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DIGITAL CONTROL SYSTEMS FOR HYDRAULIC POWER STATIONS

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1. FOREWORD

Application of the programmable controller (PC) to hydraulic power stations has already been generalized and it has become indispensable as the basic units of control eqipment. In recent years, especially, most control equipment have been built around the PC. The range of applications of the PC has many branches, from start/stop control of turbine/generator and other comparatively simple systems to systems with a speed governor function, automatic voltage regulator (AVR) function, and other advanced functions and compound systems connected with telemetering/telecontrol equipment. Digital type equipment is also being accepted in protection relay systems and monitoring and recording, etc. by the flow of digitalization of such control equipment.

The newest digital control systems for hydraulic power stations are introduced here.

2. DIGITAL CONTROL EQUIPMENT COMPOSITION

2.1 Control systems by function

Currently, there are various digital control systems for hydraulic power stations. These system are listed below by function.

(1) Turbine/generator control system
Start/stop and other sequence control.
Feed-back control (water level control, etc.)
Speed governor function (GOV)
Automatic voltage regulator function (AVR)
(2) Auxiliaries (unit and station) control system
Oil pump, cooling fan, and other control
(3) Protection relay system
(4) Telemetering and telecontrol system
(5) Data logging system
(6) Unit monitoring system

Various control systems can be built by combining or integrating these systems according to the size of the plant and the functions demanded.

2.2 Hardware configuration

The hardware can take various forms. However, it is roughly divided into integrated type designed to rationalize installation space, input/output, etc. by concentrating all the processor units and input/output units at one place and distributed type by which processor units and input/output units are installed at the necessary places.

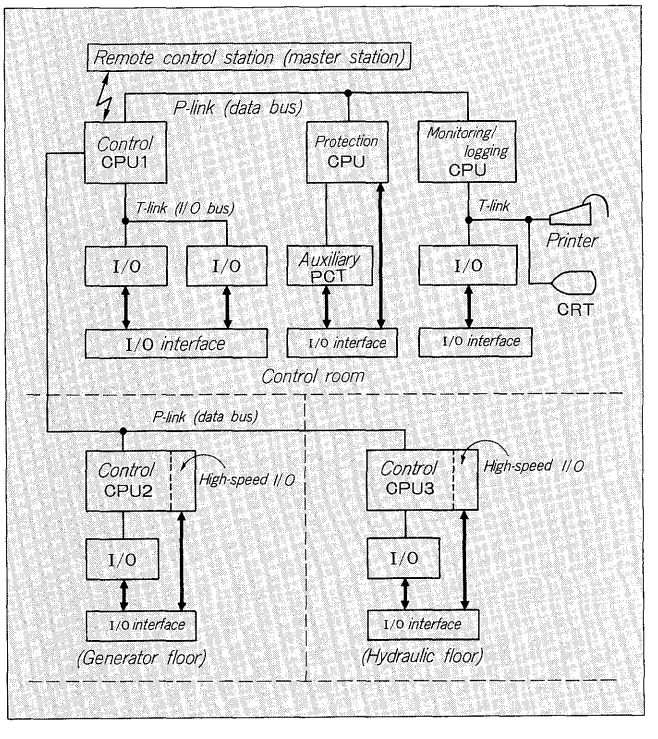
2.2.1 Integrated type control system

This system concentrates the control systems mentioned in paragraph 2.1 as much as possible and accommodates them in one PC. The concentrated functions are shown below.

(1) Turbine/generator control (including GOV and AVR)
(2) Auxiliaries control
(3) Transmission line and station service control
(4) Telemetering and telecontrol

Since interfacing between functions by ordinary I/O unit and relay is realized by PC memory, the number of I/O units can be reduced substantially and installation space can also be saved by integration.

Fig. 1 Distributed system example



2.2.2 Distributed system

Concentration of many functions at one place improves economy from the standpoint of hardware, but is also caused to drop in software design efficiently and a lengthening of design time and can lower factory test and site test efficiency. Therefore, it is vital that the PC function distribution be planned by taking into account the test process, workability, etc. at the site. The merit of suitable distribution is that it reduces the cable laying manhours. An example of a distributed system is shown in *Fig. 1*.

3. TURBINE/GENERATOR CONTROL

3.1 Sequential logic control function

The sequential logic control function has been digitalized ever since the development of the logic controller in late 1960s. Recently, however, the illuminated push-botton switch, small LED display unit, digital display, etc. have come into use as operation and display functions of control panel to improve operability and save space. The number of interface devices can also be reduced by processing the operation and display signals of these devices by software via a PC. Furthermore, the CRT is being used in generator control equipment and the control panel steadily being abolished.

Roughly speaking, sequence control performs the following functions:

(1) Start/stop control

Controls the sequence according to the generating, pumping, condenser operation, line charge, and other operation modes.

(2) Scheduled operation

Starts and stops the main unit and adjusts the load according to a preregistered operation pattern.

(3) Line CB reclosing control

Recloses the line and restarts the generator by the specified procedure when a line fault occurs and the turbine/generator is isolated and operated or is stopped and placed into the standby state and the power transmission system is reclosed.

(4) Station service automatic changeover

Performs power supply main/stand-by switching automatically or supplies power to other power stations.

3.2 Speed governor (GOV) function

In the past, the GOV function, which is an important turbine/generator adjustment function, was performed by a dedicated analog controller. However, speeding up of the operation speed and advancement of the functions of the PC, development of dedicated I/O devices, etc. have made it possible to implement this function as one PC control function.

The GOV functions are composed of frequency detector, speed droop, speed controller, nonlinear operator, opening controller, and servomotor driver (mechanical control part). Turbine type control can be implemented easily by combining these operation software.

3.2.1 Features

Compared to the conventional analog control system, this system has the following features:

(1) I/O unit

Dedicated interface units for PC I/O matching are available. Besides, since all processing is performed by software, the number of parts is reduced substantially. This is accompanied by improved reliability and simplification of the system configuration.

(2) Frequency detector

A system which detects the signal of a tooth head disk installed to the generator shaft with duplexed proximity switches is standard. Since a dedicated pulse input type frequency detection card is used for proximity switch signal input, the detection accuracy is, of course, high over a wide frequency range. Detection reliability is improved by monitoring the input state and change width.

Since the high-speed detection function is also processed by software inside the controller, the installation of a high-speed relay is unnecessary.

(3) Frequency adjuster

A parallel type PID system is used in frequency adjustment operation. Therefore, controllability is, of course, improved and the circuit configuration is simple and constant selection is easy from the standpoint of control system optimum design. A turbine soft start function is also provided. After the turbine starts, the speed tracks the value set at the speed setter (65F) quickly and without any overshoot.

Since the 65F set position is tracked automatically at the system frequency at synchronization in the automatic mode, automatic speed matcher (15) is unnecessary.

(4) Opening controller

Two kinds of opening controller control software are available: one for hydraulic servo and one for electric servo.

The control software for hydraulic servo has a constants table capable of setting the actual E/H converter characteristics data directly and corrects the nonlinearity of the E/H converter based on this table so that accurate and smooth control is possible.

The control software for electric servo has cushioning characteristics to prevent a penstock pressure rise at load rejection.

3.3.2 Option functions

The following governor optional functions are available. A system which transfers the operated result from each option function to each setter by direct numeric is used to improve the control performance.

(1) Upper reservoir water level control

This function is used to maintain the upper reservoir level constant by operating the turbine in the load state corresponding to the reservoir inflow. A function which monitors the upper reservoir water level, generator output, etc. as required and generates turbine/generator start and stop commands according to the inflow can also be added.

(2) Maximum output limiter

This is used at power stations with a large water head variation to limit the guide vane (or needle) opening so that

the maximum output is not exceeded without regard to the water head.

(3) Load distribution control (joint control) function

This function is used to distribute the necessary load to each unit at a selected ratio at power stations with multiple turbine/generators.

(4) ALR and AFC functions

This function is used to perform peak load operation or frequency control at dam type power stations, etc. Usually, the power requirement of each power station is computed by the central control station computer and the power stations are suitably controlled for that command value.

3.3 Automatic voltage regulator (AVR) functions

Similar to the GOV functions, it has become possible to implement the AVR functions as a PC control function in place of the dedicated analog adjuster used in the past. The AVR functions consist of two systems: voltage control loop made up of a voltage detector, voltage droop operator, and voltage regulator and field current control loop made up of a field current detector and field current regulator. The output of these systems regulates the generator voltage by means of an SCR gate controller and SCR converter (made up of hardware).

An automatic power factor regulator (APfR) or automatic reactive power regulator (ARPR) and excitation limiter (OEL/UEL) are also provided as standard.

3.3.1 Features

Compared to the conventional analog control system, this system has the following features:

(1) I/O unit

An auxiliary PT.CT unit, SCR gate pulse generator unit, and other dedicated interface units are available for PC input/output matching. Since all these units are software processed, the number of parts is reduced considerably. This improves reliability and simplifies the system configuration.

(2) Detector

For the generator voltage, current, power, and reactive power needed in operation, the instant value of the voltage and current is input from a common interface unit and operation is performed by software processing. Therefore, the detection delay is small and full functions can be realized without using transducers.

(3) Voltage regulator

Since a parallel type PID system is used in voltage regulation operation, controllability is, of course, improved and the circuit configuration is simplified and constants selection can be performed easily from the standpoint of optimum design of the control system.

A soft start function at voltage generation is also provided. Since this initial value tracks the generator voltage, voltage rise from zero to the rated value is performed smoothly and the voltage setter (90A) set value is tracked without any overshoot. Since the 90A setting position is tracked automatically by the line voltage at synchronization in the automatic mode, voltage matcher (60) installation is unnecessary.

(4) Excitation limiter

The reactive power limiting characteristic is a table system. Moreover, since the characteristic is shifted according to the generator voltage, an arbitrary limiting curve matched to the characteristics of the machine is obtained easily.

(5) Field current limiter

The field current limiting characteristic uses the approximate expression $[I^2 t \geq 33 + t]$ of the data specified by JEC114-1979 (ANSI-C50.13). Moreover, a 10 seconds safety margin and short-time ceiling margin are considered in this so that the field current can be limited without sacrificing controllability.

(6) Automatic adjustment of total gain

A function which automatically compensates the gain for an exciter and generator interlinkage flux increase accompanying a frequency rise at load tripping and excitation voltage rise accompanying a voltage rise, and other excitation system apparent gain increases is provided so that a stable control characteristic is obtained in all operating states.

3.3.2 Option functions

The following AVR option functions are available. A system which transfers the operated result from each option function to each setter and operator directly by numeric value is used to improve control performance.

(1) Line-charge function

This function is used to suppress an abnormal rise of the power receiving end voltage by the Ferranti phenomena by raising the generator output terminal voltage smoothly from a low voltage to the rated voltage at system charging.

(2) Power swing stabilizer (PSS)

Mainly, this function is used to prevent a drop of the damping torque and increase the stability of generator control systems which occurs when the generator has a high output and low power factor.

(3) Line drop compensator (LDC)

This function is used to compensate for the voltage drop across the line impedance to maintain the power receiving end voltage constant at power stations which require a long line to the substation.

4. AUXILIARIES CONTROL SYSTEM

Since auxiliaries control has many I/O channels even though the control circuit is simple and does not have much cost merit, formerly it was exempted from digital control. However, with appearance of low-cost type PC and terminal type I/O units in recent years, the trend is toward digitalization of auxiliaries control also. The pressure switch (or pressure transducer), level switch (or liquid level transducer), etc. for auxiliaries control are input by terminal type I/O units installed at the site near these and are fetched to the PC via a I/O bus (T-LINK). This makes it possible to reduce the number of interface cables with the on-site devices considerably. The site adjustment

and testing man-hours can also be reduced. Since only circuit breakers, main contactors, thermal protection relays, and other major devices are necessary at the control panel, the panel interior wiring is simplified and mounting efficiency is improved and a fresh configuration is possible. Moreover, since the unit interface standardization and compacting are possible by unitizing the control panel as a control center, it can be made more effective.

5. MAN-MACHINE INTERFACE

Hydraulic power station control PC dedicated man-machine interface units are available. These units are designed to improve operation support and maintainability.

5.1 Procedure monitoring unit

This unit performs advance status confirmation and troubleshooting when sequence congestion occurs. Display of 16 characters 7 digits can be displayed in Japanese on one screen (maximum 255 screens).

The turbine/generator status is grouped into STOPPED, STARTING, PARALLEL, and STOPPING. During the starting and stopping operations, the state of advance of the sequence can be judged positively by subclassifying the sequence statuses and automatically displaying the device status corresponding to each condition. Moreover, once control congestion occurs, updating of the screen stops at that point so that the cause of the congestion can be ascertained to assist in analysis and recovery work.

A preliminary status screen display example is shown in *Fig. 2*.

5.2 Operating panel

A dedicated operating panel from which display and modification of the constants, timer set values, etc. needed in supervision and control can be easily performed on-line without using the program loader is available. Data item selection and setting modification can be performed by numerical keypad. The data display section consists of two digital displays and a units display. One display is used for item number display and one unit is used for data display. The units corresponding to the data is displayed on the units display so that the possible of erroneous reading is small.

Since selective status display (20 channels) and selection measurement and setting keys (12 × 2) are provided, a supervisory and control system matched to the plant can be built.

The operating panel is shown in *Fig. 3*.

6. PROTECTION SYSTEM

A protection system from generator to main transformer can be built with one digital relay unit by using dedicated hardware.

6.1 Protection relay characteristics

Since data sample cycle control corresponding to the frequency of the generator is performed at the data input section, high precision operation characteristics are guaranteed even in wide frequency region from low frequency at generator starting to high frequency at load tripping.

Moreover, all-around protection can be realized by combining the following functions:

(1) Current operation function
(2) Voltage operation function
(3) Power operation function
(4) Impedance operation function
(5) Frequency operation function
(6) Phase comparison function
(7) Proportional differential function
(8) Suppression function
(9) Time-reverse operation

Fig. 2 Procedure monitoring unit display example

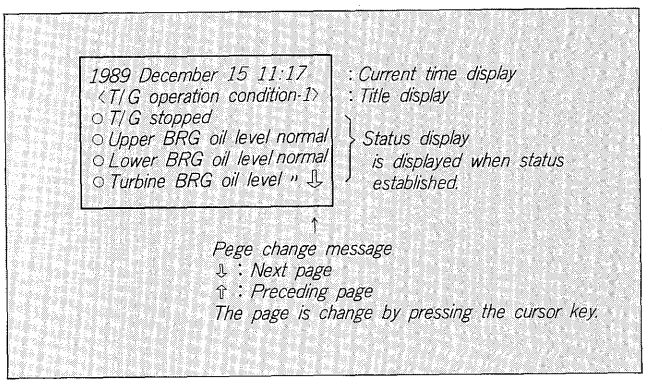


Fig. 3 Operating panel

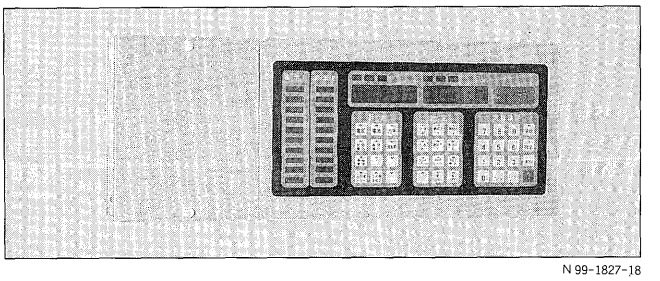


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Fig. 4 Example of digital protection relay setting display panel

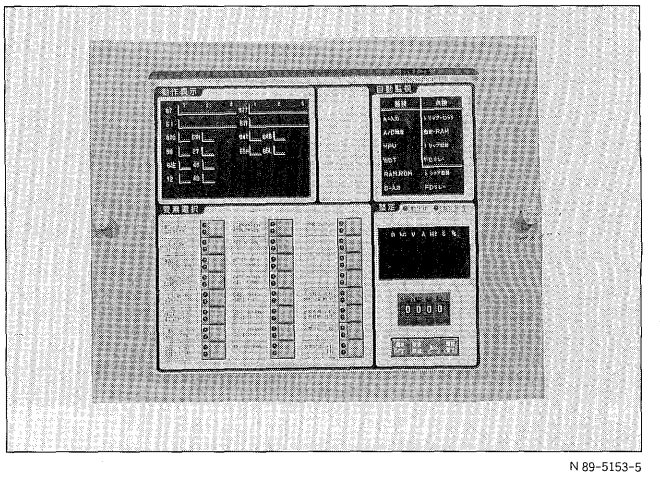

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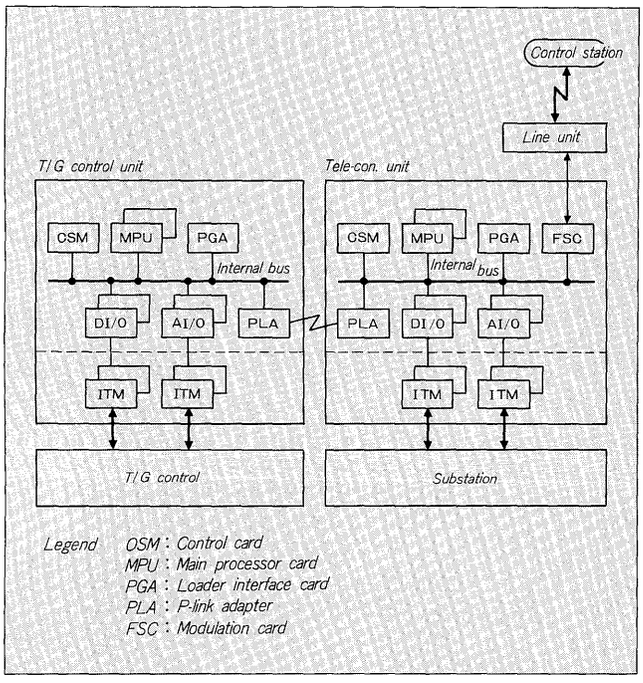
Fig. 5 Connected system example



6.2 Output section

The output section has a relay output part for operating an external lock-out relay system and P-link interface for sending operation relay detailed information to the PC unit.

6.3 Setting display panel

The operation relay display section, protection function selection section, and setting display section are grouped on a designed panel. Operation and inspection are easy. A setting display panel example is shown in *Fig. 4*.

6.4 High reliability

When higher operation reliability is demanded, a normal dual system can be built by using two protection relay units. In a dual system, when normal, the result of operation of both systems is added and output to an external lock-out relay. However, when trouble was detected by the automatic inspection function and normal supervision function, a faulty system bypass signal is output and protection by healthy system is possible.

7. REMOTE SUPERVISORY AND CONTROL SYSTEM

Formerly, the telecontrol system and T/G controller were installed separately, but the appearance of an advanced functions PC made it possible to fuse telecontrol system local system and T/G control PC. As the fusion method, there are cases where the telecontrol system local station PC and T/G control PC are connected by a data bus and cases where a telecontrol system transmitter consisting of one card is installed in the T/G control PC and data processing and editing are performed by the control PC.

The former case is used at large power stations which have substations, etc. in the compound and require a large transmission capacity. The latter case is used at medium and small power stations with a comparatively small transmission capacity. An example is shown in *Fig. 5*.

Since the transmission specifications are compatible with the conventional type telecontrol system, it can be easily applied to replacement of existing power station controllers.

Table 1 Example of monitoring items

Monitoring item	Monitoring contents
Bearing temperature	Starting and stopping process, temperature rate of change at operation, temerature rise at operation
Vibration (noise)	Level monitoring corresponding to T/B operation status, frequency distribution monitoring by frequency analysis
Bearing oil level	Level monitoring corresponding to T/G operation status
Oil leakage	Total oil level monitoring
Brush sparking	Sparking noise level monitoring
Others	Auxiliaries operating time and speed monitoring

8. UNIT MONITORING AND DATA LOGGING SYSTEM

In advancing unmanning and automation of thermal power stations, conventional period patrol by maintenance personnel and other methods are taken for maintenance and inspection. However, recently, automation of inspection and maintenance while rationalizing and reducing the number of experienced maintenance men has been demanded. The unit monitoring and data logging system using sensor technology and PC is one way of meeting this demand and the maintenance and improvement of operation reliability by the quick detection of faults and patrol inspection improvement and labor-saving, etc. are achieved. This system consists of a sensor unit which detects the device status, input/output unit and CPU unit which performs data judgement by means of monitoring algorithm and CRT and printer unit which performs data display and printing.

For fault status, correction operation is performed on the information detected directly or indirectly, as required, and the hourly difference and seasonal difference are removed from the monitored data and monitoring is performed continuously according to the algorithm set so that optimum evaluation is possible. When an abnormality is detected, an alarm is generated and the data needed in troubleshooting can be offered by displaying and printing the preceding and following related data at the same time. Moreover, since the data obtained continuously can be output as daily report and monthly report data in the specified format, as required, the recorder formerly installed is unnecessary.

Monitoring item examples are shown in *Table 1*.

9. CONCLUSION

At thermal power stations, there is a sense that each equipment has already been digitalized. In the future, it will be necessary to consider balanced fusing of these equipments and total minimization of the manufacturing and adjustment costs, space factor, etc. From the standpoint of maintenance, the construction of a system which allows further advance of the establishment of preventive maintenance incorporating AI, etc. and connection with service centers by using communication circuits and personal computers, etc. and implementation of selective plant and control system monitoring and inspection is considered.

New facilities including these technologies and application of the PC even for replacement is expected in the future. The authors will be happy if this paper provides reference in planning.