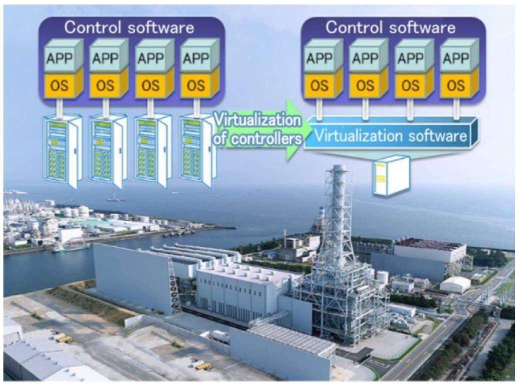
Application of Virtualization Technology to Plant Controllers



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A plant control system has a distributed configuration with multiple controllers for each object or function to be controlled. Therefore, it is difficult to reduce costs by reducing the number of controllers. In order to solve this problem, Mitsubishi Heavy Industries, Ltd. (MHI) is promoting the application of virtualization technology, which is becoming increasingly popular in IT systems, to plant controllers. By applying virtualization technology, multiple controllers can be integrated into and implemented on a single physical hardware, and significant cost reductions and reduction of energy consumption and CO_2 emissions of the controller itself can be expected. This time, to put the virtualized controller into practical use, we have developed methods required for plant controllers for (1) improving the real-time performance and (2) switching the system in a redundant configuration. We have confirmed that the prototype with the control period of 50 msec satisfies the real-time performance and availability required for plant controllers. This report describes on this development.

1. Introduction

A plant control system has a distributed configuration with multiple controllers for each object or function to be controlled as shown in **Figure 1**, making it difficult to reduce costs by reducing the number of controllers. In addition, since controller software is developed for the hardware on which it is to be used, when it is necessary to use hardware with different specifications due to the discontinuation of production of electronic components that make up the controller or other reasons, the software needs to be updated and revised each time, which leads to high maintenance costs. To solve these problems and to contribute to the reduction of CO_2 emissions through the rationalization of facilities and development, we are focusing on virtualization technology, which is becoming increasingly popular in the IT system field, and are working on the application of the virtualization technology to plant controllers.

This report explains the advantages and challenges of applying the virtualization technology to plant controllers, describes methods of improving the real-time performance and switching the system in a redundant configuration, which are solutions to these challenges, and presents the results of evaluating the effectiveness of each solution.

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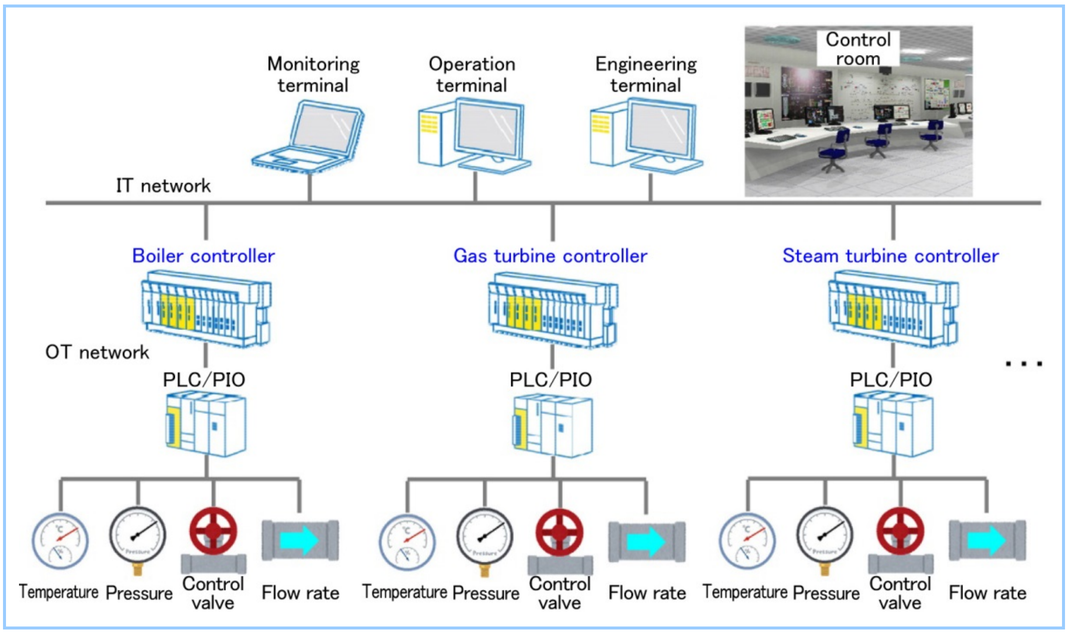

Figure 1 Configuration example of distributed plant control system

2. Application of virtualization technology to controllers

2.1 What is virtualization technology?

Virtualization technology enables software-based control, such as integration and division, of resources without being restricted by their physical limitations, by abstracting physical hardware through software to handle physical resources (e.g., CPU, memory, hard disk and network) as logical resources. This technology enables multiple virtual computers to operate on a single physical hardware, the efficient use of hardware resources without waste, reducing costs, and is becoming more widespread in IT systems such as cloud services. **Figure 2** shows an example of application of the virtualization technology in IT systems.

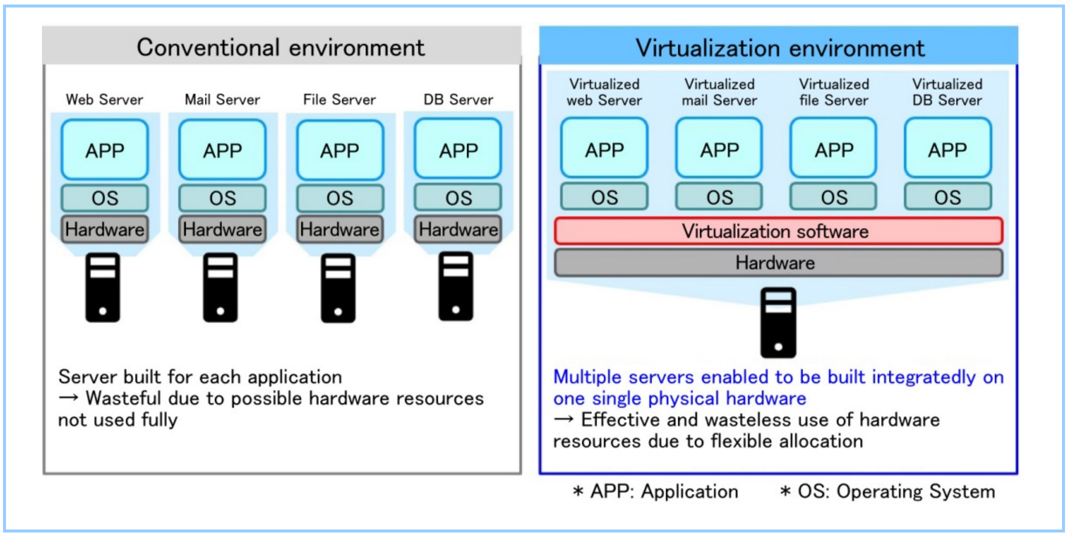

Figure 2 Application example of virtualization technology in IT systems

2.2 Effects of applying virtualization technology to plant controllers

Figure 3 shows a configuration diagram when the virtualization technology is applied to controllers. In addition to the cost-reducing benefits of integrating controllers, since this technology abstracts the hardware, the hardware specification recognized by the software running thereon does not change even if the physical hardware is changed. Therefore, even if the hardware is revised or changed due to the discontinuation of production of electronic components or other reasons, the software can operate without any modification, thus the costs of updating or revising the software can be reduced.

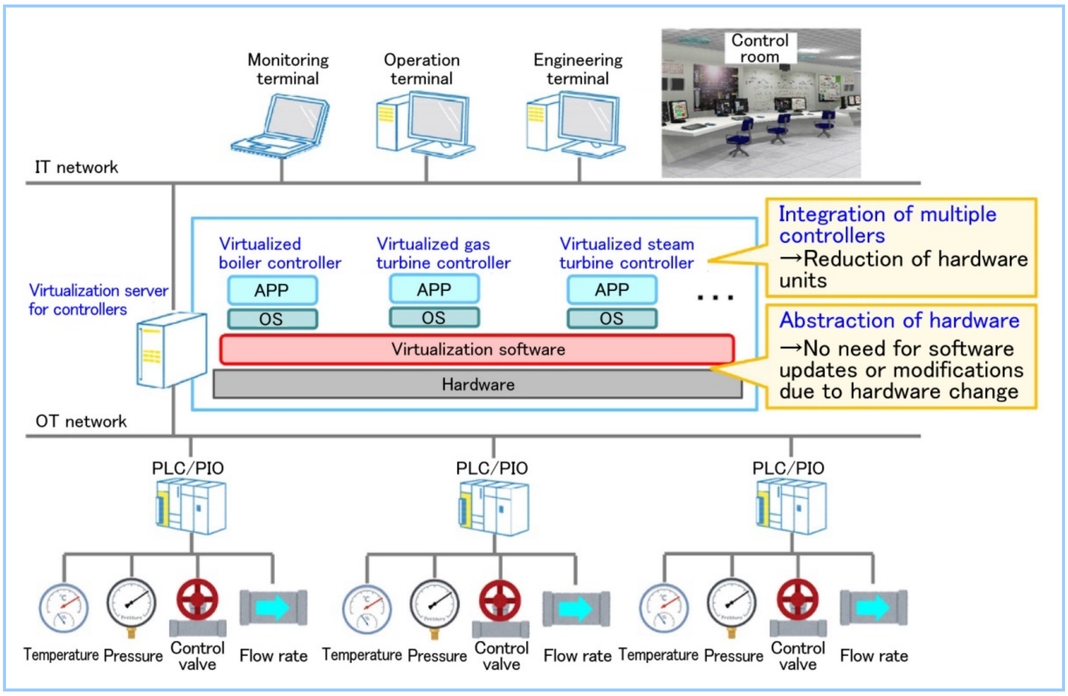

Figure 3 Configuration example of application of virtualization technology to controllers

2.3 Challenges in practical application of virtualized plant controller

The application of virtualization technology brings benefits. However, in order to put it into practical use, the virtualized controller needs to have the same performance as controllers used in a conventional environment and the ability to keep the system operating without stopping (availability).

Plant controllers need to send control signals in real time to safely control the objects to be controlled. However, when the virtualization technology is applied to controllers, the real-time performance is expected to decline due to processes in hardware emulators and virtualization software, which are specific to virtualized controllers.

In addition, plant controllers are required to have high availability, and so have a redundant configuration consisting of a dual system of "active side" and "standby side". The virtualized controller still needs to be redundant, and is required to quickly switch from the active side to the standby side and output a control signal to the controlled objects in the event of an anomaly. However, we haven’t developed a system switching method for virtualized controllers and evaluate the performance of switching time.

Therefore, to put the virtualized controller into practical use, we have developed methods required for plant controllers for (1) improving the real-time performance and (2) switching the system in a redundant configuration.

3. Prototyping of virtualized controller

Two virtualized controllers were constructed on one physical hardware using virtualization software Kernel-based Virtual Machine (KVM)[(1)], and two physical hardware units were used to construct a dual-redundancy configuration. **Figure 4** and **Table 1** show the configuration diagram and environment, respectively. It is assumed that in the initial state the virtualized controllers on the physical hardware 1 side (active side) operate, and a switch to the virtualized controllers on the physical hardware 2 side (standby side) is made if an anomaly occurs on the physical hardware 1 side.

In addition, based on the actual control system configuration, the operational technology (OT) network for exchanging data such as control signals between the controller and the controlled object and the IT network for exchanging data necessary for operators to perform monitoring and management between the controller and the engineering terminal were built. The virtualized controllers execute a control signal transmission program to transmit control signals to the controlled object at regular cycle. In this evaluation, the transmission cycle was set to 50 msec, assuming there is a plant controller.

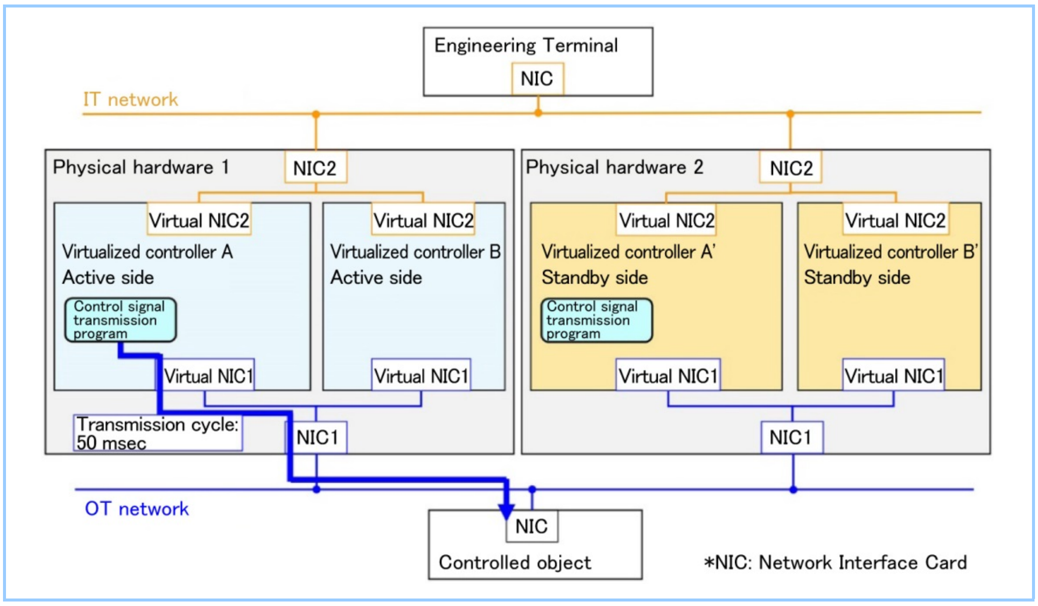

Figure 4 Evaluation configuration of virtualized controllers with redundancy

Table 1 Evaluation environment

System	Item	Information and version
Physical hardware	OS	Ubuntu 18.04 64bit (Linux Kernel 5.4.54)
	CPU	Core i5-9500vPro 3GHz
	MEM	8 Gbyte
	PREEMPT-RT patch	5.4.54-rt33
	Virtualization software (Hypervisor)	KVM (Kernel Virtual Machine)
Virtualized controller	OS	Ubuntu 14.04 32bit (Linux 3.12.74)
	Core number	2 cores
	MEM	2 Gbyte
	PREEMPT-RT patch	3.12.74-rt99

4. Improvement of real-time performance of virtualized controller

4.1 Application of real-time performance improvement method

In order to improve the real-time performance of virtualized controllers, the following methods (a) to (c), which are described in the reference (2), were adopted.

(a) Reduction of task switching overhead by changing exclusion control

In order to ensure real-time performance, it is necessary to promptly execute without delay a task with a higher priority than the task being executed when it occurs. In a normal kernel, a preemption prohibition time (overhead) occurs due to a spinlock, which is responsible for exclusion control. Therefore, we applied the PREEMPT_RT patch(3) to the kernel to perform preemptible exclusion control and reduce the overheads when switching tasks.

(b) Reduction of processing delay by changing scheduling priority of hardware emulator (QEMU)

Access from the virtualized controller to hardware resources such as the CPU and communication interface is processed through the hardware emulator (QEMU) running on the host computer. If a queuing time occurs in the execution of the hardware emulator, the processing of the virtualized controller is also delayed. Therefore, the priority of the hardware emulator is set to a level higher than for other tasks that do not require real-time performance in order to reduce the queuing time.

(c) Avoidance of resource conflict by static allocation of CPU core

If the CPU core that the virtualized controller accesses is in another use (conflict), processing delay due to queuing occurs. Therefore, we eliminated processing delays by allocating the CPU core for the use of each virtualized controller separately to avoid conflicts.

4.2 Evaluation of real-time performance of virtualized controller

4.2.1 Evaluation method

In general, real-time performance is the capability of executing a process within a certain constraint time. In the case of our plant controller, if the interval of receiving control signals from the controller measured by the controlled object exceeds the constraint time (twice the control cycle, 100 msec in this report), it is determined that the control signal is interrupted and detected as an anomaly. In this evaluation, the interval of receiving periodic control signals was measured at the controlled object, and the difference from the transmission cycle of the virtualized controller was evaluated as the "reception delay" as shown in **Figure 5**. During the measurement, file transfer and writing processes were executed for applying a system load.

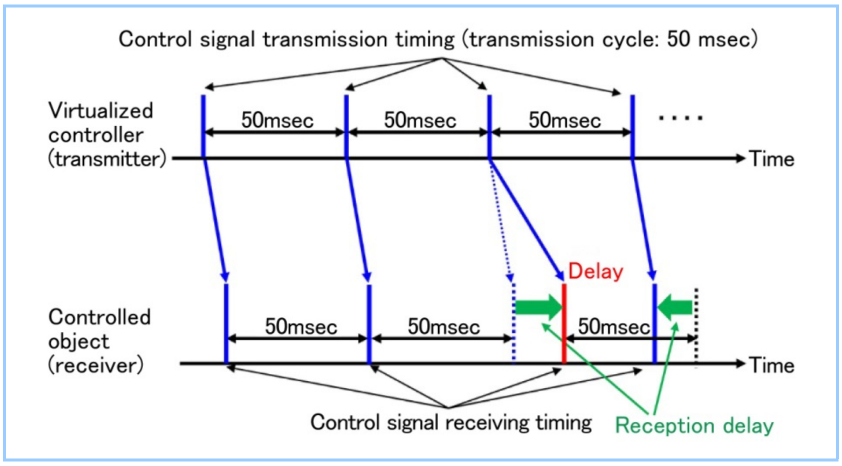

Figure 5 Reception delay

4.2.2 Evaluation result

Control signals were transmitted 1.44 million times (20 hours continuously) to the controlled object, and the reception delay was measured before and after the application of the real-time performance improvement method. **Figure 6** shows the measurement results. It was confirmed that the average, the maximum and dispersion of the reception delay were reduced and the real-time performance of the virtualized controller was improved by applying the real-time performance improvement method.

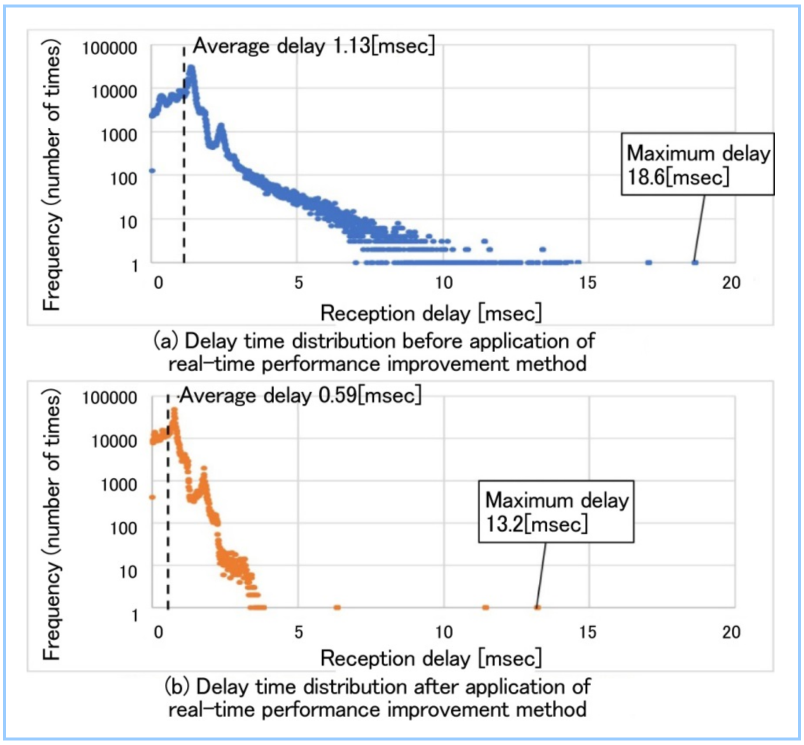

Figure 6 Reception delay distribution for 1.44 million times (20 hours) of measurement

5. Development of system switching method in redundant configuration of virtualized controller

5.1 System switching method

The establishment of automatic switching to the standby side at the time of an anomaly in a redundant configuration requires the system to automatically detect the anomaly and perform the switching. We adopted a system switching method in which the duplex virtualized controllers send each other periodic signals called confirmation signals. When one controller can no longer receive the other's confirmation signal, the controller determines that the other has stopped, switches the system, and comes on the active side. **Figure 7** shows a schematic diagram of the switching method.

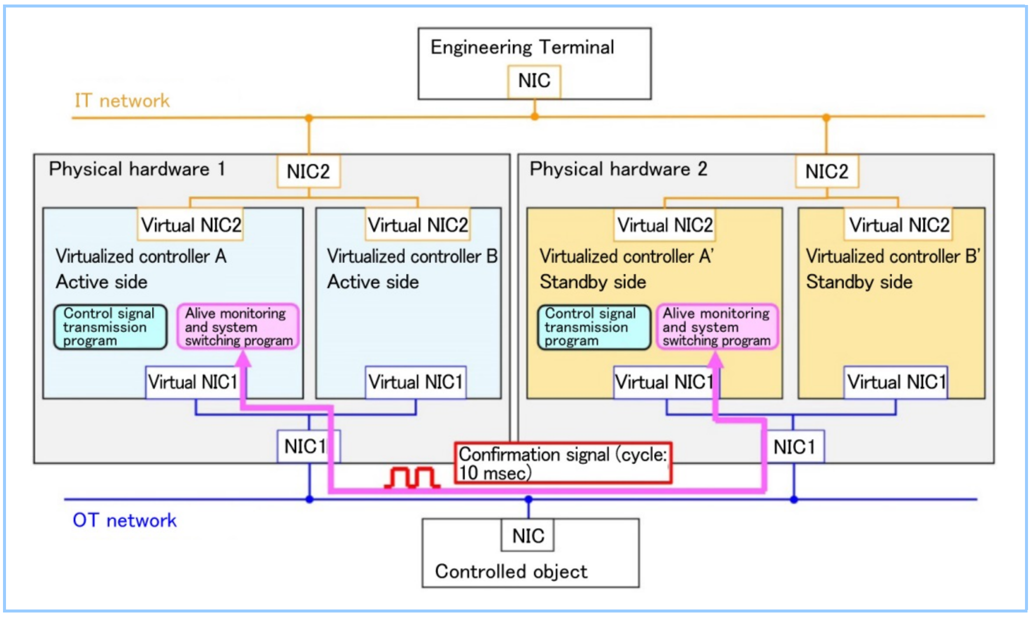

Figure 7 System switching method in redundant configuration of virtualized controllers

The procedure of the system switching method is as follows.

- In the initial state, the virtualized controller A of the physical hardware 1 is on the active side and the physical hardware 2 is on the standby side.
- Control signals are sent only from the active side.
- The virtualized controllers on the active side and the standby side send and receive confirmation signals to each other via the OT network in 10 msec cycles.
- If the standby side does not receive a confirmation signal from the active side while the standby side sends the confirmation signal three times, the standby side switches to the active side and starts sending control signals.

Some commercially available redundant servers exchange confirmation signals for alive monitoring via dedicated lines or IT networks. On the other hand, in plant control, it is important not to send the wrong signal to the controlled object. When a wire disconnection on the network occurs, both of the duplex virtualized controllers would be on the active side and output control signals. When using a dedicated line or an IT network, the controlled object would receive control signals from the two, which leads to a risk of malfunction (**Figure 8** (a)).

Therefore, we adopted a method of exchanging confirmation signals via the OT network (Figure 8 (b)) in this development. In this case, even if a wire disconnection on the network occurs and both of the duplex virtualized controllers become on the active side, both control signals do not reach the controlled object, so a malfunction of the controlled object can be avoided.

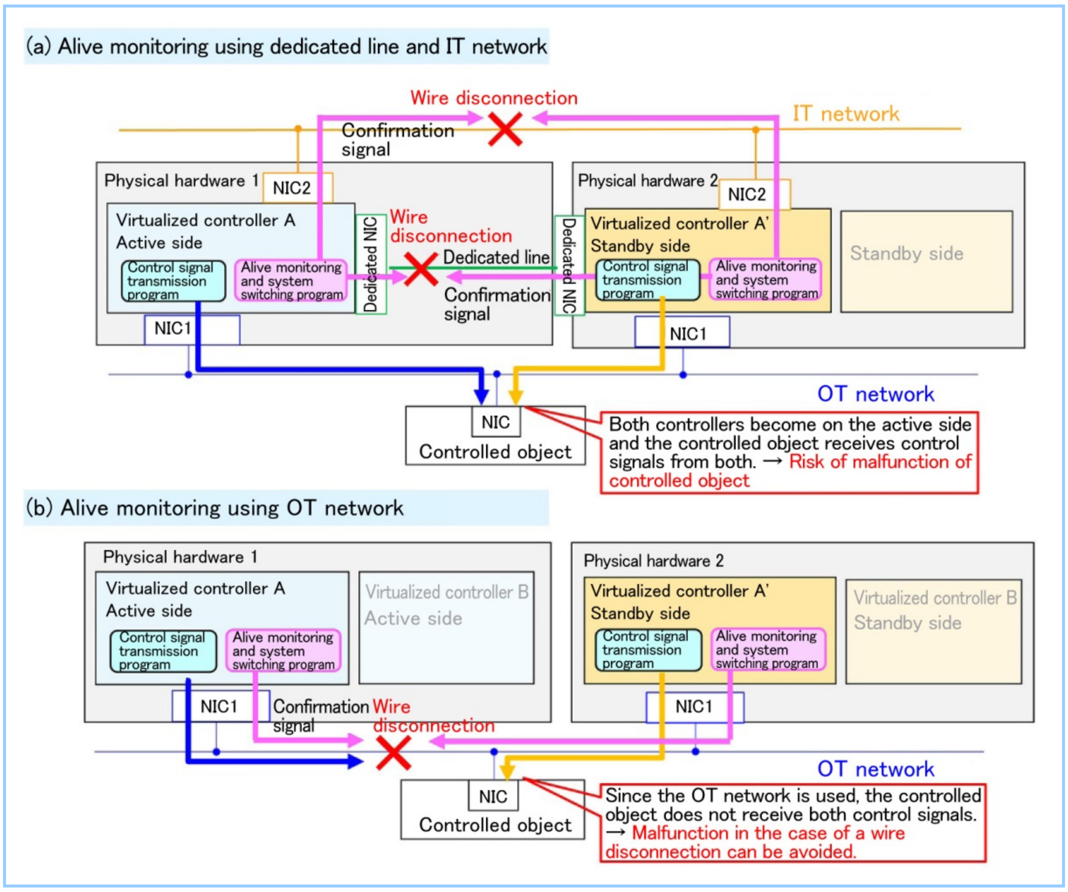

Figure 8　Behavior at the time of a network wire disconnection

5.2 Evaluation of switching time between active and standby sides

5.2.1 Evaluation method

We evaluated the time span of receiving the control signals immediately before and after switching the signal transmitter as the switching time between active and standby sides in the dual-redundancy configuration (**Figure 9**). As described in section 4.2.1, when the reception interval of control signals exceeds the control cycle (twice 50 msec in this report), it is detected as an anomaly. Therefore, the target value of the switching time was set to 100 msec or less in this evaluation. In order to apply a load to the system, file transfer and writing processes were executed on the virtualized controller on which the fixed-cycle control signal transmission program runs.

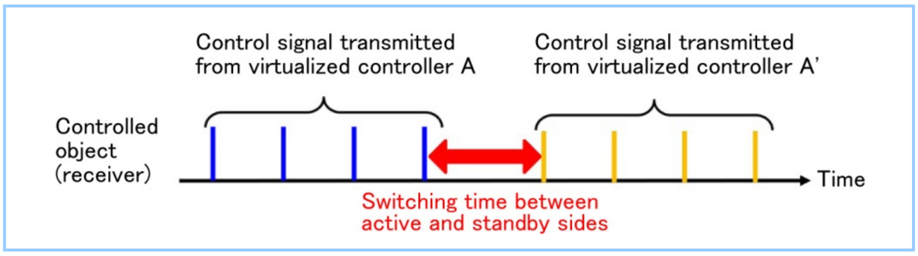

Figure 9　Switching time between active and standby sides

5.2.2 Evaluation result

With the virtualized controller A of the physical hardware 1 on the active side, two switching trigger cases were generated by (1) shutting down the virtualized controller A and (2) shutting down the physical hardware 1, and the switching time between active and standby sides was measured 10 times for each case. **Figure 10** shows the results.

It was confirmed that the switching time was less than the target value of 100 msec in both cases, which means that the virtualized controller can still make switching within the time required as a plant controller.

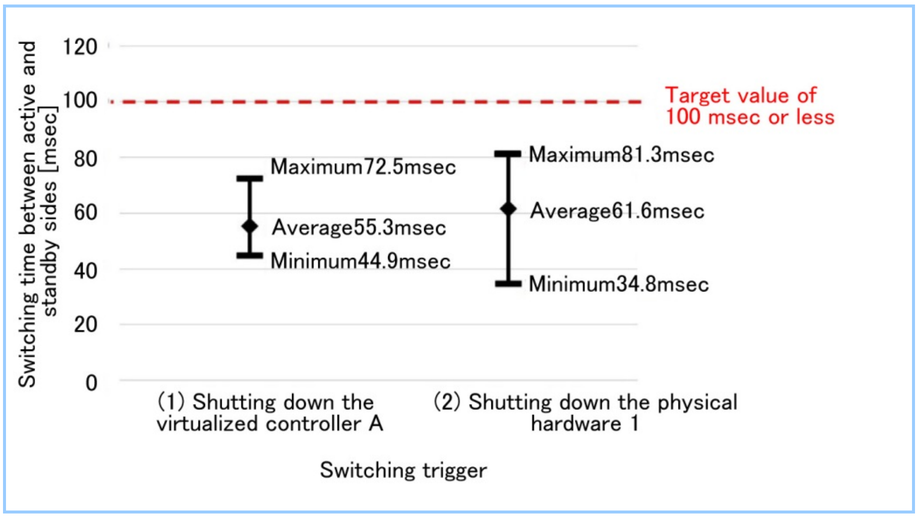

Figure 10 Measurement result of switching time between active and standby sides (Measured 10 times each under both conditions)

6. Conclusion

Aiming to reduce costs and CO_2 emission by applying the virtualization technology to plant controllers, we have developed technologies of (1) improving the real-time performance of the virtualized controllers and (2) switching the system in a redundant configuration, in order to put the technology into practical use. As a result, we have confirmed that the prototype controller to which the virtualization technology is applied satisfies the real-time performance and availability required for plant controllers.

We will continue our research to apply this technology to applications including our controller Netmation, which is used in thermal power plants, factories, etc. and work to improve the sophistication of our products.

References

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