An Intelligent Operator Support System for Initial Emergency Responses in NPPs

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1. Introduction

Normally, a nuclear power plant (NPP) is operated by operators in a main control room (MCR). The MCR operators perform complex and mentally taxing activities; information gathering, planning and decision making [1]. Especially in emergencies, operators experience time pressures and high workloads because they should perform their tasks within a limited time. Besides, human errors and miss diagnosis are easy to be carried out because plant parameters are rapidly changed in emergency situations. The Three Mile Island (TMI) accident in the United States shows the risk of wrong diagnosis and inappropriate manipulation which was conducted by operators [2]. Therefore, a lot of research on operating supporting system to help operators has been done.

This paper presents a framework and a prototype system for an operator support system in the early state of emergency situations. The system, named as Emergency Guidance Intelligent System (EGIS), replaces a part of Emergency Operating Procedures (EOPs) which is for the early state of emergency situations. The plant state and required tasks are based on critical safety functions (CSFs) of NPPs. Hence, this system provides intuitive information and helps the operators to perform an emergency initial response in a short time. In addition, the system assists operators by providing an expected scenario.

2. Concept of EGIS

In the case of APR1400, EOPs is consisted with 4 procedure categories. First, Standard Post Trip Action (SPTA) has a role to monitoring critical safety functions (CSFs) status and recover them when CSF status is not satisfied. Then, operators diagnose a nuclear power plant status through the Diagnosis Action (DA). From this diagnosis result, decision making is conducted whether to proceed the Optimal Recovery Procedure (ORP) or the Functional Recovery Procedure (FRP) [3]. The schematic of EOPs is shown below Fig. 1.

In this paper, 6 CSFs are selected: Subcriticality, Core Cooling, Heat Sink, RCS Integrity, Containment Integrity and RCS Inventory. As explained above, the SPTA is a procedure checking CSF status and providing tasks in order of CSFs. The DA is an algorithm to diagnose a plant state. The target scope of EGIS is to substitute SPTA and DA. EGIS monitors each CSF, displays CSFs status with color and provide appropriate tasks when it is required (CSF module) and diagnosing an expected scenario (Diagnosis Module). Each CSF module operates in parallel. Therefore, EGIS is expected that help operators reduce time consumption and human errors. Fig. 2. is a schematic figure which shows a comparison between EGIS structure and EOPs.

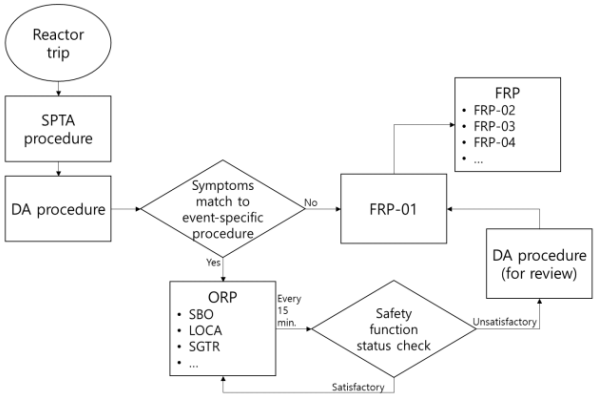

Fig. 1 General structure of a CE-based EOP system [4]

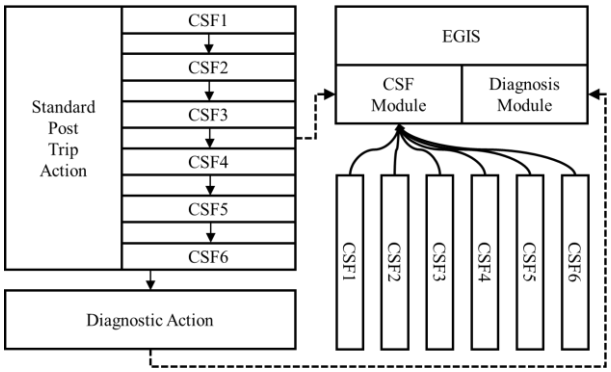

Fig. 2. Comparison between emergency operating procedures and EGIS

3. EGIS Framework

3.1. Overview of EGIS

EGIS prototype model is developed in a compact nuclear simulator (CNS) developed by the Korea Atomic Energy Institute (KAERI) [5]. Plant parameters are delivered to EGIS through the shared memory of CNS. EGIS consists of 4 functions: CSF status checking function, plant state monitoring function, diagnosis functions and interface function. The 3 functions (i.e. CSF status monitoring function, plant state monitoring function, diagnosis function) receive plant parameters from CNS and deliver each result to interface function. CSF status function and plant state

monitoring function use embedded logic tree (if-then else logic) and neural network is used in diagnosis function.

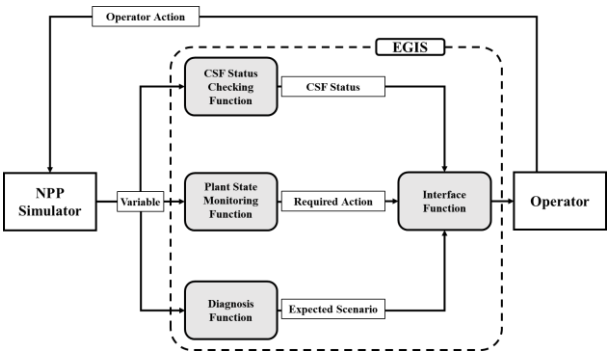

Fig. 3. EGIS Function Architecture

3.2. CSF Status Checking Function

The CSF status function is that evaluates the real time CSF status. Since the CNS is modeled on Westinghouse type nuclear power plant, a total of 6 CSFs (i.e. Subcriticality, Core Cooling, Heat Sink, RCS Integrity, Containment Integrity and RCS Inventory) are selected. This function is designed with CSF tree procedure. The function receives parameters, evaluate the CSF status and deliver color data (i.e. red, orange, yellow, green) to the interface function. It is safer from red to green.

3.3. Plant State Monitoring Function

The objective of plant state monitoring function is monitoring plant parameters, evaluating plant states and displaying appropriate tasks when CSF is in an unsafe state. In addition, this function provides support system information (e.g. component cooling water system, electric system) which is not easy to find in the early state of emergency situation.

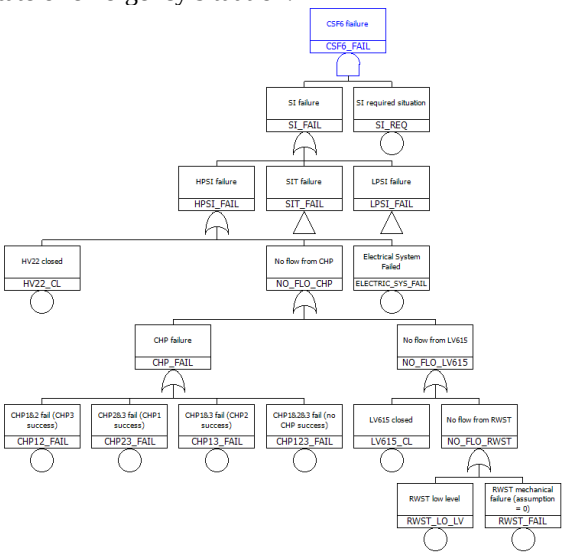

Fig. 4. CSF6 Logic Diagram

All the tasks are categorized with each CSFs and it is determined with the embedded logic tree. Basically, one component failure affects the system, and the affected system finally is connected with the specific CSF. the logic tree example is shown in Fig. 4. In the case of CSF6 (RCS Inventory), the function is related with safety injection (SI) and SI consists of high pressure safety injection (HPSI), low pressure safety injection (LPSI) and safety injection tank (SIT). Each system is connected with each component. And those component parameters are monitored by the monitoring function. In the case of HPSI, electric system is assigned as shown in Fig. 4.

3.4. Diagnosis Function

The goal of diagnosis function is that diagnoses plant state and provides an expected appropriate procedure from ORPs and FRPs. This function uses Gated Recurrent Unit (GRU) which is one of the recurrent neural network. The target scenario is consisted with 5 cases (i.e. simple trip, loss of coolant accident, steam generator tube rupture, excess steam demand event, loss of all feedwater). The detail contents are not covered in this paper.

3.5. Interface Function

The interface system is a human machine interface that displays result from above 3 functions (i.e. CSF status checking function, plant state monitoring function, diagnosis function) appropriately. The first thing that can be noticed when looking at the interface system is the state of each CSF with color information. The priority of the CSF is shown with the colors of the respective CSF blocks. When the operator clicks on a CSF block that operator is required to do tasks, failed components, required tasks and a related system is displayed. If there is no required action, operator can transfer a procedure which is shown in diagnosis block. An overview of interface system is shown below Fig. 5 and real time EGIS prototype is shown in Fig. 6

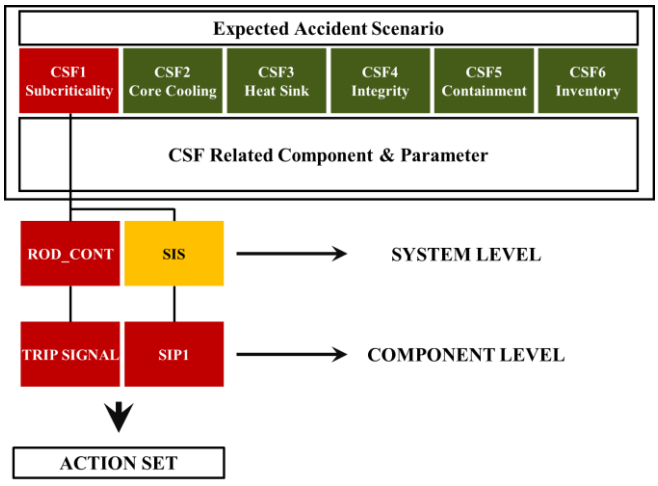

Fig. 5. Interface System Prototype Schematic

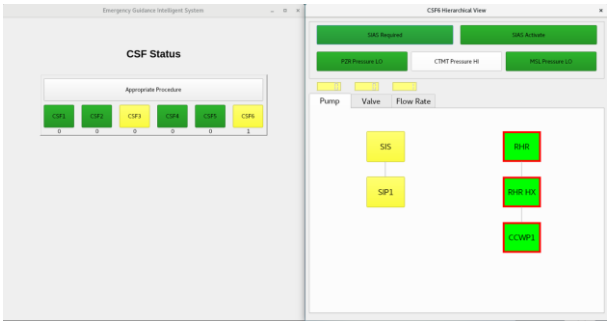

Fig. 6. Interface System Prototype Schematic

4. Conclusion

In the early state of emergency situation, operators experience high stress and it can cause misdiagnosis and unsafe acts. In the case of advanced MCRs, fully digitalized systems, it is easy to develop an operator support system. In this paper, EGIS was proposed which aims to substitute SPTA and DA. This support system, EGIS has been developed to support operators in initial emergency response. EGIS has a strong point by providing intuitive information and reducing time that is required to do tasks using EOPs. Therefore, EGIS helps to minimize workload and time pressure. In this paper, the framework and prototype of EGIS is introduced.

EGIS is required to secure the reliability of the instrumentation and control (I&C). Future work will include the development of module, I&C fault detection, to secure the reliability of this system.

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