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Preliminary Study on Architecture of Reactor Protection System for Prototype SFR

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1. Introduction

A prototype sodium-cooled fast rector (SFR) with 150MW of electricity was under development at KAERI. It is a pool-type reactor and is composed of a primary heat transfer system (PHTS), intermediate heat transfer system (IHTS), and a superheated steam cycle. [1] As for the instrumentation and control system, the modern digital technology will be adopted for the prototype SFR in order to increase its availability and reliability. The digital technology has a lot of advantages such as expandability, easy use and maintenance including on-line testing but is vulnerable to common mode failures if the same hardware and software is used in redundant or multiple channels of safety-related systems. So, the practical provisions for minimizing the likelihood of common mode failures should be implemented in safety-related instrumentation and control systems such as the reactor protection system of the SFR.

The prototype SFR has two scram control rod systems which are independent each other and are being tried to have diverse features. To meet the two scram rod systems, two independent reactor protection systems, each of which has four redundant channels will be implemented for the prototype SFR. Further, two independent and diverse reactor protection systems which will be implemented with CPU-base PLC and FPGA-base PLC are being designed in order to have diverse features.

2. Diversity of Reactor Protection System

With modern digital technology, a consideration of the common mode failures is being more important for multiple safety-related systems which have the same function for example the redundant reactor protection system. Some new regulatory guide such as NUREG/CR-6303 and NUREG/CR-7007 by NRC are suggesting the attribute of diversity as shown in Fig. 1. [2][3] The prototype SFR has two independent scram control rod drive mechanisms to shutdown the core in cases of design basis events. Accordingly, two reactor protection systems will be equipped in the prototype SFR. Each of the reactor protection systems has four redundant channels.

To accommodate the diversity, two reactor protection systems will use the different and diverse digital equipments. One of the reactor protection systems will be based on the safety-grade CPU-base PLC and the other is based on the FPGA-base PLC. These devices have different features including hardware, software and development environment including human resources. Thus, the reactor protection systems will be able to satisfy the diversity requirements in an achievable and practicable way.

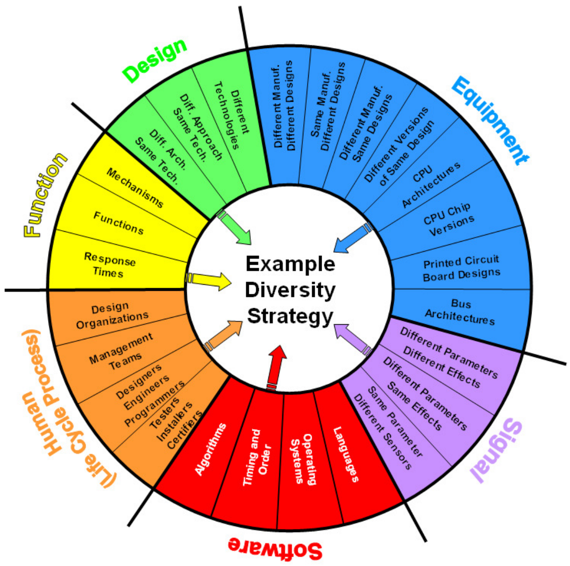

Fig. 1 Six diversity attributes

For implementing the diverse protection systems, the trip parameters were analyzed and segmented into two reactor protection systems. Each of the reactor protection systems should trip the reactor against all design basis events, independently. For example, the core outlet average temperature and the ratio of the power to PHTS flow rate can detect the design basis event of loss of PHTS flow. It means that the core outlet average temperature and the ratio of the power to PHTS flow rate can be processed to detect the same design basis event in each of two diverse reactor protection systems, separately.

Table I shows all the trip parameters which are detecting to the design basis events. As shown in the table, the parameters can be segmented into the each of two reactor protection systems.

Table I: Trip parameters

Trip Parameter	Design Basis Events				
	Loss of PHTS Flow Rate	Loss of Heat Sink in IHTS or SGS	Subassembly Fault	Reactor Vessel Leak	SG leak
Core outlet average temp.	O				
Power to PHTS Flow ratio	O				
Core inlet temp.		O			
SG shell outlet temp.		O			
DND			O		
Individual S/A outlet temp.			O		
Reactor hot pool sodium level				O	
Containment vessel sodium level				O	
IHTS pressure					O
Rupture disk burst					O

According the characteristics of the trip parameters coping with each design basis event, the trip parameters of each reactor protection systems are followings:

- The trip parameters of the reactor protection #1 are core outlet average temperature, core inlet temperature, delayed neutron detection (DND), reactor hot pool sodium level and IHTS high pressure.
- The trip parameters of the reactor protection systems #2 are power to PHTS flow ratio, steam generator (SG) shell outlet temperature, individual subassembly (S/A) outlet temperature, containment vessel sodium level and rupture disk burst.

The parameters related to the level of neutron flux such as power level, linear logarithmic power level, and ramp rate of the power level will be considered after design of neutron flux instrumentation system.

For achieving higher diversity, all subsystems of one reactor protection system is independent of subsystems of the other reactor protection system from sensor to the reactor trip switchgears which can cut the independent electric power to each of the control rod drive mechanism. Fig. 2 shows the schematic architecture of the reactor protection system.

3. Conclusions

In this study, the diverse architecture of the reactor protection system for the prototype SFR is suggested. The architecture can achieve the highest level of diversity discussed in NUREG/CR-6303. The diverse systems are fully separated and isolated from sensors to the reactor trip switchgears with diverse hardware and software and follow a suggested architecture for diversity in NUREG/CR-6303 by using two different digital technologies such as CPU-base PLC and FPGA-base PLC. Detailed analysis for segmentation of the trip parameters for diverse reactor protection systems and study of two independent scram control drive mechanism will be performed in further study. After that, total response time, likelihood of diversity, safety, reliability and availability of the reactor protection systems will be also discussed.

REFERENCES

[1] Hahn D.H. et al., KALIMER-600 Conceptual Design Report, KAERI/TR-3381/2007.
[2] NUREG/CR-6303, Method for Performing Diversity and Defense-in-Depth Analyses of Reactor Protection System
[3] NUREG/CR-7007, Diversity Strategies for Nuclear Power Plant Instrumentation and Control Systems

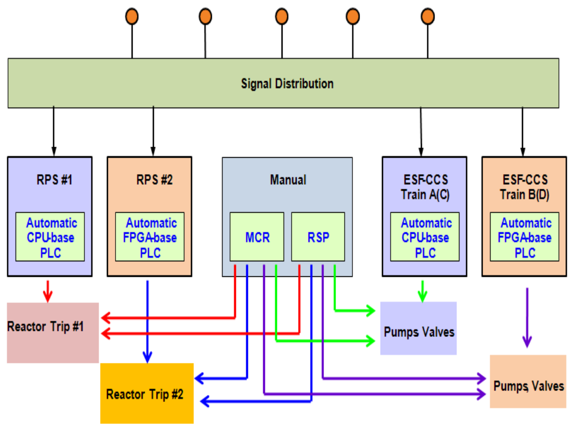

Fig. 2 Schematic diagram of reactor protection system