Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, Oct 24-25, 2024

Regulatory Basis of Function Allocation on Adaptive Automation in a Small Modular Reactor (SMR)

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1. Introduction

Small modular reactors (SMRs) can respond flexibly to small or medium-sized power demands, meeting localized power needs that do not require large amounts of power. In addition, SMRs are becoming increasingly attractive for other purposes beyond power generation, such as hydrogen production and desalination. These advantages of SMRs can overcome the inefficiencies of conventional nuclear power plants in generating large amounts of power and transmitting it to the grid.

However, it has been pointed out that SMRs are difficult to secure competitiveness in terms of power generation cost compared to conventional large nuclear power plants. Therefore, the trend of SMR development in Korea and abroad is introducing strategic and innovative design technologies to minimize construction costs. Examples include reactor modules that can be manufactured in factories and manufacturing technologies based on 3D printing technology.

In addition, innovative operating concepts are being introduced that allow multiple reactor modules to be operated by a relatively small number of personnel in one integrated Main Control Room (MCR). These innovative operating concepts are favorable in terms of SMR operation and maintenance costs. Innovative approaches to the operation and maintenance of SMRs are made possible by the integration of advanced ICT technologies, i.e. technologies that increase the level of automation of SMRs.

Therefore, it is necessary to establish a regulatory system that considers the innovative design characteristics of SMRs. This study proposes a regulatory basis for the safety evaluation of increased level of automation in relation to the concept of multi-module integrated MCR operation.

2. Research Method and Content

Automation in SMRs can be broadly categorized into two types: functional automation and task automation. Functional automation refers to the ability of an SMR system to perform many of the functions required to achieve its goals (e.g., safety and power production) without human intervention. Automation of these functions is already common in large existing nuclear systems. Examples include the automation of protection functions, which are central to plant safety, and the automation of feedwater control, water level control, and turbine control functions. Automation of tasks means that a specific system takes over a human task. An example is automation where a system checks for specific conditions through an operating procedure and performs a specific task defined to be performed under those conditions.

SMRs are being developed to enable safe and efficient operation by introducing these automation technologies from the early conceptual design stage. In Korea, it is known that such automation technologies are being actively introduced and applied to the development of innovative SMRs (i-SMRs).

Increasing the level of automation of SMRs is one of the key concerns for safety assessments from a regulatory perspective. In particular, human factors regulations require in-depth safety assessments not only of the safety of the automation system, but also of the interaction between the automation system and the human operator. The interaction between automated systems and human operators is called adaptive automation. Therefore, it is necessary to establish a technical basis for human factors regulations for adaptive automation. In particular, the definition of the safety functions of SMRs and the power generation functions that can affect the safety functions, as well as the allocation of each defined function, are closely related to adaptive automation.

Approaching adaptive automation from a human factors regulatory perspective fundamentally starts with how increasing the level of SMR automation can impact safety. The increased level of automation has highlighted the following positive perspectives, generally.

- Increasing the level of automation ultimately leads to improved system performance. Improved system performance ultimately leads to improved safety.
- Increasing the level of automation reduces the burden on operators. Automating the most demanding operator tasks can improve safety.
- Increasing the level of automation can minimize the operator tasks and thus minimize the frequency of human error. By reducing the frequency of human error, safety is improved.
- Increasing the level of automation increases the automation of operations and maintenance tasks. By reducing the number of safety degradation factors that can occur during operations and maintenance tasks, safety is improved.

The positive perspectives above seem to point in the same direction: increasing automation and improving safety go hand in hand.

However, it has long been recognized that for safety-critical and complex systems, including SMRs, increasing the level of automation can lead to the following concerns.

- The problem of situational awareness as the level of automation increases is that the more complex and dynamic the system, the less successful human performance can be guaranteed (Endsley, 1996).
- Low workload at high levels of automation can lead to boredom and fatigue due to a lack of cognitive involvement (Kaber & Endsley, 2004).
- High workloads that are demanded in a hurry induce a rapid decline in situational awareness, which leads to poor job performance and makes it difficult to recognize changes in the system (Endsley, 1993).
- Automation systems support operator performance. However, if the automation system deteriorates or fails, the operator may no longer trust the automation system and overall task performance may not improve (O'Hara & Higgins, 2020).

Therefore, the human factors regulatory approach to adaptive automation of SMRs is basically that no concept of operation that excludes the operator is acceptable, even as the level of automation of SMRs increases. This basic regulatory approach can be summarized in three points

- High-level supervision and management functions should be assigned to the operator rather than the automation system.
- The operator must be able to respond appropriately to unplanned or unexpected events or accidents.
- The operator must be able to respond appropriately to degradation or failure of the automation system.

Ultimately, the safety assessment of adaptive automation is focused on reviewing that the optimal level of automation has been established from a safety perspective. The optimal level of automation is directly related to the function allocation criteria set by the operator. Therefore, reasonable technical criteria must be in place to appropriately allocate defined functions (especially safety functions) to the automation system and the operator according to the design characteristics of the SMR.

Safety assessments of adaptive automation should be based on the following functional allocation criteria

- Fully automated functions shall ensure safety without operator intervention in any case. However, means shall be provided to monitor the performance of the fully automated functions.
- Functions that involve knowledge-based decision making should minimize automation. However, automation may be assigned as a means of supporting knowledge-based decision making.
- For functions that involve a high cognitive load due to the technical limitations of automation, automation should be supplemented by functions that allow the operator to perform the function with minimal cognitive burden by accepting procedural information.
- If the automation of a function minimizes the need for an operator, it must be possible for the operator to continuously monitor the operational status of the automated function. It must also allow for immediate operator intervention in the event of degradation or failure of the automated function.

3. Conclusion

In order to be competitive in the global market, innovative SMRs developed in Korea must be guaranteed safe from a regulatory perspective. Therefore, the review guidelines for large light water reactor nuclear power plants need to be improved so that they can be utilized for the review of SMRs. In terms of human factors regulation, new human factors issues may arise from the introduction of the multi-module integrated MCR operation concept. In particular, new function allocation criteria for adaptive automation that accompanies the increase in automation level should be established. The function allocation criteria for adaptive automation proposed in this study is expected to be utilized as a technical basis for regulators' safety assessments.

ACKNOWLEDGEMENT

This work was supported by the Nuclear Safety Research Program through the Regulatory Research Management Agency for SMRS (RMAS) and the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. 1500-1501-409).

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