Fault Tree Analysis of the RPS Trip Signals for KSNP

Seung-Cheol Jang, Kyung-Ran Min, Seok-Joong Han
Korea Atomic Energy Research Institute,150, Dukjin-dong, Yuseong-gu, Daejeon, 305-353
scjang@kaeri.re.kr

1. Introduction

The performance and unavailability analysis of the reactor protection system (RPS) was performed, based on the operating experience of the Korean standard nuclear power plant (KSNP). The RPS unavailability was evaluated by the system fault tree analysis, based on as-built/as-operated design and the plant specific component reliability data[1]. The sensitivity analysis of system unavailability was also performed according to some configuration changes decribed as limiting conditions of operation (LCO) in technical specification

2. Overview of the RPS

The RPS designed for accident prevention provides an automatic or manual rapid shutdown of the reactor to protect the core and the reactor coolant system boundary In KSNP. The RPS comprising four identical protective channels can be roughly divided into three segments - bistables, logic matrices, and initiation circuits - as illustrated in Figure 1.

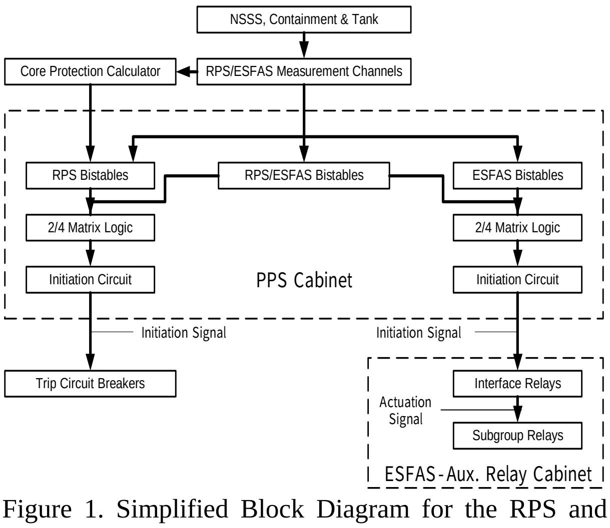

Figure 1. Simplified Block Diagram for the RPS and ESFAS in KSNP

Except for the manual trip, the RPS has 11 different types of automatic trip parameter, *e.g.*, variable over-power (VOPT), high logarithmic power (LGP), high local power density (LPD), low departure from nucleate boiling ratio (DNBR), high/low pressurizer pressure (PZPR), high/low steam generator level (SGLV), low SG pressure (SGPR), high containment pressure (CTPR), low reactor coolant flow (RCFL). Of them, some trip parameters (*e.g.*, low PZPR and SGPR, high/low SGLV, high CTPR) are shared with the engineered safety feature actuation system (ESFAS). Except for thermal margin calculation, e.g., LPD and DNBR, each monitored parameter is represented to each RPS channel as a voltage signal. Trip signals for thermal margin are generated externally by core protective calculator (CPC), and input to each RPS channel.

The KSNP RPS channels – bistables, logic matrices, initiation circuits - are tested on a sequential monthly basis. Generally, the channels to be tested are placed in bypass. All of sensors/transmitters are tested and calibrated every refueling. The diverse protection system (DPS) is tested every three months. Finally, each trip circuit breaker (TCB) is tested seven times per month during operation, and five times during refueling.

3. System Fault Tree Analysis and Results

The top event of RPS is defined by the failure to interrupt power to the control element drive mechanism (CEDM) buses. The fault tree of each trip signal was based on as-built/as-operated design of a KSNP. The fault trees cover measurement devices, CPC, bistables, bistable output relays, logic matrix relays, interposing relays, initiation relays, TCB, shunt and under-voltage trip devices, signal processors and control circuits for the DPS, manual switches, and supporting system.

Generally, four types of data are required to quantify the system fault tree, namely 1) component failure data, 2) common cause failure (CCF), 3) unavailability due to test and maintenance, and 4) human error probability. The plant-specific component reliability data was used, which was estimated from the total operating experience of 8.63 commercial reactor years during a period of 1995 through 2000 at four units [1]. Since only a few of CCF events was found from the field data, *e.g.*, multiple hunting of ex-core neutron flux chambers, however, insufficiency of CCF evidence led to use the generic CCF data. The final CCF probabilities or rates were calculated by Beta-method, of which parameter values were obtained by the CEN-327[2]. They are distributed with a wide range of 0.02 to 0.5 depending on component type, for instance, 0.49 for CPC, 0.04 for bistable, 0.02 for logic matrix relay/contact, 0.06 for trip circuit breaker (TCB), 0.25 for undervoltage tip device, 0.19 for shunt coil, 0.1 for other components, and so on.

Test and maintenance outages were modeled in the system fault tree. The average of test and maintenance outages was investigated by the interview with site staffs. Unavailabilities due to test and maintenance per channel were estimated to be about 4.0e-3 to 1.0e-4 for

CPC or bistables (including measurement loop), 3.0e-4 to 5.0e-5 for logic matrices, 3.0e-3 for DPS, etc.

Two types of operator errors were considered in the fault tree: post-accident event (*e.g.*, failure of manual trip) and pre-accident event (*e.g.*, miscalibration). The operator error probability was estimated by THERP [3]. The failure probability for manual trip were estimated from approximately 0.001 for the RPS regardless of trip parameters. In particular, it was conservatively assumed that there was high dependency between miscalibration events for an input parameter.

The system fault trees were quantified using the KIRAP code [4]. The mean unavailability for each RPS trip parameter ranges from approximately 5.0e-7 to 9.1e-6, as shown in Table 1. The unavailabilities for digital trip signals (DNBR and LPD) and linear and log power signals (VOPT, LGP) are comparatively higher than others, because of higher component failure probability for ex-core neutron flux measurement channels. The dominant contributor to RPS failure probability is CCF for the TCBs with the contribution of about 61 % for LPD and DNBR, 80% for VOPT and LGP, 99% for others. Other dominant contributors are CCFs of elements within the trip channels coupled with failure of manual trip. The uncertainty results for the RPS parameters are also involved in Table 1.

Table 1. Results of the RPS Unavailability Analyses*

Trip Parameter	Unavailability (Mean)	Uncertainty**		
		5%	50%	95%
VOPT	6.58e-6	5.92e-7	3.18e-6	2.19e-5
Hi LGP	6.90e-6	6.27e-7	3.44e-6	2.35e-5
Hi LPD Lo DNBR	9.11e-6	8.25e-7	4.51e-6	2.98e-5
Hi PZPR	5.01e-7	9.46e-9	1.13e-6	1.78e-6
Lo PZPR	5.58e-6	3.34e-7	2.25e-6	2.07e-5
Lo SGLV	5.52e-6	3.08e-7	2.21e-6	2.05e-5
Hi SGLV	5.52e-6	3.01e-7	2.16e-6	2.09e-5
Lo SGPR	5.55e-6	3.20e-7	2.24e-6	2.08e-5
Hi CTPR	5.55e-6	3.19e-7	2.23e-6	2.08e-5
Lo RCFL	5.57e-6	3.33e-7	2.23e-6	2.01e-5

*) All Channels are in service. **) Monte Carlo sampling with the sample size of 10,000.

As a part of the sensitivity analyses on the system unavailability, the RPS fault trees were also quantified for two cases; 1) one channel is in bypass, and 2) additional one channel is in the failed condition. These are LCO that are concerned in the current technical specifications for KSNP. The sensitivity results of these cases for the RPS unavailability are shown in Table 2.

Test and maintenance for a channel is generally placed in bypass, not a tripped mode. It means that one channel bypass (Case 1) brings an automatic change of the system operation mode from the two-out-of-four into the two-out-of-three coincidence logic. It leads to an increase of about three times or less than the system unavailability of the base case (Table 1). Plant may be continued in power operation by current technical specifications, even though additional one channel is placed in the tripped mode due to its inoperability (Case 2). It means that inoperability of additional one channel failure changes system operation from the two-out-of-three into the one-out-of-two coincidence logic. In this case, the system unavailabilities of the RPS trip parameters make additional increases of one-order or less than Case 1.

Table 2. Results of Sensitivity Analysis on the RPS Unavailability

Trip Parameters or Signals	Results of Sensitivity	
	Case 1*	Case 2**
VOPT	1.66e-5	1.23e-4
Hi LGP	1.78e-5	1.26e-4
Hi LPD	2.12e-5	1.35e-4
Lo DNBR	2.12e-5	1.35e-4
Hi PZPR	6.14e-7	3.77e-6
Lo PZPR	7.00e-6	3.13e-5
Lo SGLV	6.24e-6	2.35e-5
Hi SGLV	6.24e-6	2.35e-5
Lo SGPR	6.47e-6	3.04e-5
Hi CTPR	6.46e-6	3.03e-5
Lo RCFL	6.82e-6	3.86e-5

*) One channel is in bypass. **) Case 1, plus additional one channel is in trip condition.

3. Conclusion

The unavailability and sensitivity analyses of the RPS were performed on the plant-specific fault tree basis. The mean unavailability ranges from approximately 8.8e-6 to 5.5e-6 for each RPS trip parameters. The contribution of common cause failures reaches approximately 97% or more to the overall system unavailability. The results of the study, namely, RPS fault trees and plant-specific data can be useful for the risk-informed applications like the improvement of technical specifications.

ACKNOWLEDGEMENTS

This study was sponsored by the Ministry of Science & Technology (MOST). The authors would like to acknowledge the cooperation of the Korea Hydro and Nuclear Power Co. (KHNP) for data collection.

REFERENCES

[1] Jang, S.C., *et al.*, “Performance Analysis of the Safety Related I&C Components Based on Operational Experience during the Period of 1995-2000”, KNS Spring Meeting, 2005.

[2] CE Owners Group, “RPS/ESFAS Extended Test Interval Evaluation,” CEN-327, Combustion Engineering, 1986.

[3] Swain, A. D., and Guttmann,H. E., “Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications,” NUREG/CR-1278, U.S. NRC, 1983.

[4] Han, S. H., *et. al.*, “User’s Manual for KIRAP Release 2.0, KAERI/TR-361/93, Korea Atomic Energy Research Institute 1993.