Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, South Korea, October 24-26, 2018

COMPARISON OF RELIABILITY ANALYSIS OF THE REACTOR PROTECTION SYSTEM BETWEEN JORDAN RESEARCH REACTORS AND NUCLEAR POWER PLANTS

Mahmood Al-Hajjat*, Gunnyong Park
1. Korea Advanced Institute of Science and Technology, 373-1, Guseong-dong, Yuseong-gu, Daejeon 305-701. 2. Korea Institute of Nuclear Safety, 62 Gwahak-Ro, Yuseong-Gu, Daejeon 305-338, Republic of Korea.
***Corresponding author: Mahmood.hajjat@jaec.gov.jo**

Objectives

⇒ The main objective of this research is comparing the Reactor Protection System (RPS) reliability for the JRTR with a typical Nuclear Power Plant model.
⇒ Drawing a fault trees for failing to trip the reactor for the two systems.
⇒ Estimating the Probability of failure of each system.

Abstract

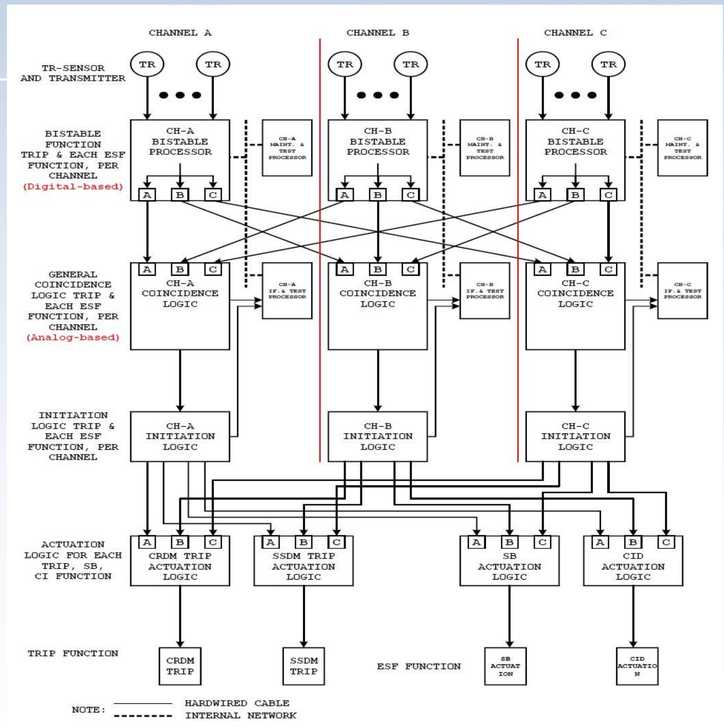
• The Jordan Research and Training Reactor (JRTR) is a multi-purpose open-tank-in-pool type reactor with a nominal power of 5 MWth (upgradable to 10 MWth). JRTR is currently in its final testing stages. In this Poster, a comparison on the reliability of the Reactor Protection System (RPS), as a part of the instrumentation and control systems, between JRTR, representing the research reactors, and typical nuclear power plants. A detailed fault tree of RPS of JRTR and a typical power plant is investigated and quantified using AIMS-PSA software. The fault trees for failing to trip the reactor for the two systems are analyzed in details and used after that to obtain the minimal cut sets for the RPS and the probability of failure of each system.

Introduction

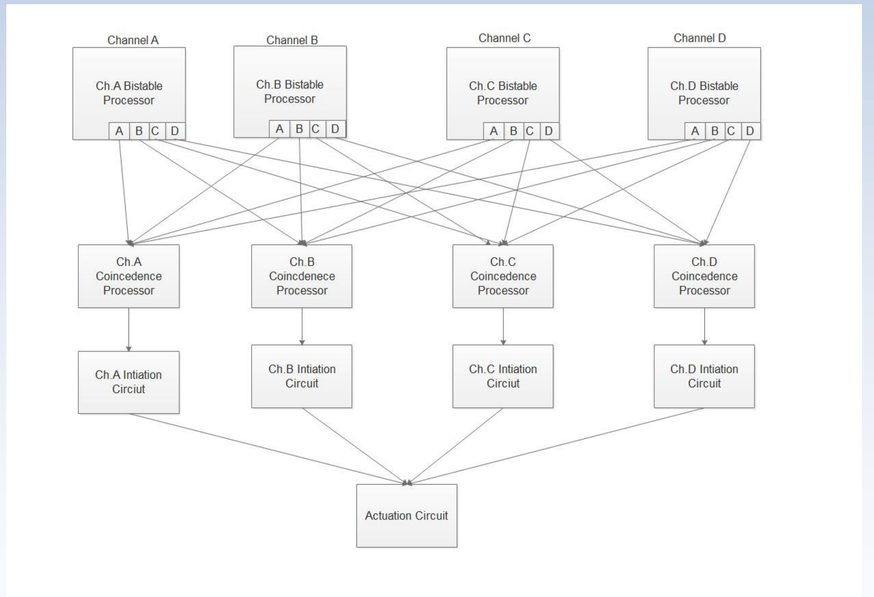
The RPS for JRTR is designed based on 2-out-of-3 voting logic received from three redundant channels as shown in Figure (1). Each channel consists of the following components:

1- Sensors
2- Bi-stable processor (BP)
3- Coincidence circuit (CC)
4- Initiation circuit (IC)
5- Actuation circuit (AC)
6- Interface and test processor (ITP)
7- Maintenance and test processor (MTP)
8- Other equipment necessary to monitor selected reactor conditions and to provide reliable and rapid reactor protective action.

Generally, the main difference between the Nuclear Power Plant Protection System (PPS) and Research Reactor Protection System (RPS) is the existence of four redundant channels in PPS comparing to three channels in RPS. Accordingly, the applied voting logic in PPS is 2-out-of-4 instead of 2-out-of-3 in the RPS.



Channels of JRTR Reactor Protection System



Group of NPP RPS Components

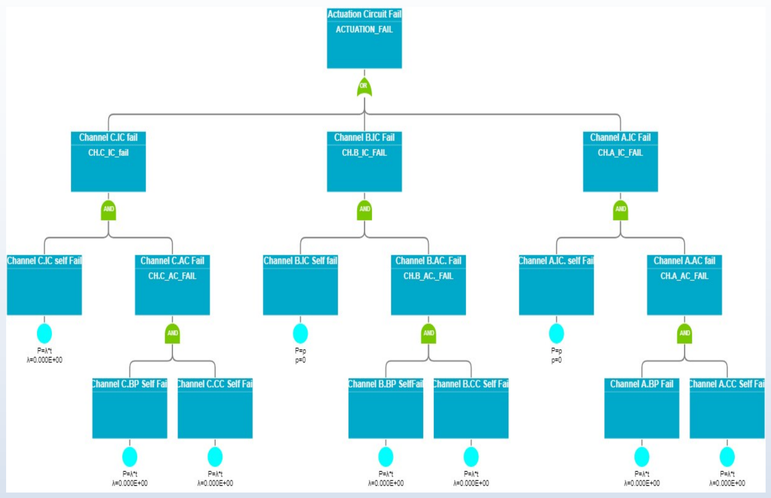
Problem Description

• As the JRTR RPS is not Fully Digitalized System and consists of 3 channels, While NPP RPS System is fully digitalized and consists of 4 Channels, So the PPS is Superior to withstand the failure of the channels. If the system failure is considered more conservatively, the PPS can Perform the protective actions when two channels are failed to operate.
• A second issue is about the organization of the components. In the PPS, it uses digital system for the bi-stable and coincidence logic, but the RPS uses relays for designing the coincidence logic.The fully digital system gives advantages about the usability and maintenance, but the implementation of fully digital system should be faced with the hardware cost issue.Even though the RPS is not a fully digital protection system, it complies with the safety requirements. Moreover, the RPS reduces the implementation cost that is designed to combine digital processor and analog relays.

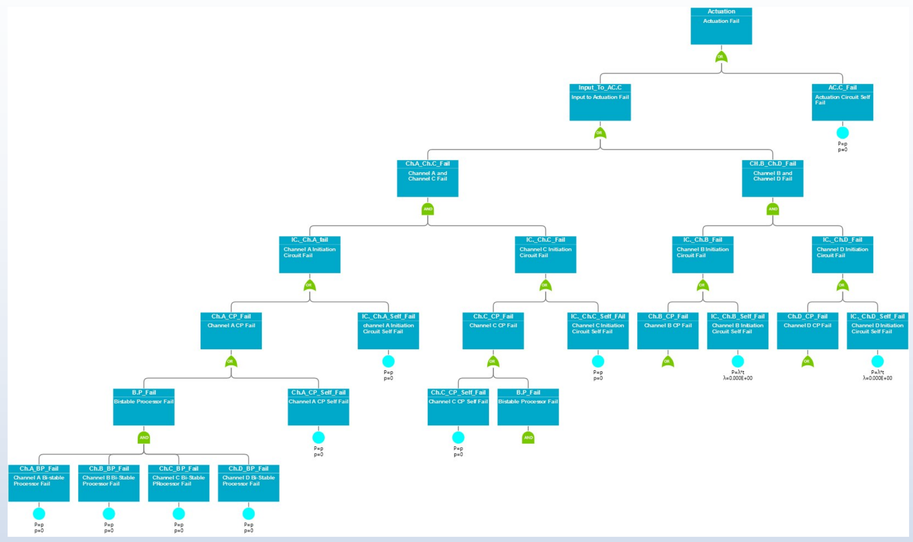
Results Discussion & Reliability Evaluation:

The AIMS-PSA was used for the comparison of the reliability of the RPS of research reactor and power plant based on minimal cut-sets of fault tree. In addition, a comparison between the costs of implementation of the Hardware was estimated. Table (1) shows a comparison between research reactor and power plant RPS components.

RPS Components	Research Reactor	Nuclear Power Plant
Bistable	Digital (PLC)	Digital (PLC)
Coincidence	Analog (Relays)	Digital (PLC)
Initiation	Analog (Relays)	Analog (Relays)
Actuation	Analog (Relays)	Analog (Circuit Breakers)



Simplified RPS fault tree



Simplified PPS fault tree

Results

Minimal cutsets of fault tree for the RPS

No.	Value	F-V	Acc.	BE#1	BE#2
1	4.36E-06	0.994527	0.994527	RPRYW	
2	1.07E-08	0.002441	0.996968	RPOMW	RPOPH_TRIP
3	1.04E-08	0.002372	0.999 34	RPIMW	RPOPH_TRIP
4	2.72E-09	0.000 62	0.999961	RPPMW	RPOPH_TRIP
5	1.98E-11	0.000005	0.999965	RPOMW	RPMWW

Minimal cutsets of the fault tree for the

No.	Value	F-V	Acc.	BE#1	BE#2
1	7.60E-06	0.991417	091417	RPRBW	
2	2.31E-08	0.003014	0.994431	Circuit_B_fail	Ciecuit_D_fail
3	2.31E-08	0.003014	0.997444	Circuit_B_fail	Circuit_D_fail
4	8.98E-09	0.001171	0.998615	RPUVW	RPSHW
5	5.35E-09	0.000698	0.999313	RPOMW	RPOOH-Trip

the RPS unavailability for research reactors is 4.38E-06. This reliability result is mainly caused by the CCF of the relays CCF of Relays (RPRYW). The coincidence, initiation, and actuation logics of the RPS are designed by using relays. For that reason, a CCF of relays can be a critical factor. In case of PPS in nuclear power plant, the unavailability is 7.60E-06. This result is caused by the CCF of TCBs (RPRBW). The Trip Circuit Breakers (TCBs) is used for the actuation circuit. Generally, the failure rate of the circuit breaker is higher than in other components such as relay, digital processor, etc.
According to the above tables, it can be noticed that the reliability of RPS for JRTR that is used three channels are almost similar to PPS in the nuclear power plant that used four channels.

Conclusion

A moderately detailed fault tree of research reactors and power plants was developed and quantified using AIMS-PSA. The fault trees were developed for the research reactor protection system with three channels and for the power plant protection system with four channels. The top of the fault tree was for estimating and calculating the probability of failure of each system to safely shutdown the reactor by inserting the control rods and providing the engineered safety features.

Evaluating the reliability started with studying and recognizing the fault tree parameters, this evaluating was concerned on the fault tree technique, and then analyzing each system based on the architecture. Each system was separated to groups, actuation, initiation, coincidence, and bi-stable.

Finally, the fault trees for failing to trip the reactor for the two systems were drawn and analyzed. After that, the probability failure of each component, the CCF and HE are involved in, then the minimal cutsets are obtained for the RPS and PPS.

The probability of failure of each system were close to each other that indicate that reliability is close to each other and hence the RPS for research reactor with three channel and analog C.C similar to PPS with four channels and digital C.C.