Fundamental BOP I&C Systems Structure in Nuclear Power Plants

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Abstract

Digital instrumentation and control (I&C) systems using distributed control systems (DCS) are essential elements for nuclear power plants (NPPs) seeking higher reliability, availability and maintainability. Hitachi can boast its broad new build and refurbishment project experience in Japan and other markets since the 1970s. Through its continuous involvement in NPP design, fabrication, construction and maintenance over 30 years, Hitachi has increasingly integrated digital I&C systems with its own DCS suite. This paper focuses on the fundamental characteristics of Hitachi's Balance of Plant (BOP) I&C systems structure for new build nuclear projects.

1. Introduction

Digital technology has been applied to BOP I&C systems since the 1980s (since the beginning of the technology's own evolution), and digitization scope was finally expanded to safety systems in the 1990s. Because Hitachi applies a "phased approach", in which new technology is introduced first into non-critical systems and then is expanded to a wider scope after having field operating experience, new technologies such as remote multiplexing transmission and CRT-based operation of pumps and valves are introduced first into non-critical systems as typified by BOP.

This paper introduces Hitachi's approach for developing system concepts and summarizes Hitachi's standardized fundamental BOP I&C systems configuration which established the basis of the total digitization system successfully deployed in Japanese ABWR in the 1990s and which can be flexibly adapted to any project-specific requirements,. This paper also addresses up-to-date digital technology which Hitachi is working to apply to BOP I&C systems and expand to the entire plant I&C systems of the future.

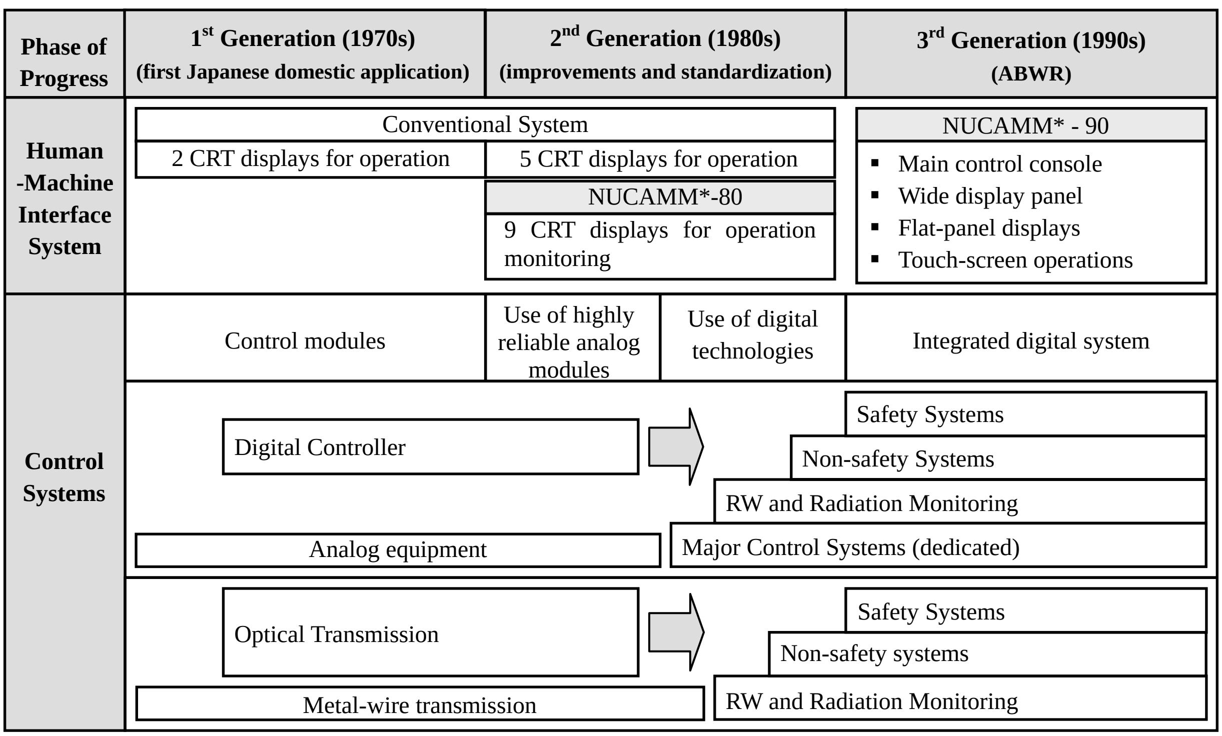
2. Hitachi Nuclear I&C Systems Experience [1]

Figure 1 shows the evolution of Hitachi I&C systems, an industry in which Hitachi has been engaged since the early 1970s.

In the 1st generation of development, redundancy was developed and applied to the major control systems, dramatically improving their reliability and performance.

In the 2nd generation, the optical information transmission system and digital processing technology was first applied to the radioactive waste processing system. Then, to improve NPP reliability and maintainability, digital technology gradually has been applied to non-safety systems such as BOP.

In the 3rd generation, digital technology was applied to the I&C facilities of the entire plant, including the neutron monitoring system, the safety protection system, the reactor recirculation internal pump control system, and the control rod control system. Hitachi expanded the use of digital technology throughout the plant and completed the "NUCAMM-90" total-digital system, integrating instrumentation, control, protection and HMI.



***NUCAMM**: **Nu**clear Power Plant **C**ontrol **C**omplex with **A**dvanced Hu**m**an-**M**achine Interfaces

Figure 1: The Evolution of Hitachi Nuclear I&C Systems

3. BOP Design Concept

3.1 BOP Mechanical System Design

BOP mechanical systems have been making progress as well as I&C technology. For example, in response to market requirements for increasing thermal output, Hitachi's basic turbine type has changed from the original TC4F-35 (tandem-compound 4-flow turbine with 35" blades) to the current TC6F-52. Similarly, moisture separator reheater, turbine driven reactor feed water pump and drain-up system have been applied in order to improve thermal efficiency. Figure 2 shows the history of Hitachi nuclear turbines. As one can see, turbine systems have developed in parallel with the progress of NPP technology. One should also note that the BOP mechanical system varies based on reactor type. For example, CANDU and PWR have a deaerator in the feed water pump suction line to collect the feed water heater drain while BWR does not.

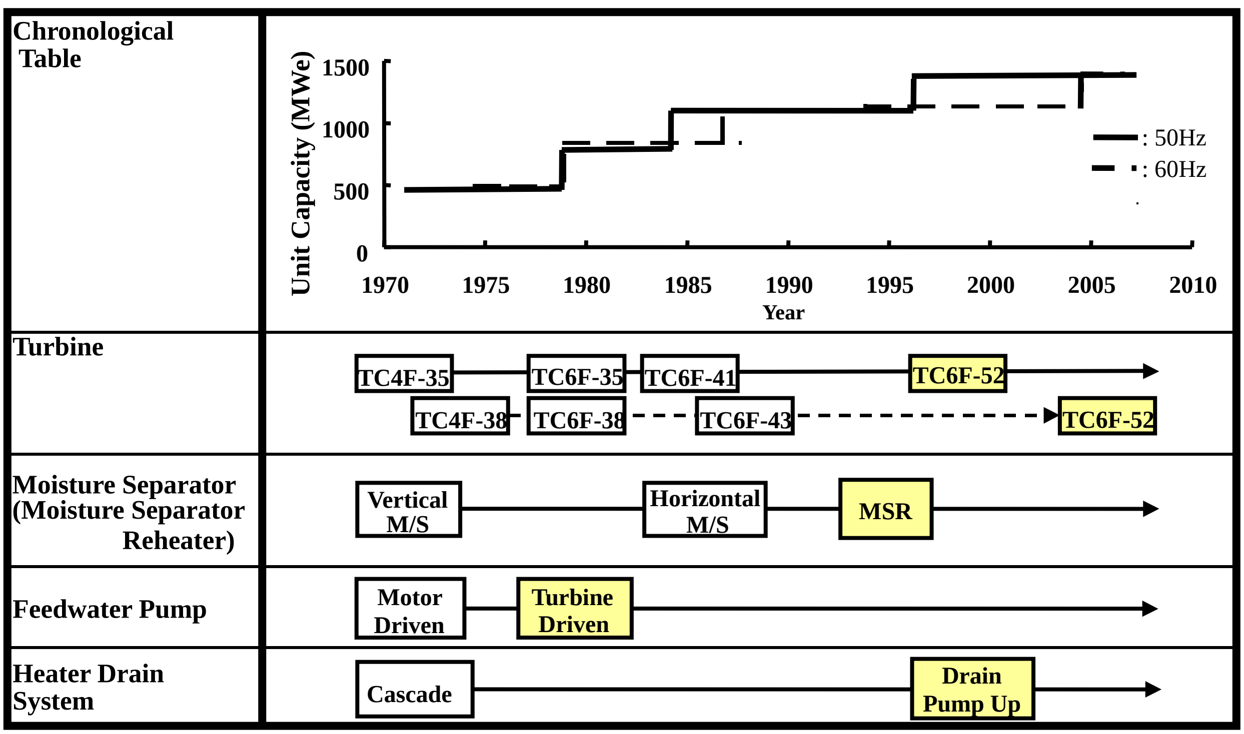


Figure 2: The History of Hitachi Nuclear Turbines

3.2 BOP I&C System Design Concept

This section describes Hitachi's BOP I&C system design concept. Some of the points covering the entire I&C system concept are included also.

(1) Digitization

Most of Hitachi BOP I&C systems are digitized. When deciding on digitizing an I&C system, various factors such as process requirements (response time, accuracy, etc.), operating location (local or MCR) and signal level (standard current signal or non-standard) should be evaluated first. Then, each required BOP function is allocated to appropriate controllers considering functional distribution (diversity, redundancy and CPU load) and in-depth distribution (safety, protection and control). As a result of Hitachi's evaluations and decades of experience, the up-to-date Hitachi standardized BOP I&C system consists of 4 sets of controllers; (1) "BOP1", mainly for power train; (2) "BOP2", mainly for T/G auxiliaries; (3) "BOP3", mainly for local control; and (4) "EHC", for turbine control. The reduction in the amount of hardware and the application of redundancy have improved system reliability and economic efficiency. The introduction of user-friendly maintenance tools has improved maintainability.

On the other hand, some systems are deliberately not digitized: for example, the Turbine Supervisory Instrument, which deals with special signals such as vibration detector signals, is not digitized. It is important to evaluate the necessity of digitization and allocate optimally the scope of digital systems and conventional systems based on process needs.

(2) Input and Output Redundancy

Although BOP is considered "non-critical", a failure of some BOP signals may affect plant electrical output or damage main machinery such as the Turbine and Generator. I/O redundancy is one of the best solutions to avoid the electrical output disturbance and main machinery damage caused by I/O failures.

Hitachi has evaluated all BOP I/O points to identify whether redundancy is necessary or not based on process and mechanical requirements. When applying I/O redundancy, identical input or output signals are configured to be either "OR" or "AND" based mainly on the operating mode (normally in operation or normally in standby) so that a single I/O failure does not cause a change in the operating status. In some cases, redundancy is achieved by applying the 2-out-of-3 logic configuration.

(3) Improvement in Operations and Monitoring

Hitachi has developed state-of-the-art human-machine interface technologies for Japanese ABWRs as shown in reference [2]. By applying Hitachi's standard ABWR HMI system with optimized device allocations and enhanced plant operation automation, operator workload can be reduced, and plant crews can concentrate on monitoring (rather than operating) the process so that enhanced operability and improved reliability can be achieved. Although the technologies are ABWR-specific, many of the basic methods, such as using flat panel displays employing touch-screen operations and diversified HMI implementation, can be applied to the I&C systems of all other reactor types.

As a BOP issue, centralizing the turbine local control is one of the BOP-specific points. In a conventional system, PID parameters for control valves need to be tuned at pneumatic controllers located adjacent to each control valve, which may force additional field maintenance. In an ABWR, all the turbine local controls are digitized to eliminate local pneumatic controllers and local control modules in MCR, which were prepared in conventional systems. Furthermore, in ABWR, all the related processes can be monitored and tuned in the MCR to improve operability. This technology can be applied in all other reactors including CANDU plants.

(4) Improvement to Maintenance

For non-safety systems including BOP, Hitachi has developed a “software isolation tool” that allows plant crews to isolate arbitrary input signals and to force values on them. This tool has eliminated the necessity for separate signal simulators and external cabling to simulate inputs when testing, calibrating, etc. The difference between the software isolation tool and a “normal” software maintenance tool is that the software isolation tool supports functions for assisting various maintenance activities. For example, the “isolation” work history can be archived in the isolation tool to keep traceability, which a “normal” software maintenance tool does not support.

(5) Optical Multiplexing Transmission

Optical multiplexing transmission is one of the key technologies for reducing cabling costs. By installing I/O modules near the instruments/actuators (i.e., in the local area) and by transmitting the signals to the MCR after multiplexing them, a significant number of cables can be eliminated. Additionally, by applying optical transmission, noise immunity can be assured.

4. Hitachi's Standard BOP I&C System Implementation

This section describes Hitachi's standard BOP I&C system for project cases which Hitachi has experienced. The following 3 BOP I&C system project cases are covered:

1) Supplying the entire BOP I&C System
2) Supplying part of the BOP I&C System along with another vendor
3) Supplying the BOP I&C System as a sub-component of the Turbine/Generator

4.1 Case 1: Supplying the Entire BOP I&C System

This is the case which Hitachi has experienced in all Hitachi-supplied NPPs in Japan, and this uses the Hitachi standard digitized BOP I&C system which can be deployed to any NPP simply by adjusting plant-specific features only. Figure 3 represents the general ABWR BOP I&C system configuration. Although Figure 3 specifically represents Hitachi's ABWR configuration, it can be applied to any other NPP type such as CANDU, because (a) the BOP process and mechanical concept design is typically similar regardless of reactor type and (b) the DCS has inherent scalability and modularity to adapt itself to most applications.

Hitachi's digitized BOP I&C system typically consists of 4 sets of controllers (see 3.2(1) above): (1) "BOP1", mainly for power train; (2) "BOP2", mainly for T/G auxiliaries; (3) "BOP3", mainly for local control; and (4) "EHC", for turbine control. Each of these controllers has the features listed in section 2 for better reliability, availability and maintainability.

Finally, by preparing a gateway interface ("GW"), communication with other vendors' products supporting different network protocols is easily achieved. For example, this BOP case can adapt itself to project formations in which the Nuclear Island I&C system and/or HMI are based on non-Hitachi products.

The benefits of this case can be summarized as follows:

- A large amount of hardware such as relays, converters and local control modules can be reduced or eliminated by implementing the corresponding control logic in a software-based DCS.
- A unified interface with the HMI system realizes a simple, consistent and easy-to-maintain design.
- Support of a unified product series provides consistent maintainability and reduced variety of spare parts.

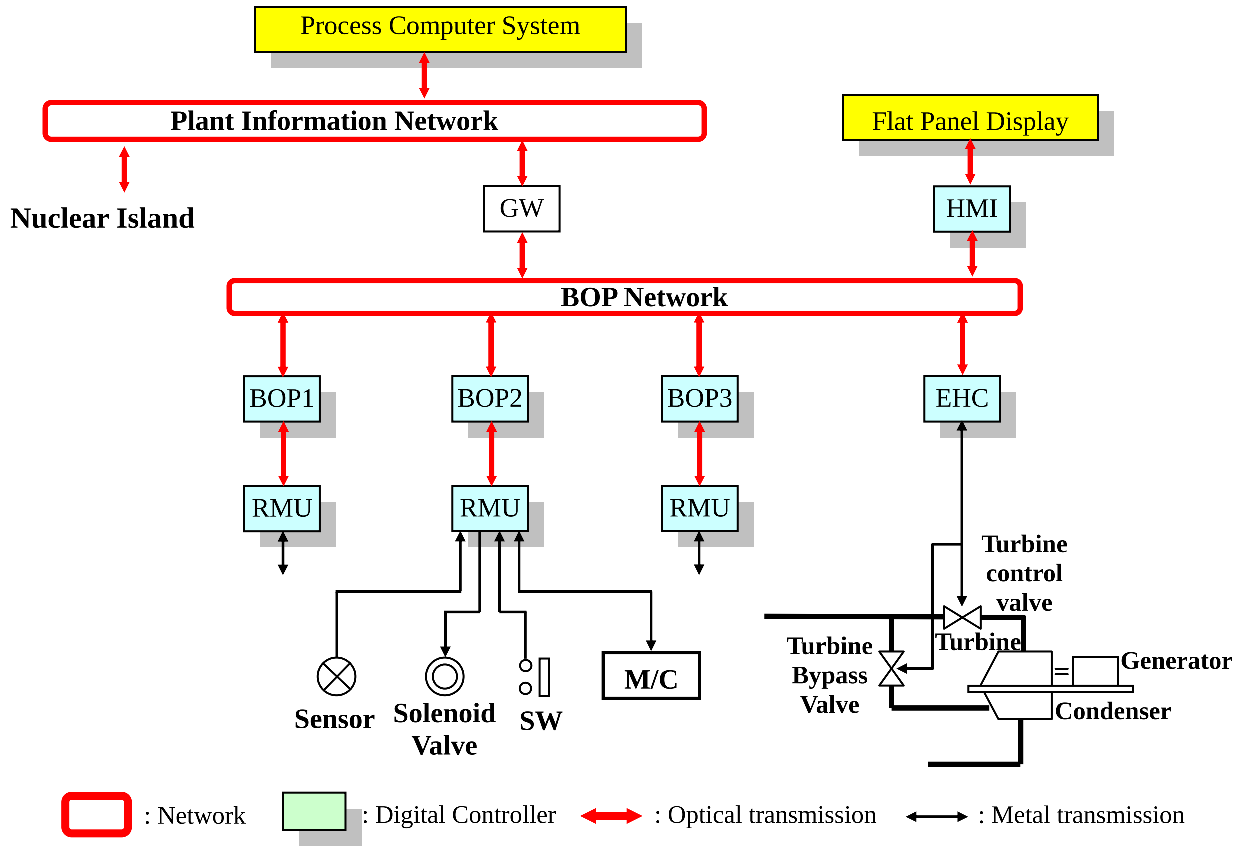


Figure 3: General Configuration of Hitachi's BOP I&C System

4.2 Case 2: Supplying Part of the BOP I&C System Along with Another Vendor

This case is represented by the Hitachi-supplied BOP I&C systems for the Qinshan CANDU plant, whose general system configuration is shown in Figure 4.

The BOP I&C system configuration was divided based on the scope for machinery systems. For example, the Power Train I&C system was supplied by other vendors applying conventional (i.e., non-digitized) systems.

The Qinshan project case forced Hitachi to implement additional interfacing effort compared with Case 1; however, Hitachi was able to handle this situation due to its accumulated project management experience [1]. For example, the inter-vendor interfacing principle was decided during the first project phase, and an interface point list identifying all the inter-vendor interfaces was created and shared by both vendors.

The Qinshan project was successful with the BOP I&C implementation method causing no significant field trouble before or after the plant start of commercial operation; however, judging from Hitachi's experience, this project could have had more benefit if it had been implemented like Case 1. The major benefits which could have been realized are listed below:

- Hardware for the Power Train I&C system could have been replaced by one set of controllers.
- All the local control devices installed outside of the MCR Panel, which were prepared by others, could have been eliminated by implementing them in the MSR controller supplied by Hitachi.
- Application of RMU to multiplex transmissions between local devices and the MCR could have substantially reduced the cabling effort.

To summarize, Hitachi is capable of managing this project case by applying Hitachi's accumulated project implementation know-how; however, Case 1 model is recommended considering I&C system efficiency. Actually, Hitachi is presently promoting the delivery of BOP DCS solely by Hitachi for all the plants in which Hitachi will be involved in the future.

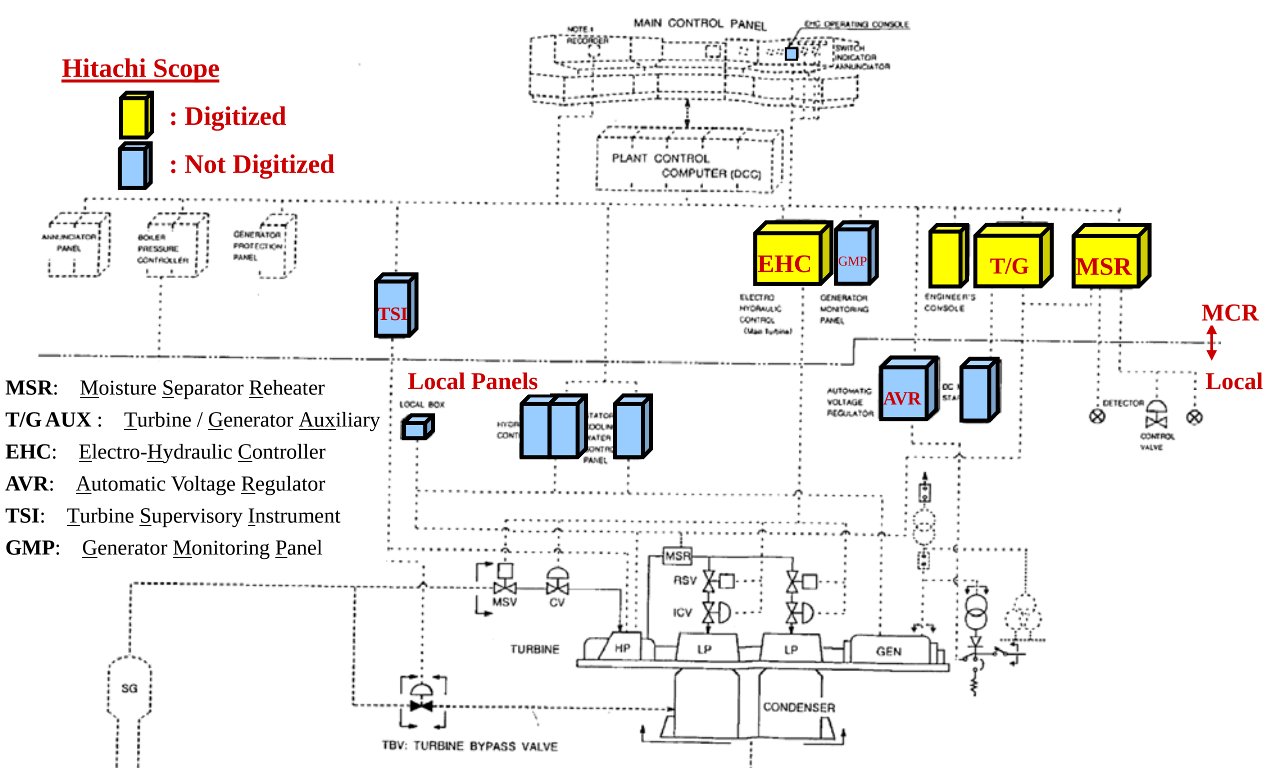


Figure 4: General T/G and Auxiliary System Configuration in CANDU

4.3 Case 3: Supplying the BOP I&C System as a Sub-component of the Turbine/Generator

In this case, Hitachi has supplied EHC (Electric-Hydraulic Controller) and AVR (Automatic Voltage Regulator) as a sub-component of the Turbine and Generator while the other BOP I&C components were supplied by one or more other vendors. EHC controls turbine speed and its control logic and parameters are closely related to the turbine characteristics; therefore, EHC design is standardized to optimize itself for use in combination with a Hitachi Turbine. On the other hand, by appropriately tuning the necessary parameters, the Hitachi EHC can be applied to non-Hitachi turbines. Similarly, the AVR can be tuned for use with non-Hitachi equipment.
As in Case 2, various interfaces with such components as sequencer controllers and HMI devices should be carefully handled.

5. Applying Up-to-Date Technology to BOP I&C System

(1) Fieldbus Networks

The use of fieldbus networks has become increasingly widespread in non-nuclear industrial applications as a result of fundamental digital transmission technology evolution. Although it is not currently an NPP I&C architecture mandatory requirement, fieldbus technology deployment to NPP is expected to introduce significant benefits such as installation cost reduction and improvement of operating efficiency. Hitachi is planning to develop fieldbus interface modules whose possible network protocols will be HART, Profibus and Foundation Fieldbus. Because of its non-criticality, BOP may be the first major system in which fieldbus technology will be applied and whose validity and economical efficiency will be evaluated. Similarly to the application of RMU (Remote Multiplexing Unit), the use of fieldbus device networks could further eliminate a significant quantity of external cabling, specifically direct I/O point/channel-to-device cabling.
Figure 5 illustrates a typical fieldbus network configuration.

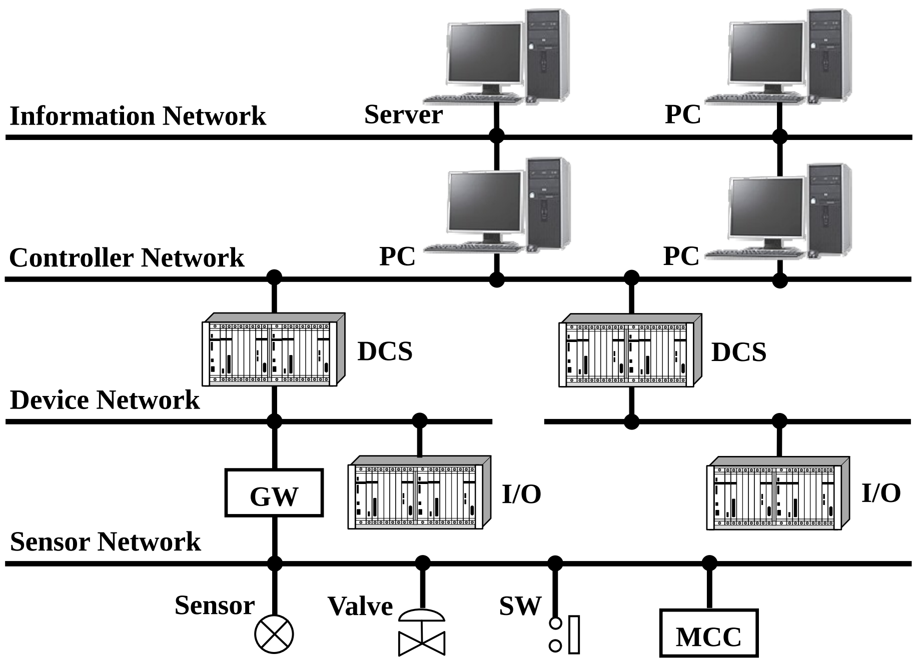


Figure 5: Typical Fieldbus Network Configuration

The principal benefits of applying fieldbus to NPPs are shown below:

- Reduction of external cabling and related hardware such as I/O modules by eliminating point-to-point connections between field devices and DCS I/O.
- Improved reliability and maintainability by enabling on-line diagnoses facilitating preventive maintenance.
- Improved testability by allowing easy and time-saving control loop tests.

On the other hand, the potentially negative issues, which Hitachi understands should be addressed, are as follows:

- Data transmission speed vs. the response time requirements.
- Radioactive resistance of the device and identification of required functions on accidents involving radioactive material release.
- Compliance to international standard such as IEC 61508 SIL 3 and environmental qualification such as seismic qualification for use in safety applications.

(2) Other Technologies

Other technologies whose feasibility Hitachi will be studying are shown in the following list:

- Application of wireless field LAN.
- Web-based remote monitoring and/or maintenance.

The above technologies are hot-topics in the non-nuclear field and will introduce significant benefits to operating efficiency; however, careful technical studies of such aspects as security and noise immunity are necessary. To minimize risk and gain field experience, Hitachi will first apply these new technologies to the non-nuclear industry (e.g., I&C for fossil fuel plants) and then to NPP non-critical systems such as BOP. The results of this step-wise application will determine if more extensive use is possible.

6. Conclusion

For over 30 years, Hitachi has successfully delivered BOP I&C systems for domestic and international projects by adapting them to any plant-specific requirements. The result is that Hitachi has established a standard BOP I&C system configuration which can be deployed regardless of the reactor type or the project formation. Hitachi is ready to supply its BOP I&C system to any type of NPP solely by Hitachi.

In addition, up-to-date technologies such as fieldbus are currently under investigation for use in NPP applications to achieve even higher efficiency, availability and serviceability.

7. REFERENCES

[1] K. Ishii, H. Harada, S. Masunaga and P.E. Marko, **"Hitachi's Project Management Experience on Distributed Control Systems (DCS) in Nuclear Power Plants", 28th Annual Conference of the Canadian Nuclear Society (2007)**

[2] Y. Takano, M. Nakamura and F. Murata, **"New Technology for BWR Power Plant Control and Instrumentation", Hitachi Review Vol. 41 (1992), No. 5**