Development of Integrated Response Time Evaluation Methodology for the Plant Protection System

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***Abstract*– Safety analysis for a nuclear power plant establishes not only an analytical limit in terms of a measured or calculated variable but also an analytical response time required to complete protective action after the analytical limit is reached. If the two constraints are met, the safety limit selected to maintain the integrity of physical barriers used for preventing uncontrolled radioactivity release will not be exceeded during anticipated operational occurrences and postulated accidents. Setpoint determination methodologies have been actively developed to ensure that protective action is initiated before the process conditions reach the analytical limit. However, regarding the analytical response time for the plant protection system (PPS), an integrated evaluation methodology considering the whole design process has not been systematically studied. In order to assure the safety of nuclear power plants, this paper proposes a systematic and integrated response time evaluation methodology that covers safety analyses, system designs, response time analyses, and response time tests. This methodology is applied to the PPS for the advanced power reactor 1400 nuclear power plant in Korea. The quantitative evaluation results are provided herein. The evaluation results using the proposed methodology demonstrate that the PPS completely satisfies the requirement of the analytical response time.**

I. Introduction

Studies on setpoint determination methodologies for the plant protection system (PPS) have been actively performed [1]-[5]. The objective of determining a trip setpoint for the PPS that typically consists of a transmitter, a signal conditioning processor, a protection system cabinet, and a final actuator is to meet the requirement of the analytical limit assumed in performing the safety analyses. However, the response time assumed during the safety analysis shall also be satisfied by the PPS. The response time is another critical factor required to ensure that the PPS satisfies the crucial assumptions of the safety analysis [6]-[10].

Although the response time evaluation considers substantially the PPS channel on the critical trip signal path, the evaluation task such as analysis or test has been separately performed. The response time of the PPS for a nuclear power plant was recently evaluated using a combined technique of analysis and test [11]. However, the approach does not cover the whole design process that contains safety analyses, system designs, response time analyses, and response time test. In this case, the safety of a nuclear power plant cannot be guaranteed since the related process variable could exceed the analytical response time (ART) generated by the results of the safety analysis.

In order to solve the problem regarding the response time evaluation for the PPS, this paper proposes the integrated response time evaluation methodology that ensures the PPS meets a critical requirement of the ART. The proposed methodology has been applied to the PPS instrumentation channels for the advanced power reactor 1400 (APR1400) to fully verify the satisfaction of the ARTs for the low steam generator level (LSGL) reactor trip parameter.

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II. Methodology

The safety analysis considering design basis events is performed to ensure the safety limit of a nuclear power plant. The result of the safety analysis consists of the analytical limit (AL) and the ART as shown in Fig. 1. The PPS must perform its own safety functions before the plant process variable exceeds the AL. The trip setpoint should be determined considering all kinds of uncertainties on the PPS. The allowable value is required to ensure that the trip setpoint does not exceed the AL by limiting the variation allowance of the trip setpoint when tested periodically [12]-[14].

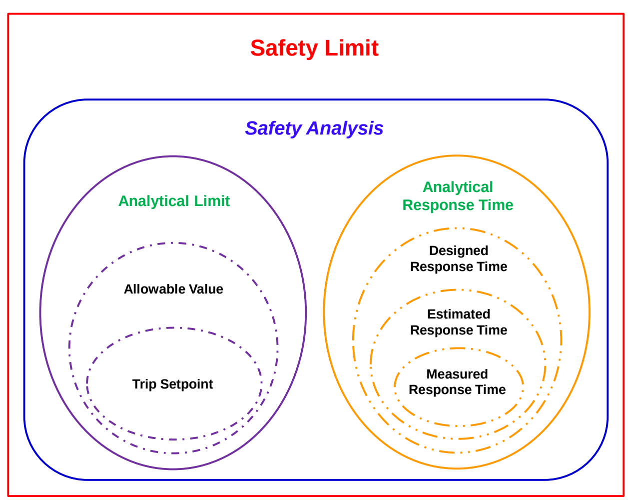

Fig. 1. Relationship between analytical limit and safety analysis response time

The two elements are the most crucial for the PPS and the relevant research has been recently performed in detail [1]. In addition, the ART assumed in performing the safety analysis is a very important factor to ensure the safety limit. The ART must be satisfied by systematically and conservatively considering the designed response time, the estimated response time, and the measured response time as illustrated in Fig. 1.

A. Analytical Limit

The PPS instrumentation channel is composed of a transmitter, a signal conditioning processor, a logic cabinet, and a reactor trip switchgear system (RTSS). The trip setpoint is a more conservative value than the AL by the amount of the total channel uncertainty calculated by combining all identified uncertainty elements in the PPS instrumentation channel. The number of signal conditioning processor can be changed based on the specific design features of the PPS. In that case, since the trip setpoint is set into the PPS cabinet, the RTSS that receives the output actuation signal of the PPS is excluded in calculating the total channel uncertainty. However, the response time evaluation must include all the equipment including the RTSS.

B. Analytical Response Time

The proposed methodology herein deals with the whole design process that covers the safety analysis, the system design, the response time analysis, and the response time test, as shown in Fig. 2.

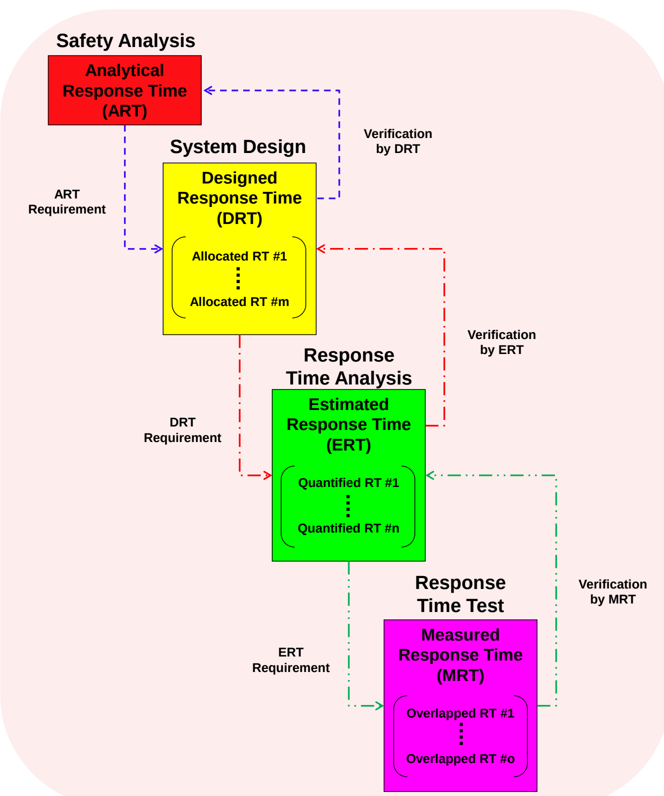

Fig. 2. Response time evaluation process

Each output of the design process is the ART, the designed response time (DRT), the estimated response time (ERT), and the measured response time (MRT). The DRT is the sum of individually allocated response times to the PPS. Each component of the PPS has its own design requirement related to the response time. The DRT should be demonstrated to be less than the ART. The ERT is the sum of individually quantified response times to each component of the PPS. Each quantified response time should meet the corresponding allocated response time and then the ERT should be validated to be less than the DRT. The MRT is the sum of individually overlapped response times to each component of the PPS. Each overlapped response time should satisfy the corresponding quantified RT and then the MRT should be justified to be less than the ERT.

III. Quantitative Evaluation

The proposed response time evaluation methodology is applied to an LSGL reactor trip parameter for the APR1400. The quantitative evaluation results regrading safety analysis, system design, response time analysis, and response time test are provided herein.

A. Safety Analysis

In performing the safety analysis regarding loss of condenser vacuum (LOCV) event determined as a limiting anticipated operational occurrence, the analytical limit of 40.7% [1] and analytical response time of 1.25 s were assumed. For the safety analysis regarding feedwater line break (FLB) event determined as a limiting postulated accident, the analytical limit of 28.4% and analytical response time of 1.25 s were assumed. As a result, the analytical limits for LOCV and FBL are 40.7% and 28.4%, respectively, and the ART has a margin of 1.25 s for both limiting events.

B. System Design

The ART determined through the safety analysis is used as a response time design requirement of the PPS. The DRT, which means the summation of each response time allocated to the individual components of the PPS channel, should be within the ART. Fig. 3 shows that both the DRT is less than the ART and the margin is a positive value.

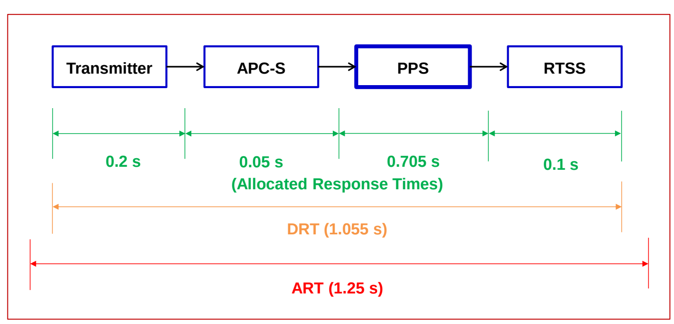

Fig. 3. Response time allocation for LSGL reactor trip function [11]

As illustrated in Fig.3, the LSGL reactor trip function channel is composed of transmitter, auxiliary process cabinet-safety (APC-S), PPS, and RTSS. The DRT of 1.055 s is determined adding individual response times for all components. This means the response time of each component should be determined so that the DRT does not exceed the ART. The ART of 1.25 s is a response time assumed in performing safety analyses regarding the trip parameter.

C. Response Time Analysis

For LSGL reactor trip parameter, the ERT is calculated summing the response times of transmitter, APC-S, PPS, and RTSS. In this case, the PPS should be analyzed in detail to consider the worst-case operating conditions because the PPS contains software modules programmed with dedicated cycle times.

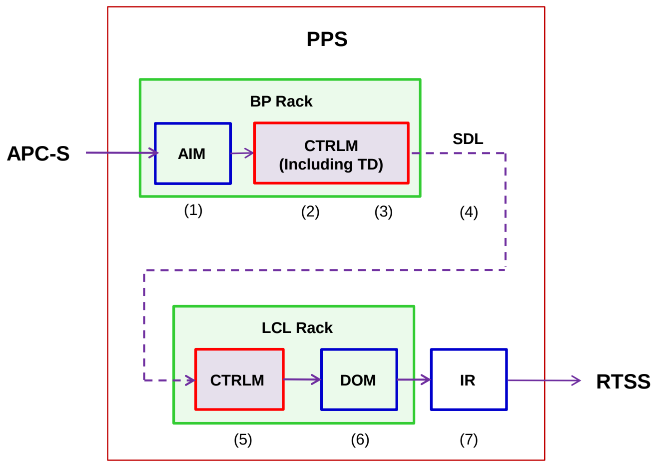

Fig. 4. Response time analysis for PPS [11]

The PPS consists of bistable processor (BP) rack, safety data link (SDL), local coincidence logic (LCL) rack, and interposing relay (IR) as illustrated in Fig. 4. The BP rack includes analog input module (AIM) and control module (CTRLM) including time delay (TD), and the LCL rack contains CTRLM and digital output module (DOM).

TABLE I. INDIVIDUAL PPS RESPONSE TIME [11]

Components	Response Time (s)
(1) AIM	0.02
(2) CTRLM	0.058
(3) TD	0.48
(4) SDL	0.013
(5) CTRLM	0.034
(6) DOM	0.012
(7) IR	0.025
Total Response Time	0.642
Response Time Requirement	0.705

The detailed response time for the individual PPS components is described in Table I and indicates the analyzed RT of 0.642 s does not exceed the allocated RT of 0.705 s. Therefore, it can be demonstrated that the allocated response time is met by the response time analysis technique.

Since the analyzed RT for the PPS is 0.642 s and the remaining three parts are the same as the allocated RT, the ERT for the LSGL reactor trip parameter is 0.992 s that is less than the DRT of 1.055 s. The ERT of 0.992 s is less than the DRT of 1.055 s by a margin of 0.663 s. Therefore, the result of response time analysis is acceptable since the margin is a positive value.

D. Response Time Test

When the response time test is not performed on all components and systems at the same time, an overlap test should be implemented and then the test results should be added to ensure that the channel response time meets the corresponding requirement.

The response time test results for LSGL reactor trip parameters #1 and #2 are depicted as Tables II and III, respectively. The response time tests were performed on the trip parameter that has four redundant channels A, B, C, and D. Tables II and III indicate that each MRT does not exceed the ERT of 0.992 s. Therefore, it has been verified that the ERT is completely satisfied by the MRTs. In addition, the DRT envelopes the ERT and does not exceed the ART.

TABLE II. STEAM GENERATOR #1 LSGL RESPONSE TIME [11]

Systems	Channel Response Time (s)			
	CH. A	CH. B	CH. C	CH. D
(1) Transmitter	0.091	0.055	0.104	0.120
(2) APC-S & PPS	0.610	0.609	0.614	0.615
(3) RTSS	0.084	0.084	0.084	0.084
MRT	0.785	0.748	0.802	0.819
ERT	0.992			
DRT	1.055			
ART	1.250			

TABLE III. STEAM GENERATOR #2 LSGL RESPONSE TIME

Systems	Channel Response Time (s)			
	CH. A	CH. B	CH. C	CH. D
(1) Transmitter	0.066	0.064	0.076	0.075
(2) APC-S & PPS	0.603	0.620	0.618	0.619
(3) RTSS	0.084	0.084	0.084	0.084
MRT	0.753	0.768	0.778	0.778
ERT	0.992			
DRT	1.055			
ART	1.250			

IV. CONCLUSION

The integrated response time evaluation methodology which covers the whole design process was applied for the LSGL reactor trip parameter of the APR1400. It was demonstrated that all the response time design, estimation, and measurement completely and systematically satisfy the response time requirement of safety analysis. Therefore, the results of this study suggest that the proposed methodology can be used as a tool for guaranteeing the safety of a nuclear power plant.

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REFERENCES

[1] C. J. Lee, S. M. Baek, S. J. Lee, “Setpoint Methodology Improvement Considering Beyond Basis Events for Safety-Related Instrumentation,” *IEEE trans. Nuclear Science*, vol. 61, no. 4, pp. 2120-2130, Aug. 2014.

[2] S. H. Yang, S. H. Kim, Y. J Chung, S. Q. Zee, “Trip setpoint analysis for the reactor protection system of an advanced integral reactor,” *Annals of Nuclear Energy*, vol. 34, no. 4, pp. 319-325, Apr. 2007.

[3] Robert J. Dodson, Madeline Anne Feltus, “Low temperature overpressurization protection system setpoint analysis using RETRAN for Salem, *Annals of Nuclear Energy*, vol. 23, no. 6, pp. 487-498, Apr. 1996.

[4] C. R. Tuley, Richard B. Miller, “Westinghouse setpoint methodology for control and protection systems,” *IEEE trans. Nuclear Science*, vol. 33, no. 1, pp. 684-687, Feb. 1986.

[5] K. I. Han, “OPΔT and OTΔT Trip Setpoint Generation Methodology,” *Journal of the Korean Nuclear Society*, vol. 16, no. 2, pp. 106-115, Jun. 1984.

[6] Guidance on Digital Computer Real-Time Performance, U.S.NRC, NUREG 0800, SRP, BTP 7-21, 2007.

[7] Performance Monitoring for Nuclear Safety-Related Instrument Channels in Nuclear Power Plants, ANSI/ISA-67.06.1, 2002.

[8] Periodic Testing of Electric Power and Protection Systems, U.S.NRC Regulatory Guide 1.118, Rev. 3, Apr. 1995.

[9] IEEE Standard for Criteria for the Periodic Surveillance Testing of Nuclear Power Generating Station Safety Systems, IEEE Std. 338, Sep. 10, 1987.

[10] Effect of aging on response time of nuclear plant pressure sensors, NUREG/CR 5383, 1989.

[11] C. J. Lee, S. Han, J. H. Yun, S. M. Baek, “Response Time Evaluation for the PPS Using a Combined Technique of Analysis and Test,” Transactions of the Korean Nuclear Society Autumn Meeting, Oct. 2015.

[12] Setpoint for Safety-Related Instrumentation, U.S.NRC Regulatory Guide 1.105, Rev. 3, Dec. 1999.

[13] Setpoints for Nuclear Safety-Related Instrumentation, ISA-S67.04, Part I, Sep. 1994.

[14] Nuclear Power Plants-Instrumentation Important to Safety - Determination and Maintenance of Trip Setpoints, IEC-61888, Aug. 2002.