Role and Opportunity of Nuclear I&C in the Fourth Industrial Revolution

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1. Introduction
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With the world facing the limits of growth, the expectations for the 4th Industrial Revolution should be huge. We stand on the brink of technological revolution that will fundamentally alter the way we live, work, and relate to one another.[1] Korea is necessary to move to the position where it can lead the industrial revolution through the strong IT foundation. However, such a strong IT sector is limited to a few hardware, and the software capability, which is the essential driving force behind the new revolution, is still pursuing advanced countries. The 4th Industrial Revolution is building on the 3rd digital revolution and characterized by a fusion of technologies between the physical and cyber world through connectivity.[1]

At the same time, we can recognize 'Industry 4.0' as an implementing tactic. While the 4th Industrial Revolution refers to a systemic transformation including the overall society, Industry 4.0 focuses on manufacturing specifically at least in the current context.[2] Authors suggest the manufacturing does not necessarily mean the production of products, but also applies to energy production such as electricity.

Four design principles are recommended in Industry 4.0: (1) Interoperability, (2) Information transparency, (3) Technical assistance, and (4) Decentralized decisions.[2] From a technical point of view, these principles are consistent with the direction leading nuclear industry towards improved performance and safety. The authors have pointed out that the recent nuclear regulatory environment in Korea has begun to emphasize the probabilistic approaches.[3] The probabilistic approaches are obviously associated with the reliability of hardware, software, and human, and the reliability is strongly related with monitoring, diagnostics, and prognostics, which can be called nuclear I&C. I&C can evaluate the stream of reliability. They are no more fixed or static property in the 4th Industrial Revolution.

As usually, due to the adverse effects of the Proven Technology principle in nuclear industry, it is difficult for the advanced I&C technologies to penetrate into nuclear fields in the short term. Nevertheless authors hope to set a mid- to long-term vision and make a roadmap upon the initiation from this statement.

2. Technical Status

2.1 New Industrial Trend

Author tried to categorize the commonly referred natures of Industry 4.0 into three areas: 1) infrastructure, 2) big data analytics, and 3) customization. The message is simple: These nature will help early detection of defects and production failures, thus enable their prevention, increase productivity, quality, and agility benefits that have significant competitive value.[2] Authors re-interpreted these natures in terms of nuclear terminologies and mentioned a few challenges:

1. Infrastructure: Although on-line measurement has increased compared to the past, the development of novel sensing elements is slow. The difficulty of measurement due to harsh environment and the delayed introduction of wireless sensors does not seem to be well reformed. Data collection has begun on the central servers, but the type, depth and quality of the data need to be refined.
2. Big data analytics: Normally researchers are using the simulation data but particularly after core damage, but the phenomena are suspicious so that we may not be able to proceed the next analysis using the data from the simulation. That is, as long as the question associated with the confidence of the simulation itself is constantly being raised so we cannot be free from 'Garbage in, Garbage out.' Various data mining techniques are the most advanced part in the research field. However it is necessary to increase the applicability to real situations by improving the connection with real conditions.
3. Customization: All values are essentially focused on this category. The highlighting point of Industry 4.0 must be the care on 'individual' item. An individual item has its own uniqueness and it is worth being taken care so called 'customized.' This ultimately aims to maximize profits while the degree of safety is maintained.

2.2 Conventional Trend in Power Industries

According to the status report issued by the government, the improvement of safety and reliability and the reduction of unnecessary maintenance cost is expected through Industry 4.0 to monitor health status and forecast failures in large plants.[4]

According to the World Nuclear Association, 80% of the O&M (Operation and Maintenance) cost of a typical commercial Nuclear Power Plant (NPP) corresponds to labor costs. Unexpected downtimes at NPPs indicated that it is not a matter of simple business problems, but rather that the adverse effect on base-load loss and social acceptance. In addition, the report compares the O&M costs for other power generation sources, and it can be seen that not only NPPs but also other power generation sources have similar problems.

Most of the maintenance techniques have been developed based on experience with operation and failure accumulated over a long period of time. Recently this is getting augmented by virtue of powerful infrastructures and algorithms. Authors reviewed applications for monitoring, diagnosis and prognosis in NPPs.[5] Based on the technical review, overseas advanced companies are introducing an intelligent monitoring and diagnosis system so called fleet-wide health management to maximize the availability of facilities as the number of old plants increases in Figure 1.[6] Korean utility has also an online centralized monitoring & diagnosis center that can monitor the operation status of the main equipment of the power plants in real time.

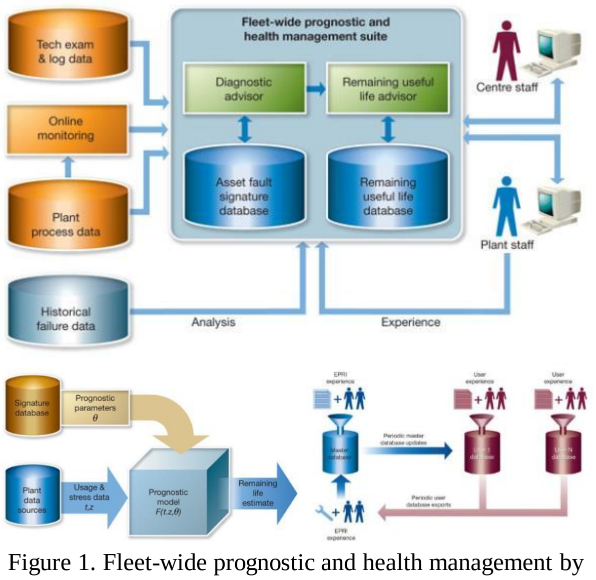

Figure 1. Fleet-wide prognostic and health management by EPRI [6]

It should be noted that the quantitative analysis of how these infrastructure are affecting the performance and safety of power plants are difficult to be identified. Through these experiences, the data is constantly secured from the power plants and the algorithms are developed so that the technology barrier is getting raised. In the case of facilities requiring advanced technology, Korea is likely to introduce foreign producers, and they are dependent in connection with long-term service contract. Furthermore, the quality of overseas advanced companies on proven sensors, hardware, acquisition systems are higher than us, so if the content of Industry 4.0 is not taken into consideration from the design stage, it may take the initiative in all related technology fields.

2.3 Nuclear Regulatory Trend

The changes in the nuclear regulatory environment of Korea will be briefly described as follows.

Authors have emphasized the role and opportunity of nuclear I&C associated with developing Probabilistic Safety Assessment (PSA) models.[3] Particularly, it is expected that the boosted I&C can adjust over- and under conservatism in analyzing risk due to the increased capability of human performance and the reduction of data uncertainty.

Even though there are a little differences between countries, PSA has performed important roles in optimizing regulatory resources while nuclear safety keeps higher.[3] The nature of PSA seeks the practical observation for reducing risk so the PSA model enables engineers to find the relative priority of accident scenarios, weak points in achieving accident prevention or mitigation, and insights to improve those vulnerabilities.

Even though PSA was carefully and limitedly utilized in the licensing process for NPPs, it became mandatorily incorporated into accident management plans and Periodic Safety Review (PSR). The technical position of PSA is therefore getting more important recently. This should be the results of improved PSA models with less epistemic uncertainty and more reliable failure data accumulated during the past decades.[3]

This is why the technical hierarchy: the I&C strengthened by Industry 4.0 or 4th Industrial Revolution – the reliability analysis augmented by I&C – improved PSA models by realistic hardware, software, and human reliability: must be incorporated in Figure 2.

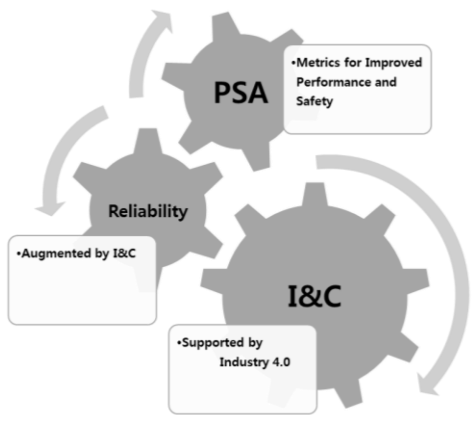

Figure 2. Technical hierarchy to improve performance and safety through nuclear I&C

3. Contributions of I&C Technologies

3.1 Evolution of I&C Technology

The story goes naturally to the relationship between I&C and Artificial Intelligence (AI). Although it may be a little difficult to extend the concept of I&C into that AI, authors think there are many similarities in that it is a link between plants (or machines) and humans. Power plants and humans are connected by signals (infrastructure), making decisions (data analytics) and manipulating individual controllers (customization). This is roughly consistent with the three characteristics of the 4th Industrial Revolution mentioned above. When the conventional I&C is set as Level 1, though remarkable technical growth, the current AI may be able to be classified as shown in Figure 3.

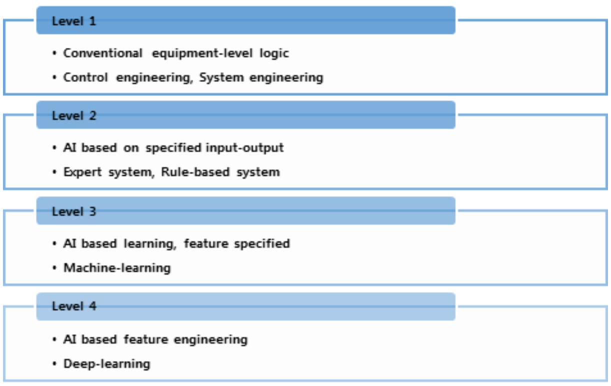

Figure 3. Technical hierarchy to improve performance and safety through nuclear I&C

3.2 Applications on Design Principles of I&C Systems

We are also able to project four design principles in Industry 4.0 into the applications of NPPs as shown in Table I. Those applications are selected from the something similar in other fields.

3.3 Reliability Enhancement through Analytics

Ultimately, through enhanced I&C technology, what we can achieve results in predicting the health condition and lifespan of individual items, which means efficient operation and accident prevention. Of course, the enhanced I & C technology will also make a significant contribution to accident mitigation and recovery after the breakdown. In this section, authors will make a technical comment on how to predict reliability related with big data analytics, which is the bridge between I&C and PSA, and is strongly software-based approach.

The key to analyzing data is finding features. 'Feature extraction' is defined as the process of extracting useful information related to system state from raw data. There are three types of data for status diagnosis and failure prediction: (1) Value, (2) Waveform, (3) Multi-dimension.[7]

Usually features based on value have been used for process monitoring for systems, while waveforms are used for the mechanical component or structures. Multidimensional type data has received relatively less attention. This is because data collection, storage and computation costs are high and efficient image processing techniques have not been developed. However, as the cost of data collection, storage and computation is lowered and efficient image processing technology is developed, the multidimensional type have very high potential in the future.[7]

Table I. Application in NPPs under Industry 4.0

Design Principles	Definition	Application in NPPs
Interope-rability	Ability of machines, devices, sensors, and people to connect and communicate with each other	Robust, ubiquitous, and qualified sensing system under normal & accident conditions. Sensor network or virtual sensors. Low- or no-power sensors. Detection of nano- or micro-size degradation.
Informa-tion transp-arency	Ability of information systems to create a virtual copy of the physical world by enriching digital plant models with sensor data.	Super-speed simulation for operator aid. Cyber security.
Technical assistance	Ability of assistance systems to support humans by aggregating and visualizing information comprehensibly	Advanced virtual/augmented operator or maintenance crew aid systems.
	Ability of cyber physical systems to physically support humans	Remote, automated robot, drone, or other unmanned utilities operated by artificial intelligence.
Decentralized decisions	Ability of cyber physical systems to make decisions on their own and to perform their tasks as autonomously as possible	(Semi-) Automated operation and remote operation. Data-informed decision-making.

The causes of failures vary widely, but it is common to classify them as a stress-strength model and a damage-endurance model. Over-stress failure is accidental, while damage failure is those that occur slowly over time due to degradation due to time. Before and after the occurrence of damage failures, there have been a lot of models to determine whether a phenomenon is underway and thus a possibility of failure.

Diagnostics and prognostics predicts the degraded state and remaining useful lifetime (RUL) of the system as shown in Figure 4.[8] Enabling techniques can be divided into data, model, and algorithm. As the results vary greatly depending on the quality of the data, the study on the insufficient data and noise problem is actively needed. The expression of the degradation is divided into a physics-driven model and data-driven model. Strictly speaking, the physics-based model should include terms relating to all operating conditions. Under these definitions, the physics-based model is extremely limited in that it represents the behavior of degradation. So after setting up the initial simplified model and quantifying the uncertainty of the variables, we then modify the model by adding it to the initial model. Efforts to develop such simplified models may also reduce the cost of developing complex models.

Under Industry 4.0, the data-driven technology for failure models is getting relatively increased. This is because it is difficult to find the physics of failure due to the increase of the complexity of the target system, and various and abundant data can be secured. Itemized customization is also one of the reasons why data-drive technology is highlighted.

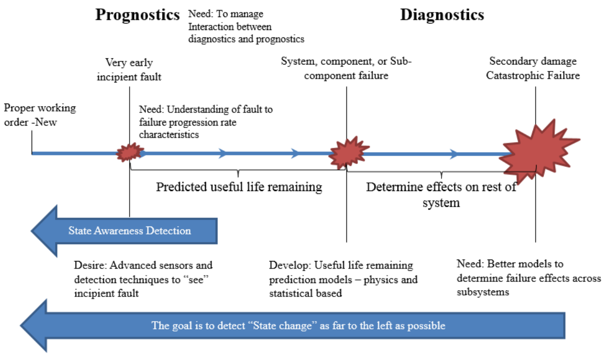

Figure 4. Technical concept of diagnostics and prognostics

It should be noted that, in general, complex systems including NPPs are said to use fault diagnostics and prognostics to prevent failures in advance. However, since defective parts are replaced very early in advance and/or redundant and diverse parts are installed, it is a fact that the necessity of fault diagnosis and prognostics is halved. Nevertheless, it is important to improve the economics of NPPs while maintaining safety confidence.

4. Conclusions

It would be meaningful to draw a picture of how a 60-year-old NPP built from now on will develop in the future. Sharing this motivation, authors introduced and came up with a few technical issues emerging in the 4th Industrial Revolution.

If we do not form a solution chain by our self-awareness, we cannot defend against the attacks of advanced corporations overseas. Therefore, we should at least build-up the capabilities for each field, even if they are not at the level of overseas standards.

Even though the practice research of using the dispatched methodologies is important in terms of tool proficiency, more important research should be identifying the key problems, collecting high-quality data, and developing field-applicable products. Authors emphasize the focus on high contribution in terms of reliability enhancement.

Private companies are gradually releasing data monopolies. As Korean power utilities have initiatives to release the data, high-quality data and their applications will be gathered and developed respectively, which will be able to dominate the world market in a short time, and be a good place for the development business of developing countries.

The development of I&C is meaningful in itself, but it is also important to demonstrate its effectiveness by incorporating it into the nuclear regulatory environment. Therefore, it is necessary to first show the role of I&C by first solving the potential parts of PSA that I&C can contribute to, and it will be important to broaden the scope of I&C gradually in such environment.

The 4th Industrial Revolution or Industry 4.0 will be actively pursued for the purpose of improving the constitution of the industrial sectors for the time being as a national agenda. Author looked at the new role of I&C as a solution to the weaknesses of NPPs from a fundamentally different point of view.

Acknowledgement

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