Study on the MMIS Concept Design Method for Innovative Small Modular Reactor

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1. Introduction

Recently, the need for small modular reactors has emerged greatly, and there has been an increasing interest in the development of SMR technology, which has increased safety and economics compared to large nuclear reactors. These SMRs have the feature that greatly reduces the structures of the existing large nuclear power plants to make them integrated, and the output power is designed to be less than 300MW to ensure high safety. In addition, through the modularization of the reactor, the power can be adjusted as needed and various operation functions such as hydrogen production can be implemented as well as electric power operation. However, in order to ensure the economic and export competitiveness compared to large nuclear power plant, it is necessary to optimize staffing by applying the latest technologies such as operation automation, system simplification, smart sensor technology and predictive diagnostics in order to operate multiple modules in one main control room. In this paper, we will introduce MMIS development strategy and conceptual design method for innovative SMR(ISMR).

2. Main Requirements for ISMR MMIS

The ISMR is composed of an integrated reactor and steam generator, and electrical power of one module is 300MWe or less. Safety function of ISMR is applied with the passive emergency core cooling function, passive auxiliary feed water system, heat transfer function through the wall for cooling and decompression of the containment. With ISMR structure characteristics and safety function, Main requirements for MMIS(Man-Machine Interface System) design are as follows [1].

- Operation of 4 modules in one main control room
- 3 MCR operators
- Operator’s allowable time for action is 72 hours or more
- Plant outage response time is more than 72 hours.

3. Review of Operation Concept for ISMR MMIS

5 MCR(Main Control Room) operators performed normal operation, alarm response, abnormal operation, emergency operation in one MCR of APR1400 large nuclear power plant. However, 1 RO(Reactor Operator) should monitor integrity of 4 reactor modules and perform normal operation, alarm response, abnormal operation, and emergency operation in one MCR of ISMR[1]. MMIS concept design for operation support needs to be developed considering new operation approach for ISMR as described in Table1.

Table 1 Example of New operation approach

Condition	Approach
Normal operation	SS/STA/RO monitors 4 reactor module. STA can support all operation condition
Abnormal operation/ Emergency operation	When an abnormal(or emergency) situation occurs in one module, perform an abnormal(or emergency) response procedure for corresponding module: operator can select manual mode or automatic mode. Operator monitors the automatic mode execution process and results, override the automatic mode execution procedure if necessary. If necessary, the STA(Shift Technical Assistant) can perform the monitoring role of RO. In case that emergency accident occurs in more than 2 modules at the same time, it is necessary to assign priority for emergency accident response and automate response task. SS(Shift Supervisor) should confirm and monitor performance of EOP in 4 module. STA task can be automated that check safety function status check every periodic time.

4. Review of Concept of MMIS Architecture and MCR Configuration

4.1 Development Principle of ISMR MMIS Architecture

ISMR MMIS needs to be developed through latest technology for securing safety & economics and technology competitiveness. Therefore, following development principles needs to be applied in ISMR MMIS.

- Simplicity: Simplified MMIS Platform configuration, simplified MMI component, and simplified interface among systems
- Robustness: Defense-in depth application in the control algorithm
- Predictability: Function of plant and system can be achieved even in various operation mode and

operation state based on predictable function

- Operability: Automation of start-up and stop operation, automatic test under operation, convenient operation using simple manipulation.
- Fault diagnosis: Easy fault identification and resolution in 4 modules
- Maintainability: Function for easy maintenance activity such as on-line calibration and integrity check etc.
- Design Implementation for MMIS: Design of Independence, Redundancy, and Diversity & Defense-In Depth based on simple design application

4.2 Configuration Concept of ISMR MMIS Architecture

When considering above 7 development principles, Table2 provides configuration example of ISMR MMIS architecture. As described in the Table2, each system can be considered to be applied to each of the 4 modules and to be applied as 1 whole system for 4 modules[1]. MMIS architecture of ISMR can be configured through optimal function and conventional proven technology considering concept of module and plant as shown in Table 2.

Table 2 Example of ISMR MMIS Architecture

System	Function	Configuration
Module Protection and Monitoring system	- Protection function - Monitoring function of safety function - H/W based manual actuation function	Same configuration for each module
	- BOP protection function	Integrated configuration for all modules
Module Power Control and Monitoring System	- Automatic control function(NPCS and PCS, etc) - Monitoring System(Monitor control component failure and integrity)	Same configuration for each module
Information Processing System	- Monitoring plant state - Alarm processing function - Soft control function - Procedure based operation function(Auto and Manual) - Predictable and diagnostic function	Same configuration for each module

4.3 Configuration Concept for ISMR MCR

If we conceptually review the main control room configuration plan for ISMR, two types of MCR configuration can be considered[1]. Figure1 is similar to APR1400 and composed of 3 operator consoles, 4 LDPs for each module, common LDP for all module, and safety console for each module. Example1 has the characteristics that distinguish between normal operation means and backup means. But, it is difficult to identify all conditions of each module. Figure 2 shows integrated form of LDP and safety console for each module, it has the advantage of being able to identify the condition of each module at once. But, it is difficult to easily differentiate safety and non-safety information due to the mixed information. Therefore, review and assessment is required from a variety of perspectives.

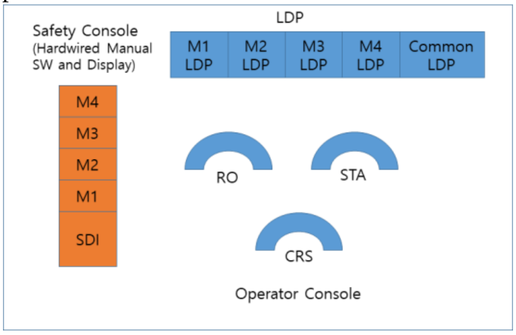

Figure 1 Example 1 for MCR configuration

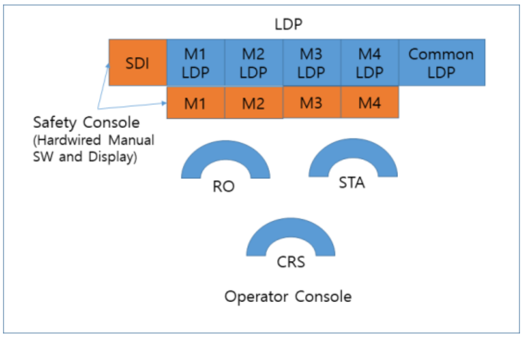

Figure 2 Example 2 for MCR configuration

5. Conclusions

As ISMR requires multi-modules operation in one MCR, high level automation to reduce operation workload such as multi-module monitoring and response for alarm and control should be applied compared to large nuclear power plant. Also, optimized staffing for ISMR should be able to smoothly perform the operation of normal, abnormal, and emergency operation for each module. Technical basis has to be established to resolve high level automation and optimized staffing issues. This issues needs to be systematically considered in all of the design fields from concept design phase.

REFERENCES

[1] Review Report of Conceptual design method for ISMR MMIS(2022, KHNP)
[2] NUREG/CR-7126 "Human Performance Issues Related to the Design and Operation of Small Modular Reactors"