Transactions of the Korean Nuclear Society Autumn Meeting
Goyang, Korea, October 24-25, 2019

An Intelligent Operator Support System for Standard Post Trip Action in Nuclear Power Plants

Jung Sung Kang[a], Seung Jun Lee[a*]
[a] *Department of Nuclear Engineering, Ulsan National Institute of Science and Technology, 50 UNIST-gil, Ulju-gun, Ulsan, 44919, Republic of Korea*
[*] *Corresponding author: sjlee420@unist.ac.kr*

1. Introduction

Since nuclear power plants have a huge consequence on the public in the event of an accident, safety should be strictly secured. An inappropriate operation or diagnosis conducted by operators can greatly affect the safety of nuclear power plants. To prevent this problem, operators use emergency operating procedures (EOP) in case of an emergency situation. In case of APR1400, Standard Post Trip Action (SPTA) is performed to check the status of critical safety functions (CSFs) and recover them. Then, an accident diagnosis is performed through the Diagnosis Action (DA) when an emergency accident is occurred. The diagnosis made by the DA determines whether to proceed the Optimal Recovery Procedure (ORP) or the Functional Recovery Procedure (FRP) [1].

However, under an emergency situation, operating tasks are carried out under very stressful situations. Operators experience time pressures because they have to perform their tasks within a limited time. In addition, diagnosis is carried out with very the situation that plant parameters are rapidly changed. Indeed, the Three Mile Island (TMI) accident in the United States shows the risk of wrong diagnosis and inappropriate manipulation [2]. Many researches on supporting system to help operators have been conducted with reference to symptoms and plant parameter changes.

This study is a framework for supporting system for reducing operator human error. This framework replaces SPTA among the SPTA, DA, ORP, and FRP described above. This framework targets the early stage of an emergency situation among the whole emergency procedures. Hence, this system is possible to reduce the workload in the early stage of an emergency situation where the stress of the operator is concentrated. In addition, reduction in situation awareness, a disadvantage of automated systems, can also be mitigated.

2. Intelligent-SPTA

The existing SPTA procedure focuses on identifying and recovering nine CSF states: Subcriticality, Maintaining essential support system, RCS Integrity, RCS Pressure, Core Heat Removal, RCS Heat Removal, RCB Isolation, RCB Temperature and Pressure and RCB Combustible Gas Control Verification. In carrying out the procedure, operators check plant parameters and execute equipment and activate systems depending on the situation. The SPTA is a procedure that lists the tasks related with 9 CSFs. Fig. 1. Is a schematic figure which shows the SPTA structure.

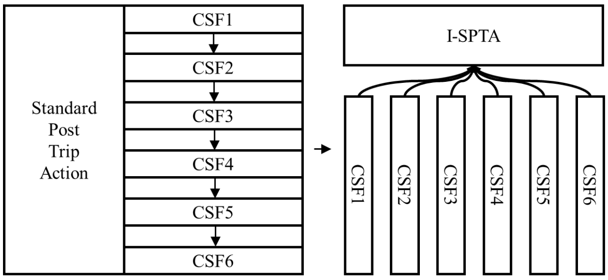

Fig. 1. Comparison between SPTA and I-SPTA

The Intelligent-SPTA (I-SPTA) proposed in this study checks the CSF states at the same time. And I-SPTA suggests tasks that require operator action based on priorities.

3. I-SPTA Framework

7.1. Overview of I-SPTA

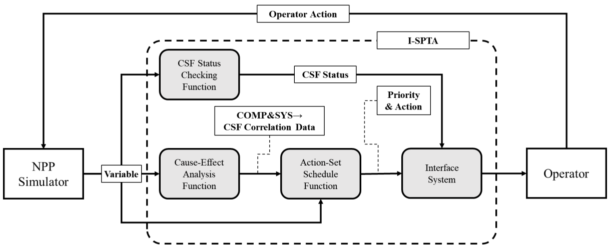

Fig. 2. I-SPTA Function Architecture

I-SPTA prototype model is developed in a compact nuclear simulator (CNS) developed by the Korea Atomic Energy Institute (KAERI) [3]. A simulator data which is produced by CNS is delivered by shared memory. There are 3 functions which receive plant parameters: CSF status checking function, cause-effect analysis function and action-set schedule function.

As the name suggest, CSF status checking function checks CSF status based on CSF diagnosis procedure and delivers CSF status to an interface system. The cause-effect analysis function checks components and systems on the basis on CSF. If a fault exists in a component or system, it provides a mapping data about which CSF the system is associated with. The action-set schedule function provides schedule data which tasks should be performed preferentially. Finally, the interface system collects all the information from 3 above functions and provides it to the operator.

7.2. CSF Status Checking Function

The CSF status function, as described above, is a function that evaluates the current status of the CSF with the data received. Since the CNS is based on the Westinghouse type nuclear power plant, a total of 6 CSFs (e.g. Subcriticality, Core Cooling, Heat Sink, RCS Integrity, Containment Integrity and RCS Inventory) will be evaluated, unlike the APR1400. This function is designed with rule-base system. The function receives specific parameters and evaluate the CSF status in four colors (e.g. red, orange, yellow, green) according to the preset diagnostic tree. It is safer from red to green.

7.3. Cause-Effect Analysis Function

The cause-effect analysis function is a function that provides mapping data between failed components & systems and CSFs. A correlation between systems and CSFs can be identified with the built-in logic tree. Basically, one component failure affects the system, and the affected system finally has an effect on the specific CSF. In the case of CSF1, logic tree is shown below Fig. 3. A system that directly affects reactivity in the CNS is the reactor protection system (RPS). If the RPS is not working, the safety injection (SI) system will intervene. As can be seen in Fig. 3., CSF1 correlates with RPS, HPSI, LPSI and accumulator. If an abnormality occurs in the source range neutron flux, this affects the reactor trip system and operators can figure out that there is a problem with CSF1.

In addition to the systems like SIS that directly affect the CSFs, there are support systems that indirectly affect CSFs in nuclear power plants, like component cooling water systems (CCW). These support systems perform cause-effect analysis using multi-level flow modeling. MFM can analyze the effects of each other on systems [4]. Finally, the correlation between the support system and the CSF can be identified.

7.4. Action-Set Schedule Function

The cause-effect analysis function shows which CSF the defect is related to. In addition, I-SPTA provides task priorities. The tasks were selected based on the procedures and priorities were selected according to the table classified below. From D to A, it means a higher priority task. Figure 4 is a logic tree that organizes the priorities of ESFAS in accordance with Table 1. In this way, task priorities are qualitatively evaluated and classified into four categories.

Table I: Task Priority Standard Table

CLASS	Description	Example
A	Operator should take immediate action	ESFAS entry condition is satisfied but it does not activate
B	Operator need to take actions quickly	ESFAS is activated due to satisfaction of entry condition but ESF is not reached with the target value
C	Operator check required but not urgent	ESFAS is activated by satisfying the ESFAS Entry Condition and the Target Value is attained, but there is a problem with the related system or device. Ex) One of the three Safety Injection Pumps is broken
D	No operator action required	

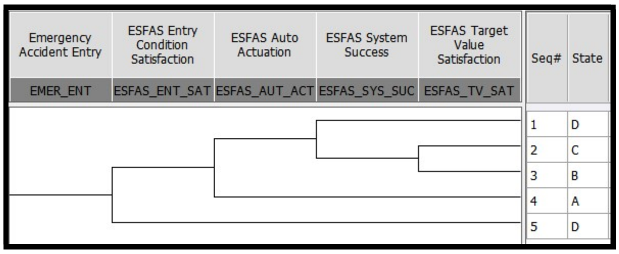

Fig. 4. ESFAS Task Priority Logic Tree

7.5. Interface System

The interface system is a human machine interface that is processed and displayed to the operator based on the data provided by these three functions.

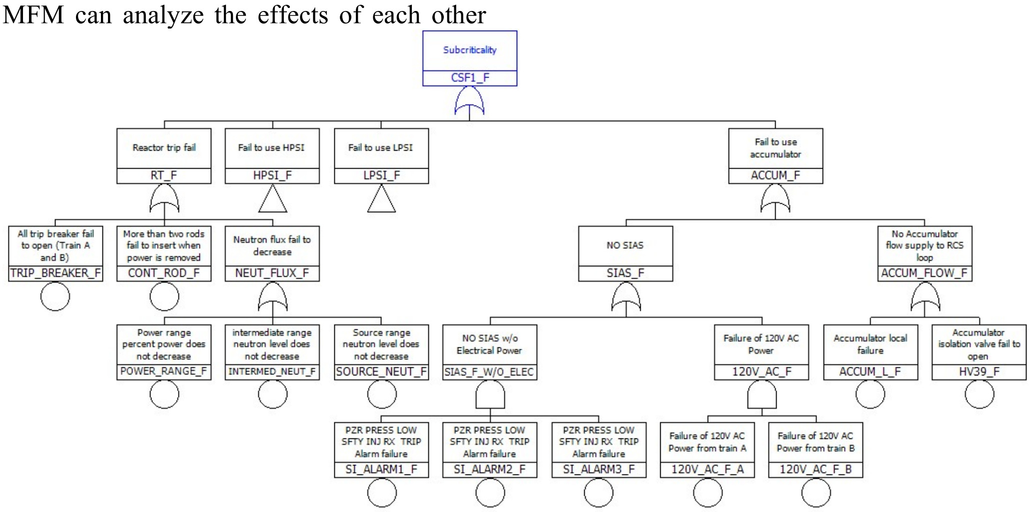

Fig. 3. Logic Tree for CSF1 Subcriticality

The first thing that can be noticed when looking at the interface system is the state of each CSF. The priority of the CSF can be determined according to the colors of the respective CSF blocks. When the operator clicks on a CSF block that needs action, the failed systems are indicated and the components associated with those systems are followed. Finally, action sets related to the component are arranged according to the action priority. An overview of interface system is shown below Fig. 5.

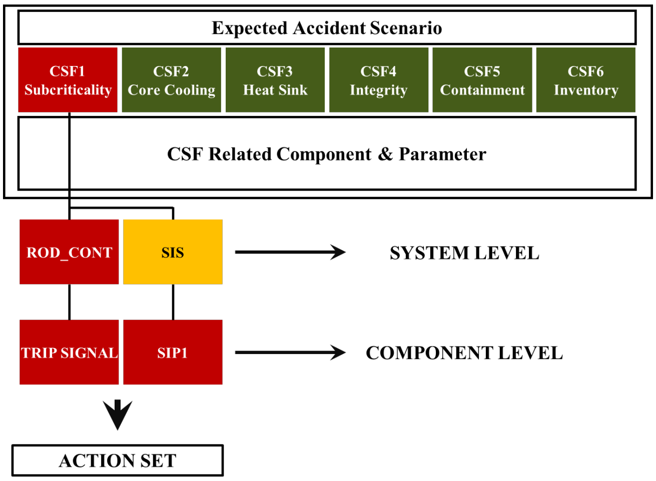

Fig. 5. Interface System Schematic

4. Conclusion

This support system, I-SPTA has been developed to make the SPTA procedures performed in an emergency initial operation more intuitive and efficient. In an emergency accident situation, the operators are exposed to a high stress environment. In this case, high workloads cause human error of operators. From that point of view, I-SPTA can minimizes the workload of operators in early state of an emergency situation. However, it is very important to secure the reliability of the instruments. Future work will include the development of module, instrument error fault detection, to secure the reliability of this system.

ACKNOWLEDGEMETN

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT). (No.NRF-2018M2B2B1065653)

REFERENCES

[1] J. Park, W. Jung, J. Kim and J. Ha, A study on the systematic framework to develop an effective diagnosis procedure of the nuclear power plants, KAERI/TR-2597, p. 4-6, 2003.

[2] J.P. Bongarra and J.J. Persensky, Implementing requirements for upgrading emergency operating procedures: a regulatory perspective, In Conference Record for 1988 IEEE Fourth Conference on Human Factors and Power Plants, p. 208-213, 1988.

[3] KAERI, Advanced Compact Nuclear Textbook, 1990.

[4] M. Lind, An introduction to multilevel flow modeling. Nuclear safety and simulation, 2(1), p. 22-32, 2011