An Improved Response Time Test Methodology for the Plant Protection System and Engineered Safety Feature – Component Control System

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Abstract: The safety instrumentation and control system for the advanced power reactor 1400 (APR1400) nuclear power plant has been improved in terms of hardware configuration and communication system that address critical trip signals. For the optimized power reactor 1000 (OPR1000) nuclear power plants, a lumped test method has been applied in order to conduct the periodic response time test required by the Technical Specifications. This paper proposes a new methodology that covers the response time test for the plant protection system and engineered safety feature – component control system, using a distributed approach. Furthermore, the lumped method used for the OPR1000 is provided in detail to compare with the proposed method for the APR1400. The test results are also presented herein and indicate that the proposed method is appropriate and reasonable to meet the response time design requirement.

Keyword: Distributed approach, engineered safety features actuation system, instrumentation and control, lumped approach, reactor protection system, response time test

1 Introduction

The safety instrumentation and control (I&C) systems that perform reactor trip and engineered safety features actuation functions are required to meet two important requirements of the response time and trip setpoint so that the process variables do not exceed the safety limit during design basis events[1-6]. The response time evaluation methodologies for the nuclear safety I&C systems have been studied and developed[7-9]. In addition, the response time test methodology for the digital plant protection system has been suggested for the nuclear power plants (NPPs) of the optimized power reactor (OPR) 1000[10].

Since the safety I&C system should perform its intended safety functions within the allowed time after a process variable reaches the trip setpoint, it is indispensable to establish the setpoint determination methodology. Recently, the setpoint methodology for the safety I&C system has been developed to enhance the NPP's safety by considering the beyond design basis events as well as the design basis events[11]. The safety functions should also be tested periodically in accordance with the relevant regulation and industry standard[12,13].

The advanced power reactor (APR) 1400 nuclear power plant, which incorporates significant enhancements in connection with safety as well as increased power capabilities into its design, has been developed based on the reference plant of the OPR1000. Particularly, the safety I&C system has been improved in the aspects of hardware configuration and communication system that address critical trip signals. The safety I&C system consists of four instrumentation channels and the cabinets of each channel are located in a separate I&C equipment room. When it comes to the OPR1000, the safety system cabinets of four channels are installed together in the same zone. In addition, since the communication system of the OPR1000 between the digital plant protection system (DPPS) and digital engineered safety features actuation system – auxiliary cabinet (DESAFAS-AC) is comprised of the fiber optic transmitters, fiber optic cables, and fiber optic receivers, the response time test for each system was performed separately.

However, in case of the APR1400, the communication system between the plant protection system (PPS) and engineered safety feature – component control system (ESF-CCS) has been changed to the dedicated safety grade high speed link. So, the digital processor module in each system is connected directly without a process which converts an electrical to optical signal. Thus, it is necessary to devise a new and appropriate response time test methodology to cover the distributed hardware configuration and the improved communication system.

This paper proposes an improved response time test methodology applied to the APR1400 nuclear power plant and presents the detailed review of the existing test method that has been used for the OPR1000. Also, the quantitative test results by the new method are compared with those of the OPR1000 reference plant, and it is verified that the proposed methodology is reasonable and appropriate to meet the design requirement for the safety I&C system's response time.

2 Test Methods for OPR1000

The response time for the DPPS that consists of four adjoining cabinets located in the main control room is tested using the lumped approach that measures at a time all the output signals from four cabinets regarding the reactor trip function[10]. As shown in Fig. 1, the reactor protection system (RPS) consists of four channels of transmitters, remote shutdown panel (RSP), protective process cabinet (PPC), DPPS, and reactor trip switchgear system (RTSS). The engineered safety features actuation system (ESFAS) includes the DESFAS-AC instead of the RTSS.

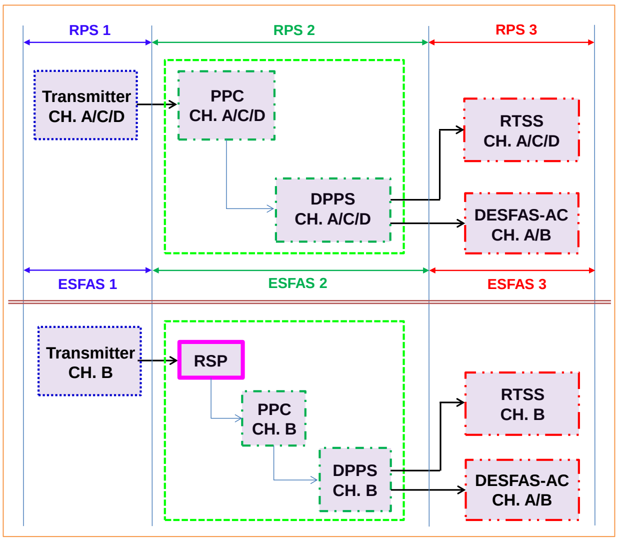

Fig. 1 Trip Signal Flow Path for RPS and ESFAS for OPR1000

In the case of the low pressurizer pressure (LPP) trip parameter, the channel B's RPS and ESFAS signals pass the RSP in order for the operator to use the measured process value in case of fire at the main control room. The response time test for the LPP is divided into three intervals, and the total response time is determined by adding them. The method to calculate the response time of the ESFAS is identical.

As depicted in Fig. 1, the relationships between the response time design requirements and response time test results for the RPS and ESFAS for the OPR1000 are shown in equations (1) and (2), respectively.

$$R_{RPS1} + \sum_{i=1}^{m} R_{RPS2(i)} + R_{RPS3} = \sum_{j=1}^{3} T_{RPS(j)} + M_{RPS} \quad (1)$$

$$R_{ESFAS1} + \sum_{i=1}^{m} R_{ESFAS2(i)} + R_{ESFAS3} = \sum_{j=1}^{3} T_{ESFAS(j)} + M_{ESFAS} \quad (2)$$

Where R is the response time design requirement and T is the response time test result. M stands for margin that is greater than zero. In addition, m corresponds to a positive integer, which is greater than one.

Regarding the LPP trip setpoint calculation, the total channel uncertainty for the RPS and ESFAS for the OPR1000 is given as equation (3), considering the channel B that has the longest signal flow path[7,11]. Since the trip setpoint is set into the DPPS, the total channel uncertainty is calculated by incorporating the relevant uncertainties from the transmitter to the DPPS.

$$TCU_{OPR1000} = \sqrt{\sum_{i=1}^{m} TRUF_i^2 + \sum_{j=1}^{n} RRUF_j^2 + \sum_{k=1}^{o} PRUF_k^2 + \sum_{l=1}^{p} DRUF_l^2} + B \quad (3)$$

Where the terms *m*, *n*, *o*, and *p* are integers, which are greater than one.

TCU = total channel uncertainty
TRUF = transmitter random uncertainty factor
RRUF = RSP random uncertainty factor
PRUF = PPC random uncertainty factor
DRUF = DPPS random uncertainty factor
B = bias

2.1 RPS Response Time Test

The RPS portion of the DPPS cabinet is divided into the voltage to current converter, bistable logic, RPS 2-out-of-4 coincidence logic, and shunt trip (ST) relay or under voltage trip (UVT) relay, as shown in Figure

2. The response time test equipment (RTTE) consists of two parts of start and stop. The start part generates a simulated input signal that exceeds the trip setpoint and then sends it to the signal processing device.

In addition, another trip signal is necessary to combine with the 2-out-of-4 coincidence logic. The RTTE indicates four channels' response time results, measuring one starting time and four stopping times and calculating the elapsed time from the same starting time to each channel's stopping time[10]. For testing the channel B of the DPPS cabinet, the initiation signal is provided to the RSP and the test results are received from UVT or ST relays of four DPPS channels, using the RTTE, as shown in Fig. 2.

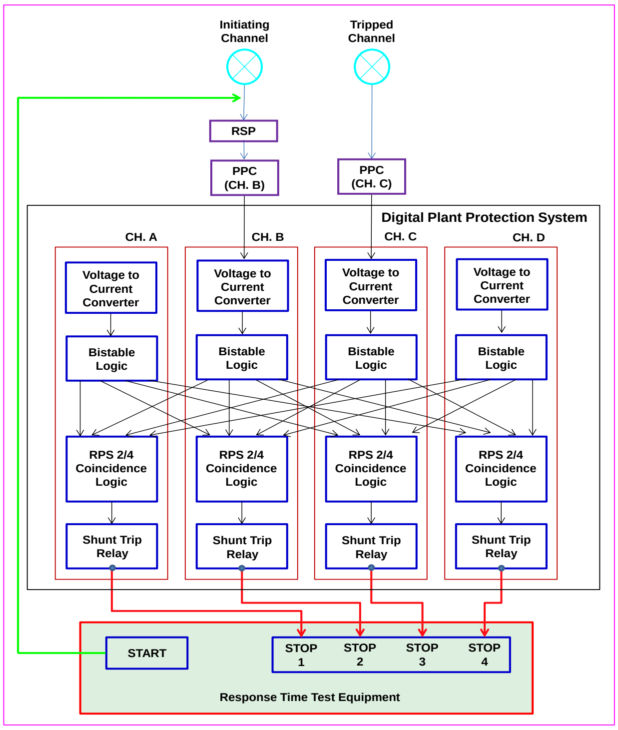

Fig. 2 RPS Response Time Test Method for OPR1000[10]

2.2 ESFAS Response Time Test

2.2.1 DPPS Test Method

Fig. 3 shows that the ESFAS portion of the DPPS cabinet is the nearly same as the RPS portion with the exception of the ESFAS 2-out-of-4 coincidence logic and fiber optic transmitter. The response time of the DPPS is tested separately from the DESFAS-AC cabinet since it is possible to receive the test output signal from the fiber optic transmitter by disconnecting the fiber optic cable between the DPPS and DESFAS-AC.

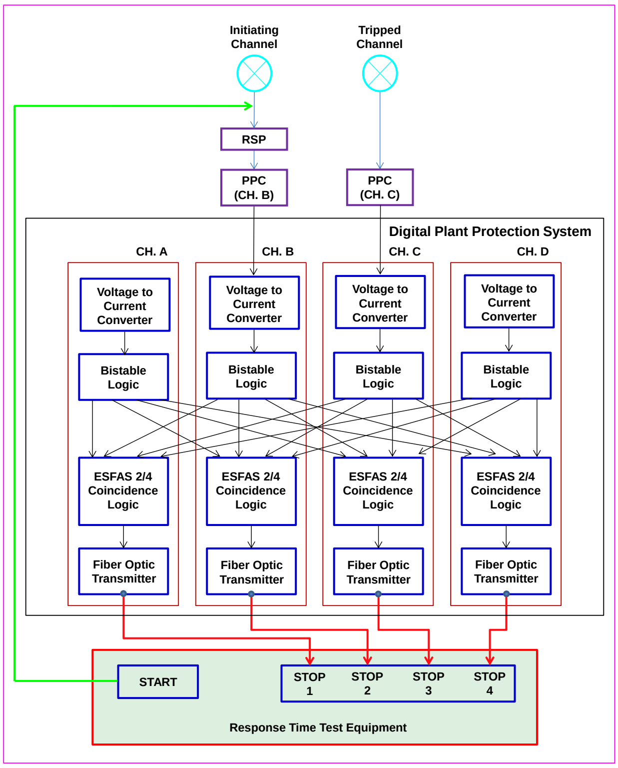

Fig. 3 ESFAS Response Time Test Method for the DPPS[10]

2.2.2 DESFAS-AC Test Method

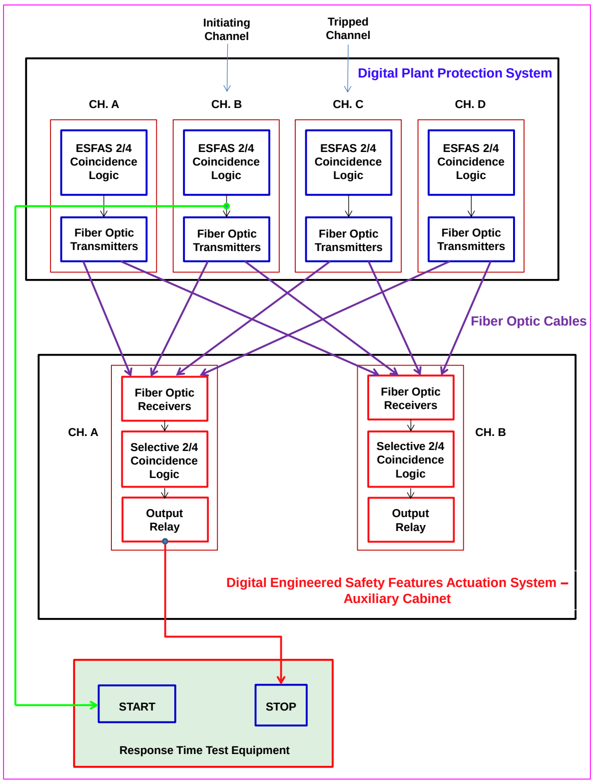

Fig. 4 ESFAS Response Time Test Method for the DESFAS-AC[10]

For the response time test of the DESFAS-AC cabinet that consists of fiber optic receivers, selective 2-out-of-4 coincidence logic, and output relay, the RTTE displays the test result by calculating the elapsed time between when it receives the starting signal from the DPPS and when it gets the stopping signal from the output relay of the DESFAS-AC, as shown in Fig. 4. In this case, the RTTE does not generate the simulation signal, since it does not need to generate a simulated signal that exceeds the trip setpoint in the bistable logic. The trip output of the ESFAS 2-out-of-4 coincidence logic is generated by pushing the manual ESF actuation button on the maintenance and test panel of the DPPS.

2.3 Test input signal combination

Table 1 indicates the detailed input signal combinations for the RPS response time test that are minimum conditions to fulfill the 2-out-of-4 coincidence logic. The signal combination for the ST relay is different from that of the UVT relay, considering the diversity of the RPS response time test. The combination for the safety injection actuation signal (SIAS) is also diverse from the containment isolation actuation signal (CIAS). The possibility of confusing a tester due to the different signal combination is low, since four channels of the DPPS are configured as a set of adjacent cabinets in the main control room[10].

Table 1 Test Input Signal Combination for OPR1000

DPPS Output Signal	Initiating Channel	Tripped Channel
ST (RPS)	A/B/C/D	D/C/B/A
UVT (RPS)	A/B/C/D	C/A/D/B
SIAS (ESFAS)	A/B/C/D	D/C/B/A
CIAS (ESFAS)	A/B/C/D	C/A/D/B

Even though the corresponding channel output signal is needed to carry out the response time test for a channel, the longest response time among four results is conservatively selected as a final value, and this approach is also available based on the physical arrangement of the DPPS cabinets[10].

3 New Test Methods

There are two crucial items to be considered in developing the response time test methodology for the safety system with new designs. Firstly, the signal combination to make trip conditions should be determined considering the distributed configuration. In addition, comparing with the OPR100 that uses the lumped approach, the distributed approach that each channel is tested separately without combining all channels' test results should be applied to the APR1400. Secondly, the PPS and EFS-CCS should be tested at the same time. Regarding the OPR1000, it is possible to test the two systems separately because the connection is configured with the combination of the electrical and fiber optic transmission. However, the communication between two systems for the APR1400 has been changed to the safety grade high speed link which does not have any termination that can be connected to the RTTE. Thus, there are no available injecting and detecting points to perform the response time test.

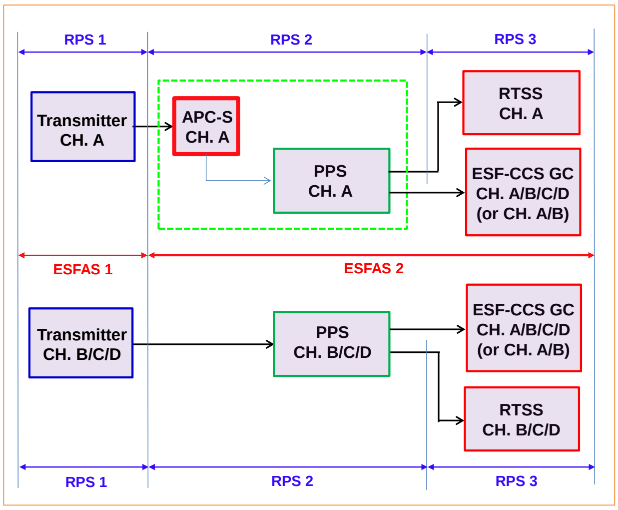

Fig. 5 Trip Signal Flow Path for RPS and ESFAS for APR1400

As illustrated in Fig. 5, the RPS comprises four channels of transmitters, auxiliary process cabinet – safety (APC-S), PPS, and RTSS. The ESFAS is composed of the ESF-CCS group controller (GC) instead of the RTSS. The ESF-CCS GC includes four channels (A, B, C, and D) for the SIAS and two channels (A and B) for the CIAS. Only the channel A of the RPS and ESFAS passes the APC-S that performs signal conditioning and splitting for the safety field sensor signals, since the LPP process value needs to be split into two things in order to send them to the PPS and the diverse indication system.

The response time test for the RPS LPP is divided into three intervals, and the total response time is determined by adding them. However, the response time test interval for the ESFAS LPP consists of two intervals because there is no appropriate test output point at the ending portion of the PPS cabinet to disconnect the communication cable between the PPS and the ESF-CCS GC.

As indicated in Fig. 5, the relationships between the response time design requirements and response time test results for the RPS and ESFAS for the APR1400 are shown in equations (4) and (5), respectively. In particular, the calculated margin must be sufficient to guarantee that the actual response times for the RPS and ESFAS functions do not exceed their own response time design requirements.

$$M_{APR1400\ RPS} = R_{RPS1} + \sum_{i=1}^{m} R_{RPS2(i)} + R_{RPS3} - \sum_{j=1}^{3} T_{RPS(j)} \quad (4)$$

$$M_{APR1400\ ESFAS} = R_{ESFAS1} + \sum_{i=1}^{m} R_{ESFAS2(i)} + R_{ESFAS3} - \sum_{j=1}^{2} T_{ESFAS(j)} \quad (5)$$

Where *M* stands for margin that is greater than zero, *R* is the response time design requirement, and *T* is the response time test result. Additionally, *m* is a positive integer.

In terms of the trip setpoint for the LPP trip parameter, the total channel uncertainty for the RPS and ESFAS for the APR1400 is given as equation (6), considering the channel A that has the longest signal flow path[7,11]. The total channel uncertainty is calculated by reflecting the relevant uncertainties from the transmitter to the PPS because the trip setpoint is programmed in the bistable logic of the PPS.

$$TCU_{APR1400} = \sqrt{\sum_{i=1}^{m} TRUF_i^2 + \sum_{j=1}^{n} ARUF_j^2 + \sum_{k=1}^{o} PRUF_k^2} + B \quad (6)$$

Where the terms *m*, *n*, and *o* are integers, which are greater than one.

TCU = total channel uncertainty
TRUF = transmitter random uncertainty factor
ARUF = APC-S random uncertainty factor
PRUF = PPS random uncertainty factor
B = bias

3.1 Test input signal combination for APR1400

The signal combinations for the response time test are determined to reduce human errors that may occur during the test. Since each channel is separately located in its own I&C equipment room, the signal combination should be easily understandable and memorable. The simplest ST signal combinations based on the sequential approach are exactly identical to those of the UVT, as indicated in Table 2. Additionally, the signal combination for the ESFAS SIAS is equal to the CIAS. As a result, all the signal combinations for the ST, UVT, SIAS, CIAS are exactly same as AB, BC, CD, DA, in which the front character indicates the initiating channel and the rear one corresponds to the tripped channel.

Table 2 Test Input Signal Combination for APR1400

PPS Output Signal	Initiating Channel	Tripped Channel
RPS (ST & UVT)	A/B/C/D	B/C/D/A
ESFAS (SIAS & CIAS)	A/B/C/D	B/C/D/A

3.2 RPS Response Time Test for APR1400

The PPS has eight cabinets for four channels and each channel includes two cabinets. The PPS cabinets in each channel are geographically distributed into four separate channelized I&C equipment rooms. The bistable logic in a channel receives measurements of the process variables, separated from those in the redundant channels. There is a separate bistable function per process variable. The bistable function determines the trip state by comparing the process variable measurement to its corresponding trip setpoint. The RPS 2-out-of-4 coincidence logic algorithm determines the state of the coincidence output based on the status of four pairs of trip inputs per one cabinet and their respective trip channel bypass inputs. Two trip inputs from the same channel's bistable logics are processed by the OR logic and then the output signal is sent to the full

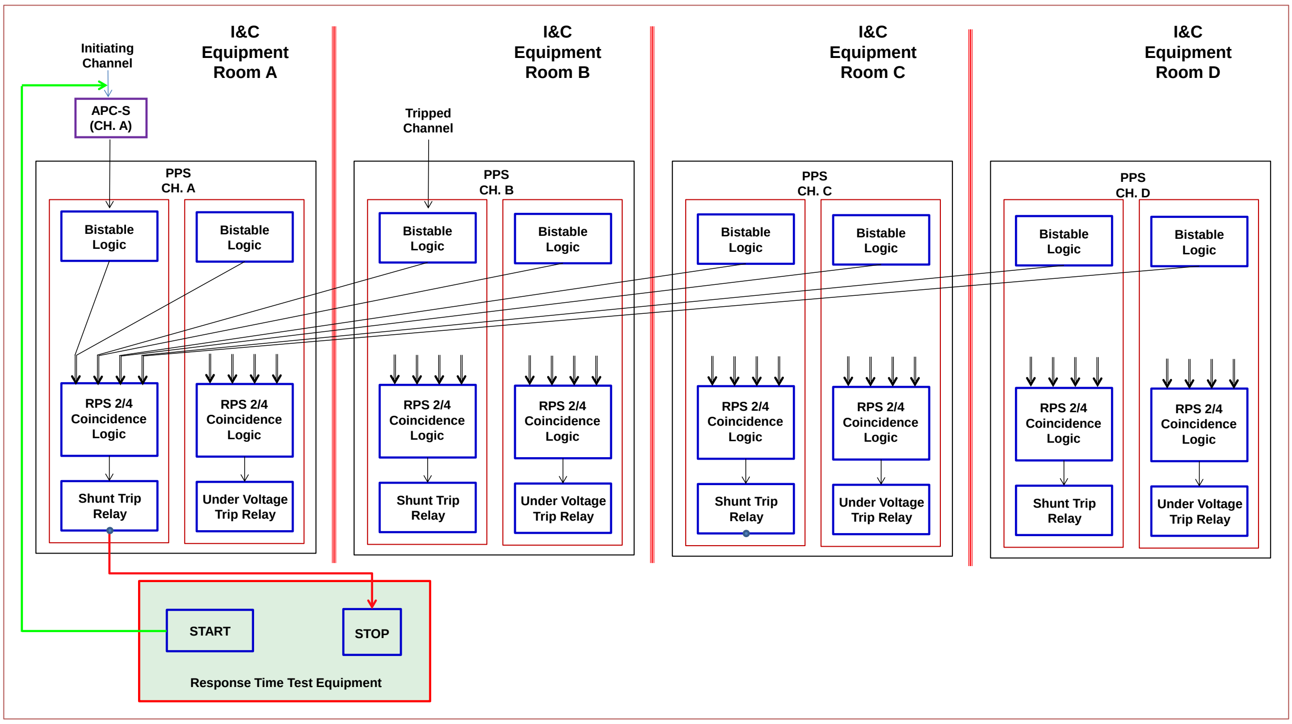

Fig. 6 RPS Response Time Test Method for the APR1400

2-out-of-4 coincidence logic. A trip channel bypass blocks its respective trip input in the coincidence logic and changes the coincidence logic to 2-out-of-3. Each of the RPS initiation outputs from the coincidence logic are connected to the ST relay and UVT relay blocks, which include each selective 2-out-of-4 coincidence initiation circuit. However, each of the ESFAS initiation outputs form the coincidence logic are combined in a selective 2-out-of-4 coincidence within the ESF-CCS GC without passing the trip relays in the PPS cabinet.

The PPS response time test for the APR1400 is performed using the RTTE that sends a starting signal to the APC-S in the tested channel and obtains a resulting signal from only the corresponding PPS channel instead of all four ones. Fig. 6 illustrates the response time test configuration for channel A of the PPS. With regard to the RPS function, a process value from the APC-S in a channel is provided to the PPS in the same channel. Even though each of eight RPS 2-out-of-4 logics receives eight trip inputs from eight bistable logics, Fig 6 shows that eight trip inputs are transmitted to only one RPS 2-out-of-4 logic by considering the complexity.

If the processed value exceeds the trip setpoint set into the bistable logic, a trip signal is generated and then provided to all 2-out-of-4 coincidence logics of four channels. Each 2-out-of-4 coincidence logic output is connected to UVT and ST relays, which are installed a part of each corresponding initiation circuit. The response time test for the signal path which has the UVT relay is tested separately from the ST relay, as illustrated in Fig. 6. The RTTE consists of both start and stop parts. The start portion generates a simulated input signal that exceeds the trip setpoint and then sends it to the APC-S. In addition, another trip signal is required to fulfill the 2-out-of-4 coincidence logic. The RTTE displays the response time test result, measuring both starting and stopping times and calculating the elapsed time between them.

3.3 ESFAS Response Time Test for APR1400

The ESF-CCS GC consists of four channels and each channel is divided into two redundant cabinets that include a selective 2-out-of-4 coincidence logic, as illustrated in Fig. 7.

The ESF-CCS GC cabinets in each channel are geographically distributed into four separate channelized I&C equipment rooms. The first cabinet of each ESF-CCS GC receives four ESFAS initiation signals from four first PPS cabinets and performs a selective 2-out-of-4 coincidence logic. Four ESFAS initiation signals from four second PPS cabinets are provided to the second cabinet of each ESF-CCS GC

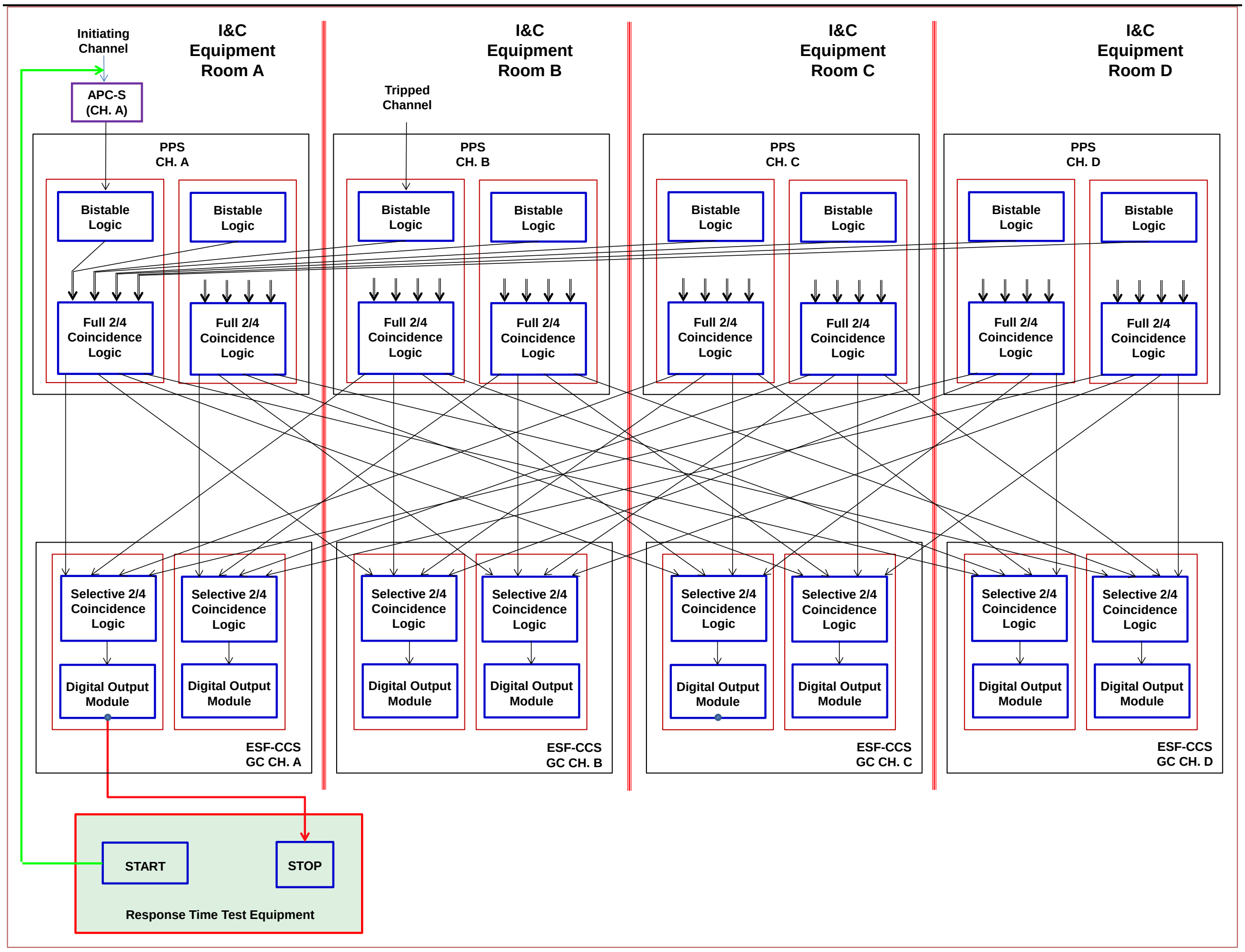

Fig. 7 ESFAS Response Time Test Method for the APR1400

that also conducts a selective 2-out-of-4 coincidence logic. The output of the selective 2-out-of-4 coincidence logic of the ESF-CCS GC is transmitted to the digital output (DO) module that is connected to the stop portion of the RTTE.

For the ESFAS parameters such as SIAS and CIAS, the PPS and the ESF-CCS GC are tested together at a time, since the communication system between the PPS and the ESF-CCS GC does not provide an available test point, and the PPS and ESF-CCS GC cabinets are located together in the I&C equipment room. The response time test method regarding the start portion of the RTTE is equal to the RPS response time test. The RTTE indicates the test result by calculating the elapsed time between the starting and stopping times.

4 Test Results

4.1 RPS Test Results for OPR1000

As depicted in Fig. 2, the RPS channel B consists of the RSP, PPC, and DPPS cabinet that have their own response time design requirements of 0.13s, 0.05s and 0.225s, respectively, and its total response time requirement is 0.405s. The other channels' requirements are the same as 0.275s since the trip signal path does not include the RSP. Table 3 indicates the test results for the RPS in conjunction with the LPP trip parameter. All the results for the DPPS cabinet meet the associated response time requirement.

Table 3 Test Results for RPS LPP for OPR1000

Channel	Req. (s)	ST Response Time (s)	UVT Response Time (s)	Margin ST/UVT (%)
A	0.275	0.147	0.156	46.5/43.3
B	0.405	0.186	0.183	54.1/54.8
C	0.275	0.141	0.166	48.7/39.6
D	0.275	0.162	0.146	41.1/46.9

4.2 ESFAS Test Results for OPR1000

As depicted in Fig. 3, the ESFAS 2-out-of-4 coincidence logic and fiber optic transmitter in the DPPS cabinet are used instead of the RPS 2-out-of-4 coincidence logic and ST relay. Since the DPPS cabinet's response time design requirement is equal to the RPS one of 0.225s, the total response time requirement of the ESFAS channel B is 0.405s. The other channels' requirements are the same as 0.275s since the RSP is not included in the trip signal path. Tables 4 and 5 indicate the test results for the DPPS cabinet in conjunction with the LPP trip parameter, respectively. All the results for the DPPS cabinet meet the associated response time requirement.

Table 4 Test Results for DPPS SIAS for OPR1000

DPPS Channel	Req. (s)	SIAS Channel A (s)	SIAS Channel B (s)	Margin A/B (%)
A	0.275	0.143	0.164	48.0/40.4
B	0.405	0.157	0.176	61.2/56.5
C	0.275	0.151	0.165	45.1/40.0
D	0.275	0.140	0.163	49.1/40.7

Table 5 Test Results for DPPS CIAS for OPR1000

DPPS Channel	Req. (s)	CIAS Channel A (s)	CIAS Channel B (s)	Margin A/B (%)
A	0.275	0.171	0.149	37.8/45.8
B	0.405	0.176	0.188	56.5/53.6
C	0.275	0.154	0.148	44.0/46.2
D	0.275	0.140	0.157	49.1/42.9

Table 6 Test Results for DESFAS-AC for OPR1000

DESFAS-AC Channel	Req. (s)	SIAS (s)	CIAS (s)	Margin (%) SIAS/CIAS
A	0.300	0.078	0.079	74.0/73.7
B	0.300	0.077	0.076	74.3/74.7

As depicted in Fig. 4, the DESFAS-AC cabinet that has the response time design requirement of 0.3s is tested separately from the DPPS cabinet and consists of two channels. The RTTE receives the start signal from the DPPS cabinet so that the test result is cross-checked between two cabinets. Table 6 indicates the test results for the DESFAS-AC in conjunction with the LPP trip parameter. All the results for the DESFAS-AC cabinet meet the associated response time requirement.

4.3 RPS Test Results for APR1400

As indicated in Fig. 6, the RPS channel A is comprised of the APC-S and PPS that have their own response time design requirements of 0.05s and 0.225s, respectively. The other channels' requirements are the same as 0.225s since the trip signal path does not include the APC-S. Table 7 indicates the test results for the RPS in conjunction with the LPP trip parameter. All the results meet the associated response time requirement. Furthermore, all the margins between the requirements and test results have increased comparing with those listed in Table 3 for the OPR1000.

Table 7 Test Results for RPS LPP for APR1400

Channel	Req. (s)	ST Response Time (s)	UVT Response Time (s)	Margin ST/UVT (%)
A	0.275	0.097	0.086	64.7/68.7
B	0.225	0.089	0.086	60.4/61.8
C	0.225	0.105	0.099	53.3/56.0
D	0.225	0.111	0.084	50.7/51.1

Fig. 8 shows the comparison of each channel's margin for the RPS response time, and it confirms that the APR1400 has more margin than the OPR1000. The maximum margin of each channel was used to compare the two plants.

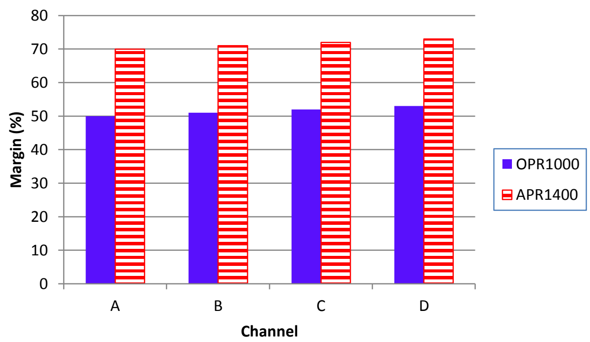

Fig. 8 RPS response time margin

4.4 ESFAS Test Results for APR1400

As indicated in Fig. 7, the ESFAS channel A is comprised of the APC-S, PPS, and ESF-CCS GC that have their own response time design requirements of

0.05s, 0.225s, and 0.240s, respectively, and its total response time requirement is 0.515s. The other channels' requirements are the same as 0.465s since the trip signal path does not contain the APC-S. Table 8 indicates the test results for the ESFAS SIAS in conjunction with the LPP trip parameter. All the results that cover both the PPS cabinet and the ESF-CCS GC meet the associated response time requirement. In addition, the majority of margins are greater than 70 percent.

Table 8 Test Results for ESFAS SIAS for APR1400

Channel	Req. (s)	SIAS GC1 (s)	SIAS GC2 (s)	Margin (%) GC1/GC2
A	0.515	0.145	0.119	71.8/76.9
B	0.465	0.118	0.117	74.6/74.8
C	0.465	0.136	0.135	70.8/71.0
D	0.465	0.145	0.118	68.8/74.6

Regarding the ESFAS SIAS for the OPR1000, the response times of the DPPS and DESFAS-AC are separately tested, and the margins are shown in Tables 4 and 6, respectively. Although the margins for the DESFAS-AC are greater than 70 percent, those for the DPPS are much less than 70 percent. Therefore, all the ESFAS SIAS response time test margins for the APR1400 are higher than the OPR1000.

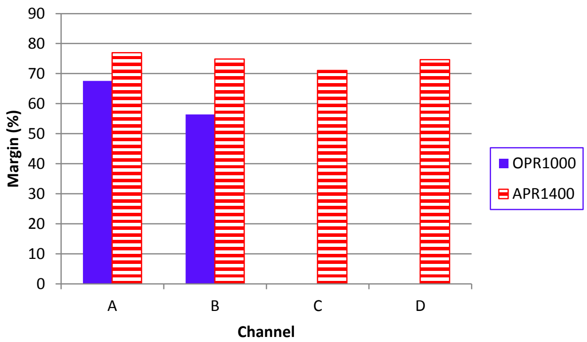

Fig. 9 ESFAS SIAS response time margin

Fig. 9 shows the comparison of each channel's margin for the ESFAS SIAS response time, and it confirms that the APR1400 has more margin than the OPR1000. In case of the ESFAS SIAS, the ESF-CCS GC for the APR1400 consists of four redundant channels, comparing to two channels of the DESFAS-AC for the OPR000. The maximum margin of each channel was used to compare the two plants and the OPR1000 shows the average value of the DPPS and DESFAS-AC margins.

In addition, the test results for the ESFAS CIAS in conjunction with the LPP trip parameter are listed in Table 9. All the results meet the associated response time requirement, and the response time test margins are greater than 70 percent.

Table 9 Test Results for ESFAS CIAS for APR1400

Channel	Req. (s)	CIAS GC1 (s)	CIAS GC2 (s)	Margin (%) GC1/GC2
A	0.515	0.145	0.119	71.8/76.9
B	0.465	0.118	0.117	74.6/74.8

Regarding the ESFAS CIAS for the OPR1000, Tables 5 and 6 show the response time test margins for the DPPS and DESFAS-AC, respectively. The margins for the DESFAS-AC are greater than 70 percent but those for the DPPS are much less than 70 percent. Therefore, all the ESFAS CIAS response time test margins for the APR1400 are higher than the OPR1000, as shown in Fig. 10. Particularly, the maximum margin of each channel was used to compare the two plants and the OPR1000 shows the average value of the DPPS and DESFAS-AC margins.

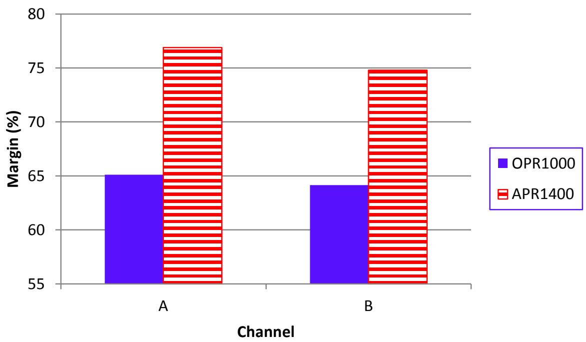

Fig. 10 ESFAS CIAS response time margin

5 Conclusions

The proposed methodology using a distributed response time test approach has been applied to the APR1400. It was confirmed that all the test results satisfy the associated response time design requirements and the test margins are greater than those of the OPR1000. Therefore, it is reasonable and appropriate for the new method to be applied to the

PPS and ESF-CCS GC for the APR1400. In addition, this method will be used for the periodic response time test required by the Technical Specifications for the APR1400.

References

[1] Guidance on Digital Computer Real-Time Performance, U.S.NRC, NUREG 0800, SRP, BTP 7-21, 2007.
[2] Performance Monitoring for Nuclear Safety-Related Instrument Channels in Nuclear Power Plants, ANSI/ISA-67.06.1, 2002.
[3] Effect of aging on response time of nuclear plant pressure sensors, NUREG/CR 5383, 1989.
[4] Setpoint for Safety-Related Instrumentation, U.S.NRC Regulatory Guide 1.105, Rev. 3, Dec. 1999.
[5] Setpoints for Nuclear Safety-Related Instrumentation, ISA-S67.04, Part I, Sep. 1994.
[6] Nuclear Power Plants-Instrumentation Important to Safety - Determination and Maintenance of Trip Setpoints, IEC-61888, Aug. 2002.
[7] C. J. Lee and J. H. Yun, “Integrated Response Time Evaluation Methodology for the Nuclear Safety Instrumentation system,” IEEE trans. Nuclear Science, vol. 64, no. 6, pp. 1211-1218, Jun. 2017.
[8] B. R. Upadhyaya, C. Mehta, D. Bayram, “Integration of Time Series Modeling and Wavelet Transform for Monitoring Nuclear Plant Sensors,” IEEE trans. Nuclear Science, vol. 61, no. 5, pp. 2628-2635, 2014.
[9] Y. Yasu, M. Nomachi, Y. Nagasaka, R. Ball, Y. Tajima, C. Timmermans, “UNIDAQ, real-time response of the system,” IEEE trans. Nuclear Science, vol. 43, no. 1, pp. 9-12, 1996.
[10] C. J. Lee and J. H. Yun, “A Lumped Response Time Test Methodology for the Digital Plant Protection System,” Proceedings of Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 18~19, 2017.
[11] C. J. Lee, S. M. Baek, S. J. Lee, “Setpoint Methodology Improvement Considering Beyond Design Basis Events for Safety-Related Instrumentation,” IEEE trans. Nuclear Science, vol. 61, no. 4, pp. 2120-2130, Aug. 2014.
[12] Periodic Testing of Electric Power and Protection Systems, U.S.NRC Regulatory Guide 1.118, Rev. 3, Apr. 1995.
[13] IEEE Standard for Criteria for the Periodic Surveillance Testing of Nuclear Power Generating Station Safety Systems, IEEE Std. 338, Sep. 10, 1987.