Recent Technologies in Nuclear Power Plant Supervisory and Control Systems

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OVERVIEW: Supervisory and control systems for nuclear power plants are important not only as means for executing control logic but also as means for providing a human-machine interface for operators. Hitachi, Ltd. is accordingly doing continuous R&D work on high-quality supervisory and control systems, and through such work has developed such products as integrated digital systems for centralized monitoring and control of Advanced Boiling Water Reactors (ABWRs), and simulators for use in training personnel in reactor operation. At the same time, remarkable progress has been made in recent years in developing such human-machine interface technologies as graphical user interfaces and multi-window systems, fueled by the ongoing technology revolution and the increasingly widespread use of personal computers. And incorporating these technologies and increasing their reliability are becoming important issues. To address these issues, Hitachi has developed (1) a client-server architecture to realize efficient plant monitoring and operation functions, (2) a high-performance controller as a core means of preserving system reliability, and (3) a system featuring added flexibility and expandability by connecting (1) and (2) via a network. The system was installed to provide digital supervision and control of liquid and solid radioactive waste treatment equipment at Tohoku Electric Power Co., Inc.'s Onagawa Nuclear Power Plant No. 3.

INTRODUCTION

THE deregulation in the electric power industry and the changing price structure for electric-power fees have made it vitally important to increase the operation rate of power plants and reduce plant construction and operation costs.

At the same time, however, the demand is increasing to improve and maintain safety and reliability in nuclear power plants, which shoulder a main portion of the base load of electric power supply.

Against this background, Hitachi, Ltd. has recognized the vital role that supervisory and control systems play in nuclear plants as an interface between operator and equipment, and is continuously striving to develop such systems as a basis for the fusion of human and machine. As a result of these efforts, the company has compiled a record in developing simulators for use in training personnel in plant operation, and has developed a supervisory and control system that both uses general-purpose technology and satisfies the reliability requirements demanded of equipment for nuclear power plants. The system has been installed in Tohoku Electric Power Co., Inc.'s Onagawa Nuclear Power Plant No. 3 to provide digital supervision and control of liquid and solid radioactive waste treatment equipment at that facility. This paper provides an outline of the details and functions of the system.

HUMAN-MACHINE INTERFACE

Developments in Human-machine Interface

In nuclear power plants it is essential to understand what is happening in the plant as a whole at all times. To achieve this with a minimum of difficulty, plant operation and monitoring data is amassed and compiled in a central control room. Thus, in the early generation of nuclear power plants, an interface was provided between the equipment and its operators in the form of the hard switches and meters that the central operation and control room is required to have.

Hitachi, Ltd. then developed its "NUCAMM-90 (Nuclear Power Plant Control Complex with Advanced Man-Machine Interface 90)," a system which applied ergonomic design and the latest technology in

Fig. 1—New Supervisory and Control System for Radioactive Waste Treatment Equipment.
Mouse operation of 4 CRT displays enables supervision and operation of all liquid and solid radioactive waste treatment equipment.

electronics and computer to achieve not only plant supervision and operation but also improved reliability and maintainability.

With the continuing progress in recent years of personal computer technology, however, graphical user interfaces and window systems have become quite common and in fact indispensable in day-to-day business. One of the major issues of today is how to incorporate these new technologies into nuclear power plant supervisory and control equipment while at the same time maintaining sufficient reliability.

Human-machine Interface Requirements

Liquid and solid radioactive waste treatment systems in nuclear power plants treat radioactive waste generated by the plants, then store it temporarily so that it can be re-used. From the standpoint of operation supervision, the features of these systems are (1) only a small number of personnel are needed to do the supervision work and (2) all operations are executed in priority order through multiple CRT terminals, since the basis of operation is to automatically operate all the system equipment in sequence. Since supervisory operation data can be read from all of the CRT terminals, multiple operators can share the same data.

Additionally, to ensure sufficiently good acknowledgment and response time in emergency situations, the system is equipped with dedicated hard switches, indicators and recorders exclusively for the following purposes.

(1) Essential alarms (details displayed on CRT terminals)
(2) Shutdown of automatic sequential operations
(3) Recording relevant external-release parameters

CRT Operation Display

Since the core of this system is supervisory operation via CRT terminals, as mentioned earlier, the following points are taken into consideration in determining interface specifications.

(1) Since the majority of operations are done automatically (sequential control), continuous monitoring of plant conditions is essential.
(2) To further enable the clear understanding of plant

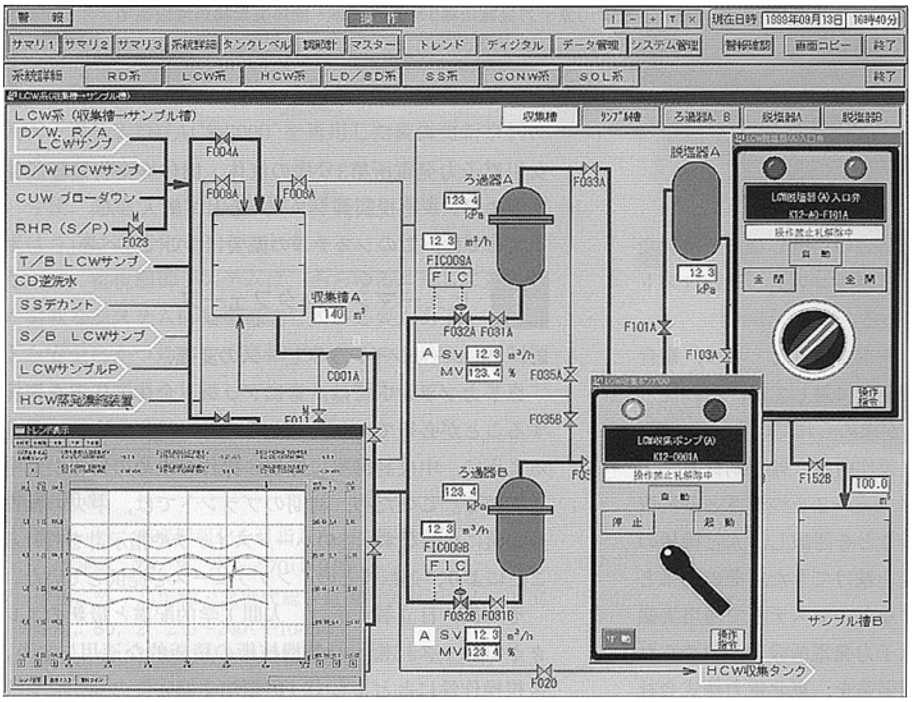

Fig. 2—Example CRT Operation Display.
By clicking with the mouse on the control equipment (pumps, air-operated valves, etc.) at the top of the system diagram, an operation switch window modeled after an actual hard switch appears in a pop-up display. Multiple displays can be shown with this switch window. In addition, trend graphs can be displayed on the same CRT, enabling operations such as valve opening and closing to be performed while monitoring the tank level.

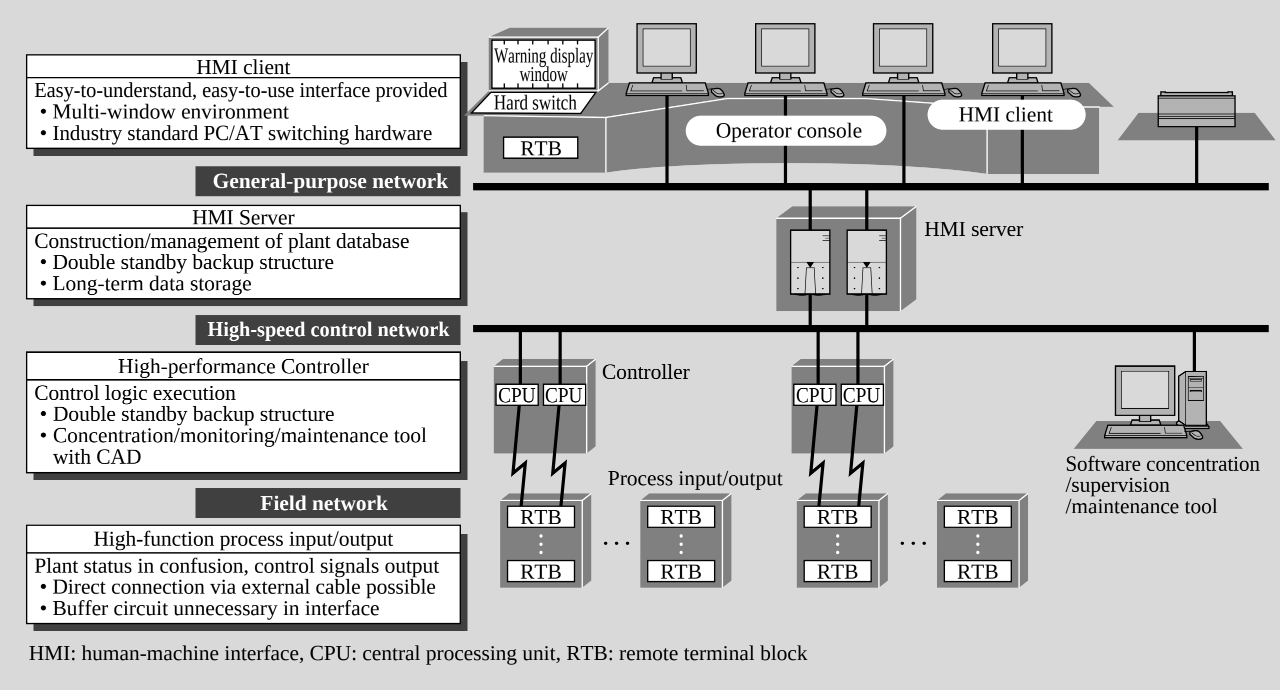

Fig. 3—System Configuration.
Layered HMI system/controller architecture. Linking elements via a network makes the system highly flexible and expandable, as a whole becomes much easier to maintain.

conditions, operators are provided with system diagrams that show the operational status of all plant equipment, trend graphs that show such factors as tank levels, and alarm display screens.
(3) There are some cases in which equipment units are operated individually during non-operational hours, i.e., during periodic inspections.

Under these conditions, a mouse operation and multi-widow environment interface was constructed. Fig. 2 shows an illustrated example of the operation and supervision of individual equipment units.

The system makes use of a desktop metaphor (the method of displaying features on CRT screens as desktop work to be done) that serves as a model of a human-machine interface for PCs based on window systems. Since conventional hard switches are generally used in equipment operating at the site in electric power generation stations, a symbol that accurately depicts the actual switch appears on the CRT's operation switch window, and the unity between visibility and operability is maintained. With respect to operation via CRTs, after deciding on the operation/supervising mode selection hard switch as the operation mode, every attempt to prevent erroneous operation is made through a procedure (including confirming operation) that comprises (1) selecting a unit to be operated from the CRT screen and displaying its switch window, (2) selecting an operational direction button (i.e. "open" or "close" for a valve), and (3) pushing an operation-executing button.

DIGITAL CONTROL SYSTEM

Fig. 3 shows the overall configuration of the new supervisory and control system. The system architecture is modeled on that of conventional supervisory and control systems for nuclear power plants. Specifically, it comprises two layers — a human-machine interface (HMI) system that handles data needed for supervisory operation and a controller that executes a control logic based on process signals and outputs specified signals to the control equipment. This type of architecture enables the interface between layers to be simplified, thus achieving a simple yet reliable structure for the system as a whole.

HMI System

This system makes use of industry-standard "PC/AT" compatible hardware. With the remarkable advances made in recent years in the area of graphic processing, the hardware through its multi-window environment provides an easy-to-understand, easy-to-use human-machine interface to the operator.

Process data are accumulated from a controller, and duplex servers are provided with functions for plant database management and for preserving long-term data such as trend data and report data of all types. A server-client architecture that links these over a general-purpose network (e.g. Ethernet*) makes the system highly flexible and expandable, enabling HMI clients to be increased as necessary and exclusive servers to be added for extra functionality.

Digital Controllers

In developing our next-generation power plant supervisory and control system, we were able to make the system highly reliable and compact through the use of “HIACS-7000 (Hitachi Integrated Autonomic Control System 7000),” which has been used in thermal power plants, and adapting it for nuclear power plant application.

The highly reliable protocol used in NUCAMM-80, 90 was applied to a control network that links all controllers and HMI servers, and sufficient responsiveness and reliability were obtained through the architecture and use of a high-speed duplex optical fiber loop network.

The system’s RTB (remote terminal block), a direct-cable-connected process input/output device, has an analog signal conversion function, an internal low-power circuit, and a separate function for high-power level process signals. Thus it does not require a buffer circuit as conventional input/output devices do. In addition, it contains a circuit that can directly interface the air-operated valves that make up most of the device’s control equipment, enabling the amount of internal wiring to be greatly reduced and the amount of control panel material to be halved.

Centralized Software Maintenance Tool

The advantages of incorporating digital devices into a system are that it makes it possible to monitor the system operating status internally and to easily make revisions or modifications to the system’s logic and internal constants.

The system features a centralized software maintenance tool with a CAD function that significantly improves its maintainability. With this maintenance tool, on-line monitoring and parameter tuning can be done using CAD drawings, and it also becomes possible to confirm the system’s internal status via displayed engineering values in addition.

*: Ethernet is a registered trademark of Xerox Corp.

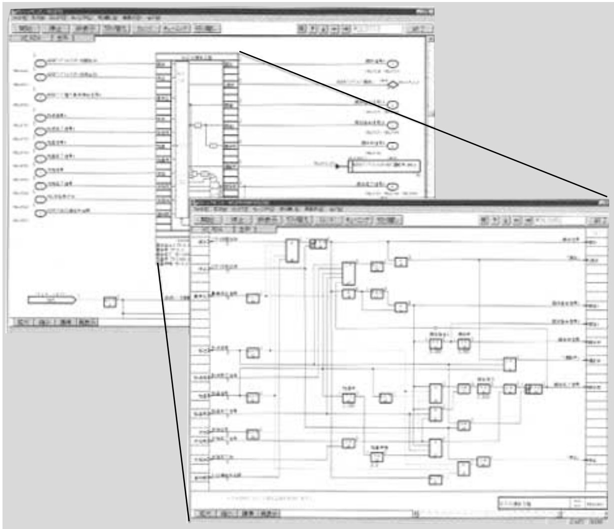

Fig. 4— Centralized Software Maintenance Tool with CAD. On-line monitoring is enabled via a display equivalent to a control logic diagram. A hierarchical display makes it possible to use the top layer for ordinary monitoring and the bottom layer for detailed inspections.

This greatly improves the system from the viewpoint of ease of use.

In the control logic representation, hierarchical-design methodology is added to visualized software that uses the functional component “macro”. The hierarchical design enables all the system functions to be expressed as one major function “macro”(large macro). Thus, a control circuit can be described simply (Fig. 4). Through the conversion of this function into a component, its standardization, and through the use of CAD drawings and software with a centralized control structure, the CRT screens become much easier to read and recognize.

CONCLUSIONS

This paper has described a supervisory and control system we have developed for nuclear power plants. The highly reliable system, which applies general-purpose technology that makes it economically feasible, provides digital supervision and control of liquid and solid radioactive waste treatment equipment.

The key technology to the system is its reliance on human-machine interfacing, and it applies the latest in HMI technology to ensure that high reliability is maintained.

In future work, we intend to accumulate data on the system’s performance at Tohoku Electric Power Co., Inc.’s Onagawa Nuclear Power Plant No. 3, and to develop means of making the system even safer and easier to operate.

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