Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22-23, 2025

Security Regulation Prospects for Nuclear Power Plant Digital Twins

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Keywords : Digital Twin, Nuclear Power Plant, Digital System, Cyber Security

1. Introduction

Recently, cutting-edge digital technologies such as deep learning and artificial intelligence are rapidly expanding to all technological fields, and nuclear power plants are no exception. It is expected that greater flexibility will be allowed in the operation of nuclear power plants in the future as digital technologies are increasingly adopted. On the other hand, there is a possibility that various situations may arise where existing operational experiences and procedures cannot be applied as they are. SMRs, which are currently under development worldwide, are adopting design concepts that are different from existing nuclear power plants, such as power output matchup with renewable energy, load follows, autonomous operation, and remote wireless communications. If digital twin technology, which is already being applied in other industries, can be applied to nuclear power plants, it is expected that problems that may occur throughout the entire life cycle from design to construction, operation, and decommissioning can be proactively addressed. However, in order to do so, sufficient review of cyber security in particular must be conducted, and related regulatory standards must also be prepared promptly.

2. Application of Digital Twins to Nuclear Power Plants

2.1 Digital Twin Concept and Current Status

A digital twin refers to an identical implementation of a physical object, process, or system in the real world in the virtual world. By utilizing cutting-edge technologies such as sensors, the Internet of Things (IoT), and artificial intelligence (AI), real-time data can be collected and analyzed to update virtual models, accurately predict real-world situations, and simulate various scenarios to make optimal decisions. The elements required for implementing digital twins are summarized as follows:

① Implementing physical objects, processes, or systems in the real world as various forms of digital models such as 3D models and simulations
② Collecting data from physical objects in real time through sensors, IoT devices, etc. and reflecting them in virtual models
③ Predicting the situation of physical objects and supporting optimal decision-making by simulating and analyzing various scenarios
④ Physical objects and digital models are bidirectionally linked to communicate in real time and continuously update data

Digital twins are being utilized in various industrial fields, and their value has already been proven by being applied to production facilities such as smart factories, construction of infrastructure such as roads and bridges, and shipbuilding and operation. In addition, they are being utilized in various fields such as aviation, defense, and logistics, and the scope of utilization is expected to expand further to include power generation and power grid operation.

2.2 Current Status of Nuclear Power Plant Digital Twin Research

Nuclear power plant digital twin research is attracting attention as a key technology for maximizing the safety and efficiency of nuclear power plants. Research is underway to virtualize the MMIS system, which acts as the brain of a nuclear power plant, and simulate and verify it in an environment identical to any actual situations. This will allow for the prediction of various scenarios that may occur at the power plant in advance and the establishment of optimal response measures. In addition, it seems possible to implement major facilities such as reactors, turbines, and pipes and building structures as digital twins to monitor their status in real time and improve maintenance efficiency. Applying AI technology will allow for the analysis of nuclear power plant data and early detection of abnormal signs, enabling accident prevention and rapid response. Currently, the KHNP has completed the development of the MMIS digital twin for the APR1400 reactor, and Doosan Enerbility and the KAERI are also conducting digital research. The expected effects of applying digital twins are as follows.

① Safety Improvement: accident prediction and prevention, emergency response simulation, equipment abnormality detection and diagnosis
② Efficiency Increase: operational data analysis and derivation of optimal operational requirements,

predicting the time of necessary maintenance, optimizing power plant design and construction

③ Regulatory Verification Utilization: safety verification and regulatory compliance verification through simulation, pre-verification with digital twins when Introducing new technologies

2.3 Security Issues

Although applying digital twins has the potential to improve the efficiency and safety of nuclear power plants, it can also raise new regulatory issues in terms of cybersecurity. The main regulatory issues are as follows:

① Reliability and Safety Verification of Digital Technology:

Most digital twins are equipped with artificial intelligence models, especially deep learning models, and their operation methods are complex, making it difficult to evaluate reliability using traditional software verification methods. In particular, when making decisions directly related to the safety of nuclear power plants, prediction errors or malfunctions in digital twin models can lead to serious accidents. In addition, recently pointed out bias in learning data of AI models and vulnerability to hostile attacks are also obstacles to safety verification.

② Cybersecurity issues:

Digital twins require two-way communication with the nuclear power plant control network, and in the case of SMRs, there are cases where the control network must be opened to the outside for load following and remote control, which may increase opportunities for cyber attacks.

③ Gap between technology and regulatory system

In many cases, the regulatory system cannot keep up with the ultra-fast development of digital technology. In particular, there is a lack of regulatory standards and guidelines specialized for digital technology for nuclear power plants. Therefore, the current conservative regulatory method may lead to delays in licensing and uncertainty for new technologies.

④ Increased dependence on digital systems

With the introduction of digital technology, the size of the power plant's resident workforce is expected to be significantly reduced, as in the case of SMRs. In the event of an emergency, the digital system will be relied on more than the operator's judgment, which may lead to difficulties in training and securing specialized personnel. In addition, issues regarding ownership and management of nuclear power plant operation data may arise.

In order to resolve these regulatory issues, it is necessary to establish a continuous response system for new cyber threats. From the regulator's perspective, an evaluation methodology is needed to verify the reliability and safety of the simulation model adopted by the digital twin. In addition, regulatory research and establishment of regulatory standards are needed to strengthen nuclear power plant cybersecurity in accordance with the development of digital technology, and a flexible regulatory approach that can accommodate environmental changes as quickly as possible is needed rather than the existing regulatory approach.

3. Conclusions

It is a well-known fact that various digital technologies have already been applied to the APR1400 developed with our technology. Until now, nuclear power plants have maintained a closed network structure network policy that separates the control network and the OA network to ensure the safe operation of the power plant. However, SMRs currently being developed worldwide are targeting autonomous operation, power output matchup with renewable energy linked operation, load follows, and remote communication, so it is expected that it will be difficult to maintain a closed network structure network policy any longer. The application of the latest digital technologies, such as digital twin nuclear power plants, is expected to increase the safety and efficiency of nuclear power plants, but on the other hand, there is concern that they will become vulnerable to cybersecurity. In order to enjoy the benefits of digital twin technology, uncertainty in the licensing aspect must be removed quickly, and from the regulator's perspective, it is necessary to quickly develop related standards and procedures.

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