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Reliability Evaluation of the Safety I&C System for the iPOWER

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1. Introduction

The importance of safety in designing and operating nuclear power plants has been emphasized all the more since the unexpected Fukushima accident occurred. Many engineers and researchers consider a passive safety system an attractive alternative because it can enhance both the safety and the economics of nuclear power plants (NPPs). The construction cost of the NPP is minimized by the adoption of a passive safety system that reduces the number of active components, valves, cables, and so on [1]. As part of the innovative Passive Optimized World-wide Economical Reactor (iPOWER), the trip algorithm of the plant protection system (PPS) was also introduced and analyzed [2]. The design target of the iPOWER is to practically eliminate radioactive material released to the environment under all accident conditions including natural disaster-induced accidents [1]. The first top tier requirement of the safety instrumentation and control (I&C) system for the iPOWER is to design a simplified and high reliable system.

This paper proposes a simplified and high reliable safety I&C system, and it is demonstrated using reliability evaluation that the proposed safety I&C system is more reliable.

2. Methods and Results

The reliability block diagram (RBD), which is an intuitive method to construct and interpret, is a success-oriented diagram that represents the way the components work together to perform the desired function of a system. The interrelation of events needed for success is expressed in the way that the blocks are connected in the block diagram [3,4]. It is reasonable to use the RBD at the concept design phase in order to check the reliability level of the I&C system for the iPOWER, comparing with the corresponding system of the Advanced Power Reactor 1400 (APR1400).

2.1. Safety I&C System Configuration in the iPOWER

As illustrated in Fig. 1, the iPOWER PPS consists of 4 independent divisions in which two analog based channels A and C are diverse from the remaining two digital based channels B and D. Each channel of the PPS contains one bistable processor rack, two coincidence processor racks, and two selective 2-out-of-4 initiation circuits performing undervoltage trip and shut trip. Regarding the reactor protection system (RPS), analog based channels A and C can perform the reactor trip function even if the common cause failure (CCF) in channels B and D occurs. The iPOWER RTSS consists of 4 independent channels in which channels A and C are diverse from channels B and D. Channels A and C can generate reactor trip even if channels B and D fail at the same time. Therefore, the diverse protection system to carry out the reactor trip function is not required in connection with the PPS and RTSS. For the engineered safety features actuation system (ESFAS), the iPOWER ESF-CCS does not employ group controllers that perform the actuation logic using four channel's ESFAS signals from the PPS. As the coincidence logic to avoid spurious actuation is included in both PPS and ESF-CCS group controller (GC) redundantly, the GC has been removed to simplify the critical ESFAS signal path in the ESF-CCS. To reduce the possibility of spurious EAFAS actuation in the EFS-CCS, the PPS is required to employ at least two redundant coincidence processors which are directly connected to loop controllers (LCs).

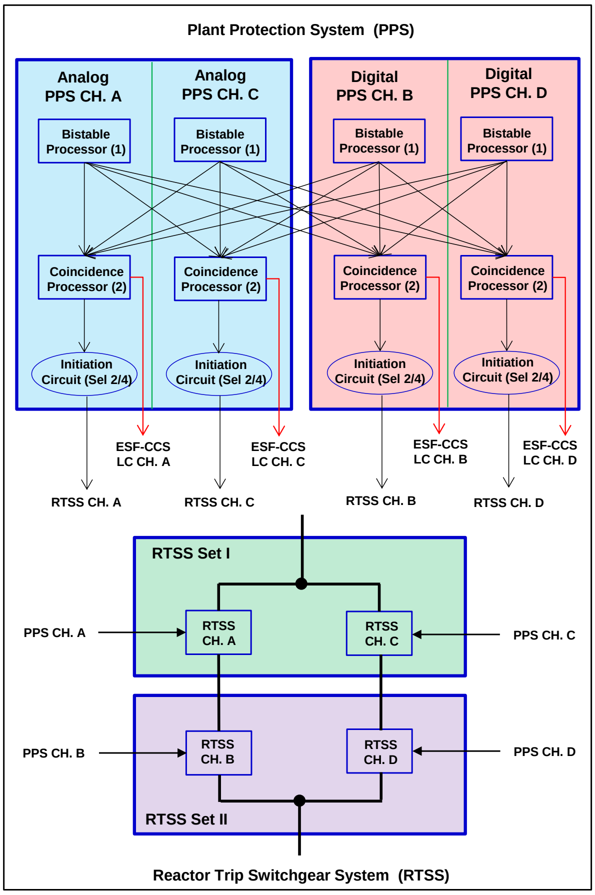

Fig. 1. RPS and ESFAS for the iPOWER

2.2. Reliability Evaluation for the iPOWER

To evaluate the reliability of the RPS and ESFAS for the iPOWER, unavailability analysis using a reliability block diagram method is performed. Unavailability means the probability that the RPS or ESFAS fails to conduct its intended function when demanded.

The software tool used for unavailability analysis is Reliability Workbench version 12 produced by Isograph. There are four main assumptions considered in analyzing the unavailability of the RPS and ESFAS. Firstly, bistable processor, coincidence processor, and initiation circuit in analog channels A and C use the failure rate data from NUREG/CR 5500 [5]. Secondly, components in digital channels B and D use the same data used for POSAFE-Q platform. Thirdly, the periodic test interval is 720 hours. Lastly, beta factor method is used for the common cause failure.

The analysis results show that the RPS and ESFAS unavailability values for the iPOWER are 2.444 x 10^{-7} and 1.397 x 10^{-4}, respectively.

2.3. Reliability Evaluation for the APR1400

The POSAFE-Q platform based PPS for the APR1400 consists of four redundant channels including twelve cabinets, as illustrated in Fig. 2. Each channel contains two bistable processor racks, three coincidence processor racks, and two initiation circuits configured with 2-out-of-3 voting logics. The RTSS consists of 4 redundant channels configured with a selective 2-out-of-4 logic. Even if the complexity of the ESF-CCS increases due to the GC with full 2-out-of-4 voting logic, the configuration reduces the spurious ESFAS actuation.

The same method of reliability block diagram is applied to compare the reliability of the safety I&C system with the APR1400. The RPS and ESFAS unavailability values for the APR1400 are analyzed as 2.536 x 10^{-6} and 2.513 x 10^{-4}, respectively. Table I summarizes the unavailability results evaluated for the iPOWER and APR1400. The RPS and ESFAS for the iPOWER have lower unavailability values than the APR1400. This indicates the safety I&C system reliability of the iPOWER is higher than the APR14000.

The main reason that the iPOWER RPS has better reliability than that of the APR1400 is based on the diversity between RPS divisions that reduces the probability of the common cause failure in four divisions. The iPOWER ESFAS reliability is also better than the APR1400 since the ESF-CCS does not contain GCs as well as the diversity between PPS channels A&C and B&D.

Table I. Unavailability Analysis Results

	RPS	ESFAS
iPOWER	2.444 x 10^{-7}	1.397 x 10^{-4}
APR1400	2.536 x 10^{-6}	2.513 x 10^{-4}

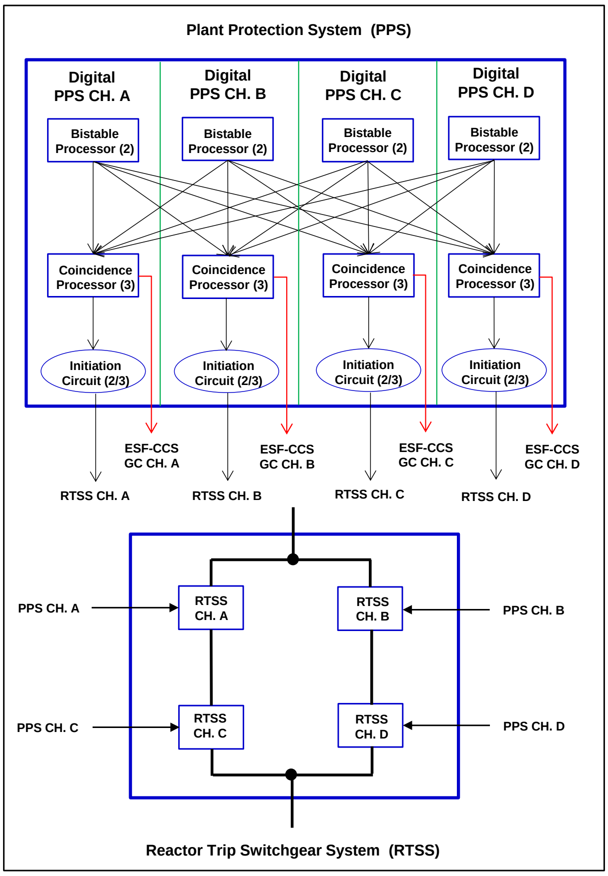

Fig. 2. RPS and ESFAS for the APR1400

3. Conclusions

The simplified and highly reliable RPS and ESFAS designs were proposed as part of the development of the iPOWER. Unavailability analysis was conducted using the reliability block diagram method and the result was compared to that of APR1400 in order to evaluate the appropriateness of the proposed RPS and ESFAS. It was confirmed that the iPOWER RPS and ESFAS are more reliable than the APR1400.

REFERENCES

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