Development and Commercialization of New Digital Protection and Control Equipment

Chikashi Komatsu
Jun Noro
Mitsuyasu Kido
Shoji Yoshida
Kazuyuki Hyodo
Hiromichi Yamada

OVERVIEW: Protection and control equipment are used to ensure a reliable supply of electric power by detecting abnormal voltage or current levels when lightning strikes or other incidents occur and by signaling circuit breakers to trip, thereby disconnecting the section of the grid containing the fault. In addition to the higher reliability requirement, in view of next generation of technologies, Hitachi developed new generation of digital relays featured with real-time network functions suitable for mission critical protection application, and distributed system configuration applicable for new applications such as wide area protection for maintaining power system stability. Also this new digital relays support unit replacement to prolong the life time of total equipment that is currently in demand from the market.

INTRODUCTION

PROTECTION and control equipment for electric power systems and conversion equipment have the task of maintaining safe power system operation by being quick to detect when a lightning strike or other fault occurs, and then outputting trip signals to circuit breakers to remove the fault.

The market for protection and control systems is undergoing considerable change. In addition to higher reliability requirement, in view of next-generation technologies, Hitachi has developed new generation of digital relays featured with real-time network functions suitable for mission critical protection application using the IEEE 1588 protocol, and distributed system configuration applicable for new applications such as wide area protection for maintaining power system stability.

Also this new digital relays support unit replacement to prolong the life time of total equipment that is currently in demand from the market.

This article describes the development concepts behind this new generation of digital relays and some example applications.

DEVELOPMENT HISTORY OF PROTECTION RELAY TECHNOLOGY

Fig. 1 shows the development roadmap for Hitachi's digital protection and control equipment. The earliest power system protection relays were analog relays (electromagnetic relays, static relays, and so on), with digital relays incorporating microprocessors not being commercialized until the 1980s. Hitachi developed its first generation of digital relays in 1984 and used them widely.

The second generation of digital relays, featuring a flat display and more accurate analog signal processing, was developed in 1994. Second generation of digital relays also supported the connection of a PC (personal computer), which could be used in place of the flat display to view system status as well as recorded data for its operation.

Enhanced second generation of digital relays was introduced in 2003. It drew on the experience and

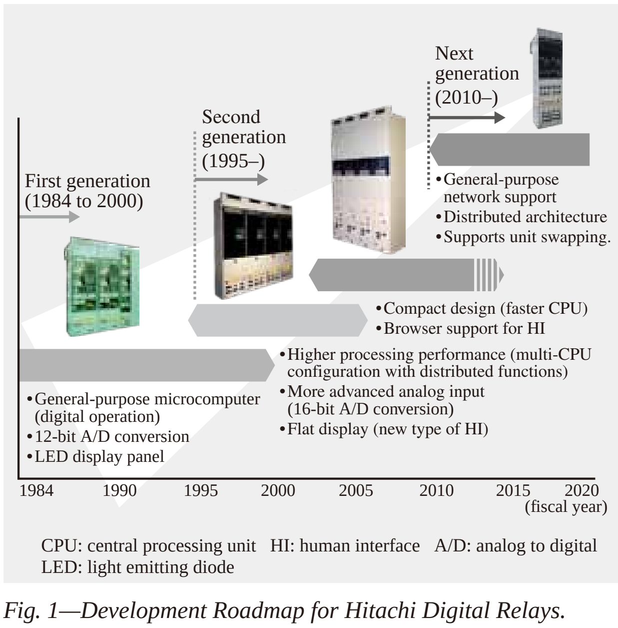

Fig. 1—Development Roadmap for Hitachi Digital Relays.
Hitachi has developed a third generation of digital relays. The first generation was released in 1984.

technical resources of the previous series and also featured compactness and less power consumption along with support for remote operation based on enhanced communication functions.

Newly developed digital relays, as third generation is applied with a distributed architecture and unit-based design contributes to the reduction of wirings inside equipment. It supports unit replacement as specified in the B-402 electrical standards of The Japan Electric Association (Digital Protection Relays and Protection Equipment) revised in 2007 and Vol. 65, No. 2 “New Functions and Performance of Protection Relays” published by the Electric Technology Research Association in 2009.

DEVELOPMENT CONCEPTS AND FEATURES FOR THIRD GENERATION OF DIGITAL RELAY

The following paragraphs list and describe the development concepts and features of newly developed third generation of digital relays:

(1) Support for next generation of communication networks

Real-time data exchange suitable for protection relay system is achieved over Ethernet* considering the future utilization of IP (Internet Protocol) network technologies for mission critical industrial applications such as power system protection relays in view of NGNs (next-generation networks) and wide area network applications.

(2) Distributed architecture

New series of digital relays has been applied with distributed architecture that supports real-time analog data and I/O (input/output) data exchange to allow various system configurations composed of processing units and I/O units to achieve appropriate real-time application.

Fig. 2 shows an example configuration of a real-time distributed system.

The role of protection relays is to acquire current and voltage information from the power system and, when a grid fault occurs, detect the fault on the section of the grid being protected based on the electrical behavior of the fault. For example, transmission line protection relays must detect ground faults or short circuits that occur on a transmission lines resulting from a lightning strike or other incident. This is done by measuring the current at each end of the transmission line and using Kirchhoff’s Laws to detect any fault inside the protected transmission line.

The protection relays at each end of the transmission line need to exchange instantaneous

* Ethernet is a registered trademark of Xerox Corporation.

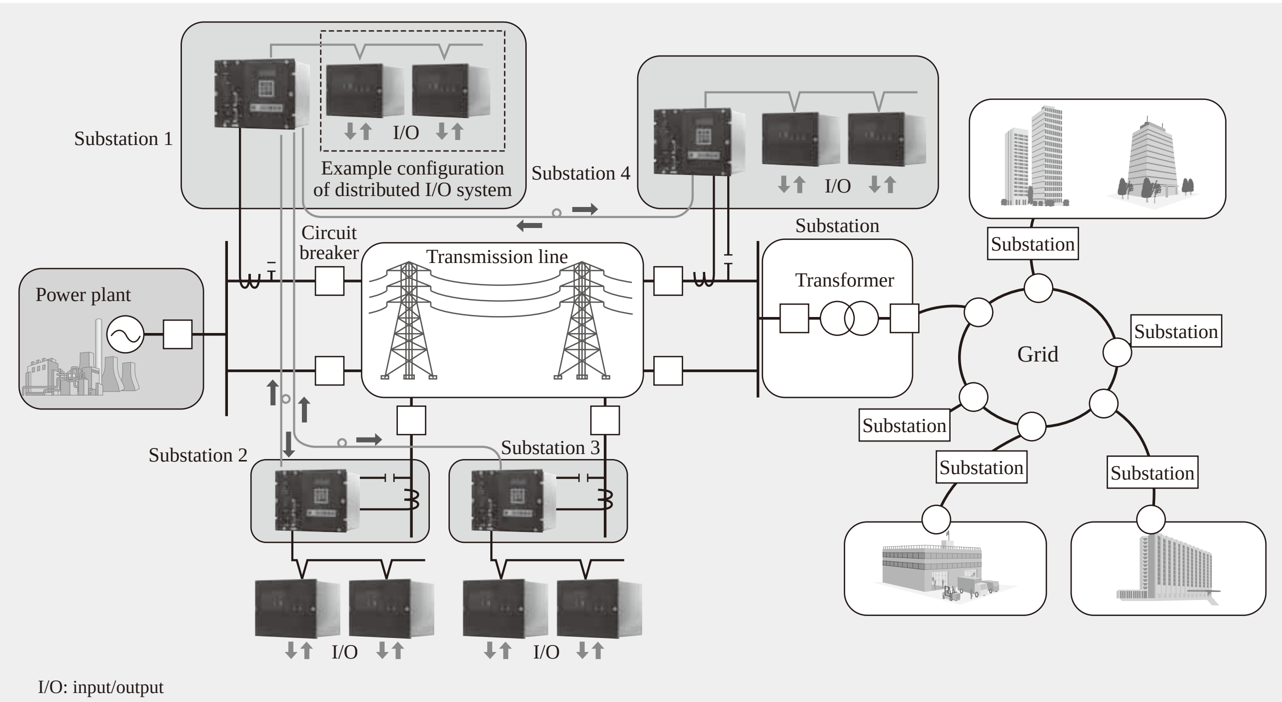

Fig. 2—Example Configuration of Distributed System Using New Digital Relays.
The system allows sharing of current and voltage information sampled from the power system at synchronized timings by units distributed across various different sites. A serial link function allows I/O also to have a distributed configuration.

current values simultaneously sampled at each end via a communication link. However, if the accuracy of sampling synchronization (the synchronization of the measurement timings at opposite ends of the line) is insufficient, the error will be large and the internal faults may not be distinguished from the external fault, and then relay may maloperate. Typically, the accuracy of the sampling synchronization between relays at each end of the line must be less than a few tens of microseconds.

Given their severe real-time performance requirements, the most important consideration for protection relay systems is how to synchronize sampling of analog values (SV). Newly developed digital relays apply optical Ethernet communications and a precise sampling synchronization technique (IEEE 1588 protocol) to synchronize sampling across distributed devices to within 1 μs (when directly connected to optical communication link).

Fig. 3 shows the configuration of the sampling synchronization function. A network I/O function is also included so that the system configuration can support I/O hardware installed in distributed locations. Fig. 4 shows a comparison of the old and new I/O functions.

(3) Compact design and reduction of wirings

The processing unit can be implemented as a single box thanks to the use of high-speed CPUs (central processing units) with the latest semiconductor technology, and large FPGAs (field-programmable gate arrays) to increase the mounting density of electronic circuits and reduce the number of circuit boards, and also space savings achieved by changes to how input converters are mounted.

Also, alarm circuits (circuits for detecting of device faults and outputting warnings) have been standardized and implemented as circuit boards, and I/O functions have been optimized to suit different applications.

The new system also minimizes wiring by using a serial link for the connections between the CPU and the I/O sections used to interface with other external equipment.

(4) More accurate analog data processing

The accuracy of the analog data processing has been improved and the dynamic range expanded by using ultra-high-speed sampling (16 times faster than previous Hitachi models) to reduce the size of the anti-aliasing analog filters, and by incorporating hardware signal processing circuits designed for ultra-high-speed sampling to increase the signal-to-noise separation ratio.

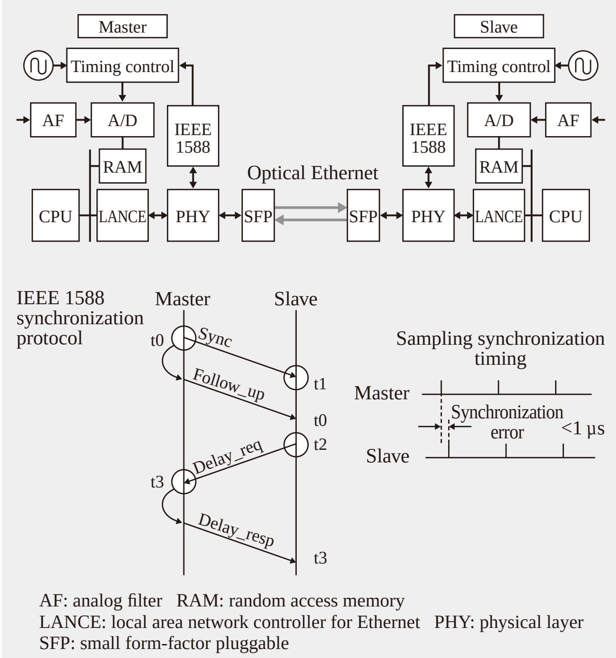

Fig. 3—Configuration of Sampling Synchronization Function Using IEEE 1588 Protocol.
Slave devices exchange IEEE 1588 synchronization control packets with a master device to synchronize with their sampling timings. This system is implemented in hardware to achieve nanosecond-order precision.

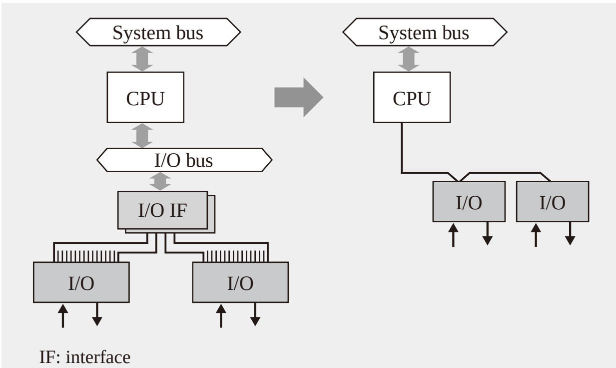

Fig. 4—Comparison of Old and New I/O Functions.
Whereas the old I/O interface consisted of parallel signals from the CPU, new series of digital relays minimizes wiring by interfacing via a serial link from the CPU. This provides flexibility for adding extra I/O or other modifications.

Also, a signal processing circuit based on the phase principle has been implemented on an FPGA and is available for use in future measurement applications.

(5) Higher reliability

Reliability was enhanced by making circuits smaller to cut the component count, incorporating a hardware-based memory monitoring function [consisting of ECC (error checking and correcting) and a memory patrol function], and upgrading the

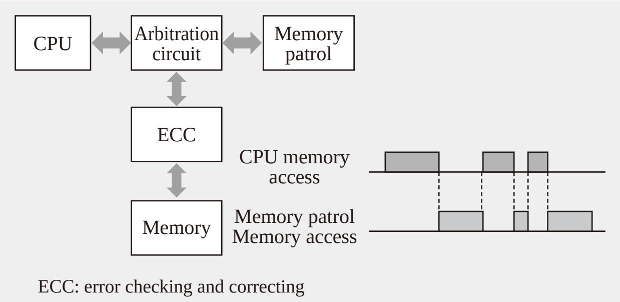

Fig. 5—Overview of Memory Patrol Function.
The memory patrol circuit periodically uses the ECC circuits to check memory data integrity using times when the CPU is not accessing memory. It is able to correct single-bit errors.

monitoring function by adding a data integrity check for preventing transient data corruption in addition to the existing function for memory integrity (hardware integrity) checking. Fig. 5 shows an overview of the memory patrol function. To perform monitoring in a way that does not affect the application, this function uses arbitration of CPU and memory access and operates in the background when the CPU is not performing any accesses. The continuous monitoring function has also been revised to optimize its operation to be better suited to actual conditions.

(6) Better operational characteristics

Ease of operation and maintenance have been improved by including a simple LCD (liquid crystal display) screen as a standard function so that relay status information can be viewed without having a PC connected. This includes relay setup, operational settings, operational status information, such as whether the relay has tripped and the input current level, and details related to trips or abnormal conditions.

Also, as the power supply has a limited operating life, it has been positioned to make it easy to replace from the front of the unit.

(7) Meeting market needs

To meet the market requirement for unit upgrades stipulated in the B-402 electrical standards and "New Functions and Performance of Protection Relays," the design separates the digital circuit (CPU unit) from the I/O section (I/O unit) to allow individual units to be replaced. This reduces modification risks associated with component availability because it allows unit-level functional modifications and minimizes the extent of equipment that needs to be replaced.

(8) Support for migration to PCM communications

New series of digital relays includes real-time communication function over Ethernet. This will be an archetype of real-time industrial application utilizing IP network interfaces and the existing PCM (pulse-code modulation) communications function used on differential current relays is provided as an optional connection. This configuration simplifies the future migration of wide area protection applications including differential relays to an Ethernet-based real-time network from the PDH/SDH (plesiochronous digital hierarchy/synchronous digital hierarchy) synchronous communication network used currently.

(9) Support for new applications

The system configuration of new series of digital relays allows for its use in future new applications such as functionally distributed protection systems and power system stability equipment over real-time communication network based on Ethernet.

COMMERCIALIZATION OF NEW TECHNOLOGY

The first product of this new digital relays to enter service was for a high-voltage transmission line relay application that combined main and backup protection (with main protection provided by a PCM current differential relay and backup protection by a distance relay) and allowed for future upgrade of protection schemes applying unit-design concept.

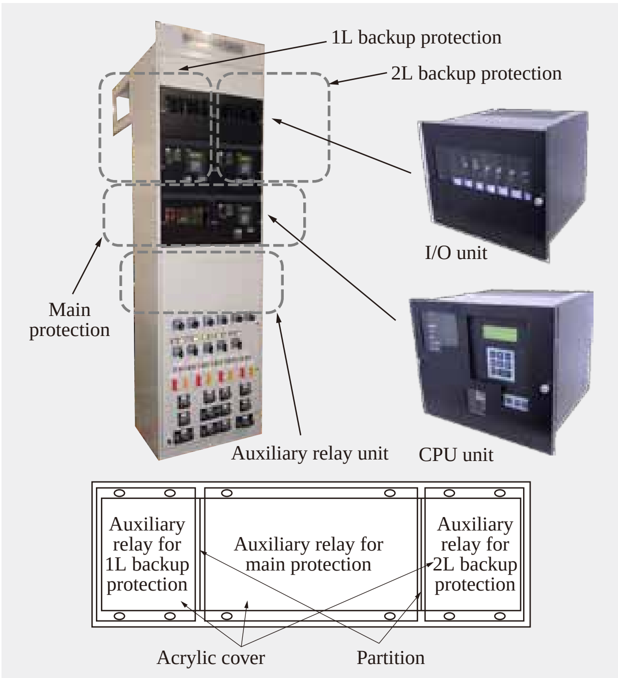

Fig. 6—Example Configuration for New Digital Relays.
The system is configured by mounting the units that provide the functions and performance in a protection equipment panel. This allows functional modifications to be made by replacing units, with the swapping of components in and out being done on a unit-by-unit basis.

As the specifications required use of the existing synchronous communication network for PCM communications, the system accorded with items (3) to (8) in the list of development concepts given in the previous section. Fig. 6 shows an example configuration for new series of digital relays.

The equipment configuration involved combining CPU and I/O units for each type of protection (main protection, 1L backup protection, and 2L backup protection). Auxiliary relay units were also partitioned by protection type inside the units, and were designed in a way that prevents anyone from touching the auxiliary relays for each protection type. In this way, any future changes to the protection type that are needed can easily be accommodated.

Also, the greater precision of the analog input section improved the accuracy of the relay itself as well as the overall system performance.

After factory testing and customer inspection testing were completed, the system was delivered to its site of installation, where it successfully passed all on-site testing and entered operation in March 2011.

CONCLUSIONS

This article has described the development concepts behind new series of digital relays and some example applications.

This new series of digital relays is the realization of a number of development concepts, including a compact design contributing to reduction of wiring, more precise analog data processing, higher reliability, better operational characteristics, and a configuration that uses replaceable units.

For the future, Hitachi plans to extend the product range of this new digital relays throughout Japan. Hitachi also intends further developments of new generation of protection applications compatible with the next-generation communication network.

REFERENCE

(1) M. Kido et al., “Development of Wide Area Distributed Digital Protective Relay Using General Network Interface and Principled IEEE1588 Precision Timesynchro Protocol,” The Papers of Technical Meeting on Power Protective Relaying, PPR-10-038 (Aug. 2010) in Japanese.

ABOUT THE AUTHORS

Chikashi Komatsu

Joined Hitachi, Ltd. in 1991, and now works at the Power Plant Control Systems Engineering Department, Information & Control Systems Company. He is currently engaged in the design of power system protection and control equipment. Mr. Komatsu is a member of The Institute of Electrical Engineers of Japan (IEEJ), the Institute of Electrical and Electronics Engineers (IEEE), and the International Council on Large Electric Systems (CIGRE).

Jun Noro

Joined Hitachi, Ltd. in 1987, and now works at the Power Plant Control Systems Engineering Department, Information & Control Systems Company. He is currently engaged in the design of power system protection and control equipment. Mr. Noro is a member of the IEEJ.

Mitsuyasu Kido

Joined Hitachi, Ltd. in 1979, and now works at the Control System Development Department, Information & Control Systems Company. He is currently engaged in the design of power system protection and control equipment. Mr. Kido is a member of the IEEJ.

Shoji Yoshida

Joined Hitachi, Ltd. in 1988, and now works at the Control Systems Engineering Department, Information & Control Systems Company. He is currently engaged in the design of power system protection and control equipment. Mr. Yoshida is a member of the IEEJ.

Kazuyuki Hyodo

Joined Hitachi, Ltd. in 2001, and now works at the Power Plant Control Systems Engineering Department, Information & Control Systems Company. He is currently engaged in the design of power system protection and control equipment. Mr. Hyodo is a member of the IEEJ.

Hiromichi Yamada

Joined Hitachi, Ltd. in 1986, and now works at the Green Mobility Research Department, Hitachi Research Laboratory. He is currently engaged in research and development aimed at improving the reliability of system LSIs. Mr. Yamada is a member of The Institute of Electronics, Information and Communication Engineers (IEICE).