ISSN 1345-3041

VOL. 95/SEP. 2001

MITSUBISHI ELECTRIC ADVANCE

Power-System Control/Protection & Radiation-Monitoring Edition

MITSUBISHI
ELECTRIC

A Quarterly Survey of New Products, Systems, and Technology

●Vol. 95/September 2001 Mitsubishi Electric **ADVANCE**

Power-System Control/Protection & Radiation-Monitoring Edition

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Technical Reports on Radiation Monitoring

Our cover story reflects the dual emphasis of Vol. 95, on power-system control and protection, and on trends in radiation monitoring. In the center is a typical control panel for a MELPRO-C protection relay, a series with major advantages described in several of the articles. At the lower left is an illustration of the DPR03 radiation detector for medical linear accelerators (LINACs) and at the upper right is a surface contamination monitor using scintillation detectors and optical fibers, readily transportable to the scene of any nuclear mishap.

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Mitsubishi Electric Advance is published on line quarterly (in March, June, September, and December) by Mitsubishi Electric Corporation.
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Overview

Power-System Protection and Control in the Network Age

*by Shin-ichi Azuma**

In recent electric power-supply systems, society's demands for further deregulation and privatization have led to a primary concern over cutting costs without compromising system reliability, making the efficient functioning of the protective and control systems that form the power grid's central nervous system more important. Mitsubishi Electric Corporation has developed two new product series for protective and control systems in the network age: the MELPRO-C series for power generation and distribution systems and the MELPRO-D series for user systems.

Both series provide for interconnection using the networks inside power stations and the intranets and realtime networks of utility companies. They facilitate the remote operation of equipment, supporting remote maintenance, monitoring, and other new functions and services. They therefore also support increases in the effective utilization of equipment, the slimming down of facilities, and the rationalization of operations.

The MELPRO-C series centers around high-performance CPUs, and the individual products are significantly smaller than previous comparable models. They can be built up into systems that meet the specific needs of particular system characteristics with flexible hardware and software options.

Again, the MELPRO-D series uses general factory automation networks to provide for simplification and integrated protection, monitoring and control, enabling low-cost implementation of systems that reduce the labor requirements of power management. ❑

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Introducing the MELPRO-C Series

*by Norimasa Kusano and Hideo Noguchi**

As part of our continuing efforts to build economically attractive and environmentally friendly electric power network systems, Mitsubishi Electric Corp. has developed MELPRO-C, a shared platform with an architecture that ties together the protection and control systems, linked by a communications network.

Protection Control Systems-The Business Environment and System Requirements

Electric power is an ideal form of environmentally friendly energy, and more efficient generation and transmission of electric power contribute to environmental protection by, for example, reducing carbon dioxide emissions. On the other hand, as various countries deregulate electric power utilities, the drive for higher profits from power distribution puts the highest priority on efficient system operations. This has led to increasing demands for slimming down equipment and high-efficiency operations while maintaining power-system reliability. Protection control systems, as the central nervous system in the power systems, are called upon to provide increasingly sophisticated intelligent functions and communication functions as shown in Fig. 1. In order to fulfill these needs, Mitsubishi Electric Corp. has developed MELPRO-C, a new intelligent electronic device (IED) platform for protection and control (see Fig. 2, 3).

Design Rules for the New Platform

The MELPRO-C applies two design rules.

DESIGN RULE 1. The intelligence to perform measurement, protection, control, monitoring, and communications functions must be capable of distribution to the vicinity of the primary equipment.

DESIGN RULE 2. This distributed intelligence must be linked by an open *de facto* protocol.

Fig. 2 External appearance of MELPRO-C

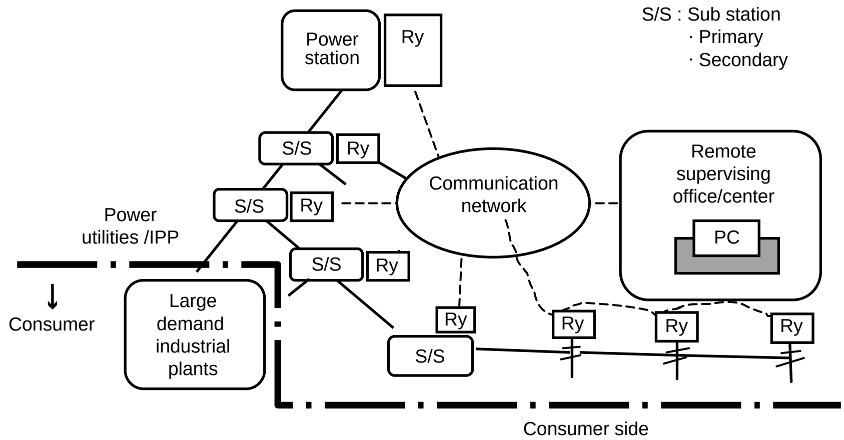

Fig. 1 Integrated protection and control system with IEDs

**Norimasa Kusano and Hideo Noguchi are with Transmission and Distribution, Transportation Systems Center.*

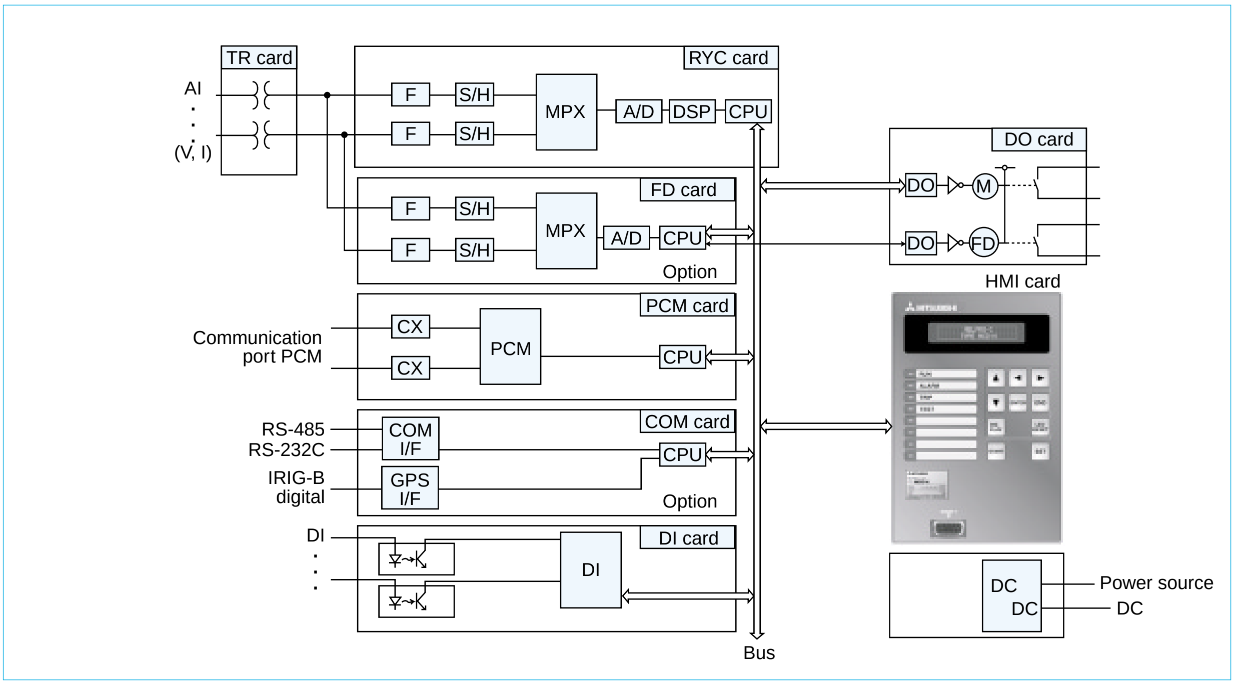

Fig. 3 Hardware block diagram

The six letters of the acronym "CHARGE" stand for the design concepts upon which the platform was built.

The Design Concept "CHARGE"

COMPACT. Taking advantage of high-performance processors and high-density mounting technology, the corporation has succeeded in creating a compact unit with a body and a required installation space only one-half that of previous units. In addition to standard models equipped with a 19-inch rack and control board, models that use an IP 65-level sealed case makes it possible to locate the equipment outdoors, near the primary equipment.

HUMAN FRIENDLY. User-friendly computer displays allow the user to determine remotely the optimal settings for the power system, and to access remotely details such as measurement information, waveform information, and event logs. The measurement information is collected in 48/96 sampling/cycles, using 16-bit resolution, thereby providing data for detailed analyses.

ADAPTIVE. The MELPRO-C has been designed so that it can be connected to upstream systems and systems from other companies using *de facto* standard protocols. The protection control unit adjustment values have been stored as multidimensional tables, allowing the program to be changed flexibly to match the relay output conditions and the conditions of use (programmable DO).

RELIABLE. The final trip output of the protection relay can be provided after a two-level check has been performed. This two-level check uses two types of independent CPUs, a standard CPU and an optional CPU, each using a different calculation algorithm, where the trip output is the result of a logical AND calculation on the results of the individual calculations performed, see Fig. 4. High levels of reliability are assured by the self-diagnostic functions performed on each of the individual functional modules built into the protection relays, see Fig. 5. Additionally, at its maximum application, four levels of password protection provide secure access to the protection/control system.

The software can be generated by the selection and configuration of modules from a module library. The results are a virtual machine running on a PC, with the same functions as the actual equipment, thus making it possible to perform re-

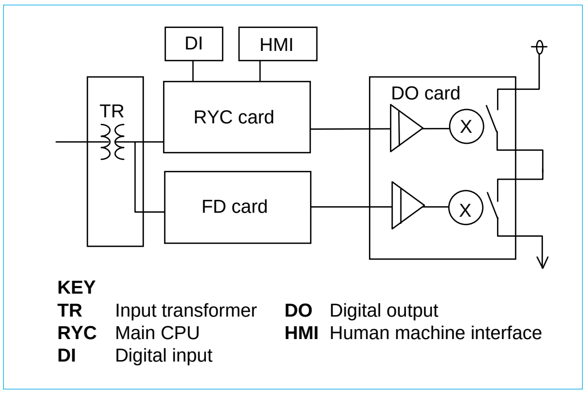

Fig. 4 Hardware-independent fail-safe function

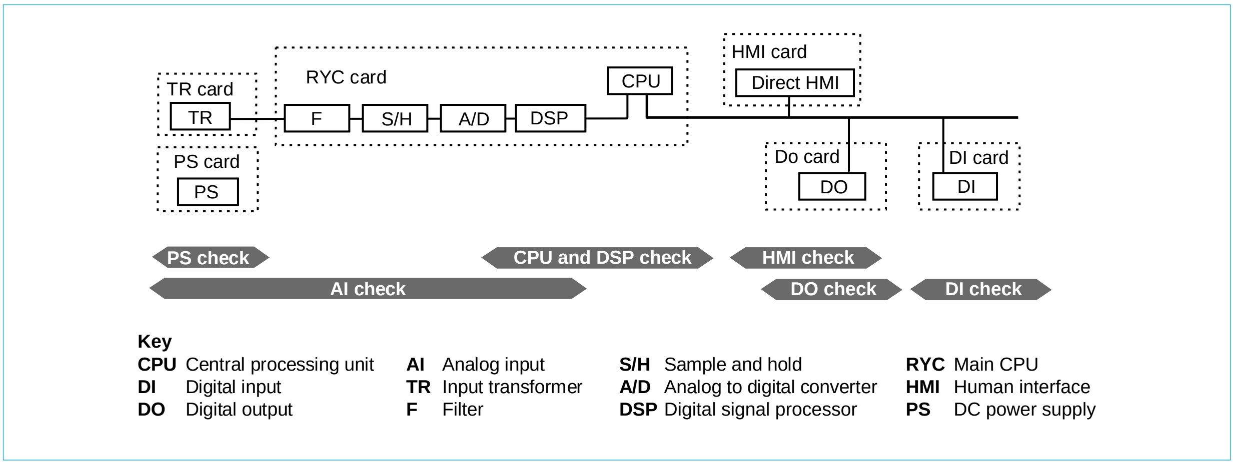

Fig. 5 Self diagnosis

sponse analyses on the virtual machine. This makes it possible to perform evaluations more efficiently under a variety of conditions before the building of the actual power network.

GROWING. In this system, both the hardware and the software are modular, allowing functions to be added as necessary using a building-block method.

The circuit reclosing function, back-up function, the number of feeder lines under protection, and the capacity of the event log are optionally available with additional hardware options. The product lineup is shown in Table 1.

ENVIRONMENTALLY FRIENDLY. The power consumed by the unit is one half of that of previous units. Also, batteries have been eliminated through the use of non-volatile memory. Efforts have been made to eliminate the use of plastics whenever possible.

MELPRO-C can be placed near primary equipment, so it is possible to greatly reduce the cable that used to be necessary between the primary equipment and the protection/control equipment.

Through the use of tried-and-true algorithms to prevent current transformer saturation, the

Table 1 MELPRO-C Series Product Line

Application	Scheme	Product
Transmission lines protection	PCM current differential	MCD-H
	Distance relay	MDT-H
Busbar protection	Current differential	MBP-H
	High impedance differential	MBP-H3
CB failure protection	High speed OC	MBF-H
Transfer protection	Ratio differential	MTP-H
Feeder line protection	OC/OCG, UV/OVG directional earth fault	MFP-H
Feeder line management	OC/OCG, UV/OVG directional earth fault, control	FTU
Generator protection	Ratio differential, negative OC	MGP-H

MELPRO-C can be applied to existing primary systems, and can contribute to the reuse of existing systems. On the secondary side, Mitsubishi Electric Corp. has developed an input conversion module with low loads and high linearity using air-core coils. This module is one-sixth the size of previous modules. A module has also been prepared that can be used when an air-core current transformer is used as the current transformer on the primary side.

In the future, we can anticipate advances in power systems based on the introduction of, for example, distributed power supplies. Mitsubishi Electric Corp. intends to continue its contributions to total system solutions for high-efficiency operation while still maintaining high levels of reliability and enhancing compatibility with primary systems. ❑

Reference

1. Arun G. Phadke and James S. Thorp, 1988, Computer Relaying for Power Systems.
2. H. Sato, T. Takano, S. Inoue, S.Oda, T. Anzai, N. Kusano, 2001, A Comprehensive Approach for Numerical Relay System Evaluation and Test, IEE DPSP 2001.

MELPRO-C Series Protection Relays and Their Basic Technological Elements

by Toshio Anzai and Takashi Oosono*

The authors have developed a new *MELPRO-C series of protection relays using the latest 32-bit RISC processors and high-density component mounting techniques. The series combines excellent performance with a reduction in size to one-half that of the corporation's preceding types. The adoption of intranet technology enables highly "open" networks to be configured, while the associated software provides high productivity and reliability.

**MELPRO is currently undergoing registration as a trademark of Mitsubishi Electric Corporation.*

The Basic Technological Elements

The basic technological elements of MELPRO-C protection relays are shown in Fig. 1. Supporting the upstream application software suite for monitoring, control and protection are the technologies for microprocessor application, equipment hardware, software productivity and network applications.

As shown in Fig.1, of these basic technological elements, software is divided into two layers, a basic layer and and an application layer. This means that as and when new technological developments result in changes to the external specifications of hardware, their influence can be handled entirely within the basic layer, exerting no influence on the application layer.

Miniaturization

By adopting an LSI implementation of the microprocessor peripheral circuitry and applying hybrid IC technology, the component count has been significantly reduced. This, combined with the latest high-density mounting technology, has reduced the size of the relays to about one-half of the corporation's preceding models, as shown in Table 1.

Again, by using a serial I/O bus to connect the processor and the input/output sections, the

Table 1 A Comparison Between MELPRO-C and the Preceding Hardware

Item	Preceding type		MELPRO-C
Cards used	Analog input	Main CPU	Main CPU
Card size (mm)	290.8 x 233.35 (two)		160 x 233.5 (one)
Processors (one each)	32-bit CISC 16-bit CISC		32-bit RISC 32-bit DSP
Performance ratio	1		1.5 (standard) 4.0 (large scale)

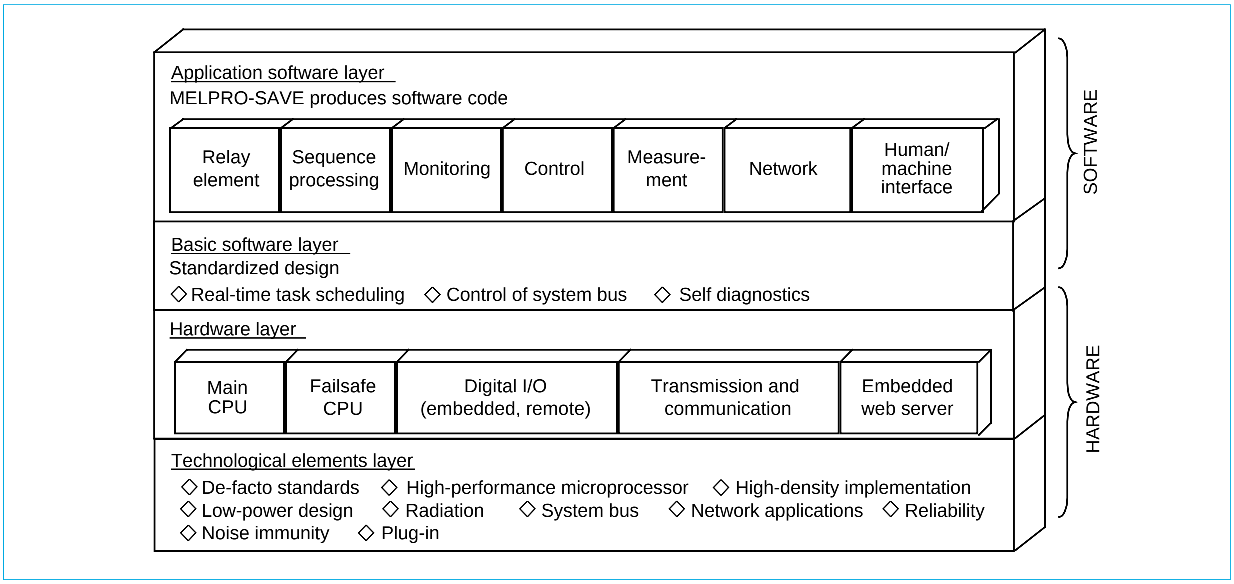

Fig. 1 Architecture of basic technological elements used in MELPRO-C relays

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space previously needed for wiring within the relay panel has been reduced.

Networks

We have provided MELPRO-C relays with the following two network functions:

- A network operating at the substation level (to provide high-level system operation and effective maintenance) that can interconnect with supervisory control and data acquisition (SCADA) systems, so that the relays can function as data terminals for supervision, control and protection within electric power systems.
- A process-level network linking monitoring, control and protection equipment and controlled-system equipment (to reduce the cost of building substations by eliminating metal cables).

The network interface specification are shown in Table 2. The network protocols chosen satisfy international standards to ensure “open” (non-proprietary) operation and low costs.

Table 2 Network Interface Specifications

Item	Specification
Substation level network	DNP3.0, UCA2.0, IEC-Standard Electrical/optical
Process level network	cc-Link, Lon, IEC61850 Electrical/optical

Adoption of Intranet Technologies

The adoption of intranet technologies for MELPRO-C relays provides remote monitoring functions that make it possible to remotely confirm the information of monitoring, control and protection equipment and operate a setting. The general intranet technology base has been supplemented to ensure the necessary operability and reliability. As a result, monitoring, control and protection equipment with the remote operation maintenance function can be configured at low cost and with outstanding ease of operation.

A typical display for a remote maintenance system is shown in Fig. 2. The human-machine interface continuously displays the names and states of the equipment, giving the operator a continu-

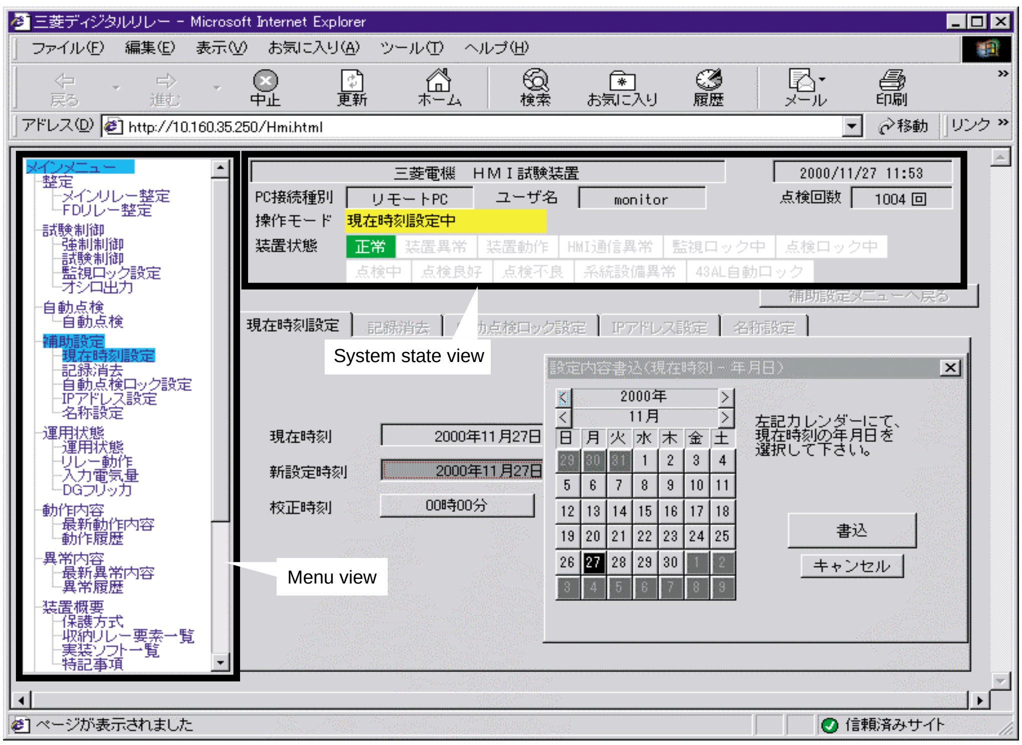

Fig. 2 Typical display on the human/machine interface

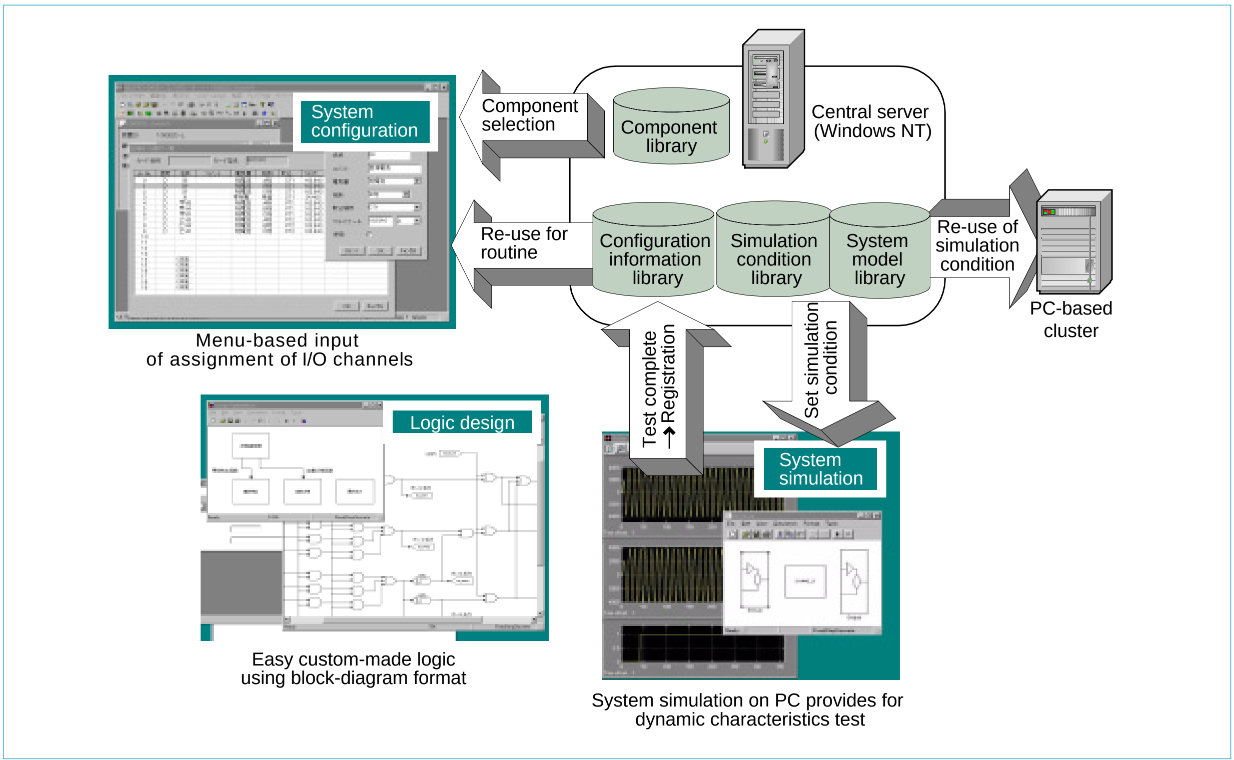

Fig. 3 Outline of the MELPRO-SAVE engineering tool

ous grasp of the condition of the various items of equipment, including abnormalities and the state of TRIP. Again, remote operations that would have a major effect on equipment functions are subjected to restrictions.

Adoption of Software Technology

The application of previously developed software technology has enabled us to develop a revolutionary engineering tool, MELPRO-SAVE. The outline of this tool is shown in Fig. 3.

This software tool has three main characteristics:

1. It does not require programming.
2. It guards against human error.
3. It provides enhanced system verification functions.

To render the tool free of programming, we first created standard software components for all relay elements, sequential logic, etc., then performed selection of components, setting of parameters, and allocation of the input and output signals by a graphic user interface. This is sufficient to generate the required software.

We implemented human-error prevention by a function that establishes a parameter automatically, maintaining consistency between parameters. For this function, we assigned the attributes beforehand to the components and the parameters.

For enhanced verification, we build not only the software provided with the product but also the model of analog input circuits and the digital input/output circuits of the hardware and the power system itself in this tool so as to make possible overall simulation on a PC.

The application of this tool reduces the cycle time for planning, design, production and verification, improves the quality of the software, and increases the flexibility of the monitoring, control and protection equipment of the power systems in which it is used.

MELPRO-C and MELPRO-SAVE offer significant total cost savings for electric power systems and their operational maintenance systems. They also facilitate flexible monitoring, control and protection systems applicable to a wide range of power systems, ideally meeting their special characteristics and operating requirements. ❑

Reference

1. H. Sato, T. Takano, S. Inoue, S.Oda, T. Anzai, N. Kusano, 2001, A Comprehensive Approach for Numerical Relay System Evaluation and Test, IEE DPSP 2001.

Applying Relay Protection to a 500kV Transmission Line with Series Capacitors

*by Shigeto Oda and Takashi Hattori**

The MELPRO-C Series MCD-H (a PCM carrier relay with a distance-relay function) has been adopted for a system in the Peoples Republic of China that includes series capacitors. The authors simulated a transmission system in which series capacitors have been installed, using a real-time digital simulator to verify the effects on the MCD-H relay of transient voltage and current phenomena when there is a system failure, allowing appropriate countermeasures to be implemented. This article reports on the transient current and voltage phenomena and on solutions for their effects on the relay.

The Application System

The MCD-H relay was ordered and installed to protect the parallel transmission line between the 500kV Datong and the Fangshan substations by the North China Power Group. In order to prevent transmission losses (and reductions in the amount of electrical energy that can be transmitted) due to increases in transmission line reactance over the long-distance transmission lines in this system, series capacitors were installed in the transmission path to reduce the reactance. The Datong and Fangshan substations are 288km apart, and the series capacitors are installed 151km from the Fangshan substation. The series capacitors provide 35% compensation for the transmission-line reactance. Note that a gap is provided in the series capacitor to allow it to short when the voltage across the capacitor exceeds a certain level. This is to protect the series capacitor when there are high voltages during failures.

Static Effect on Relays

PCM carrier current differential relays are unaffected by the installation of series capacitors in the transmission path, as the currents passing through the relays when there is an external fault do so without generating a differential current. However, with internal faults, the fault current itself is a differential current, so no problems arise with relay operation.

In distance relays, the impedance seen by the relays, as shown in Fig. 1, as affected by the series capacitors (with the compensation ratio

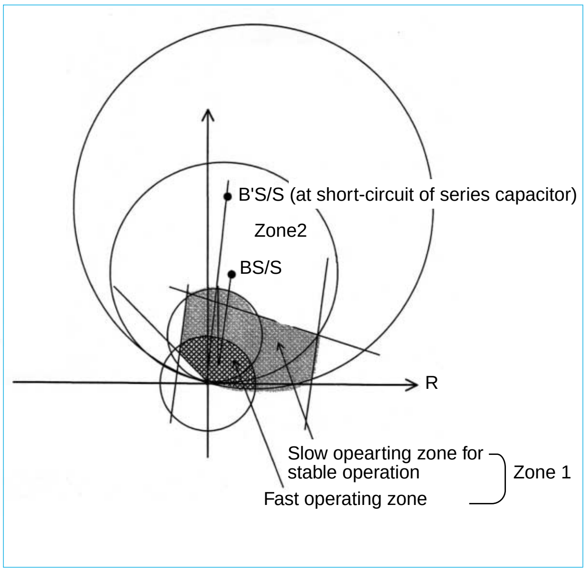

Fig. 1 Operating zone setting of AS/S distance relay element

of 35%), depends on whether there is a series capacitance (point B in Fig. 1) or whether the capacitor is shorted (point B' in Fig. 1). In Zone 1, the Zone of immediate operation, point B serves as the far end where the length of the operating region is shortened due to the influence of the series capacitors, so it is established at between 80 and 90% of point B. Operating Zone 2, which covers the far end, must be established as a Zone that is able to cover point B' at the far end, which is established envisioning the case where the gap circuit operates to cause a short when the voltage across the capacitor rises due to a fault current on the far end.

The Impact of the Relays on Operations

The maximum deviation in voltage and current that can be anticipated due to the resonance in the series capacitors and the system reactance when there is a fault or when the circuit breaker trips was observed at around 130 to 140ms. Fig. 2 shows the electric current and the voltage that was saved by the relay when there was a 3ΦS fault at the far end. (In this case, the series capacitors did not short.)

A description follows of the impact on the relays when there are transitory fluctuations in

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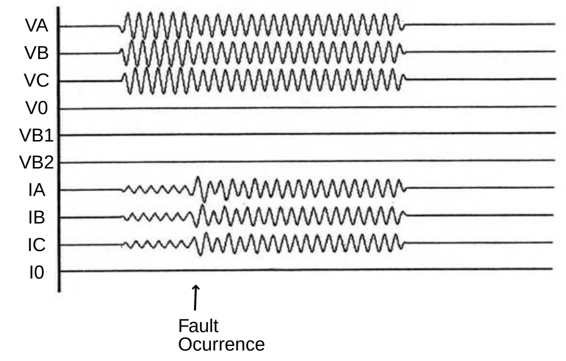


Fig. 2 Fault waveform of voltage and current saved on the AS/S relay (at F1 3ΦS fault of Fig. 4)

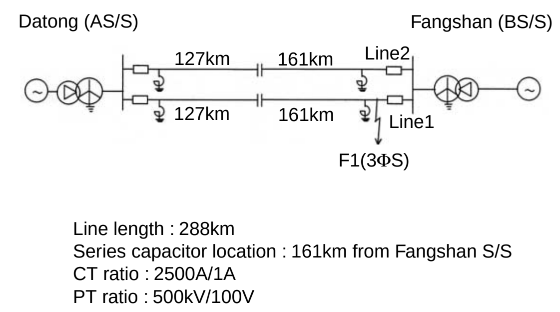
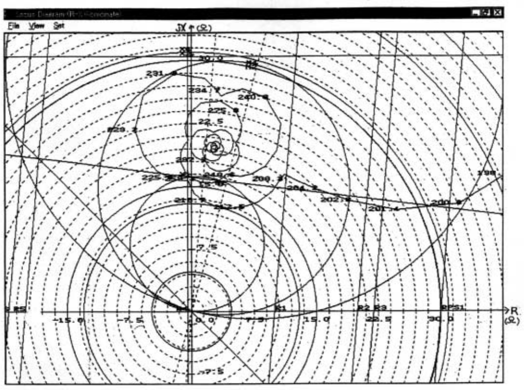


Fig. 4 Line system diagram between Datong and Fangshan

current and voltage whenever the circuit breaker operates, as described above, or when there is a fault, along with countermeasures for this impact.

A circuit that reduces the relay operating sensitivity (the differential current operating sensitivity) for a specific period of time when the circuit breaker is turned on is installed in the current differential PCM carrier relay. We have confirmed that this circuit is able to absorb the impact of the transitory differential currents when the circuit breaker is turned on.

Fig. 3 shows the impedance trajectory analysis of AS/S relay " save" data in the distance relays, when there is a fault outside of Zone 1, shown by the F1 point in Fig. 4, in the case where the serial capacitors do not short. In this case, there will be transient fluctuations in voltage and current when the fault occurs, and we have confirmed that the fault impedance rotates around the fault point before reaching it. We have also confirmed that, at this time, the fault impedance transitionally goes into the Zone 1 operating region. The Zone 1 operating region is broadly divided into two parts; a low-speed region (for obtaining stable operation with lengthy operating checks) and a high-speed region (where one can expect high-speed operation, and the operating checks are shorter). A method has been used to prevent unnecessary responses due to transient incursions, as shown in Fig. 3, by setting the region wherein these incursions can take place as a low-speed region.



Fault occurrence time: 195ms (time in figure by ms unit)

Fig. 3 Impedance locus at A S/S relay (at F1 3ΦS fault of Fig. 4)

At the same time, in systems where there is no series capacitor, even if there is a transitory incursion into Zone 1 in this way, the fault impedance moves rapidly to the fault point from the load current status (within several milliseconds), obviating the need for any broad low-speed region such as shown above.

The use of the real-time dynamic simulator as described above has made it possible to understand precisely the transient relay response in a system with series capacitors, and after appropriate countermeasures were put in place, the measures also passed verification tests using a different type of dynamic system simulation at the Chinese Electric Power Research Institute. The dynamic simulation tests at the Institute were artificial transmission line (ATL) simulator tests using a power generator, a transformer and a simulated transmission line system to perform actual testing on a simulation of the substations that are used at Datong and Fangshan, and with a dummy system transmission line at 500kV for 400km. Both simulation systems confirmed the correct operation of the relays, providing the necessary verification. At present, final on-site adjustment tests are underway for the relays, with the start of actual operations scheduled for June, 2001.❑

MELPRO-C Digital Relay System for Feeder Protection in Outdoor Installations

*by Susumu Fujita and Yasuhiro Tsunoi**

Mitsubishi Electric Corporation's MELPRO-C Series of digital relay systems apply a consistent architecture to bus protection and distribution feeder protection. In equipment providing feeder protection on power distribution systems, there is a growing need for integration of the metering, control and protection functions, and for outdoor installation. The feeder terminal unit (FTU) introduced here is an example of MELPRO-C application to a new feeder protection system that functions as a pole-mounted terminal.

Main Features

The role of the FTU in feeder protection is illustrated in the system block diagram in Fig. 1. The appearance of the FTU is shown in Fig. 2.

The FTU implements metering, supervision, control and communications functions. It is used to detect short circuit faults and phase-to-ground faults. To withstand outdoor installation it adopts a highly rugged enclosure (IP65), with a compact size of 330mm (D) by 330mm (W) by 380mm (H).

Fig. 2 Appearance of FTU

The unit is accessible from a remote or local host for referencing or changing settings and for downloading programs. Communication with a remote terminal unit makes use of twisted-pair

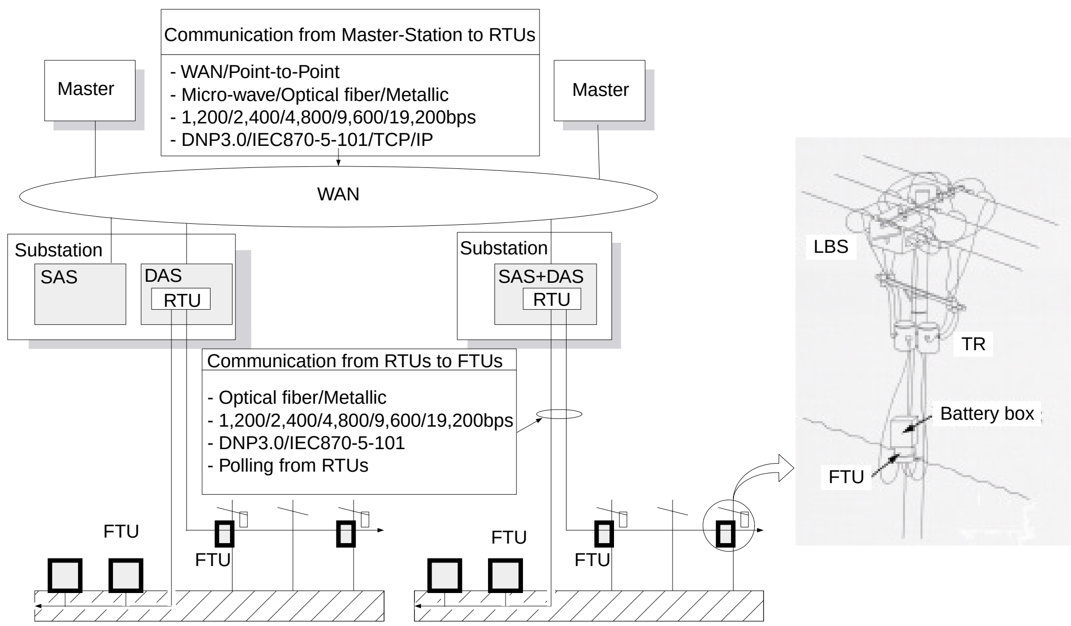


Fig. 1 System block diagram

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cable or single-mode optical fiber cable. International standard communication protocols are supported, including IEC60870-5-101 and DNP3.0 (Level 2/3). A multi-drop topology and star configuration are used for the network, on either optical fiber or metallic cable. Communication speeds of 1200, 2400, 4800, 9600 and 19,200 bits per second are supported.

The FTU implements self-closing processing, described below. Using a phase transistor for its power supply, it requires no external power source.

Functions

The data flow between FTU functions is shown in Fig. 3, while the control functions and metering functions are listed in Table 1.

The main processing functions of the FTU are described here.

LOAD BREAK SWITCH MONITOR INFORMATION TRANSMISSION. Requests from the RTU generate transmission of LBS monitor information, fault detection information, and FTU status information.

LOAD BREAK SWITCH CONTROL INFORMATION RECEIPT. Load break switch (LBS) control information is received from the remote terminal unit and is output to digital output (DO).

FAULT DATA TRANSMISSION. Detailed fault information and fault data are sent on request from a remote terminal unit.

PROGRAM DOWNLOAD AND SETTINGS UPDATE. Program data and settings in the FTU are updated on request from a remote terminal unit.

MONITOR DATA TRANSMISSION. Requests from the RTU generate transmission of the latest monitor data.

SELF-CLOSING PROCESSING. An explanation of self-closing processing is given below.

FTU STATUS MONITORING. The FTU status is monitored, and the result is passed as “ FTU status” in load break switch monitor information transmission.

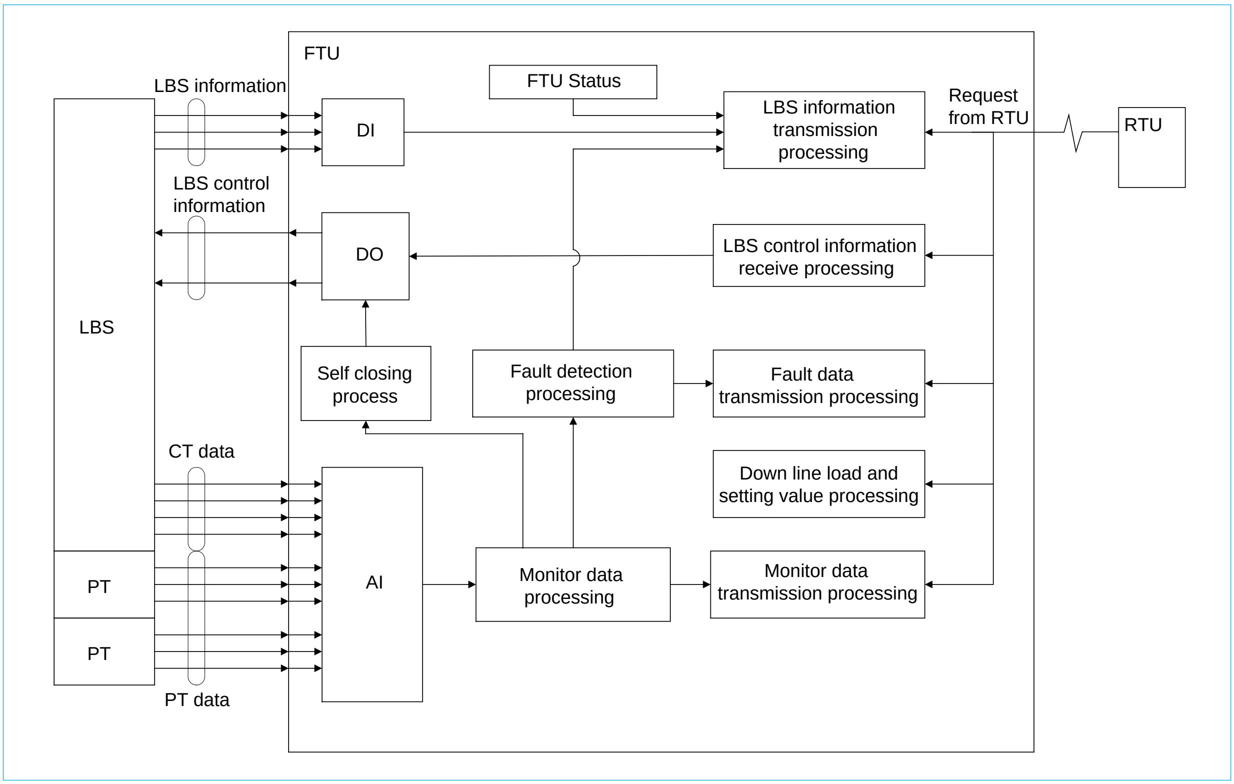


Fig. 3 Data flow

Table 1 FTU Functions

Function		Description
Remote control	LBS operation	Open/close operation of LBS.
	FTU number (pole number) setting	Identification number of FTU (pole) is set from 1 to 230.
Supervision	LBS status	Open/close status and low gas pressure are detected and notified to RTU.
	FTU status	All FTU settings, the power receiving status and battery low voltage alarm are detected and notified to RTU.
	Distribution line	a. Two to six (maximum) voltage values of FTU power supply Source side line voltage:Vab load side line voltage:Vbc b. Three current values through the built-in CT. Phase current : Ia, Ib, Ic c. One power factor Power factor: Vab-Ia, Ib d. Zero sequence current Io, I5f Over zero sequence current Io above a present value is regarded as single phase ground fault occurrence and notified to RTU. e. Short circuit occurence Over current above a present value is regarded as fault occurrence and notified to RTU.

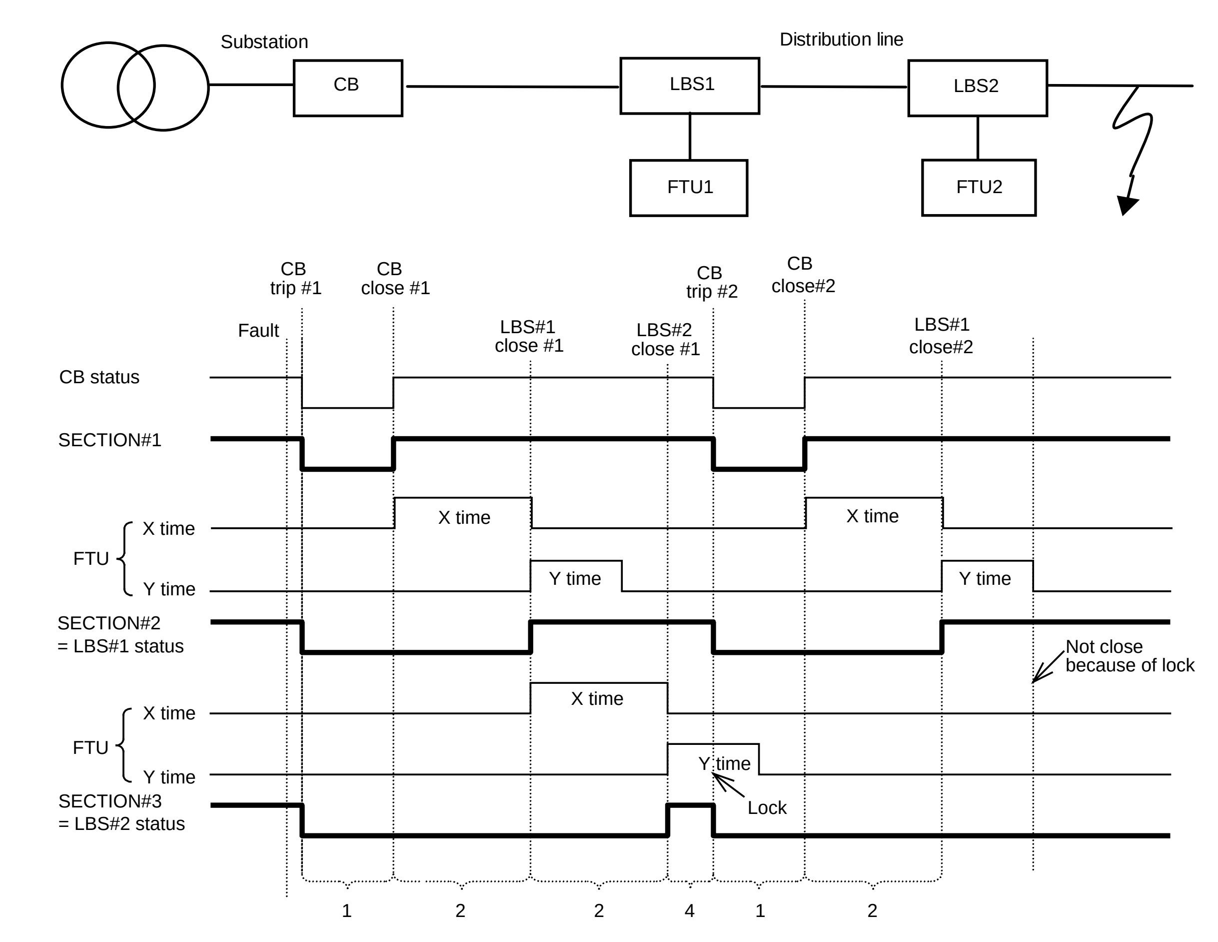


Fig. 4 Self-closing diagram

MONITOR DATA PROCESSING. Monitor data (effective values and power factor) is calculated from 30-degree sampling data at analog input (AI).

FAULT DETECTION PROCESSING. Short circuit faults and phase-to-ground faults are detected from the 30-degree sampling data.

If a fault is detected, the monitor data is saved as fault data.

Protection Function (Self-Closing Processing)

The self-closing processing function, which is one of the FTU feeder protection functions, is explained here with reference to Fig. 4.

Feeder protection by self-closing processing is used in a distribution system with no remote terminal unit or in which remote terminal unit polling is stopped.

1. When a fault occurs, the FTU detects a voltage drop on the source side and opens the load break switch.
2. If the source-side voltage is restored after the fault occurs, the load break switch is closed after (time interval X) has passed.
3. If the load-side voltage is restored after the fault occurs, lock state is set and the load break switch is not closed until the lock state has been cleared.
4. If there is a recurrence of the fault within (time interval Y) after load break switch closing control, lock state is set and the load break switch is not closed until the lock state has been cleared.
5. When the voltage on both the source and load sides is restored by forcibly closing the load break switch, the lock state is cleared after (time interval Y) has passed.

Among the likely demands for feeder protection systems in the future are increased metering information and shorter control times. To meet these needs, Mitsubishi Electric is planning to develop systems with faster communication speeds and more advanced functions, including the application of international standard IEC61850 and UCA2.0. ❑

MELPRO-D Series Protective Relays for Power Receiving/Distribution Systems

*by Kazuyoshi Fujita and Toyoki Ueda**

The MELPRO-D series of protective relays, with complex functions and communication capabilities, go beyond the fault isolation provided by conventional protective relays. Their advanced combination of control, measurement, fault record and monitoring functions is complemented by their ability to transfer information to manned control centers. They are human friendly and cost effective.

Fig. 1 Two typical members of the MELPRO-D series of protective relays for power receiving and distribution systems

The Development Concepts

In recent years, protective relays are required to do much more than their original task of isolating faults from the distribution system. They must employ information-processing, communications and semiconductor technologies to increase the sophistication and reliability of the protection they provide, while at the same time contributing to labor savings by convenient and largely service-free operation, and to lower costs (not only of their complex functions but the total cost throughout the product life cycle). The design concepts behind the new series are (1) exploiting digital technology to provide more sophisticated functions; (2) reducing labor and power requirements by exploiting network technology; and (3) reducing costs by including multiple, complex functions. Two members of the new series are shown in Fig. 1.

Characteristics of the New Series

IMPROVED PERFORMANCE. Relay operation provides multiple functions, digital filters reduce the effect of high harmonics, and digital processing has been adopted for high-speed sampling.

SOPHISTICATION AND COMPLEXITY. The series is compatible with advanced communication networks and provides enriched metering functions with fault record functions.

SIMPLER MAINTENANCE. Detailed data acquisition is possible using a PC interface, data saving functions enhance self diagnostic capabilities, digital processing ensures stable operating characteristics, and resistance to hostile operating environments has been increased.

CUSTOMER ORIENTED. Programmable contacts provide flexible response to customer needs, a very wide range of settings is possible, consistent installation dimensions are designed to facilitate replacement, and the series conforms to international standards (IEC, BS, etc).

USES ESTABLISHED RELAY TECHNOLOGY. The series embodies the corporation's traditional expertise, dating back to the analog era, and power-distribution system technology up to and including UHV systems.

EXHAUSTIVE VERIFICATION FACILITIES. The complete test facilities for verification enable simulation of the full range of power-system faults, and automated testing can be provided to expedite customer acceptance testing.

**Kazuyoshi Fujita and Toyoki Ueda are with the Transmission & Distribution Systems Center.*

System Configuration
The analog input and CPU cards and the previously separate digital output card have all been integrated onto a single relay card with an internal high-speed serial communication bus for data transfer, forming a system with high expandability, see Fig. 2.

Again, the adoption of a serial bus for communications enables a reduction in the amount of wiring required and makes for efficient (i.e., more compact) mounting, with the human-machine interface (HMI) now integrated with the motherboard.

HIGHER RELIABILITY. This is achieved by the significantly reduced component count (to approx. 50% of the previous series), and by dispensing with wiring.

EXPANDABILITY. Additional relay cards can be inserted to expand capabilities (not only relays but also digital input/output cards, etc.); optional communication cards are also available.

STANDARDIZATION. Despite the very wide range of products available in the series, the same basic hardware configuration has been adopted throughout, from those with few internal elements to those with very many.

METAL/PLASTIC HYBRID CASE. A design that makes the best use of the different characteristics of metal and of plastic moldings helps the packaging to contribute to overall reliability, see Fig. 3 and Table 1.

Molded plastic is used for the case, cover, frame and other structural elements, designed to ensure the necessary strength and advantages in installation.

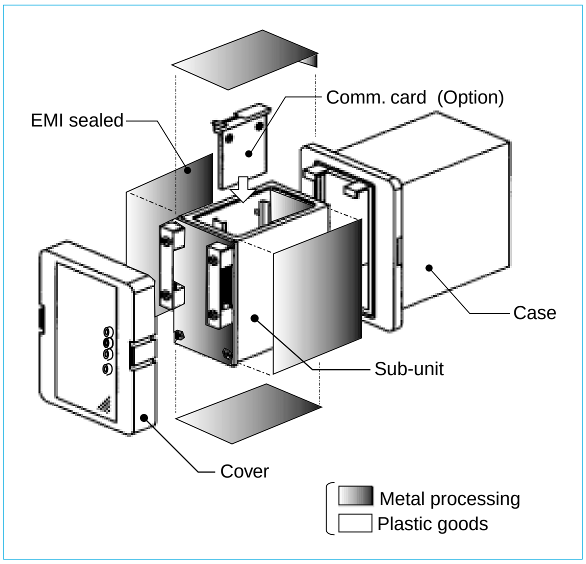


Fig. 3 Typical unit structure

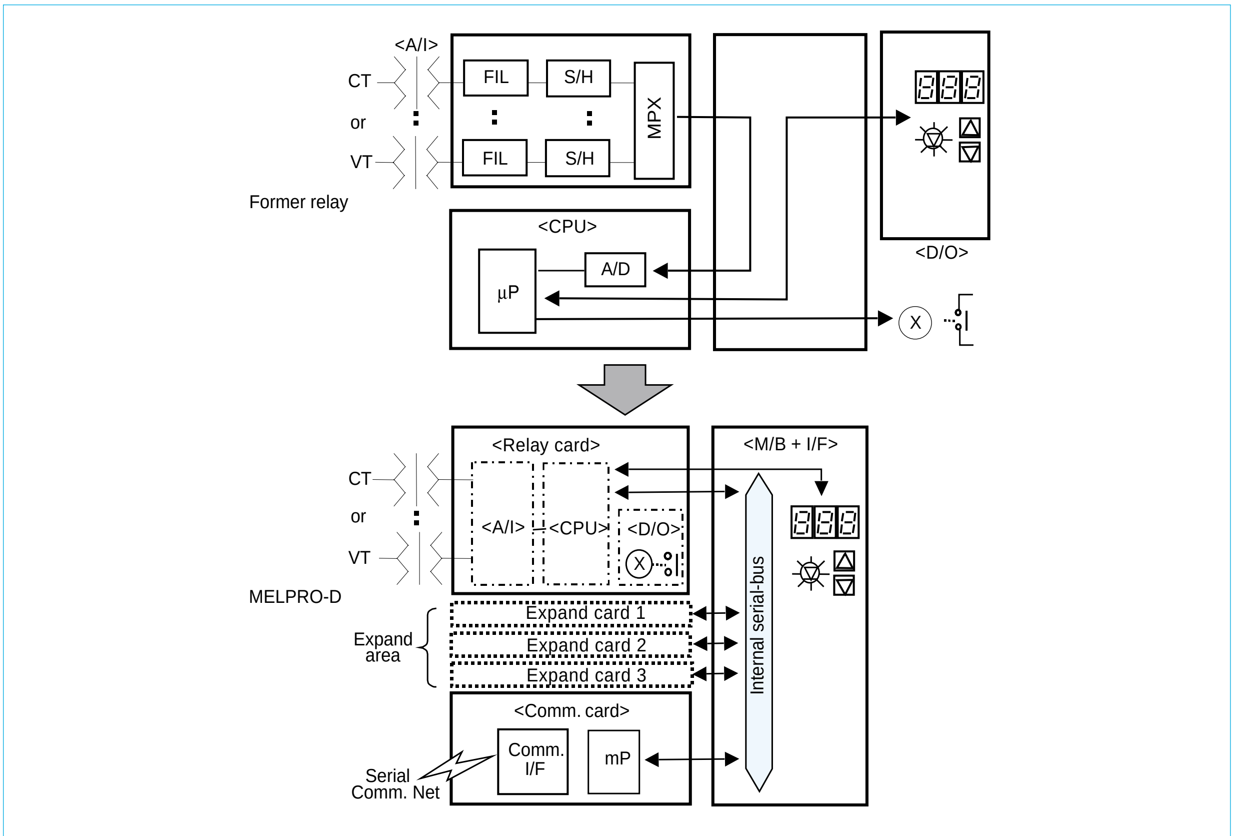


Fig. 2 Internal block diagrams of former and MELPRO-D relays

Table 1 Factors Behind Selection of Materials, Metal or Plastic.

Material	Advantages	Disadvantages		Utilization
Plastic items	Complex forms can be molded High insulation High corrosion resistance High elasticity No coating treatment necessary Low cost	Poor resistance to high temperatures Tends to sag Is not strong in thin sheets	→	Case Cover Unit frame Moving parts (hinge mechanism)
Metal	Affords protection against EMI Is strong even in thin sheets	Cost is high Prone to corrosion		Unit front and back panel EMI shield

Concerns over electromagnetic interference (EMI) with the adoption of plastic casing have been addressed by providing a metal shield around the internal components.

The MELPRO-D series provides all the elements necessary for protection of extremely high voltage and high voltage receiving and distribution systems and parallel running systems, and includes over-current, voltage, feeder, motor, and transformer protection.

With MELPRO-D protective relays, Mitsubishi Electric Corporation is writing a new chapter in the long story of corporate achievements in helping to protect the world's electric power systems. These sophisticated, flexible and highly cost-effective units are alrady finding widespread applications around the world. ❑

Overview

Current and Future Trends in Radiation Monitoring Technology

*by Keiichi Matsuo**

Mitsubishi Electric Corporation has been supplying radiation monitoring systems for all pressurized water reactor (PWR) nuclear power plants in Japan since 1969. Recently, the medical uses of radiation have been attracting attention, as heavy particle beams and proton beams have been used in the treatment of cancer and unsealed radiation sources have found applications in medical diagnostics. This has led to a marked increase in the number of facilities where radiation levels must be monitored. The large quantitative increase in the demand for monitoring equipment has been accompanied by a major departure from traditional methods of measuring radiation levels. Previously, it was sufficient if the measurements were reliable, and the external appearance and physical form of the equipment making up the system were largely immaterial. Now, however, particularly when installed at locations in the public eye, such as at hospitals, radiation measuring equipment that is both compact and good to look at is called for. Again, in the absence of any on-site radiation specialists, there is a very strong need for minimal maintenance. In this market environment, the corporation has supplemented its conventional detectors by developing new products that use the following key technologies: semiconductor radiation detectors with characteristically small size and long working life, and radiation monitors that use optical fibers to achieve outstanding resistance to interference and noise.

In the future, the customer will be linked to the service center responsible for maintaining the workplace over public telephone lines, so that abnormalities at the monitored installation can be diagnosed and the information on the situation being monitored can be transferred, with a centralized monitoring service being performed at the workplace. To achieve this, the technology for monitoring the status of the semiconductor detectors has been established (providing diagnostics for performance degradation) and will be used to configure a system that provides continuous monitoring of the health of on-site monitors and measuring equipment and can do so remotely.

The corporation's long experience in providing radiation monitoring systems for nuclear power plants and its advanced expertise in computers and communications will be dedicated to producing an enhanced product lineup for hospitals and research laboratories. The corporation is committed to providing systems that will offer clear advantages over the competition to its customers. ❑

**Keiichi Matsuo is with the Nuclear Power Department.*

A New Radiation-Management System

*by Kenichi Moteki and Kazuhiko Fuzita**

A radiation-management system is a comprehensive system for measuring and keeping track of radiation levels in and around nuclear power plants and other facilities where radioactive materials are present. Mitsubishi Electric Corporation now provides a radiation-management system based on a new approach, with the advantages of fast response, high reliability and easy maintenance.

System Configuration

The radiation-management system consists of several subsystems. These include a system for managing the exposure of individuals to radiation, a system for controlling room entry and exit, a radiation-monitoring system, and a radiation-management computer system for overall control of these systems. The total system configuration is shown in Fig. 1.

System Design Approach

The radiation-management system is designed based on the following approach.

1. Processing response is improved by separating the computer processing for radiation-exposure management from that for radiation monitoring.
2. The system is designed so that individual computers serve as backups to each other, in order to prevent local failures from causing a loss of total system function.

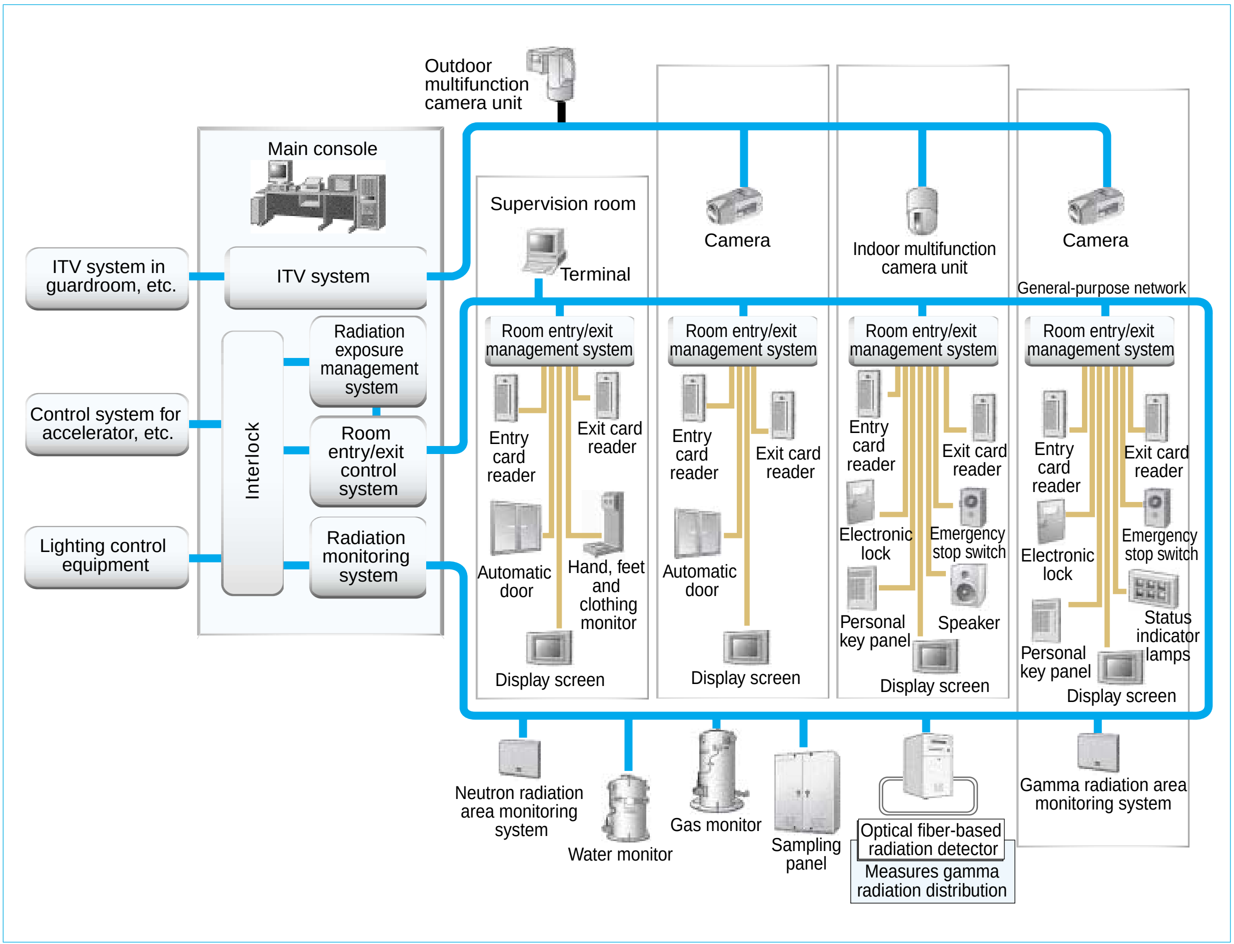


Fig. 1 Radiation-management computer system

**Kenichi Moteki and Kazuhiko Fuzita are with the Energy & Industrial Systems Center.*

3. Industry standard equipment and equipment interfaces are adopted for ease of maintenance.

System Functions

RADIATION-MANAGEMENT COMPUTER. The role of the radiation-management computer in the overall system is to perform real-time online processing of the radiation-measurement data from each of the subsystems, and to display and manage the resulting data. A conventional system with one computer responsible for all the management tasks puts an excessive processing load on that computer and risks the complete loss of system function in case of a computer failure. Distributing the processing to separate servers for each function has raised the level of reliability as well as improving system operability and maintenance.

The functions of the components making up the radiation-management computer are outlined below. The main specifications of each component are given in Table 1.

1. Radiation-management server. This server gathers and manages data from the system as a whole. It is also used for maintenance of management information.
2. Information-management system (for room entry/exit control). Information on individuals is gathered by this system, including their job classification and type of work, radiation exposure, etc. Typical screen shots are the worker registration screen (Fig. 2), list of workers (Fig. 3), and room entry/exit log (Fig. 4). This system stores the gathered information in the radiation-management server. In case of trouble with this system, backup can be implemented by switching to the information-

Table 1 Main Specifications of Components Making Up the Radiation-Management System

Equipment	Specifications	Uses
Radiation management server	Computer: ESW (ME-R, equivalent to Ultra10) OS: HP-UX, Solaris 7 Server: Oracle 8 Memory: 512 MB or more	- Data collection management - Managed information maintenance
Information management system (for entry/exit control)	Computer: Windows® PC OS: Windows® Memory: 256 MB or more	- Managing worker, job and other registered information - Storing radiation exposure management data
Information management system (for radiation management)	Computer: Windows® PC OS: Windows® Memory: 256 MB or more	- Radiation monitor settings - Storing radiation monitoring data
Remote administration terminal	Computer: Windows® PC OS: Windows® Memory: 64 MB or more	- Data and information display - Settings
Printer	Type: Laser beam Colors: monochrome or color	

Fig. 2 Worker registration screen

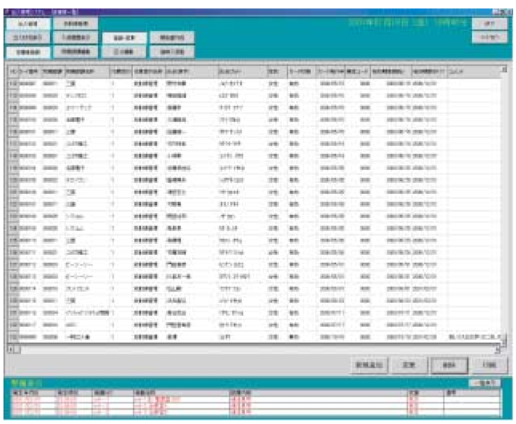


Fig. 3 List of workers

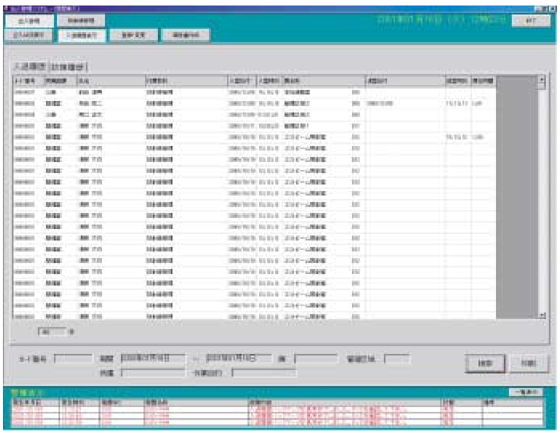


Fig. 4 Entry/exit log screen

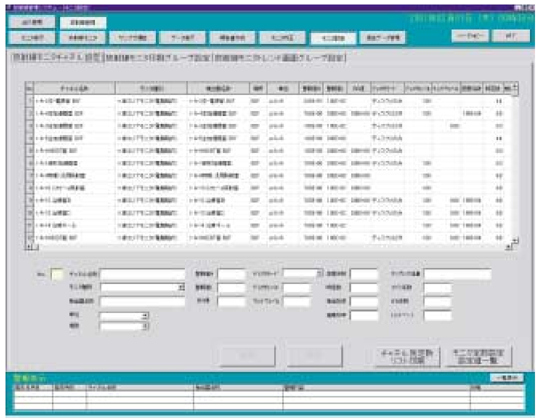


Fig. 6 Constants setting screen

management system for radiation monitoring.

3. Information-management system (for radiation monitoring). Over a local network, this system gathers and stores the settings and measurement values from the instruments used to monitor radiation levels. The basic screens include the radiation monitoring and trend graph screen (Fig. 5) and constants setting screen (Fig. 6). This system periodically stores the gathered radiation-monitoring information in the radiation-management server. In case of trouble in this system, data collection is continued by switching to the information-management system for room entry/exit control.
4. Remote administration terminal. Information is displayed and changes in settings are made using this system. For security, the authority to display and change settings is restricted by password control.

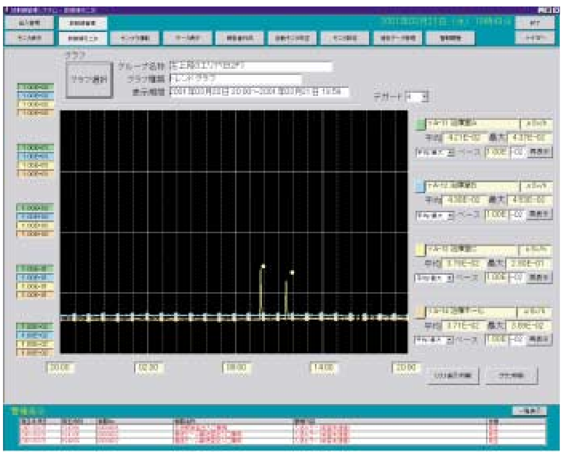


Fig. 5 Radiation monitoring and trend graph

ROOM ENTRY/EXIT CONTROL SYSTEM. The part of the radiation-exposure management system that controls room entry and exit is outlined here. It makes use of card-reader door controllers at the entry/exit points to each of several radiation controlled areas, monitoring and restricting movement through these points. Since these door controllers store the minimum necessary management information for entry into the area, they support a standalone operation mode in case of a server crash or network failure, etc., allowing them to perform an ID card check and open and close doors as necessary. The components of the entry/exit control system are described below.

1. Entry/exit control terminals. The card readers used to control movement through checkpoints provide information such as personal identity, job objective, and location. This ID card information input at a card reader is checked by the information-management system for entry/exit control, and the door is opened and closed accordingly. It can perform this checking on its own if necessary, based on a minimum amount of stored information, in case it cannot connect to the information-management system.
2. Card readers. The card readers are a non-contact type, and are used to check information on people entering the controlled area. Card information is sent through the entry/exit controller to the entry/exit control system for checking. Since the ID card uses radio waves from the card reader for emitting signals, it does not require a battery.
3. People sensors. The counting of people entering and leaving the area is monitored by people sensors in addition to the ID cards. The

people sensors monitor people entering or leaving the area by CCD camera, and can issue an alarm as necessary, to prevent someone without an ID card from going through a door at the same time as a card holder.

RADIATION-MONITORING SYSTEM. Radiation-monitoring equipment measures and monitors the dose rate of radiation within the controlled area, as well as the levels of radioactive materials in the air, exhaust and wastewater, etc. It sounds an alarm if the level exceeds a preset value. This equipment incorporates a highly compact controller inside the detector signal-processing unit, equipped with computing and communication functions. Signals from the radiation detectors are input to this controller for processing, then the digital data is sent over a local network to the information-management system for radiation monitoring. The local network can be connected as necessary to a sampler or other radiation-measurement instrument or to a control device or I/O device for data display, etc., enabling on-site equipment to be interconnected over the local network. In addition, there is environmental radiation-monitoring equipment for measuring the dose rate of radiation in a given area, detectors for detecting low levels of NaI, and ionization chambers for detecting high levels. For the monitoring equipment there are temperature controllers to keep detector temperature constant, display units to show dose rates graphically, and recording equipment. Output specifications (pulse and contact output) are also available for telemetry output.

The new radiation management system, as described above, applies the latest in hardware, package software and general-purpose LAN technology to realize a total system that incorporates a variety of user-requested functions for radiation management. ❑

Semiconductor Radiation Sensor

*by Seisaku Imagawa and Hiroshi Nishizawa**

A novel radiation measurement system has been developed using semiconductor radiation detectors to improve the life expectancy, reliability, maintainability, and miniaturization of detector equipment in radiation measurement systems for pressurized water reactor (PWR) nuclear power plants. This article will present a summary of the semiconductor-type radiation monitor technology.

Mitsubishi Electric Corp. handles measurement and control systems for PWR nuclear power plants within Japan. As part of this measurement and control, radiation monitoring equipment has the function of constantly monitoring the radiation levels in the air and in fluids, so as to monitor releases of radioactivity into the environment, protect human workers and provide early warning of problems with equipment. Note that both γ radiation and β radiation are monitored when performing the radiation measurements.

Benefits of Semiconductor Detectors

Semiconductor detectors detect radiation taking advantage of the generation of electron/hole pairs caused by the radiation (along with the drift of the electron/hole pairs). The semiconductors used in these detectors include silicon (Si), germanium (Ge), cadmium tellurium (CdTe), zinc cadmium tellurium (CdZnTe), and mercury diiodide (HgI_2).

Physical Principals of the Measurement System

Ionizing radiation such as X-rays and gamma rays do not directly ionize atoms, but rather some or all of the energy is deposited on electrons due to the photoelectric effect, the Compton effect, and pair production, and the ionizing power of the electrons causes an ionizing effect. On the other hand, α and β particles have a direct ionization effect. The electrodes of semiconductor detectors collect the electrons and holes generated by this ionizing effect, and output a radiation detection signal.

The Benefits of the Semiconductor Elements

At present, GM counter tubes, scintillation detectors and ionization chambers, etc., are generally used as the radiation detectors in nuclear power plants; however, the following advantages can be obtained by the use of semiconductor sensors as the detectors.

LONG LIFE EXPECTANCY. GM counter tubes and scintillation detectors deteriorate over time, requiring replacement every year or every few years; however, because of the stability of the materials in semiconductor detectors, the interval between replacements of semiconductor detectors is over ten years, making it possible to reduce maintenance costs.

IMPROVED RELIABILITY. In GM counter tubes, the gas deteriorates, and in scintillation detectors, the photomultiplier tube wears out over time, which can cause the readings to drift; however, fundamentally these problems do not occur with semiconductor detectors, and even in the test equipment the readings were stable.

IMPROVED MAINTAINABILITY. In scintillation detectors, the applied voltage must be adjusted or otherwise maintained periodically; but because semiconductor detectors operate at a fixed low voltage, the need for work in adjusting the detectors is greatly reduced.

MINIATURIZATION. Because semiconductor detectors are small-even when they still have the same detection capabilities as conventional detectors-the use of the semiconductor elements makes it possible to reduce the size of the detector equipment and the samplers (lead-shielded vessels), thereby both saving space and reducing costs.

A Comparison of the Characteristics of Semiconductor Elements

The semiconductor elements currently in use are as shown in Table 1. Based on this table, the specifications of the semiconductor elements used in the various radiation monitors installed in nuclear power plants were selected and used in the detectors. Detector elements with superior energy characteristics are required in area monitors and the primary steam-duct monitors, and Si semiconductor monitors were selected because they fulfill these requirements. Because

*Seisaku Imagawa is with the Energy & Industrial Systems Center and Hiroshi Nishizawa is with the Industrial Electronics & Systems Laboratory.

Table 1 Main Characteristics of the Semiconductor Detectors

Semiconductor detector	Atomic number	Density [g/cm³]	Band gap [eV]	Mobility μ [cm²/V-s]		Mean lifetime τ (s)		Operating temperature	γ-ray energy measurement [MeV]
				electron	hole	electron	hole		0.001 0.01 0.1 1 10
Si	14	2.33	1.12	1.4×10^3	4.8×10^2			Room temperature	
			1.16	2.1×10^4	1.1×10^4	2×10^{-5}	2×10^{-5}	Liquid nitrogen	
Ge	32	5.32	0.74	3.6×10^4	4.2×10^4	2×10^{-5}	2×10^{-5}	Liquid nitrogen	
CdTe	~50	6.06	1.47	1.1×10^3	1×10^2	10^{-6}	5×10^{-7}	Room temperature	
CdZnTe	~46	~6	~2	(About the same as for CdTe)				Room temperature	
HgI_2	~54	6.4	2.13	1×10^2	4	10^{-6}	10^{-6}	Room temperature	

the primary steam duct monitor must be operated at high temperatures (up to 90°C), the high-temperature type Si semiconductor monitors, which can measure at up to 90°C were selected.

Because the gas monitors require high sensitivity to β-rays that are emitted from the nuclei (which is what is measured by the detectors), the CdTe semiconductor detector, with its superior sensitivity to β-rays, was selected. Although the sensitivity to β-rays is about the same for CdTe semiconductor detectors and CdZnTe semiconductor detectors, the CdTe semiconductor detectors have a longer mean path length for the charge carriers (producing superior signal-to-noise ratios), so the CdTe semiconductor detectors were selected.

As with the gas monitors, the high range gas monitors also require high sensitivity to β-rays ; however, because this also requires operation at high temperatures (up to 100°C), the CdZnTe semiconductor detectors, which have good thermal characteristics up to such high temperatures, can also measure β-rays.

Examples of Applications of Semiconductor Detectors

Of the monitors that use semiconductor detectors, two types of monitors (area monitors and high-range β-ray gas monitors) are described below as examples.

AREA MONITORS. Area monitors are fitted to measure the amount of radiation within a specific space established in the nuclear power plant. Conventionally, GM counters have been used in area monitor detectors. Because of the extended life expectancy and improved reliability of Si semiconductor detectors, area monitors have been developed using the Si semiconductor detectors. These detectors have a wide depletion region, which is the sensitive part that has a reverse bias at the PN junction, and by placing an appropriate filter in front of the detector, the energy characteristics can be flat. Fig. 1 is a photograph of an area monitor. Along with the detector element and the pre-amplifier, the monitor also includes a check source for performing periodic calibrations. This monitor is designed to provide stable measurements even given adverse environmental conditions in terms of temperature and humidity.

β-RAY GAS MONITORS. β-ray gas monitors have conventionally used plastic scintillators. CdZnTe, with its high band-gap energy, was selected for this application of semiconductor

Fig. 1 External view of the area monitor

detectors because it can withstand use in high-temperature environments. The semiconductor-type β-ray gas monitors have exactly the same characteristics as the conventional detectors. The use of semiconductor detectors can, in practice, greatly reduce the size of the detection equipment because the semiconductor detectors do not require the light guide and photomultiplier tubes required in conventional scintillator-based equipment. However, because they will replace equipment in existing plants, the external dimensions have been set to be exactly the same as those of the conventional detectors; as shown in Fig. 2, to ensure compatibility.

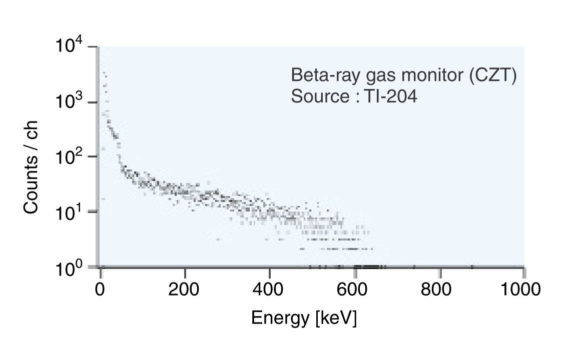


Fig. 3 Beta-ray gas monitor energy spectrum

Fig. 2 Semiconductor beta-ray gas monitor

In CdZnTe semiconductor detectors, the poor mobility-lifetime product of the carriers (especially of the holes) cause the carrier trapping phenomenon to be a problem. However, when measuring β-rays, the location of the interaction position is limited to the vicinity of the surface, and thus if the incident surface side is used as the cathode, there is little influence on the hole-trapping effect, making it possible to obtain an accurate amplitude output. Fig. 3 shows the T1-204 (β–ray maximum energy: 764keV) energy spectrum near the main regions of applicable energy.

Additionally, the temperatures over which this monitor can be used range from - 15 to +80°C, and Fig. 4 shows the measurement results of the thermal characteristics of this monitor (the gross count ratios of energy above 100keV). Because the temperature characteristic over the range from - 15 to +80°C causes fluctuations of less than ±10%, there is no need for compensation as a function of temperature.

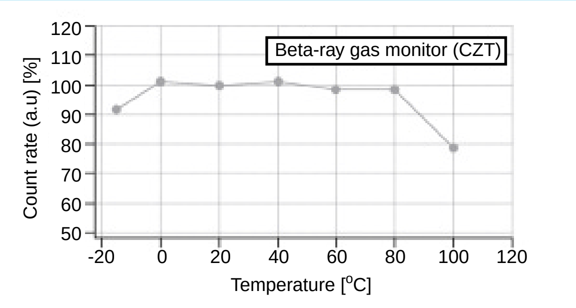


Fig. 4 Beta-ray gas monitor temperature characteristics

The research regarding gas monitors, high-range gas monitors, and mainsteam duct monitors in this report, and the current research regarding their applicability to nuclear power, is the result of joint research with:

- Kansai Electric Power Co., Inc.
- Hokkaido Electric Power Co., Inc.
- Shikoku Electric Power Co., Inc.
- Kyushu Electric Power Co., Inc.
- The Japan Atomic Power Company,

and we are deeply grateful for the wide range of advice and guidance we have received.❑

Radiation Sensing System Using an Optical Fiber

*by Ryuichi Nishiura and Nobuyuki Izumi**

The authors have developed a radiation detector using a plastic scintillation optical fiber (PSF) doped with a radiofluorescent material (or scintillator) as the detector.

This article introduces and gives the basic performance characteristics of an optical fiber radiation sensing system and a portable scintillation-type optical fiber body-surface contamination monitor.

Fiber-Optic Radiation Sensing System

An optical-fiber sensing system is a device that detects the distribution of radiation intensity along an optical fiber in a single operation. Fig. 1 is a photograph of the detector.

Fig. 1 Detector of the fiber-optic radiation sensing system

A linear type optical fiber radiation sensing system can be quickly installed in, and removed from, the work area, thus helping to reduce the exposure of workers to radiation. It can also be installed in any convenient space within a complex system of pipelines.

Principle Of Measurement Using Fiber-Optic Radiation Sensing System

The radiation detector of the optical fiber sensing system consists of a cable containing a scintillation fiber (an optical fiber doped with a scintillator, see Fig.1). A scintillator is a material that generates a fluorescent pulse when it receives radiation energy under irradiation by γ rays, for example. This fluorescent pulse propagates to both ends of the optical fiber (see Fig.2). The times at which these two pulses arrive at the detectors connected to each end of the fiber differ depending upon the location of the incident radiation. By measuring the difference in the arrival times, the location of the incident radiation can be determined, and by counting the total number of light pulses, the intensity of the radiation can be determined.

This method is called the "time of flight" (TOF) method. Fig. 3 shows an outline of the optical fiber radiation sensing system monitor.

The light-pulse signal emitted from the scintillation fiber (PSF) is converted into an electri-

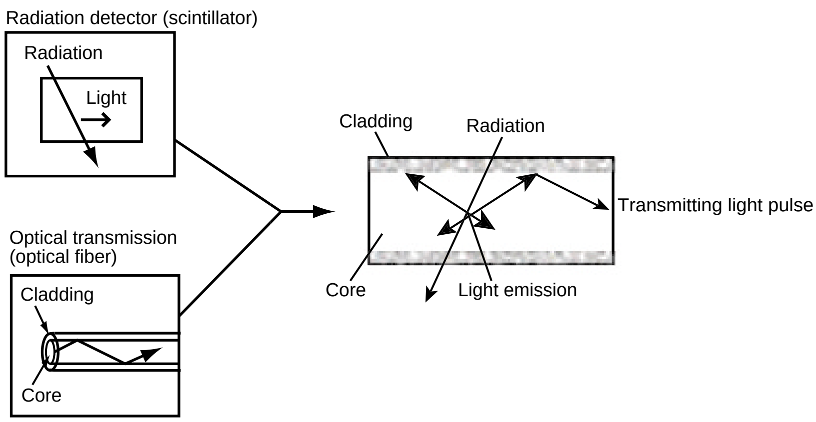


Fig. 2 Principle of detection

*Ryuichi Nishiura is with the Industrial Electronics & Systems Laboratory and Nobuyuki Izumi is with the Energy & Industrial Systems Center.

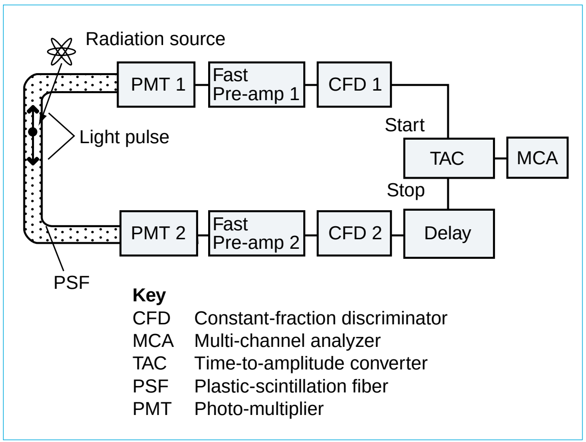


Fig. 3 Principle of measurement

cal pulse signal in a photomultiplier tube (PMT). This electrical pulse signal is passed through a wave-shaping circuit to a time-difference measurement circuit. The time-difference measurement circuit has a START side and a STOP side. The STOP side has a delay circuit that ensures that the STOP side always operates after the START side. The basic specifications of this system are shown in Table 1.

Features of the Fiber-Optic Radiation Sensing System

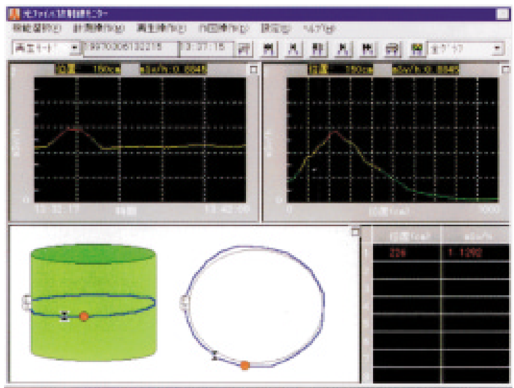
A description of the features of the optical fiber radiation sensing system follows:

1. Permits measurement of radiation-intensity distribution over a wide range.
   This sensing system permits measurement of continuous radiation intensity along the detection cable in contrast to the single point measurements made by a conventional area monitor.

Table 1 Basic Specifications of the Optical Fiber Radiation Sensing System

Type of radiation	γ rays
Measurement distance	20m (max. possible with one system)
Length	30m
Range of energies	350keV~1.3MeV
Locational accuracy	±30cm
Operating Temperature	-15 ~ +50°C
Measuring range	1 ~ 10^4µSv/h

2. The radiation-intensity distribution can be displayed visibly.
   Fig. 4 shows a typical display screen on the optical fiber radiation monitor. The lower left of the figure shows the installed condition of the cable. At the upper right, a colored marked is displayed at each position where the intensity is at least a certain value (this value can be set freely). The table at the lower right shows where the radiation intensity exceeds a certain value and also the radiation intensity at those points. The graph at the upper left shows the time change at arbitrary points.



Upper right - Radiation intensity distribution measurement results.
Upper left - Trend graph consisting of the graph at top right to which a time axis has been added.
Lower right - Peak position and peak value.
Lower left - Installed condition of the detection cable, and the peak display.

Fig. 4 Example of display screen

3. Freedom from electromagnetic interference
   - Intrinsic noise countermeasures are possible.

   The detector consists of a cable that has a total length of 30m. Measurement can be performed at a point remote from the detection zone. Also, detection of radiation and signal transmission use optical signals, hence measurement can be performed without any adverse effects from electromagnetic noise.

Example of Application of the Fiber-Optic Radiation Sensing System

One system using an optical fiber radiation monitor is a radioactive waste resin transportation monitoring system.

Used resin is passed through a transfer pipe to the waste resin storage tank. Sometimes during this process, resin collects at bends in the pipe, valves, etc., making it necessary to monitor and evaluate the situation. The use of the optical fiber radiation sensing system makes this work more efficient, and can reduce the exposure of the workers to radiation. Fig. 5 shows an example of a display indicating the transfer condition of this radioactive waste resin.

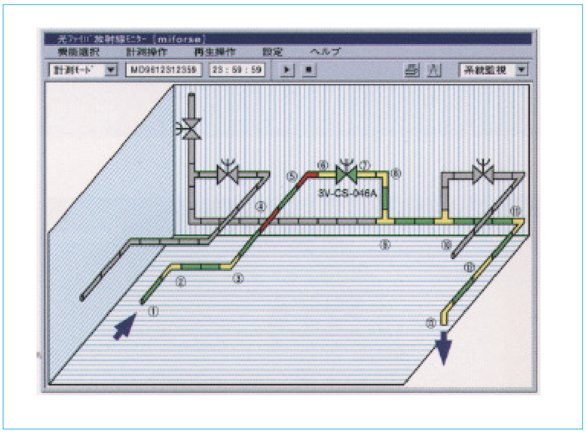


Fig. 5 Example of a screen showing the radioactive waste resin being transferred

Portable Scintillation Fiber-Optic Body-Surface Contamination Monitor

After the JCO atomic power disaster, more than 500 radiation control officers from electric power companies and elsewhere gathered at the site of the accident and checked the local residents for radiation contamination using survey meters. The problems with this method included the need for a specialist radiation control officer to operate each meter, the time-consuming measurements themselves, their cost, and the time taken for the entire operation. To overcome these problems, we developed a body-surface contamination monitor usable by anyone, that performs measurements quickly, can identify the part of the body contaminated by radiation, and can be readily transported to the required location.

Basic Specifications of the Portable Scintillation Fiber-Optic Body-Surface Contamination Monitor

The specifications of the monitor are shown in Table 2. Its performance is the same as that of a permanently installed body-surface contamination monitor. To ensure monitor mobility, we designed it for easy disassembly and reassembly.

Table 2 Basic Specifications of the Body-Surface Contamination Monitor

Radiation detected	β/γ radiation
Sensitivity	β: =0.4Bq/cm^2 (10s) γ: =4Bq/cm^2 (10s)
Effective detection area	40,000cm^2
Accuracy	±20% (measurement error for irradiation with plane-wave source)
Structure	Readily assembled.

Effectiveness

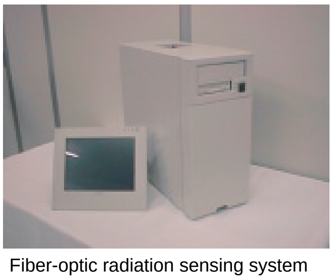
Measurements can be made much quicker than with the conventional method that detects radiation using a survey meter (5min. per person).

Technological Development

In a conventional detector, the light-emitting surface of the conventional plastic scintillator is combined with a large number of photomultipliers, resulting in a detector at least 10cm thick and fairly massive. To facilitate monitor portability and rapid assembly, we adopted scintillation-type optical fiber technology and succeeded in developing the slim, light detector shown in Fig.6. Conventional scintillation optical fiber is designed to measure γ radiation. The new optical fiber was modified by reducing the cladding thickness so that it could measure β radiation.

Fig. 6 Scintillation fiber plate

Portable scintillation-type fiber-optic body-surface contamination monitor



Fiber-optic radiation sensing system

Fig. 7 External appearance of products using optical fiber

In view of the vital importance of rapid, convenient and reliable measurements of radioactivity, Mitsubishi Electric is confident that the products and systems introduced, and the fluorescent optical fiber sensor systems upon which they are based, will have an important role in contributing to human health and safety.❑

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