Digital Upgrades of Reactor Control and Protection Systems for Operating Plants

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For the safe and stable operation of nuclear power plants over a long period of time, it is important to continuously maintain the integrity of equipment, improve safety and reliability and increase operational sophistication. The implementation of a digital instrumentation and control system is an answer to such effort. In the instrumentation and control systems of modern pressurized water reactor (PWR) plants, digital technology is already employed in all the control equipment including the main control board in order to improve safety, reliability and maintainability. On the other hand, analog equipment is still used in the reactor control and protection systems of operating plants built from the 1970s to the 1990s. Looking ahead to the operation of nuclear power plants for more than 40 years, we are proceeding with the digital upgrade of such analog equipment and have already completed the work at 20 plants. For digital upgrade, we developed a universally applicable standardized system architecture and verified its applicability together with electric power companies. Our upgrade services can be tailored to meet the varying needs of electric power companies and realize high reliability and maintainability. For example, we can provide not only upgrades of all the equipment at the same time, but also upgrades while making use of existing analog equipment, or gradual upgrades over multiple plant outages.

1. Introduction

For conventional analog equipment, long-term supply of spare parts and substantial equipment remodeling are becoming increasingly difficult, mainly because of the terminated production of circuit parts in recent years. This may become a hindrance to the continued improvement of safety and the addition of new functions. In addition to the complicated test and maintenance procedures required during plant outages, analog equipment requires skilled technical staffs and special tools for each type of equipment. With the introduction of digital equipment, however, these difficulties can be eliminated.

For the instrumentation and control systems for PWR plants include a reactor control system for controlling the plant during normal operation and a reactor protection system for emergency shutdown of the plant during an emergency, digital equipment has been gradually introduced since 1980s. Based on our experience with reactor control systems, we introduced a digital instrumentation and control system including a reactor protection system to a newly constructed PWR in 2009. With our acquired expertise, we continue to promote the digital upgrade of the reactor control and protection system in operating plants, aiming to improve safety, reliability and maintainability (**Figure 1**).

When upgrading the reactor control and protection systems in operating plants, there are many kinds of restrictions in design and implementation. Each plant has different equipment type and model to be upgraded, with different plant functions, different system interface, different installation space, and different customer's needs of upgrading sequence. To adopt to such diverse situations, we developed a universally applicable standardized compact and flexible system architecture and verified its applicability together with electric power companies and Mitsubishi Electric Corporation. Our services can be tailored to meet the various needs of electric power companies. For example, we

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can offer upgrade projects while making use of existing analog equipment, or gradual upgrades over several plant outages. So far, a total of about 800 cabinets at 20 plants have been upgraded.

This report summarizes the advantages of introducing a digital instrumentation and control system and its standardized design for operating plants.

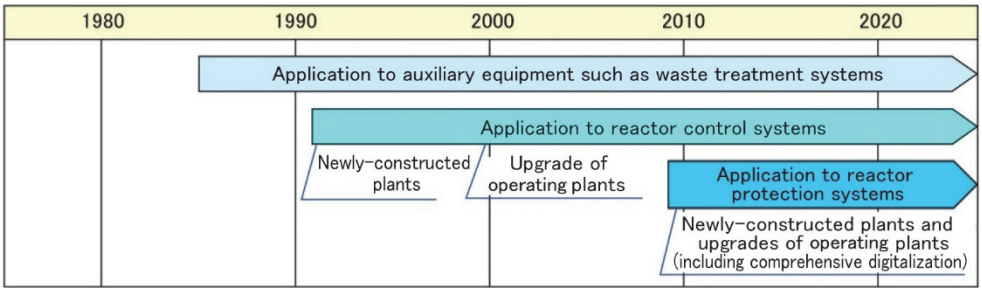

Figure 1 History of implementation of digital instrumentation and control systems in PWR plants

2. Advantages of introducing a digital instrumentation and control system

The advantages of digitalization of a instrumentation and control system can be summarized as noted below:

(1) Improvement of equipment reliability through introducing self-diagnostics

Once digital equipment is introduced, it becomes possible to continuously check the integrity of the equipment by self-diagnostics features, making it easier to detect incipient failures and identify their location. To enable a plant to maintain itself in a safe condition even in the event of a failure, we have designed the system in such a way that redundant devices (e.g., CPUs and input/output cards) will be automatically switched to keep its function and a fail-safe design for the output of control equipment will operate in accordance with the type of failure.

(2) Improvement of testability and maintainability

In reactor control and protection systems with conventional analog equipment, it is necessary to apply different maintenance procedure according to the type of circuit. However, once digital equipment based on a common platform is implemented, maintenance work and management of spare parts will be standardized.

Enabling software to fulfill the functions that have been conventionally realized by analog circuits causes no drift of set points, etc. The integrity of the equipment can be checked by comparing it to the latest version of the master software or through self-diagnostics. This eliminates the necessity of verifying the system behavior using simulated signals, thus reducing the test and inspection workload.

(3) Flexibility in future modification

In analog equipment, change of functions or addition of new functions, requires hardware remodeling such as the addition of new analog circuits and the addition/change of wiring. Therefore, there are many restrictions to be considered when remodeling, including ensuring installation space and planning of work schedule at site.

On the other hand, in digital equipment, as the control function is implemented through software, the addition or change of functions necessitates no substantial hardware remodeling. The design therefore provides a higher degree of freedom in functional modification than that of analog equipment.

(4) Sustainable supply of spare parts

In the case of conventional analog equipment, long-term stable supply of spare parts and remodeling of substantial equipment are becoming increasingly difficult, mainly because of the terminated production of circuit parts. Once digitally upgraded, maintenance parts can be procured in a stable manner.

The introduction of digital equipment makes it possible to enhance reliability, improve testability and maintainability, provide equipment modification in a flexible manner and secure the

procurement of maintenance parts. The issues related to conventional analog equipment such as equipment remodeling, and maintenance/operational difficulties have been solved.

3. Digital upgrade of operating plants: a summary of the standard design

Depending on the period of plant construction and later remodeling history based on the latest knowledges, every reactor control and protection system of the PWR plants in Japan has a different design, equipment configuration and specifications. As each plant has a different number of controlling devices and dissimilar layout designs, the functions of control equipment, the place for equipment installation and spatial restrictions are also plant specific.

When upgrading the reactor control and protection system of an operating PWR plant, it is necessary to deal with such varying restrictions of each plant. A design tailored for individual plants may lead to design complexity and cost increases. To avoid this, we have set in advance a universally applicable system architecture as the standard design, and it will be modified according to the plant-specific requirements, whereby upgrades can be carried out efficiently and flexibly.

Advantages of this standard design used for upgrades in operating plants are summarize as following four point of view.

(1) Compact system configuration

The space for installation is one of the major restrictions when upgrading existing equipment. Different from the newly constructed plants, operating plants often require the new equipment to be installed in the same space where the old equipment was. To make it applicable to any plant despite the fact that the number of cabinets and their layout and sizes vary depending on the existing equipment of each plant, it is necessary that the standard design has a compact system configuration while retaining the required functions and reliability (such as multiplexing and appropriately-distributed safety functions)

Conventionally, different facilities such as instrument racks and relay racks are installed depending on the technologies applied for analog signal processing and logical operation processing (ON-OFF control). Once digitally upgraded, the control logic for the equipment is implemented through software and the signal interface for communication between digital equipment is enabled, thereby achieving a design with a high degree of freedom in changing the existing system configuration. By making use of this advantage, multiple functions which have been so far realized by different types of equipment (analog signal processing and logical operation processing such as the reactor trip) are integrated to reduce the amount of equipment and the interface between equipment. A compact system configuration is thus realized as the standard design. An example of the functional integration is shown in **Figure 2**.

(2) Phasing approach of upgrades

The instrumentation and control system for a nuclear power plant is large in scale and typically has about 200 cabinets. It is therefore difficult to upgrade everything at the same time, especially because of the limited number of plant outage days. Accordingly, in some cases upgrades may have to be divided into several plant outages To manage this situation, the standard design has been configured in such a way that the entire system can be divided into adequate units of equipment. Therefore, even when upgrades proceed gradually over several steps, work can be completed while securing, at each step, the required reliability and functions. In the case of phasing upgrades or when only some parts of equipment are upgraded, we will enable existing equipment to be utilized as much as possible, while creating a design that can minimize installation work such as large-scale cable replacement and the subsequent installation of electrical circuits

The digital upgrading of instrumentation and control systems over several steps is currently being carried out at some plants. We are proceeding with the planned upgrades by determining in advance the configurations of system and equipment at each step before confirming feasibility

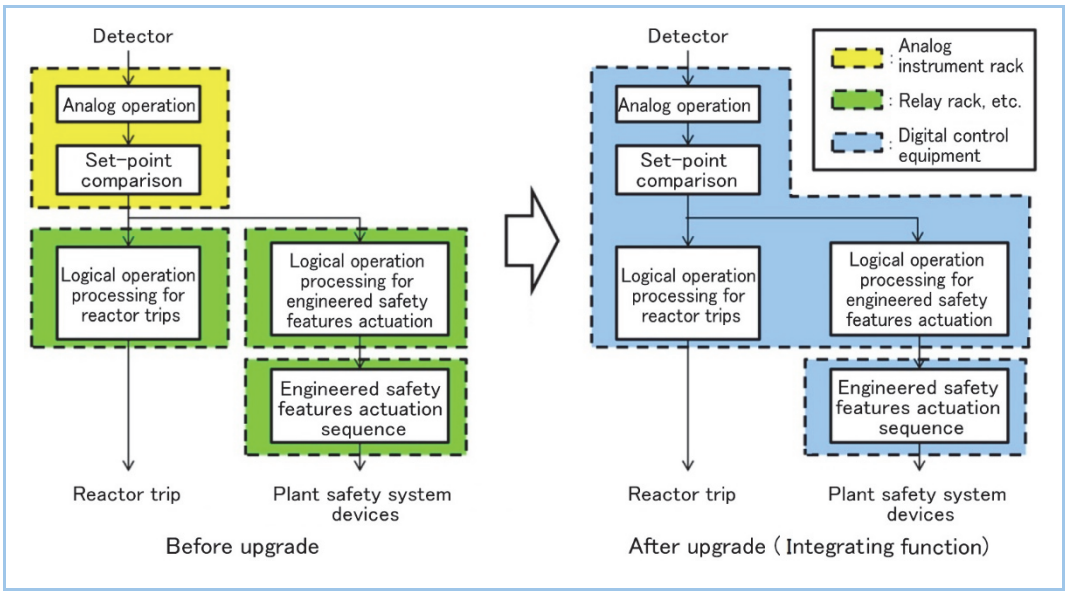

Figure 2 Example of functional integration of reactor protection system

(3) Readiness for the latest regulatory trends

To resume the operation of nuclear power plants, it is necessary to satisfy the latest regulatory requirements formulated based on the lessons learned from the Fukushima Daiichi Accident. We are determined to pursue the world's highest level of safety while designing our systems. When it comes to the reactor control and protection system, official approval is also required to show that a remodeled system for reactor protection complies with the latest regulatory requirements.

Looking at overseas trends, the need for digital upgrades is also increasing as the production of analog equipment is terminated. The regulatory framework in this area is under active discussion. Especially in the U.S., ongoing discussion about digital upgrade is related to the continued operation of plants that have been in operation for more than 60 years. By adopting such new trends/technologies, designs with a higher level of safety have been realized.

Examples of such a ongoing discussion of the regulatory requirements is the treatment of the common cause failure issue caused by the software of the redundant digital reactor protection system (software common cause failures). In PWR plants, from a defense-in-depth point of view, equipment that efficiently backs up the crucial functions of "shutdown," "cooling" and "containment" during emergencies has been installed in every plant with the digital reactor protection system. **Figure 3** illustrates an example of the diverse backup equipment configuration. The diverse backup equipment is isolated from the reactor protection system by means of isolation circuits to prevent an adverse impact on the system. The equipment is also designed with an internal duplex circuit to prevent spurious actuation.

(4) Functional expansion through upgrades

Functional expansion through upgrades can improve safety, reliability and maintainability. For example, for the improvement of safety and reliability, the three-channel detector (2-out-of-3 system) commonly used in the old reactor protection system is replaced with the four-channel type (2-out-of-4 system) found in recent plants. In applying this system, the degree of redundancy is increased, making it possible to operate by bypassing one channel during maintenance and thereby improving the maintainability.

As described above, the standardized system configuration is applied in the digital upgrade of reactor control and protection systems. While providing upgrades tailored to meet the various needs of individual plants, we also perform functional modification during upgrades, considering the latest regulatory trends. By applying the standardized system configuration, all plants have common basic specifications. It therefore becomes possible to improve safety and reliability and increase operational sophistication while sharing knowledge and experience among plants.

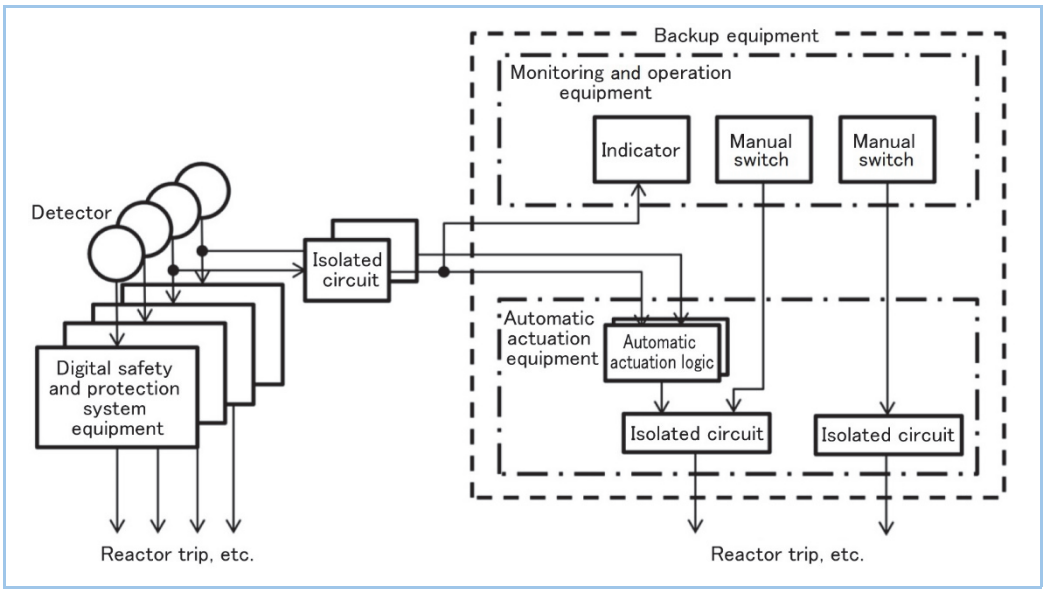

Figure 3 Example of diverse backup equipment configuration

4. Conclusion

We have promoted the digital upgrade of the reactor control and protection systems of PWR plants in Japan. Equipment upgrades have been already performed at 20 plants, accounting for a total of roughly 800 cabinets.

In terms of upgrading the reactor control and protection systems of operating plants, the issues related to conventional analog equipment such as equipment remodeling and maintenance/operational difficulties have been solved. Having developed a universally applicable standardized system architecture, we provide upgrades that are tailored to meet various needs of electric power companies to realize state-of-the-art safety, reliability and maintainability.

We are currently proceeding the upgrade of remaining plants in Japan, and planning new upgrade projects. Through these projects, we will contribute to increased safety, higher reliability and the increased operational sophistication of plants.

Also our abundant experiences will help modern digital instrumentation and control system design of the next generation plants.