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A Study on Automation Strategies in Nuclear Power Plants through Minimizing Manual Operator Interventions

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1. Introduction

The introduction of automation technology to improve the operational efficiency and safety of modern nuclear power plant (NPP)s has become an essential task. In particular, the design examples of automated operation shown in the design of modular reactors such as NuScale have important implications for the design and operation of new reactors. This paper explores the possibility of improving operational efficiency and safety through automation of operating bypass, which should be considered from the beginning of design, and investigates its applicability to domestic NPPs by considering the NuScale case.

In this paper, it is addressed the operating bypass cases in domestic NPPs and NuScale and proposed the direction of operating bypass design for future operational automation.

2. Operating Bypass

The operating bypass is used to enable routine startup and shutdown of the reactor and testing at low power. The operating bypass can be executed in the reactor protection system operator module in the main control room (MCR) and in the maintenance and test panel located in the instrumentation and control equipment room.

Currently, most of the operating bypasses in domestic NPPs are initiated manually by the operator. If the bypassed condition cannot safely maintain the plant, the operating bypass is automatically removed when it rises above a pre-determined setpoint to reliably remove the operating bypass. When the operating bypass is automatically removed, the operator must manually restart the bypass while the conditions for allowing the operating bypass are satisfied to perform the operating bypass again.

2.1 Domestic NPP: Shin hanul and SMART100

The number of operating bypass switch per reactor of domestic NPPs (Shin Hanul 1&2 and SMART100) are shown in Table 1. Domestic NPPs use 20 operating bypass switches, five for each of the four channels, as shown in Table 1 below, for manual initiation of each operating bypass function. If a large number of modular reactors, such as NuScale, are used in one MCR, the number of operating bypass switches would be a multiple of the number of modular reactors. This would require a large number of switches to be installed in the MCR, increasing the workload of the operator and the potential for human error. Therefore, new NPPs including small modular reactor (SMR) should implement automated design of operating bypass to improve these problems and automate the operation of nuclear power plants.

Table 1: Operating Bypass in Domestic NPPs

	Shin Hanul 1&2	SMART100
Auto Initiation Auto Removal per Channel	1	1
Manual Initiation Auto Removal per Channel	5	5
No. of Switch *)	20	20

* Number of Operating bypass switch installed at MCR.

2.2 NuScale

Modular NPPs such as NuScale have adopted automation design and automation systems for the operation of multiple independent modular reactors in a single MCR. In terms of operating bypass, which is the focus of this paper, there are many operating bypass functions, but most of them are designed to be automatically initiated when certain conditions are met and automatically removed when certain conditions are exceeded.

NuScale has designed two types of modular reactors: the Standard Plant type, which can use up to twelve (12) 50 MWe modular reactors [2], and the US460 plant type, which can use up to six (6) 77 MWe modular reactors [3]. The operating bypasses used by NuScale are summarized in Table 2 below.

The NuScale utilizes six operating bypass switches, three for each of the two divisions, for manual initiation of operating bypass for the permissive and override functions shown in Table 2. The number of operating bypass switches in NuScale is less than that of domestic NPPs. For the operation of six modular reactors in a single MCR, such as the US460 plant, only 36 total operating bypass switches are required.

The module protection system (MPS) has operating bypass circuits that automatically prevents the activation of an operating bypass or initiates the appropriate safety functions when permissive or interlock conditions for the operating bypass are not met and that allow a protective function to be bypassed when the function is not required and interlock features that automatically activate an operating bypass when conditions are met [2,3].

Table 2: Operating Bypass in NuScale

Operation Type	Standard Plant	US460 Plant
Auto Initiation Auto Removal per Division (Interlock function)	15	11
Manual Initiation Auto Removal per Division (Permissive function)	2	2
Manual Initiation Manual Removal per Division (Override function)	1	1
No. of Switch *)	6	6

* Number of Operating bypass switch installed at MCR per modular reactor.

As described above, NuScale has designed the operating bypass functions to use automatic initiation and automatic removal as much as possible and manual initiation or manual removal as little as possible to minimize operator intervention in the MCR. In other words, most operating bypasses are designed to be automatically initiated and automatically removed through interlocks, with a few cases (permissive and override functions) requiring manual intervention by the operator. Nevertheless, this design represents a significant improvement in terms of operational automation compared to the design of domestic NPPs.

3. Conclusions

With respect to the operation of modular nuclear power plants, minimization of operator manual means, and automation of operating bypasses are important strategies that can simultaneously improve safety and efficiency. The cases of the domestic NPPs and NuScale reviewed in this paper demonstrate the applicability and benefits of these strategies. In particular, the design of recent SMR, such as NuScale, emphasizes the importance of automation, which aims to simplify operations and improve safety.

The design phase for the automation of the operating bypass function requires collaboration among experts from various design fields. Since the operating bypass function is directly linked to the safety and efficient operation of the plant, the specialized knowledge and skills from each design field must be considered in an integrated manner. The fluid design field involves understanding the flow and pressure conditions of various fluid systems within a plant (e.g., cooling systems, steam systems), predicting and analyzing fluid dynamic situations that may arise during operating bypass, and applying these analyses in the design process. The safety analysis field is responsible for evaluating the safety of the nuclear power plant during operation bypass states, forecasting potential risk scenarios, and devising mitigation strategies. Based on these, it contributes to risk analysis, development of accident scenarios, and validation of safety system designs. The instrumentation and control (I&C) design field should be tasked with implementing the automation design of the operating bypass function, handling key tasks related to overall plant system monitoring, development of control algorithms, interface design, and system integration.

In terms of applying automatic operating bypass, it is expected that the design philosophy and interlock strategy limitations of existing nuclear power plants will make it difficult and costly to integrate new automatic operating bypass due to their original construction standards and predominantly manual control methods. In contrast, new modular nuclear plants such as NuScale are characterized by design flexibility, built-in interlock systems, and improved system integration, making them well suited to integrate advanced automation features such as automatic operating bypass with minimal manual intervention..

In conclusion, the operational automation of modular nuclear power plants is a complex technical challenge and a significant opportunity. Through the minimization of manual operator intervention and the automation of operating bypasses, we can expect to increase the safety and efficiency of nuclear power plant operations. Furthermore, the automation of the operating bypass function is expected to introduce numerous new challenges, including overall system integration and interaction, operator interfaces and training, and compliance with legal/regulatory requirements.

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