Channel Comparison System for Reactor Protection System in Virtualized MMIS

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1. Introduction

Virtualized MMIS[1] (Man-Machine Interface System), based on Digital Twin technology, has several applications such as real validation of MMIS, detecting the cause of facility problems, and providing ideas related to design change. The comparison of 4 channels for RCOPS[2] (Reactor Core Protection System) information obtained is performed by the CCC (Cross Channel Comparison) display of the IPS (Information Processing System) and the DSPM[3] (Deviation and Setpoint Monitoring Program) of the NAPS[4] (Nuclear Application Programs). Although the DSPM and CCC systems are different, these systems are based on the same or similar logic. Since these systems do not have any function that can automatically save the comparison result when a deviation occurs, the cause of the problem cannot be detected once the deviation disappears.

In this paper, we propose the CCS (Channel Comparison System) that consolidates DSPM and CCC into one system and apply the CCS to the virtualized MMIS to verify that facility problems at site can be identified.

2. Background

2.1 RCOPS, DSPM and CCC

The RCOPS composed of 4 channels generates reactor trip signals for low DNBR (Departure from Nucleate Boiling Ratio) and high LPD (Local Power Density) when the calculated DNBR or LPD exceeds the trip setpoint. Trip signals were transmitted to the PPS (Plant Protection System) and the calculated variables and setpoints are transmitted to the IPS via Ethernet. The RCOPS information includes input variables, the trip status information when the reactor is tripped, and the CEA (Control Element Assembly) information when a deviation occurs within a subgroup of the CEA. The IPS receives this information from the 4 channels of the RCOPS and selectively displays this information on the CCC display. If the information obtained from these 4 channels exhibits a deviation from the setpoint of the deviation limit, the "Comparison Failure" is indicator will turn white on the CCC display with no audible alarm.

The DSPM program within the NAPS being part of the IPS also receives the PPS and RCOPS information and selectively monitors that information. If the information received from the 4 channels exhibits a deviation from the setpoint of the deviation limit, the DSPM enables an alarm for "Comparison Failure" displayed on the list of the IPS alarms to alert operators to the occurrence of the deviation. The operator can manually print a DSPM report that outputs trip status or the information related to CEA deviation.

Virtualized MMIS has several applications such as the real validation of MMIS and its preliminary operation, detecting the cause of facility problems, providing test bed for ideas related to design change and job training for MMIS staff as well as performance test[1]. The real integrated testing is performed at the site of the nuclear power plant where the RCOPS and IPS equipment are actually connected. If the functions of RCOPS, CCC, DSPM are implemented in the Virtualized MMIS as part of the Digital Twin, various tests including an integrated testing can be performed in this system instead of doing tests at site. In the plant simulators of the nuclear power plants of the Shin-Kori Units 3&4[3], Saeul Units 3&4[5], and BNPP Units 1-4[4], a virtualized MMIS system was implemented.

2.2 Problems

The DSPM and CCC have the same logic for comparing the results obtained from the 4 channels of the RCOPS. Therefore, there are many overlapping functions between the DSPM and CCC. The deviation comparison functions and setpoints of the deviation limit are the same, and the list of monitoring variables is also similar. Since the RCOPS information of the DSPM and CCC is not shared, it is impossible to know whether the setpoints of the deviation limit are different from each other.

In both systems, the variable is not automatically recorded when the deviation occurs. Hence, it is hard to determine the cause of the deviation once the Comparison Failure alarm in the IPS is cleared, which then disappears before the operator checks the CCC or DSPM.

The Comparison Failure alarm occurred at February 2021 when the reactor power was increased and reduced in the plant simulator of the Saeul Units 3&4. The DR (Discrepancy Report) for resolving the problem was issued as the "DR-115" report. The alarm also occurred at May 2022 when the reactor power was increased at the Shin-Hanul Unit 1 in the similar situation at the plant simulator Saeul Units 3&4. During that time, detecting all the historical variables of the RCOPS in the IPS and determining the cause of the deviation was difficult because the RCOPS information was not saved in the DSPM and CCC.

The RCOPS information is continuously compared in the DSPM and CCC causing the RCOPS taking up a large amount of memory and processor. This is one of the major factors that increases the total load in the MMIS and the plant simulator.

To resolve these issues, we propose the Channel Comparison System that can be designed and tested in a virtualized MMIS environment.

3. CCS

In a real MMIS environment, collecting the RCOPS information without interconnecting the PLC and IPS systems is difficult. The CCS (Channel Comparison System) is a virtual system and was designed by consolidating DSPM and CCC into one system and improving functions of the DSPM and CCC.

In case of the Comparison Failure, the CCS records RCOPS information automatically, and the code of DSPM is optimized to reduce the load. This system can be executed and tested not only in the plant simulator but also in the standalone environment as shown in Figure 1.

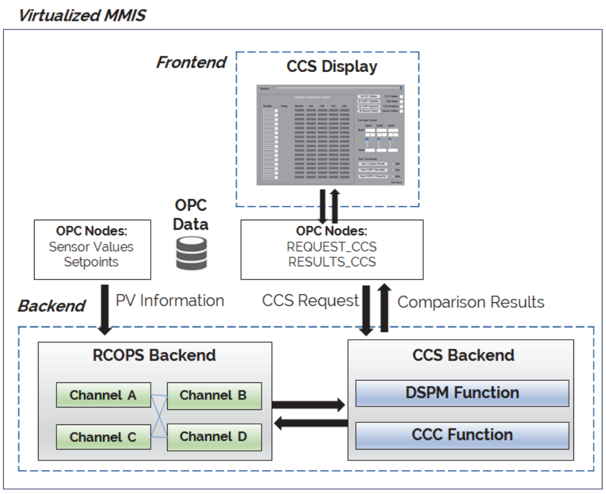

Figure 1. Test bed for CCS

When Comparison Failure occurs, the DSPM report file is created in the same format as that of the file recorded in the actual DSPM. Since the RCOPS information is stored as OPC[5] (Open Platform Communications) nodes, the historical data can be saved and viewed in the form of a data trend display.

The CCS includes the integrated testing function and the visual testing tool as shown in Figure 2. The CCS can simulate the occurrence of the deviation by manually changing the process input variable for the integrated testing between different systems.

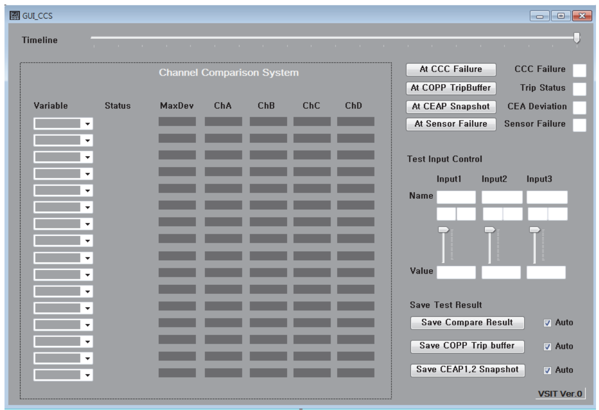

Figure 2. CCS Display

To see previous values for the DSPM and CCC, the output file made by the operator's request should be opened, so it was impossible to display the previous values on the DSPM and CCC display. The CCS display provides the timeline change function. The operator can see the previous values on the CCS display without opening the file. The change in RCOPS information can be viewed on the CCS display as well. In this system, returning the displayed variables to the timeline after the occurrence of Comparison Failure is accomplished. Furthermore, returning the displayed variables to the timeline when a reactor trip occurs or CEA deviation occurs is also accomplished. Previous values and current values are distinguished by color to avoid confusion.

This shows that a flexible display composition is possible in the virtualized MMIS environment, which is more convenient for integrated testing than the real environment.

In the CCS, the normal execution time for cyclic execution and the instantaneous time for recording the information to the file were also reduced. The actual DSPM code was imported and modified so that it can be used in the virtualized MMIS environment. Subsequently, the execution times for the CCS and DSPM were compared. The overall code optimization for the CCS was performed, and the database approach for the RCOPS information was also enhanced. For reproducibility, the testing of the execution time was conducted under the standalone environment with a personal computer environment, not a workstation. The execution results with the overall code optimization without the DB access optimization have demonstrated a significant difference as shown in Table I.

Table I: Elapsed time results for DSPM and CCS with code optimization

Task execution	DSPM	CCS
Normal cyclic execution	25.26	21.0
Report Compare results	22	1
Report COPP Trip Buffer	39	2
Report CEAP Snapshot	16	1

(unit: msec)

- *Ratio for CCS / DSPM execution time = CCS (21 msec) / DSPM (25.26 msec) = 83.1 %*

The elapsed time for the normal cyclic execution refers to the difference between the time before the first logic in the system is executed and the time after all the logic is executed. The DSPM and CCC have the comparison logic as the normal cyclic execution. These values are the average of 2000 cycle runs. The CCS with the overall code optimization without the DB access optimization reduces the load by 83.1%.

The database access method can be enhanced in the virtualized MMIS. With the DB access optimization, the load is additionally reduced as shown in Table II.

Table II: Elapsed time results for DSPM and CCS with code and DB optimization

Task execution	DSPM	CCS
Normal cyclic execution	29.239	0.631
Report Compare results	22	1
Report COPP Trip Buffer	39	2
Report CEAP Snapshot	16	1

(unit: msec)

- *Ratio for CCS / DSPM execution time = CCS (0.631 msec) / DSPM (29.239 msec) = 2.2 %*

The CCS with the overall code optimization and the DB access optimization reduces the load by 2.2%. Therefore, the functions of the DSPM and CCC can be implemented in a virtualized MMIS environment with the load being reduced down to a maximum of 2.2%. Considering that the actual load of CCC is present, removing both the DSPM and CCC and replacing them with the CCS can result in a larger load reduction rate.

Since the CCS can record the RCOPS information to a file even when there is an instantaneous deviation, the cause of the deviation can be determined. Based on this advantage, the CCS was added to the plant simulator of the Saeul Units 3&4, and the cause of the deviation was found by loading the scenario file at the time of the issue in February 2021. The cause of the deviation was found to be a difference in DNBR. Therefore, the existing issue was resolved and the DR-115 report was closed. This proves that the cause of the problems in the facility can be detected and resolved in the virtualized MMIS environment.

To apply the CCS in a real MMIS, including the CCS logic in IPS or NAPS can be considered after removing the DSPM logic from NAPS and the CCC logic from IPS.

4. Conclusions

In this study, it has been proved that the use of CCS can help in detecting and identifying the cause of problems that occur in the real facility. The CCS includes both the DSPM and CCC functions and is equipped with an automatic recording function when a Comparison Failure occurs. In addition, the load for the DSPM and CCC logic can be significantly reduced in the virtualized MMIS. The CCS has a good performance on identifying the cause of problems occurred at the real facility. It also shows that integrated testing could be easily performed through the new flexible display composition. The new display configuration in CCS has a provision to easily perform various tests including the integrated testing.

In conclusion, the CCS is considered to have powerful advantages to the real environment as analyzed through this paper and to provide operators at site with an evolved type of paradigm for troubleshooting.

ACKNOWLEDGMENTS

This research was partly supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. 2105030) and Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2022R1I1A1A01072004).

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