Development of Next-Generation Gas Turbine Control Systems

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For combined cycle gas turbine power plants, the gas turbine power plant control system has developed, as a result of extending the existing system which can control only the gas turbine. The developed system can control entire plants which incorporate waste heat recovery boilers, steam turbines, and auxiliary machines such as pumps. On the other hand, for medium and small gas turbines, a compact control system has also been developed to provide miniaturization and low price. Optimal control systems have become applicable according to the scope of target. The outlines of these systems are described.

1. Introduction

Our company manufactures power generating facilities that incorporate gas turbines derived from aircraft engines. Gas Turbines (GT) are controlled by a gas turbine control system (CSI-III) that our company originally developed based on know-how in controlling aircraft engines. While the gas turbine control system CSI-III controls only gas turbines, other parts in a power generating facility are controlled by an external Distributed Control System (DCS). For a cogeneration facility that supplies both electricity and steam, gas turbines and Heat Recovery Steam Generators (HRSG) combined have been increasingly used in recent years. A further developed form of a cogeneration facility is also emerging: a combined cycle power generation facility that uses gas turbines and Steam Turbines (ST) combined. There is a trend that the percentage of component installations other than gas turbines is increasing in power plants. Given this situation, we noted a pressing need to provide a system that takes general control of power plant operations, including the operations of gas turbines, and thereby improve the customer satisfaction measurement, specifically, flexibly meeting customer needs, expediting maintenance work, shortening lead times, etc.

By expanding the functions of the CSI-III, we developed a gas turbine power plant control system (CSI-III+) that takes general control of power plant operations, including the operations of HRSG, steam turbines, such auxiliary equipment as pumps, etc.

We also noted a strong need for a control system for medium- and small-sized gas turbines, and developed a CSI-III-based micro gas turbine control system (microCSI) that features a small size and low price. This paper provides general information on these developed control systems and their main features.

2. Gas turbine power plant control system (CSI-III+)

2.1 System configuration

Figure 1 shows the system configuration of the CSI-III+ used for a combined cycle power generation facility using gas turbines. The CSI-III+ consists of a plant system, control system, man-machine interface, and remote monitoring system (i-Monitor).

Main units of equipment comprising CSI-III+ include the following:

(1) Plant Control Station (PCS)

The PCS is installed in individual plants to be controlled, i.e., each gas turbine plant or a plant using steam turbines and common auxiliary equipment. The PCS's installed in a multiple of plants this way communicate with each other to take general control of plant operations.

(2) Operators & Engineers Station (OES)

The OES generates control commands to the PCS, monitors plant conditions, and performs the tasks related to system maintenance management. Some OES's are equipped with the engineering tools used to compile a control logic program operating on the PCS and make settings, including a change of parameters.

(3) Remote I/O (RIO) panel

The remote I/O panel connects objects to be controlled to the PCS via optical fibers, and controls

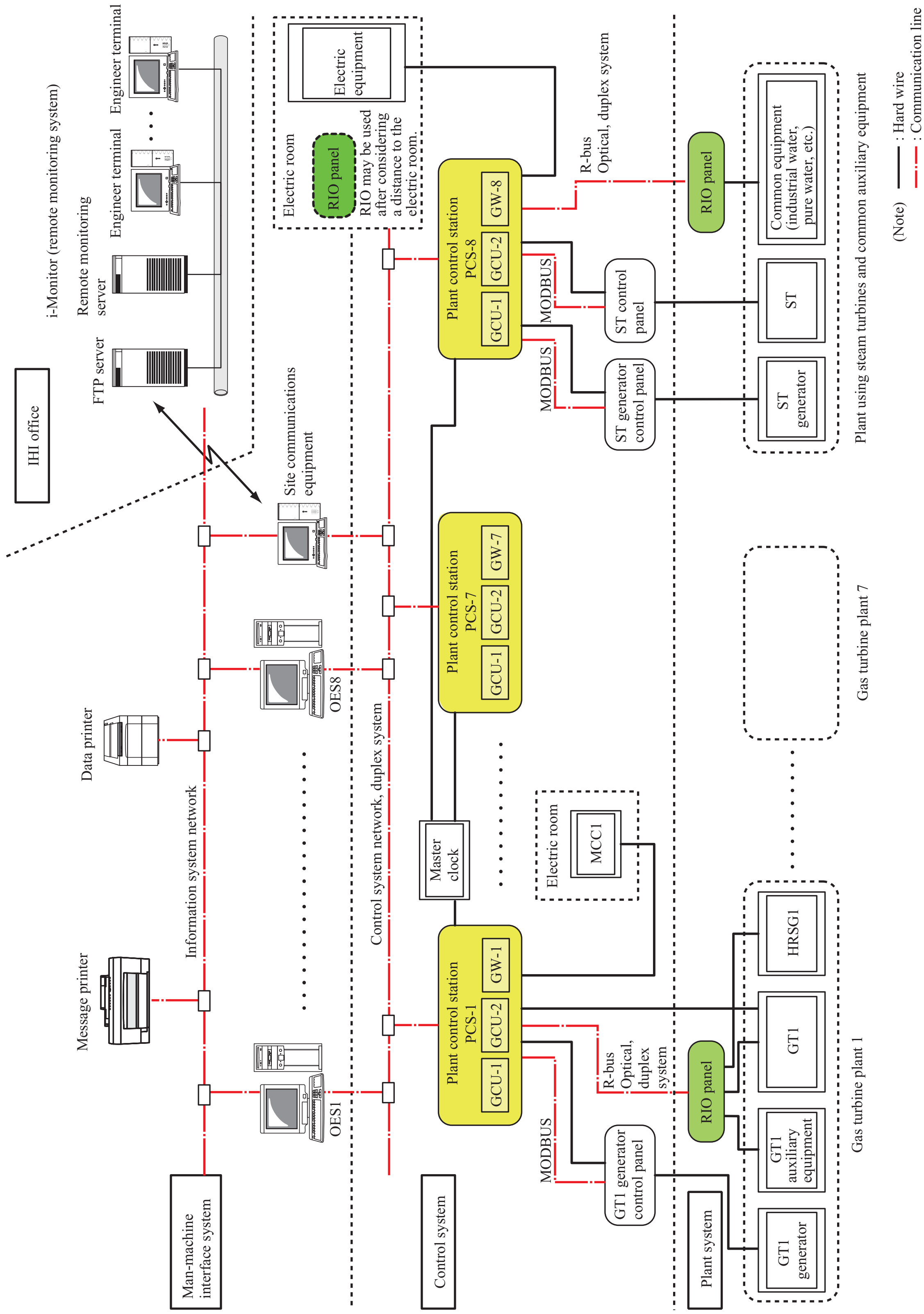

Fig. 1 Control system configuration of gas turbine power plants

these remote objects with high speed and reliability.

(4) Gateway (GW)

The PCS uses the gateway to communicate with external control devices, such as the GT generator control panel, ST control panel, etc.

(5) Site communication equipment

The site communication equipment collects data from the OES, and transfers it to i-Monitor.

2.2 Functions

Main functions of CSI-III+ are as follows.

2.2.1 Plant control function

The PCS receives analog data, digital data, RIO data, or data that is collected by another PCS, performs control operations on the received data according to a control logic, and outputs the results of control operations to control plant operations. In addition, command values specifying the energy to be generated are given to each plant such that the total energy generated by all plants agrees with a specified target value of generated energy.

2.2.2 Plant monitor and alarm functions

To monitor the conditions of plants, monitor functions are provided, including the display of various trend graphs, graphically presented system diagrams, etc. Data to be monitored are divided into some groups according to uses. Data to be collected can be registered by group.

To support the operator in doubt about a specific operation to be performed, an electronic operation manual can be retrieved from a system diagram and brought up on the screen. An annunciator function for displaying plant alarms or events, as well as a self-diagnostic function for detecting an abnormality in the PCS, are also provided.

2.2.3 Engineering functions

For CSI-III+ to operate, the following three tasks must be performed by using a special engineering tool: ①creating a control logic program, ②making a data collection condition setting and other various settings, and ③registering data in each PCS. **Figure 2** shows the special engineering tool. The tool provides a function of checking the consistency between the contents of various settings to prevent setting errors from occurring due to human mistakes and to increase the system reliability.

How a created control logic program is working can be displayed online on a block diagram so that operations being performed according to the control logic program can be easily monitored. In addition, input or output data can be cleared or fixed to a value of choice during monitoring to allow system conditioning work to be carried out efficiently.

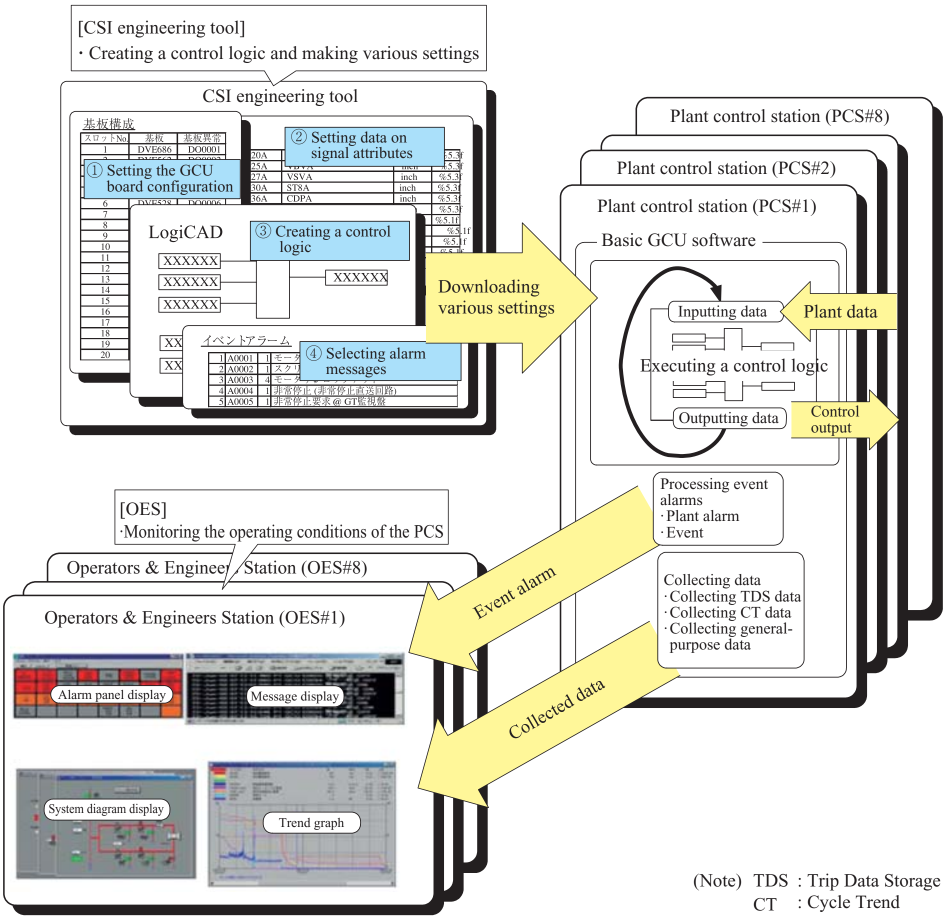

Fig. 2 Engineering tools

2.2.4 Online switching function

Set conditions and control logics must be changeable without stopping the operations of a plant. The CSI-III has a function of changing logical-block parameters used by a control logic program during the PCS control operations. In addition to this function, the CSI-III+ has an additional function of switching between control logic programs and set conditions, including the conditions for plant data collection during the PCS control operations. This online switching function is implemented using an engineering tool. Before switching is executed, PCS's are brought into a synchronized state and the consistency between conditions of all PCS's is checked so that a total plant system operates in a consistent, coordinated manner even in a situation where switching cannot be executed for some PCS's.

2.2.5 Remote monitoring function

Data sent through a public circuit is published in the in-house LAN, and various data including data on plant conditions can be viewed on the screens of engineers' terminals; the screen is equivalent to the OES screen. This helps expedite maintenance work. In addition, data can be externally transferred, for example, to a customer's server.

2.3 Features

The main features of the CSI-III+ are as follows.

2.3.1 High-speed control operation performance

Considering that gas turbines must be controlled in a short control cycle, the CSI-III+ was designed with high-speed control operation cycles, i.e., the shortest cycle of 10 ms, the same as with the CSI-III, and 20, 40, 80 and 160 ms–a total of five cycles. Multiple control operations can be performed at these control cycles simultaneously. This enables an optimum control cycle to be selected by considering the conditions of each installation to be controlled and related control conditions so that loads can be leveled off.

In data used for each operation cycle, some data are shared by multiple operation cycles. Before the start of control operations in each operation cycle, the data identification process is executed, i.e., all data that one operation cycle requires are acquired from data used in other operation cycles and the acquired data is retained so that data consistency can be maintained until control operations are completed.

Other than data to be used in the current operation (table of values to be used in the current operation), data on the results of the previous operation performed (table of values used in the previous operation) is made available to each operation cycle. If data used in another operation cycle is to be acquired, the table of values used in the previous operation performed in that operation cycle is referenced. Upon completion of the operation in one operation cycle, the contents in the table of values used in the current operation are copied to the table of values used in the previous operation. **Figure 3** shows the data identification process.

2.3.2 Creating a control logic by using a simple picture language

A control logic edit tool (LogiCAD), one of engineering tools, is provided so that a control logic program can be created easily without the need for special knowledge of software development. LogiCAD has a library of logical blocks. After you select appropriate logical blocks from the library, you paste them onto a sheet and connect them by signal wires. This way, you can visually create a control logic in the form of a block diagram.

To allow an enormous number of control logics used in one plant to be organized efficiently, groups of control logics are defined as macros so that they can be reused in multiple places within the control logic. In addition, it is possible to import control logic sheets from other plants and use them. Each control logic sheet is hierarchically presented to make it easier to check a large number of control logics and do editing work. **Figure 4** shows the control logic edit tool (LogiCAD).

Before a created control logic is transferred to a PCS, its consistency is checked by LogiCAD so that inconsistencies due to human mistakes can be prevented from being included in the control logic.

2.3.3 Achieving a high degree of reliability by using a dual redundant system

(1) Control unit designed as a dual system

Since the PCS controls the operations of a plant, it must be able to operate with a high degree of reliability. To achieve a high degree of reliability, the PCS was designed as a dual system in which two control operation units (GCU), each having the same configuration, are used.

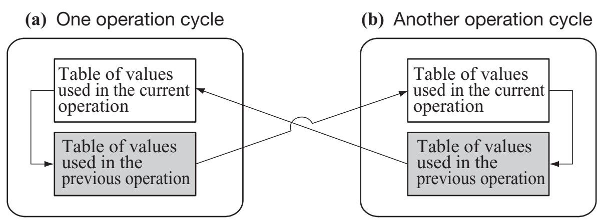

Fig. 3 Data identification

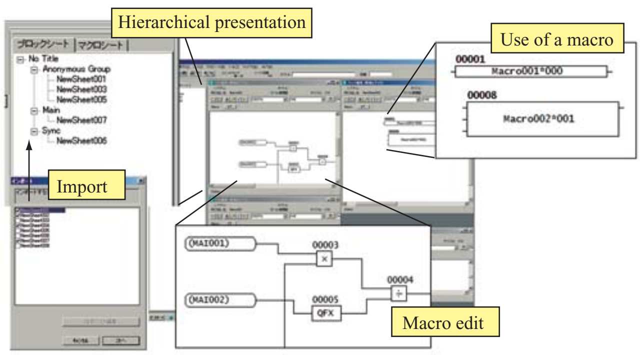

Fig. 4 Control logic editor (LogiCAD)

In this dual system, one GCU operates as a main unit; it performs control operations and controls the operations of a plant based on the results of control operations. The other GCU operates as a sub unit; it performs only control operations at all times.

If an abnormality occurs in the main unit, the active channel selector externally installed detects it and immediately switches from the main unit to the sub unit so that control operations can be continued.

Since the main and sub units perform control operations asynchronously, there is the possibility that a control command value calculated by the main unit may be different from that by the sub unit. To avoid a situation where a difference occurs between the values given by these two units, the main unit transfers its data to the sub unit via a communication board called a Dual Port Memory (DPM), and the sub unit overwrites its own data with the transferred data. Data generated by both systems can be synchronized this way. **Figure 5** shows how data is synchronized.

(2) Duplex network system

To increase the reliability and communication performance of a network, a dual network system was introduced: an information system network for communication inside a man-machine interface system, and a control system network for communication between a control system and man-machine interface system. Particularly, the control system network was designed as a duplex system so that if one system fails and data is lost, the other system takes over and performs the retransmission process.

3. Micro gas turbine control system (microCSI)

3.1 Overview

The CSI-III+ controls the operations of one entire gas turbine power plant and a high level of performance and reliability are naturally required. For a system that controls medium- or small-sized gas turbines, not only functions and performance but also small size and low price are definite requirements. With these requirements in mind, the microCSI was designed to use the same OES and engineering tools as used for conventional control systems, and only one control operation unit or GCU. The GCU hardware was made smaller based on the 3U-size compactPCI board. **Figure 6** shows the micro gas turbine control system (microCSI).

The control operation and plant monitoring functions of the microCSI are basically the same as those of the CSI-III. Since it is presumed that the microCSI may be used as a standalone unit and OES may not be required, the microCSI is designed to retain collected data in flash memory and use the data at a later time.

The OS of the GCU was reviewed. The OS of the CSI-III is RTOS which is a well-established real-time OS developed in America. To strengthen the customer support system, an iTRON-based OS was adopted for the microCSI, considering that this OS was developed in Japan, the source license can be acquired, and there is a good track record.

3.2 Comparison of OS functions

If a hardware configuration or OS has been changed, whether specified control performance can be delivered in a new hardware configuration or OS must be verified. The operating environment of the CSI-III and that of the microCSI were assumed, and the basic functions of the OS that may have an influence on the control operation performance were selected. By running the OS in each of these environments, the performance was measured with respect to the basic functions. Measurements taken in the CSI-III environment were compared with those taken in the microCSI environment. (Measurements reflect not only the performance of the OS but also a difference in the hardware environments of these two control systems.)

Measurements of speeds of responses to basic system calls, including task control, semaphore, message cue, etc., show that the response performance in the microCSI environment is equivalent to or higher than that in the CSI-III environment. Measurements of speeds of responses to switching of tasks initiated by interrupts or semaphores and switching of tasks caused

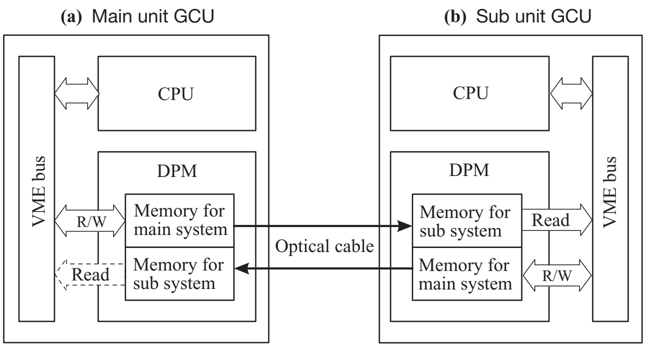

Fig. 5 Synchronized data

Fig. 6 Appearance of microCSI

Table 1 Comparison results of OS performance

Evaluation item	Unit	CSI-III environment	microCSI environment
Time to respond to interrupts	μs	17.70	1.37
Time to switch from one task to another (using semaphore)	μs	2.00	2.01
Time to switch from one task to another (using task priority)	μs	3.95	2.00

by a change in the priority of tasks also show that the response performance in the microCSI environment is equivalent to or higher than that in the CSI-III environment. **Table 1** shows the results of a comparison of basic OS functions. The performance of the microCSI as a system was later evaluated, and it was verified that there is no particular problem with its performance.

4. Conclusion

We developed the gas turbine plant control system (CSI-III+) that controls an entire power plant and the micro gas turbine control system (microCSI) that controls medium- and small-sized gas turbines and features small size and low price. As these two systems are made available, it is now possible to use a control system best suited for the size or scale of a power plant or gas turbine to be controlled.

The framework of the control operation unit (GCU) of microCSI can be applied to uses other than that for gas turbines. We would like to examine the viability of applying it to other uses in order to expand its applicability.

— Acknowledgments —

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