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RECENT CONTROL SYSTEM FOR THERMAL POWER PLANT

Seiichiro Seko
Toshioki Akizuki
Kazumi Nishida

1 FOREWORD

With the recent advance and growth of electronics technology, digitalization, which has higher reliability, operability, maintainability and excellent man-machine communication than conventional analog technology, has become the mainstream of control and supervisory systems for thermal power plants. Specifically, the trend is away from conventional computer-oriented control and toward a total digital control and supervisory system that combines and organically connects devices containing a microcomputer.

Recent digital control systems for commercial thermal power plants are intorduced here.

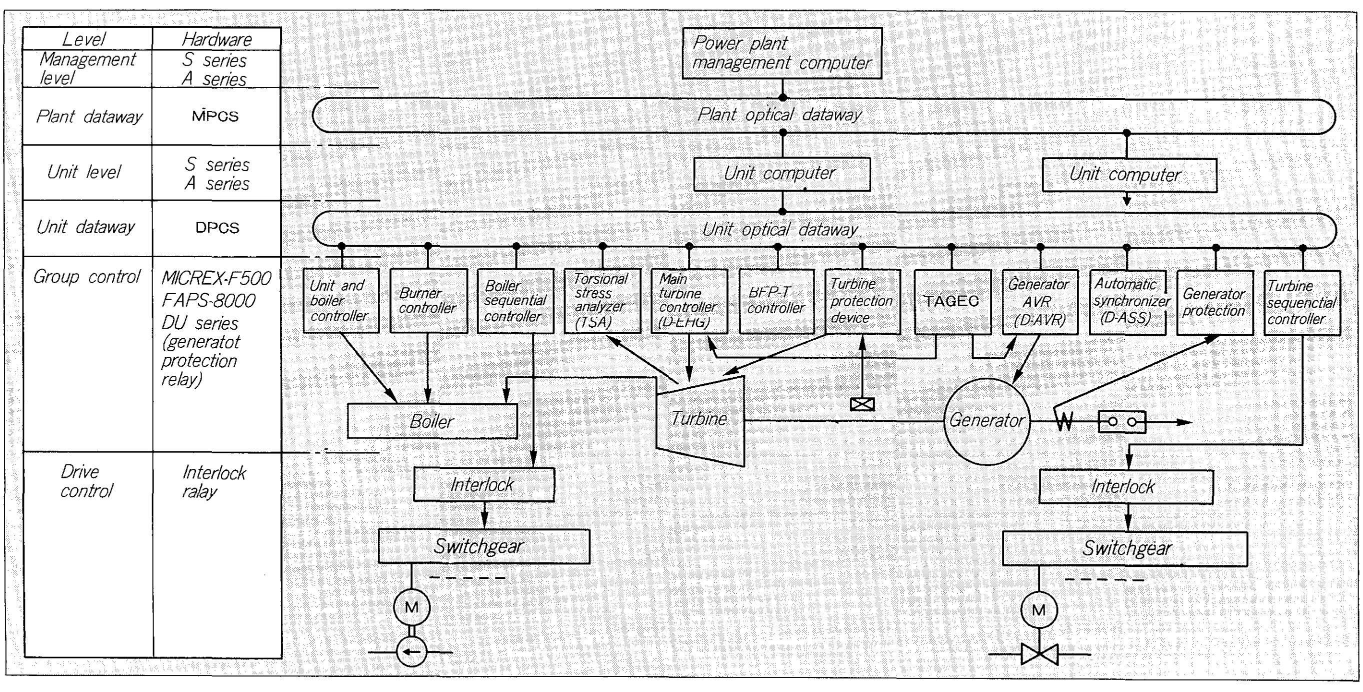
2 SYSTEM COMPOSITION

The conceptual block diagram of a control and supervisory system which considers the future is shown in *Fig. 1*. A management computer which manages the entire power plant is placed on the highest management level and connects to the unit computer installed at each unit through a plant dataway. A unit dataway connects the unit computers to the various digital control and supervision devices making up the lower group control level. The group control level connects to the final control element of each device of plant through a still lower drive control level.

In such a hierarchical distributed type configuration, the plant data and the data of various controllers are concentrated at the unit computers and plant supervision and controllers supervision, performance computation, data logging, and general plant control are performed by computer by complete man-machine communication based on these data. On the other hand, the various devices are controlled by individual controllers functionally distributed as group level.

Data is concentrated and control is distributed in this way.

Fig. 1 System block diagram



These distributed digital controllers consist of main turbine controller, boiler feed water pump turbine controller, boiler controller, sequential controller, generator automatic voltage regulator, automatic synchronizer, automatic burner controller, local controller, etc. The hardware making up these controllers is roughly grouped into the MICREX-F500 used in turbine control and sequence control and other control requiring fast operation and the FAPS-8000 used in boiler control and locl control. The torsional stress analyzer and rubbing analyzer and other supervisory devices use the hardware suited to each device.

The features and contents of each device, centered about the MICREX-F500 turbine controller and FAPS-8000 boiler controller, are introduced below.

3 TURBINE CONTROLLER

The governor, which is responsible for turbine speed control, is the one of the most important controllers in a thermal power plant.

The conventional steam turbine was equipped with a hydraulic governor, in addition to an electric governor, and used a system which distributed hydraulically the control signals from the electric governor to each control valve. New turbines are not equipped with a hydraulic governor and use a valve control system that controls each control valve directly from the electric governor.

The excellent reliability, controlability, and maintainability digital electric governor (D-EHG) developed to cope with this is outlined below.

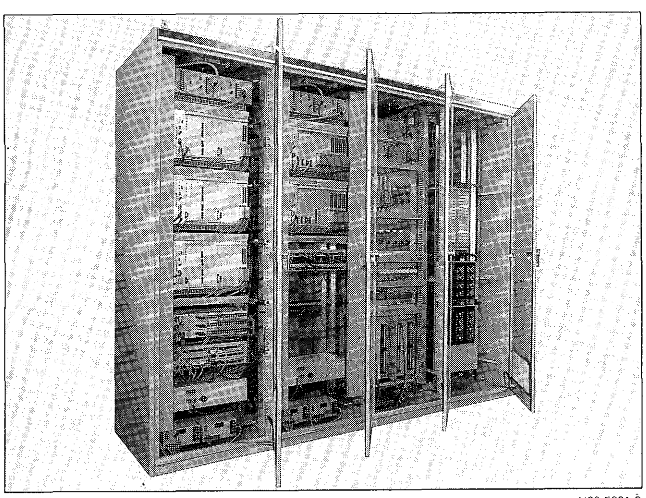
An exterior view of the D-EHG is shown in *Fig. 2*.

3.1 Functions of D-EHG

The D-EHG has the following functions:

(1) Turbine starting function
(2) Speed-up control function
(3) Synchronizing control function
(4) Initial load control function
(5) Load control function

Fig. 2 Exterior view of D-EHG



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(6) Droop characteristic function
(7) Load limiter and load limiter automatic follow-up control function
(8) Valve opening control function
(9) Valve test function
(10) Load shedding relay function
(11) Power control function (Option)
(12) Pressure control function (Option)
(13) Condensate limit pressure controller (Option)

The outline function block diagram and interface with the mechanical system are shown in the D-EHG function block diagram of *Fig. 3*.

3.2 Features of D-EHG

3.2.1 High reliability

To improve system reliability, the following was made the basic redudancy concept:

Systems capable of self-diagnose .... Duplexing
Systems at which self-diagnose is difficult .... Triplexing
Systems difficult to multiplex .... Distributing

(1) Main controller (MPU)

The MPU is the most important part of the system and is triplexed because self-diagnose to the result of operation is impossible.

(2) Serial link between MPU (P link)

Since self-diagnose is possible and its application is data correction between MPUs, the P link is duplexed (standby redundancy system).

(3) Input/output serial link (T link)

The T link is a serial link for transfer between MPU and I/O. Self-diagnose is possible, but triplexed since the MPU is triplexed from the standpoint of system composition.

(4) Input/output

As a rule, input/output is duplexed. The output value from the triplexed MPU is made 2 out of 3 or middle value selection (MVG) in an output card.

However,

- speed detection and other inputs requiring high speed
- most important analog inputs as a governor
- input/output of control operation results that can cause immediately tripping or large outside disturbances

are connected directly to each MPU and duplexed by direct connection I/O card.

(5) Control power supply

The control power supply is duplexed by receiving it with two system so that control is not disabled by loss of one system.

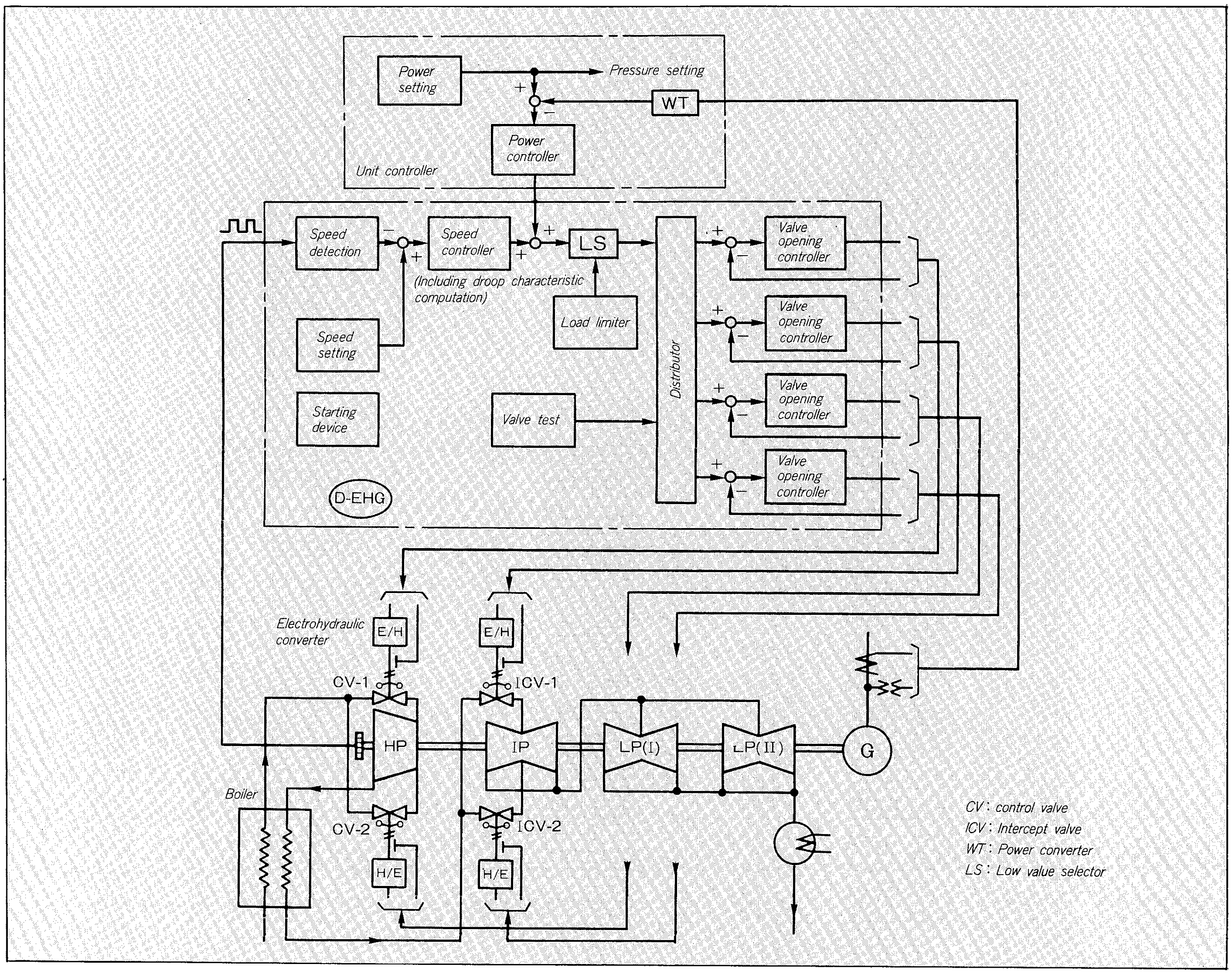
A D-EHG system configuration based on these concepts is shown in *Fig. 4*.

3.2.2 Improvement of maintainability

Maintainability is improved by:

(1) ER display (trouble display) on each card and actualization of trouble point by maintenance panel
(2) Checking of functions of spare cards by module checker
(3) On-line maintenance by pull-in and pull-out during

Fig. 3 Functions of D-EHG



The MICREX-F500 fast and

operation of the D-EHG.

(4) Visualization of program by block graphic representataion

3.3 D-EHG hardware

3.3.1 Features

The MICREX-F500, high-speed and high-ability controller, positioned at the highest level of the new Fuji Electric MICREX-F Series programmable controller is used. The main features of its hardware and software are:

(1) Standardized hardware and international compatibility
- "MULTIBUS II" (Scheduled for IEEE standardization) used
- IEC standard printed circuit board and shelf construction

(2) Open software system
- Functional control problem oriented language aimmed at flexibility and handling of diverse program representation methods (mnemonic language, ladder chart, function block diagram, etc.)
- Opening of software design to third parties

(3) Functional and reliable composite system configuration
- Custom LSI of main functions and miniaturization, speeding up, and improved reliability of hardware
- Redundancy (system configuration) coordinated with international standard construction
- Multi-functions and compounding by multiprocessor configuration

3.3.2 Hardware

The hardware consists of MPU units and I/O units as shown in *Fig. 4*. Besides the basic POW, MPU, MEM, CSM, and PGA cards, PLA and TLC transmission cards and PI, AI, DI/O direct connection I/O cards are installed at the MPU unit.

Similarly, besides the basic CSM and TLS cards, HRAO, DO and DI cards are installed at the I/O unit. The main specifications of MICREX-F500 are shown in *Table 1* and the cards are shown in *Table 2*. The features of the MICREX-F500 compared to conventional controllers are summarized below.

(1) High speed operation possible

(2) Abundant self-diagnosis and trouble diagnosis functions

(3) Multiplexing is easy.

Fig. 4 D-EHG system configuration

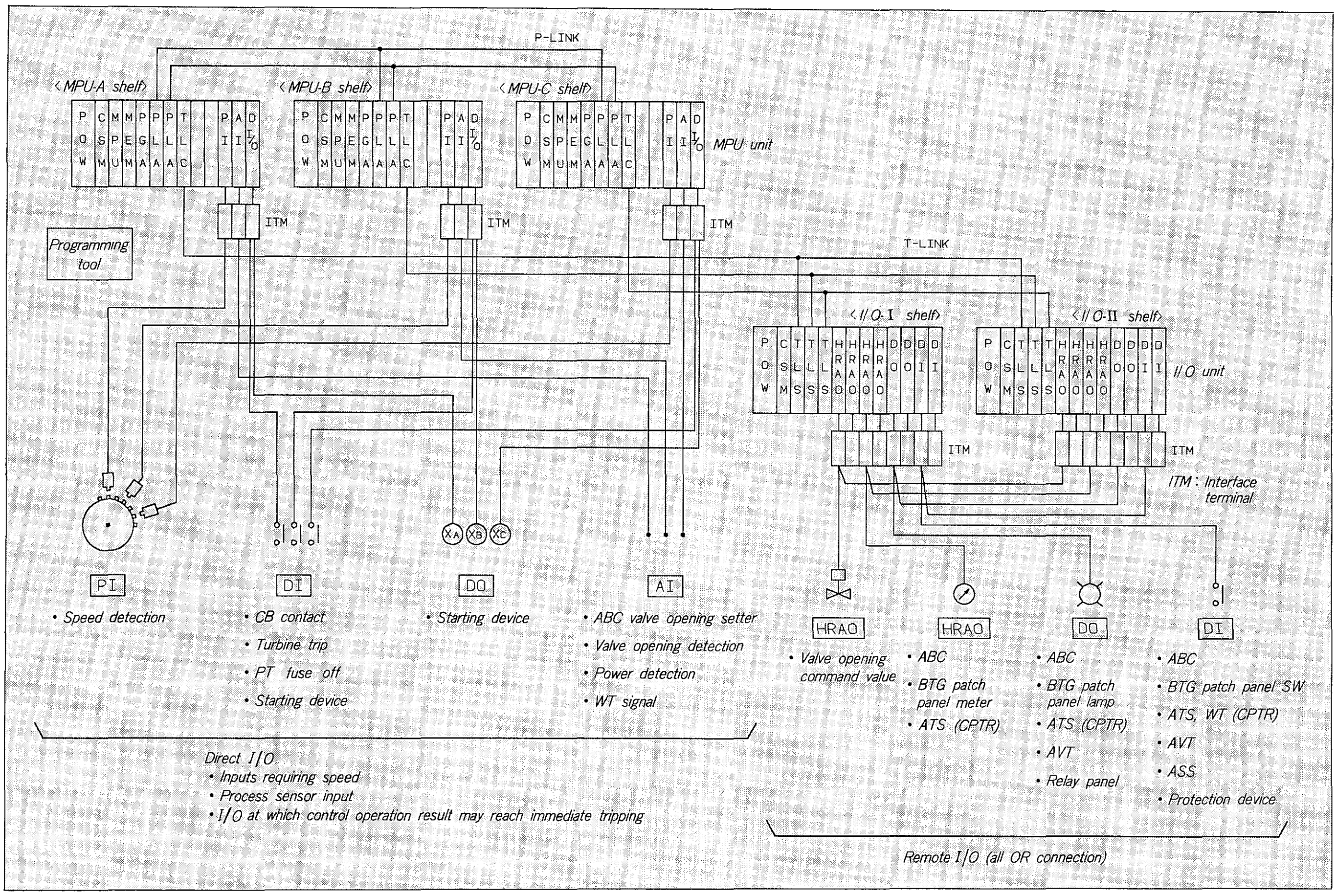


Table 1 MICREX-F500 specifications

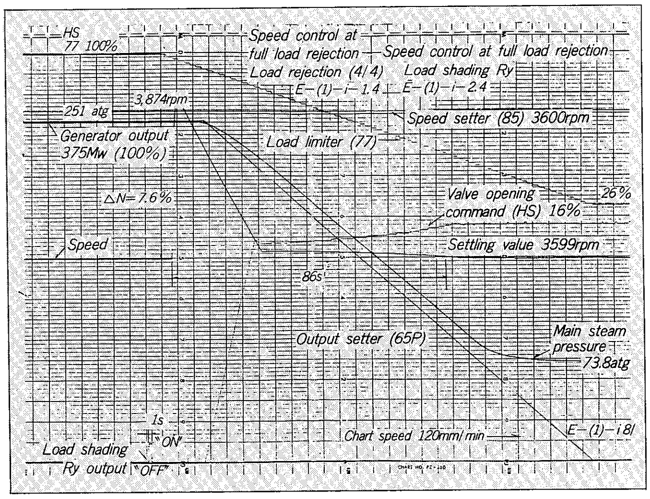
Item		Specification	Remarks
Control method		Stored program system	
Control functions		Cyclic operation control Fixed cycle operation control Process interruption control	Minimum 1ms fixed cycle
Instructions	Language	Control problem oriented	FCL
	Speed	Sequence instruction: 1.0μs Fixed decimal point operation: 10μs or less Floating decimal point operation: 20μs or less Analog operation: 20μs or less	Floating decimal point operation IEEE format (32 bits)
Memory	Program	64kW (16 bits/w): FPROM/RAM selectable	System use: 32kW, application: 32kW
	Data	32kW (16 bits/w): RAM	System use: 16kW, application: 16kW
Number of I/O points	Digital	8704 points max.	T link: 8192 points, direct connection: 512 points
	Analog	1152 points max.	T link: 1024 points, direct connection: 128 points
Internal relay data memory	Bit memory	8192 points	System data memory area
	Word memory	2kW (16 bits/w)	System data memory area
	Differentiation relay	1024 points	
	Keep relay	1024 points	
	Timer	1024 points	
	Counter	128 points	
	File memory	16kW (16 bits/w)	
Transmission IF	PIO transmission	T link: 500kbits/s	Optical transmission possible
	Between controllers	P link: 5Mbits/s	
	Dataway	DPCS-F	
Control power supply		• AC100/110V −25% +10%, 50/60Hz • DC100V	
Dielectric strength		AC2000V for 1 min.	
Temperature		0 ~ 40°C	
Humidity		20 ~ 90%RH	

Table 2 Card units

Card name	Specifications
POW	Power supply unit ◦ AC100/110V or DC110V input ◦ Plug-in type the same as card. ◦ Duplexing possible
CSM	Common control card ◦ System operation and system status output ◦ System bus common control
MPU	FEL execution card ◦ Original 32 bit ALU used ◦ Microprogram control (8kW) + nonprogram control ◦ Data memory 32kW
MEM	FEL program control card ◦ Control problem oriented language (FCL) program control ◦ Interrupt control ◦ Program memory 64kW
PGA	◦ Program loader connection card ◦ RS-232-C x 4 channels
TLC	T link connection card ◦ T link (500kbits/sec. serial) x 2 circuits
TLS	T link coupling card (10 unit) ◦ T link (500kbits/sec. serial) x 1 circuit
PLA	P link connection card ◦ P link (5Mbits/sec. serial) x 1 circuit ◦ ROM: 8kB, RAM: 2kB
DPCF	Dataway (DPCS) connection card ◦ DPCS x 1 circuit
DI	Digital input card ◦ Number of input points: 64 points ◦ Photocoupler isolation: AC500V
DO	Digital output card ◦ Number of output points: 64 points ◦ Photocoupler isolation: AC500V
AI	Analog input card ◦ Number of input points: 16 points ◦ Photocoupler isolation: AC500V
HRAO	Analog output card ◦ Number of output points: 8 points ◦ Photocoupler isolation: AC500V

(4) Shelf and card construction conforming to international standards
(5) On-line pull-in and pull-out during operation possible possible

Fig. 5 Speed control at 4/4 full load rejection



3.4 Function verification

The results of 4/4 full load rejection are shown in *Fig. 5* as an example of D-EHG function verification using a simulator. The maximum speed rise rate is the expected 7.45%.

4 BOILER CONTROLLER

Diversification of power facilities, diversification of fuel, changes in the structure of industry, etc. in recent years demand that the controller responsible for thermal power plant operation perform sophisticated and complex functions economically.

To meet these sophisticated and complex needs, an integrated digital instrumentation and control system backed by the digital control technology which has developed noticeably in recent years is necessary. This integrated digital instrumentation and control system must also amply harmonize the demand from operability and controlability,

Table 3 Features of FAPS-8000 boiler controller

Item / Classification	Old technology	Additional technology			
Control operation function	Boiler and turbine coordination control (PID operation, etc.)	Classic control theory type advanced control (IR method)	Modern control theory type advanced control (AR method)	Enhancement of plant control system protection system	Process input abnormality diagnosis and protection (reasonable full check)
Reliability	Manual operation	Automatic operation continuation by system redundancy (1:1, N:1 backup)	Separation of control operation section and manual operation section (manual operation module)	Separation of interlock logic section (relay module)	ABC erroneous output prevention (mutual diagnosis output monitor)
Maintainability	Digital apparatus inherent expandability	Continuity with analog control (visual type maintenance tool)	Automatic card test (module checker)	Controlability simulation (boiler simulator)	Trouble analysis (high speed trouble recorder)
Operability	Panel operation	Operating state central supervision and operation (supervisory panel)	Control system for plant automation (Type 72 final control element)	Erroneous operation prevention (artificial intelligence type operation support system)	Boiler high efficiency support Life forecasting support

protection, supervision, and logging of the facilities making up the plant and the essential conditions of the controllers, that is, operability, reliability, maintainability, functionality, etc.

With this design concept as the uncleus, the following equipment manufactured by integrating our many years of achievements and experience in boiler control and total control system architecture technology are used at boiler facilities and boiler burner facilities.

4.1 FAPS-8000 boiler controller

This controller is used in boiler control. It was manufactured by deeply pursuing high reliability, operability, maintain-ability, and expandability. Its details have been described already. Its features are compared with existing technology in *Table 3*.

4.2 Automatic burner controller

This controller is a part of a thermal power plant automation system. It is a sequential controller which ignites and extinguishes the burner automatically according to the boiler load. The number of inputs and outputs used in the control a 375MW class burner facility has reached approximately 3300 points. Since this processing requires a large capacity and high speed processing function, the system is built with the MICREX-F500. The system block diagram is shown in *Fig. 6*.

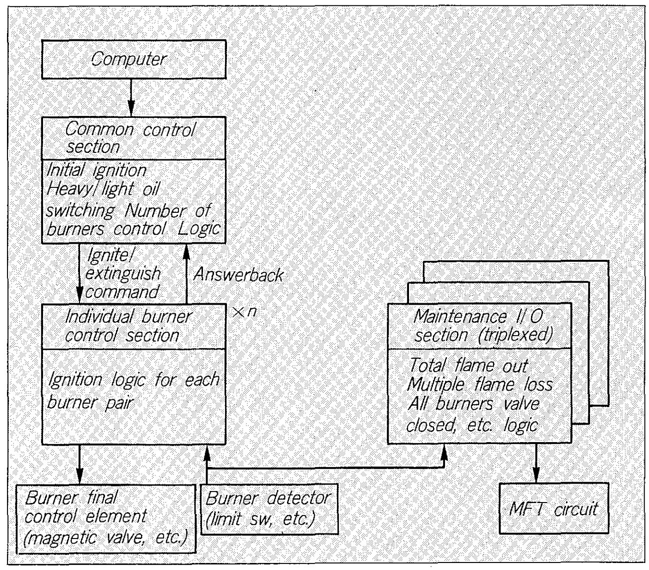
The common control section ignites and extinguishes the starting burner, controls starting light oil/heavy oil switching, automatically controls the number of burners, etc. by computer signal. The individual burner controllers ignite and extinguish the individual burners. The maintenance input/output section has total flame out, multiple flame loss, all burners valve closed, and other boiler protection functions. This circuit has a triplex configuration.

Besides various features pursuing high reliability, operability, maintainability, expandability, etc., an IEC block diagram display programming tool and a module checker are available to improve maintenance.

5 SEQUENCE CONTROLLER

Fuji Electric has delivered equipment using a sequencer to all commercial thermal power plants since a programmable controller (called "sequencer" hereinafter) was used with the automatic turbine starting and automatic valve test equipment of the Chubu Electric Power Co., Ltd. Shin-Shimizu Thermal Power Plant in 1973. By using a sequencer, detailed supervision of the sequence advance state and congestion that could not be realized with the conventional relay sequencer possible. That is, it features a detailed step sequence control system in which one step is provided for each sequence operation command and positive execution of the operation command is checked by check back signal and a time over alarm is output when the check back signal is not returned within the prescribed time. This system has been used with all plants ever since the Shin-Shimizu Thermal Power Plant delivered 14 years ago. A total digital

Fig. 6 Automatic burner control system block diagram



control system using a sequencer is build on this long record of achievements and experience. The MICREX-F500 described previously is used as the hardware.

6 AVR, ASS

6.1 AVR

To deal with large generator capacity, improvement of the reliability and maintainability and power system stability countermeasures, and other controlability is demanded of an AVR.

Therefore, digitalization of the AVR system, including the system stabilizer (PSS), reactive power regulator (AQR), etc. is planned. Especially, for large capacity machines, a triplex or duplex configuration is taken to substantially improve reliability.

The MICREX-F500 is used as the hardware, the same as turbine control.

6.2 Automatic synchronizer

The automatic controller matches the frequency, voltage, and phase of the generator voltage and system voltage and synchronizes the generator to the system automatically. Its main functions are automatic synchronization, automatic voltage balancing, and automatic synchronous closing.

The automatic synchronizing signal acts on the speed setter of the governor and when the frequency difference is large, the speed is adjusted quickly and when the frequency difference is small, the speed is adjusted gradually and the time up to matching of the frequency is shortened.

The automatic voltage balancing signal acts on the voltage setter of the AVR and matches the generator voltage and system voltage. The time up to matching is shortened by changing the control amount according to the size of the difference between the two voltages. The automatic synchronous closing function generates a closing command before the time corresponding to the required closing time of the synchronizing circuit breaker from the phase matching point of both systems on the condition that the generator voltage and system voltage frequency difference and voltage difference are within a fixed value. This function is duplexed to make it fail safe.

This equipment is digitalized and the automatic supervisory function, etc. are enhanced and high reliability is obtained by using the MICREX-F500.

7 TOTAL ADAPTIVE GENERATION CONTROL SYSTEM (TAGEC)

System stabilization by improving the performance, functions, and reliability of the generator control system is the most basic stability improvement measure. Fuji Electric developed the TAGEC (Total Adaptive GENERATOR Controller) digital control system, which improves stability considerable, cooperatively with the Kansai Electric Power Co., Ltd. and Power Central Laboratory for this purpose.

This system is a practical control system with the modern control theory multivariable feedback control system and adaptive control system applied to generator control.

The features of the TAGEC system (type II) for thermal power plant are:

(1) It is a system performs multivariable control of the exciting system and speed governing system, the two control systems of a generator. Speed governing system control is a governor compensation control type multivariable control system which only controls the speed governing system which contributes to stability. Therefore, the conventional type governor control system, with its large accumulated technology, can be used directly. generator and the dynamic characteristics of the generator change continually. Since these dynamic characteristic changes lower the control characteristic of a generator controlled by fixed control parameters, this system estimates the dynamic characteristics of the power system and generators on-line and performs adaptive control which performs ideal control that follows these dynamic characteristics changes.

(3) The ASMARC system, which operates the generator stability quantitatively, is also used as the multivariable control status amount operation function. Therefore, quantitative supervision of the stability margin impossible in the past can be performed.

Fig. 8 is an example of the TAGEC II verification results by AC and DC power system simulator at the Power Central Laboratory. The effectiveness of this system at a thermal power plant, such as a 30 to 50% improvement in stability over that of the conventional system for a system with mixed long and short undulation periods, etc., was also verified.

Fig. 7 TAGEC (II) system

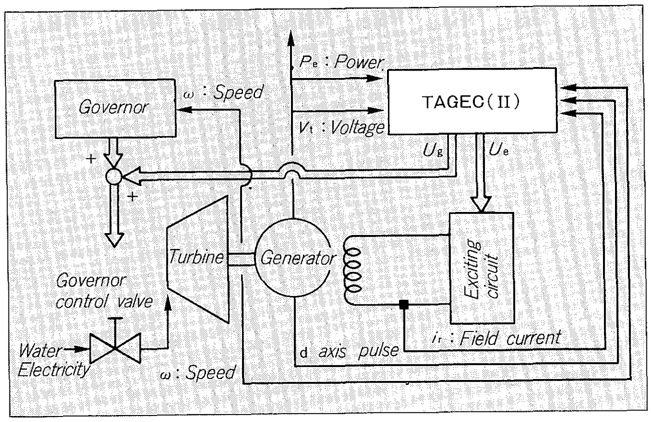
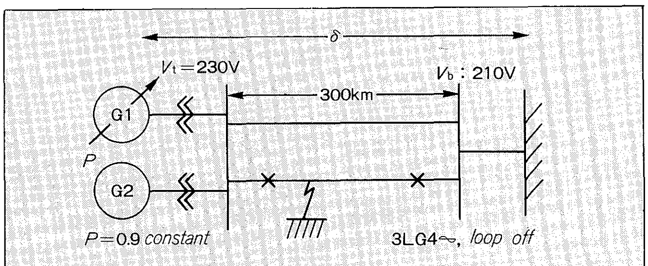
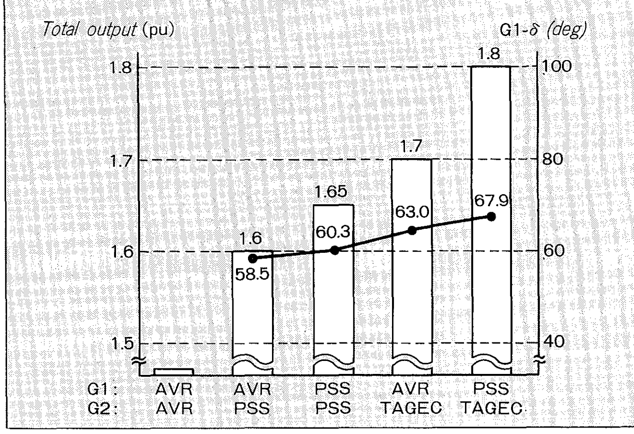


Fig. 8 Power system simulator test results



Control system	AVR/PSS	PSS/PSS	AVR/TAGEC	PSS/TAGEC
Improvement result	Base	3.1%	6.3%	12.5%

(Improvement result is G1 output evaluation for total output value.)



8 SUPERVISORY AND DIAGNOSIS EQUIPMENT

8.1 Torsional stress analyzer

The life of the shaft of a turbine generator is affected not only by power system accidents and reclosing and other severe shaft stress variations, but also by the accumulation of system closing, overload tripping, and other normal operations. This affect trends to become stronger as the capacity of the turbine is increased.

The torsional stress analyzer constantly monitors the shaft on-line for a long time to secure turbine generator reliability and make maintenance more efficient.

The features of this equipment are:

(1) Detection of the torsional stress produced at the shaft

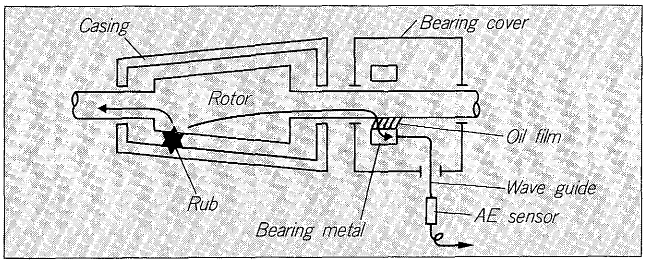


Fig. 9 Rub signal propagation path

requires special processing and an indirect detection system which can detect the torsional stress contactlessly is used.

(2) Shaft life calculation by FASMIC G500 super microcomputer and judgement of the distortion stress applied to the end coupling and generator stator coil end and other high-speed on-line processing.

8.2 Rubbing diagnosis

A system which can accurately diagnosis if the rubbing phenomena (contact of rotating part and static part), one of the main causes of abnormal vibration of a steam turrbine, is present during operation was developed.

The generated rubbing signal is detected by the rotor → oil film → wave guide → AE sensor propagation path as shown in *Fig. 9*.

The diagnosis system extracts the rubbing signal from the detection signal, which includes steam flow noise, etc., and judges if rubbing is present by quantifying the distinctive features of the extraction waveform. Diagnosis is possible for operating conditions from low speed to full load. An exterior view of the diagnosis system is shown in *Fig. 10*. The following can be output as the diagnosed result:

(1) When there is rubbing, an alarm signal is output.

(2) The rubbing position can be monitored by lighting of LED on a panel with a drawing of the turbine rotor.

(3) Changes in the relative strength of rubbing can be monitored by recorder.

(4) The rubbing sound at low speed can be monitored by speaker.

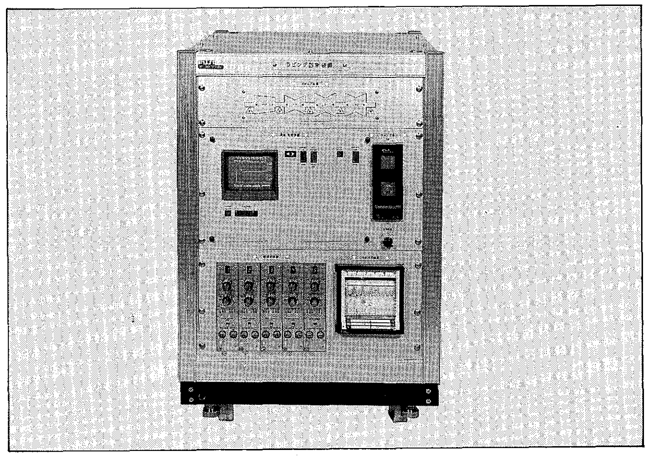


Fig. 10 Exterior view of rubbing diagnosis system

9 CONCLUSION

The description above was centered about the new digital controller using a microcontroller. In the future, a intelligence engineering applied facility diagnosis system, trouble recovery system, and adaptive control, advanced control, etc. based on modern control theory will be widely incorporated in plant control and supervision systems and the important of digitalization will increase steadily. Since Fuji Electric hardware and software have ample capabilities to meet such needs, they will be introduced over a wide range in the future.