitoring improvement is achieved, because the

Fig. 5 Configuration of integrated telecontrol system

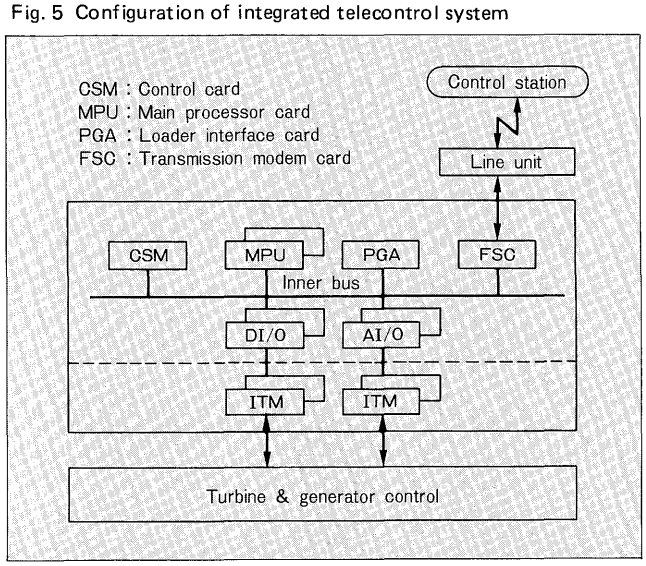


Fig. 4 Results of automatic synchronization test

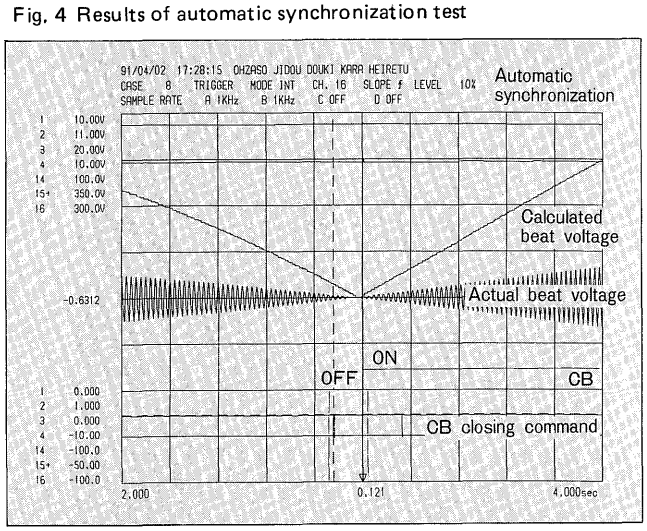


Fig. 6 External view of handy terminal

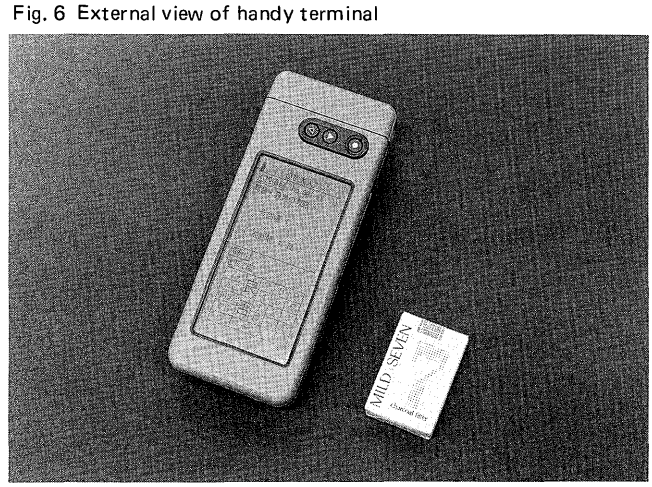


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Table 2 Aspects of protective function

Device number	Function	Protection goal	Delivery (element)				
			(a)	(b)	(c)	(d)	(e)
87	Ratio differential	Internal short circuit of of generator	○	○	○		○
51	Over-current	Overcurrent of generator (external short circuit)	○	○	○	○	○
87G	Ratio differential	Internal grounding of generator	○	○	○		○
51G	Grounding overcurrent	Grounding of generator circuit (resistance grounding)		○	○		○
64N	Grounding overvoltage	Grounding of generator circuit (transformer grounding)	○				
64B	Grounding overvoltage	Grounding of generator circuit (bus)				○	
59	Overvoltage	Overvoltage of generator (overexcitation)	○	○	○	○	○
40	Loss of field	Non-excitation of generator (underexcitation)	○	○	○		○
12	Overspeed	Overspeed of generator	○	○	○	○	○
87T	Ratio differential	Internal short circuit of of transformer	○	○	○		○
51T	Over-current	Overcurrent of transformer	○	○	○		○
64T	Grounding overvoltage	Earthing of transformer circuit	○	○	○		○
51H	Over-current	Overcurrent of station service circuit			○		○

most essential data can be obtained in a suitable format corresponding to the operating condition of the machines.

(3) Space saving

The power distribution panel's space can be reduced, because most of the data can be accessed by changing the monitor screen. Further, input/output equipment can also be reduced by a databus connection with the control PC.

3.8.2 Mini-desk system

This system does not employ the CRT-based system. The objective of this system is to reduce space, which is accomplished by: (1) an illuminated pushbutton switch, (2) a selective instrumentation system with a digital meter and (3) a fault indicator with a small LED display. These features utilize only 1/2 to 1/3 of the conventional operation and monitoring panel size.

3.9 Protective relay function

The digital protective relay is a duplex system, which under normal conditions outputs the "AND-ed" signal from both system. On the other hand, in the case of a failed condition, one system is bypassed and the duplex-mixed system forms the main system. Under consideration is the addition of a single system to the standard configuration. The hardware construction will be determined in response to the size and importance of the power plant. This configuration is likely to see increase use in the future.

In the case of hydraulic power, the protective characteristic is satisfied from the low frequency range at generator start to the high frequency range at load rejection, depending on the elements. Also satisfying the protective characteristic is the utilization of the wide range data sample period control system. **Table 2** shows the protective function elements.

4. Conclusion

The outline of the recent control and protective technology of the hydraulic power plant is explained. It is assumed that the application technology of the PC will be further developed, and the improvement in reliability, saving of manpower and the reduction of the panel installation's space will be promoted. Furthermore, the modification and modernization of the new as well as the existing plant is planned, keeping the total digital control system in mind. Fuji Electric will continuously endeavour to promote control and protective technology of the hydraulic power plant, the requirement of the customers.