Optimization of STI and AOT of RPS/ESFAS for Kori Unit 2

J. H. Ha, M. K. Kim, B. S. Chung, H. C. Oh, M. R. Seo,
Korea Electric Power Research Institute, 103-16 Munji-Dong, Yuseong-Gu, Daejeon, 305-380, Korea,
hjh@kepri.re.kr

1. Introduction

Reactor protection system(RPS) and engineered safety actuation feature system(ESAFS) of a nuclear power plant are critical safety systems to protect a reactor by inserting control rods into a reactor core and by actuating safety systems such as safety injection pumps under abnormal situations. To implement high reliability of these systems, they are designed to have redundant structures and periodically tested. Surveillance test interval(STI) and allowed outage time (AOT) are well defined and provided in the technical specifications, which are determined by engineering judgment without analytical analysis. Operating experiences and maintenance records reveal that currently adopted STI and AOT are too frequent and short, respectively, which may cause negative effects on safety. In other word, a trivial human error during the test and maintenance may directly cause reactor trip and these works require lots of cautiousness so that the site engineers get stressed a lot. It is necessary to optimize STI/AOT of RPS/ESFAS considering risk change with respect to relaxation of STI and AOT. This paper shows the methodology and the results of STI/AOT optimization of RPS/ESFAS in Kori Unit 2.

2. System descriptions

RPS/ESFAS consists of sensors, analog channels, logic cabinets, master/slave relays, and reactor trip breakers, as shown in Fig 1. Kori unit 2 has 15 trip signals and 10 ESFAS signals. Analog channels compare the input signals coming from sensors with trip setpoints in the bistables. Typical input signals are temperature, pressure and level. In order to achieve redundancy and reliability for a surveillance parameter, multiple independent channels are provided in the analog channel. Logic cabinet, which is called solid state protection system(SSPS), consists of electrically and physically independent two trains, whose main function generates a trip signal to MG-set or ESFAS signals to actuate master/slave relays. In order to verify the function of RPS/ESAFS, the technical specifications require performing surveillance test on analog channels, SSPS, master/slave relays, and trip breakers. Among them, the analog channel test needs a lot of manpower and is the most stressful work.

3. Risk analysis

3.1 Method of risk analysis

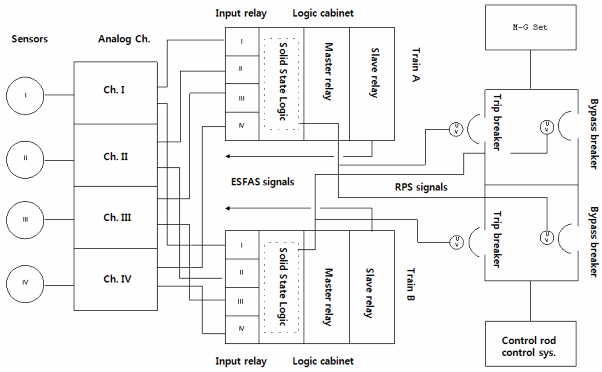

Fig. 1. Schematic diagram of RPS/ESFAS

In order to evaluate risk according to change of STI/AOTs as shown in Table 1, fault trees for RPS/ESFAS signals were constructed and merged into PSA model. Signal-specific fault trees developed have particular characteristics in the level of detail of basic events. One is a card-based basic event, which models the failure of analog circuit which belongs to analog channels. The other is a component-based basic event, which models the failure of resistors, transistors and connects in solid sate logic cards of the logic cabinet. We gathered 10 year experience data with generic data and evaluated the failure rate of basic events using Bayesian theory. Unavailability of basic event which leads to signal failure was obtained from random failure, test and maintenance, common cause failure, and human error. Each contribution is as follows:

Unavailability due to random failure of components:
The component failure probabilities were calculated with failure rate and STI.

Unavailability due to test & maintenance:
Unavailability due to test & maintenance was calculated with frequency of test & maintenance and allowed outage time or average outage time.

Unavailability due to common cause failure:
Beta factor method for 2 redundant trains and MGL method for more than 3 redundant channels were respectively used to calculate unavailability contributed from common cause failures. WACAP-15376 was used for CCF parameters.

Unavailability due to human error:
Two kinds of human errors were considered in the analysis. One is an operator error in manual reactor trip behavior, and the other is human error in the calibration activity for analog channels during test and maintenance.

Table 1. Proposed STI/AOTs

Items	Current requirements	Proposed case
Analog channel		
- STI(month)	1	3
- Test time(hour)	2	4
- Maintenance time(hour)	1	6
Logic cabinet		
- STI(month)	2	2
- Test time(hour)	2	4
- Maintenance time(hour)	6	12
Master relay		
- STI(month)	2	2
- Test time(hour)	2	4
- Maintenance time(hour)	6	12

3.2 Risk impact analysis

We performed four risk impact analyses along with STI/AOTs changes: core damage frequency(CDF), incremental core damage probability(ICCDP), large early release frequency(LERF), and incremental large early release probability(ICLERP), which are required in risk-informed regulation of KINS/GT-N24 and RG 1.177. Also, unavailability of RPS/ESFAS signals was calculated for obtaining additional risk insights. The newly developed signal-specific fault trees were substituted for that of the corresponding original PSA model. The risk impact analyses were performed by using SAREX computer code.

4. Risk analysis results

First, unavailability of the RPS/ESFAS signals was calculated with the proposed case. Table 2 shows some results of RPS signal cases. Maximum increase is 13% for "Overtemperature ΔT" signal and others are less than 10%. Noting that several trip signals are concurrently made under trip conditions, the contribution of each signal unavailability to risk is expected to be less. Before obtaining the CDF/LERF with the proposed case, only STI relaxation of analog channel was considered. Figure 2 depicts CDF change along with various analog channel STIs. It shows that the optimal STI of analog channels is two or three month. Six month, however, can be acceptable in the view of risk aspect. Apart from the effect of human error from frequent STI, it can be interpreted that the frequent STI increases risk by increasing the signal unavailability by test activity, while infrequent STI increases risk by increasing the failure probability of components. Next, risk evaluation was performed with the proposed case. The increase of CDF and LERF, as shown in Table 3, was 0.26% and 0.39%, respectively, which was within an acceptable range in KINS/GT-N24. Finally, ICCDP and ICLERP with AOT changes were evaluated, whose results were within an acceptable range in RG 1.177.

5. Conclusions

Along with STI/AOTs relaxation, Risk analysis of RPS/ESFAS in Kori unit 2 was performed. For assessment of risk, the detailed fault tree including electrical components such as resistors and transistors was developed and the plant specific database was made with 10 year operating and maintenance experiences. Analysis results showed that the impact of risk along with STI/AOTs of RPS/ESFAS on the plant was insignificant and the increases of CDF/LERF and ICCDP/ICLERP were fully acceptable according to regulatory guides.

Table 2. Unavailability of the RPS signals

RPS signals	Unavailability (Current)	Unavailability (Proposed)	Increase (%)
Low Feedwater Flow	4.10E-06	4.40E-06	7.2
Source Range	3.52E-06	3.60E-06	2.1
Overpower ΔT	3.14E-06	3.48E-06	10.8
Overtemperature ΔT	3.44E-06	3.89E-06	13.0
Pressurizer Hi Pressure	2.68E-06	2.68E-06	0.3

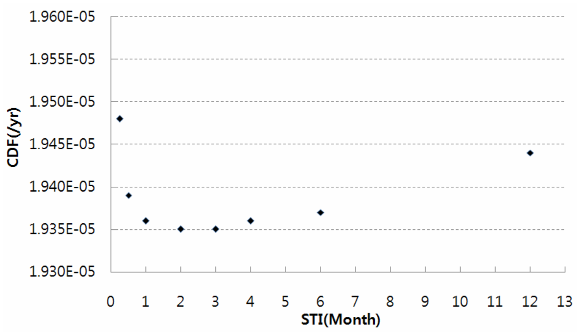

Fig. 2. Risk along with STIs change of analog channel

Table 3. Risk along with proposed STI/AOTs

Items	Current case	Proposed case	Increase (%)
CDF	1.936E-05	1.941E-05	0.26
LERF	2.296E-06	2.305E-06	0.39

REFERENCES

[1] KEPRI, Optimization of STI/AOT of RPS/ESFAS for Kori Unit 2, 2008.

[2] D. V. Lockridge, et al., Risk-Informed Assessment of the RPS and ESFAS Surveillance Test Intervals and Reactor Trip Breaker Test and Completion Times, WCAP-15376, Westinghouse Electric Company, October 2000.

[3] USNRC, An Approach for Using Probabilistic Risk assessment in Risk-Informed Decisions on Plant-Specific Change to the Licensing Basis, Regulatory Guide 1.174, November 2002.

[4] USNRC, An Approach for Plant-Specific, Risk-Informed Decision Making: Technical Specifications, Regulatory Guide 1.177, August 1998.