Performance Analysis for a 12-Finger CEA Drop Test of the SHN Unit 1

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1. Introduction

If a 12-Finger Control Element Assembly (CEA) is dropped into the core during power operation at 100%, the original Core Protection Calculator (CPC) will trip the reactor to protect safely the core with the Low Departure from Nucleate Boiling Ratio (DNBR) or High Local Power Density (LPD) trip functions. The EPRI Utility Requirement Document (URD) [1] requires that the reactor shall be designed to accommodate the event associated with an unintended control rod drop without a reactor trip during power operation. Furthermore, the Nuclear System Supply System (NSSS) Design Contract for Shin Han-ul Nuclear Power Plant 1 and 2 (SHN 1&2) [2] is specified to apply a design improvement for the purpose of preventing the unnecessary reactor trip due to a 12-Finger CEA drop, slip and erroneous signals.

2. Design Improvements, Test Methods and Analysis

2.1 Design Improvements

In order to prevent the reactor trip from a 12-Finger CEA drop, the SHN 1&2 reflects the improved system design for the reactor power reduction using the Reactor Power Cutback System (RPCS) and the turbine power reduction using the turbine setback and runback. When a 12-Finger CEA drops, the Reactor Core Protection System (RCOPS) detects the 12-Finger CEA drop and sends 12F RPC Demand signal to the RPCS. The RPCS drops the CEA Group 5 and sends setback and runback signals to Turbine Control System (TCS). The reactor power decreases due to the dropped 12-Finger CEA and CEA Group 5. Turbine power also decreases to approximately 55% power due to the setback and runback signals. CEA Group 4 is inserted by the Reactor Regulating System (RRS) to balance the reactor power with the turbine power. To prevent a reactor trip, the RCOPS applies the CEA deviation Penalty Factor (PF) after the delay time and then applies Rod Shadowing Factor (RSF) and Radial Peaking Factor (RPF) after the additional delay time with the detection of the CEA Group 5 drop. The Required Over-Power Margin (ROPM) of Core Operating Limit Supervisory System (COLSS) is increased to preserve the core safety during the applied delay times. After the delay times, nominal core protection is resumed by the RCOPS. The Fig. 1 presents the improved systems relationship for prevention of the reactor trip during a 12-Finger CEA drop event.

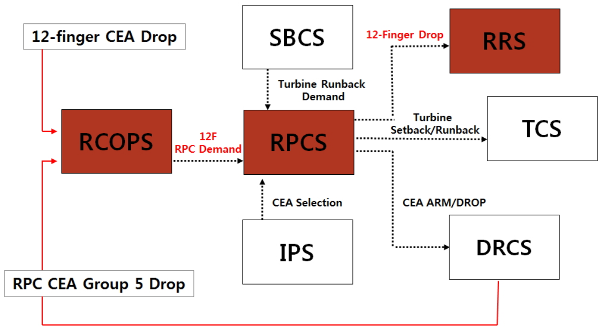

Fig. 1. Improved Systems Relationship

2.2 Test Methods and Comparison

During the SHN 1 Power Ascension Test (PAT), the demonstration test for single 12-Finger CEA drop will be performed to verify the adequacy of design modifications for the RCOPS, RPCS and the RRS. There are two test methods as the demonstration test for a single 12-Finger CEA drop. One is to really drop a single 12-Finger CEA and the other is to utilize the erroneous signal for a single 12-Finger CEA. Table 1 shows comparison results between the two test methods.

The real single 12-Finger CEA drop test is performed by cutting the power supply for a relevant CEA in the Digital Rod Control System (DRCS) cabinet. It is easy to initiate the test. RCOPS DNBR and LPD are more limiting than those of erroneous signal case because of the asymmetric power distribution.

The erroneous signal test is conducted by the RCOPS I/O simulator. Since the RCOPS I/O simulator should be installed and a test scenario injecting the erroneous signal should be established before the test, the test process is more complicated. The system restoration is simple, because there is no need to withdraw the dropped 12-Finger CEA. According to the comparison results between the two test methods, the test was determined to drop really the CEA due to the benefit of initiating the test and for verification of the design changes at more limiting case.

Table 1: Comparison Results of the Two Test

Tests	12-Finger CEA Drop	Erroneous Signal
Test Method	Cut-off of the Power Source of DRCS	RTTE (Response Time Test Equipment) or RCOPS I/O simulator
Test Procedure	1. 12-Finger CEA Drop 2. Group 5 drop by the RPCS 3. COLSS LHR/DNBR out of service 4. TBN Setback/Runback 5. TBN Bypass Valves Opened 6. RRS AWP occurred 7. CEA Group 4 auto insertion by RRS 8. Perform the AOP for restoration	1. Erroneous CEA drop signal 2. Group 5 drop by the RPCS 3. TBN Setback/Runback 4. TBN Bypass Valves Opened 5. CEA Group 4 auto insertion by RRS 6. System Restoration
Test Difficulty	• Easy test start • Hard restoration of systems with the withdrawal of the dropped CEA	• Difficult injection of the erroneous signal • Easy restoration of systems without unbalanced power distribution
Reactor Trip Factor	• RCOPS DNBR • RCOPS VOPT	• HPPT

2.3 Performance Analysis

Plant responses are evaluated during the 12-Finger CEA drop test. The KISPAC code [3], ROCS [4] and the CPC Fortran [5] are used for the analysis. The KISPAC code is a best-estimate nuclear power plant simulation tool which is used to analyze the thermal hydraulic responses of the plant during performance related design bases events. The ROCS code is a steady state diffusion code used for the reactor core design. The CPC Fortran is the RCOPS simulation code.

The test will be conducted with dropping CEA #46 as shown in Fig. 2. The Overall plant responses including design changes in SHN 1 are simulated with the KISPAC code. Core-wise response and excore detector signals are simulated by the ROCS code. During the simulation, excore detector signals at the diagonally opposite region of the 12-Finger CEA dropped core area are calculated because the power at this core region is higher and the RCOPS channel in this region will be the limiting condition. The RCOPS responses are simulated with the CPC Fortran code with the plant parameters from the KISPAC code and the excore detector signals from the ROCS code. The KISPAC-ROCS-CPC Fortran code predictions for the single 12-Finger CEA drop (Group B, #46 which is located in the red box assembly in the Fig 2.) test are plotted in the Fig. 3 through the Fig. 9.

The Group B CEA #46 causes the most limiting un-symmetric power distribution according to the pre-analysis of the core design. The most possible reactor trip functions are low DNBR, high LPD and high pressurizer pressure trips. Upon dropping the single 12-Finger CEA, the RPCS is actuated to rapidly reduce the reactor power by dropping the Group 5 CEA into the core (see the Fig. 3 and the Fig. 5). The Turbine Control System (TCS) reduces the turbine power to approximately 55% by the turbine setback and runback signals (see the Fig. 4). The CEA Group 4 and Group 3 are inserted by the RRS to balance the turbine power with the reactor power (see the Fig. 5).

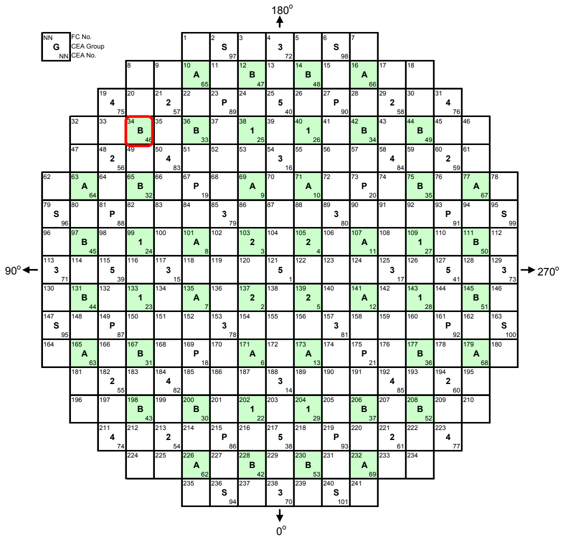

Fig. 2. CEA #46 in the Core Map of the SHN1, 2

As shown in the Fig. 6, the high pressurizer pressure trip signal is not generated and the trip margin is sufficient. Instantaneous decrease in the turbine power from the steam generator results in a sharp increase of the steam generator pressure (see the Fig. 7). The Fig. 8 shows the trend of power and the results of auxiliary trips of the RCOPS channel located in the opposite side of the 12-Finger CEA drop for 600 seconds. Fig. 8 shows that PHICAL, which is the neutron flux power of the RCOPS, is greater than the BDT, which is the core thermal power, due to the asymmetric core power distribution. According to the Fig. 8, the Variable Over-Power Trip (VOPT) of the RCOPS is not occurred during the transient. The Fig. 9 presents the results of the DNBR and the LPD after the drop of the 12-Finger CEA for 600 seconds. There are two step changes in DNBR and LPD which are correspond to the delay times in the RCOPS. Overall behaviors of the plant and the RCOPS are reasonable and the reactor trip is prevented during the scenario.

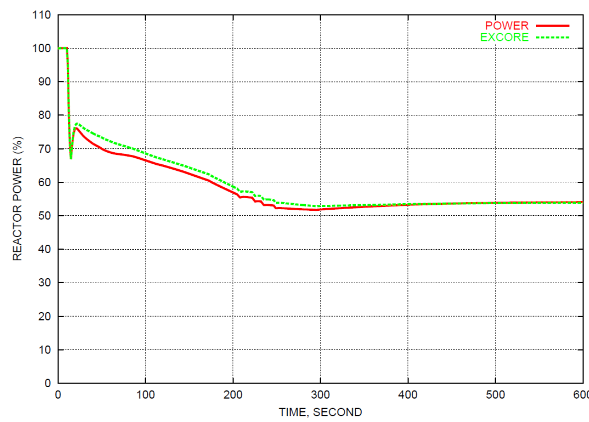

Fig. 3. Reactor Power vs. Time

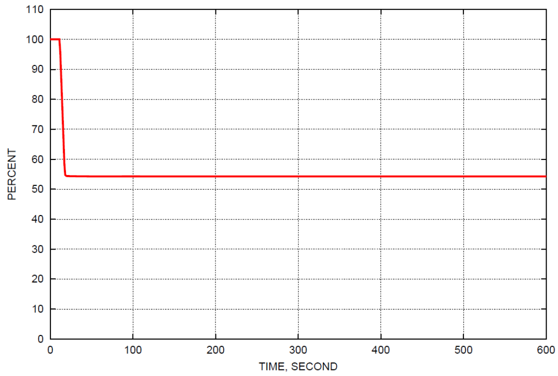

Fig. 4. Turbine Power vs. Time

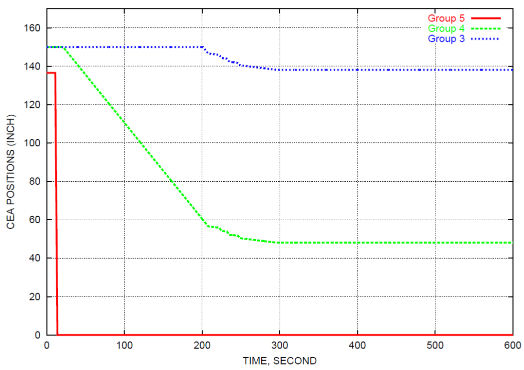

Fig. 5. CEA Positions vs. Time

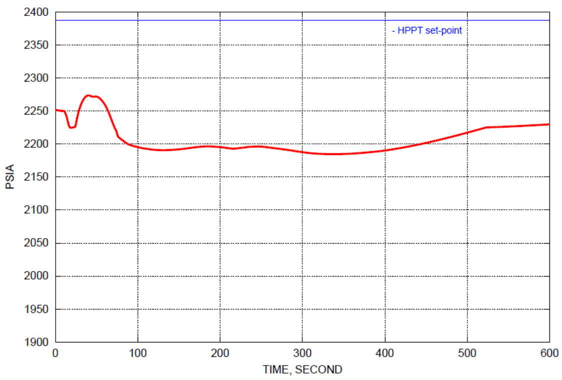

Fig. 6. Pressurizer Pressure vs. Time

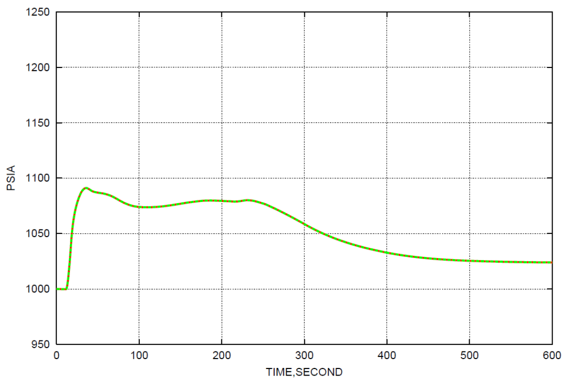

Fig. 7. Steam Generator Pressures vs. Time

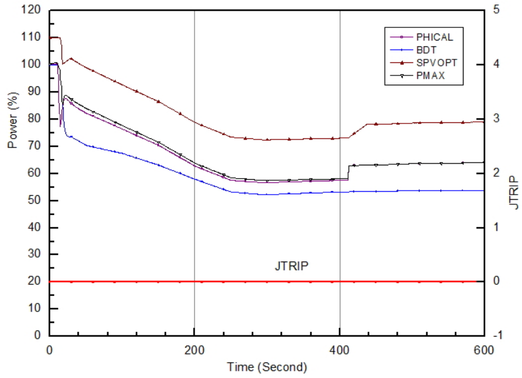

Fig. 8. Power and Aux. Trip of the RCOPS vs. Time

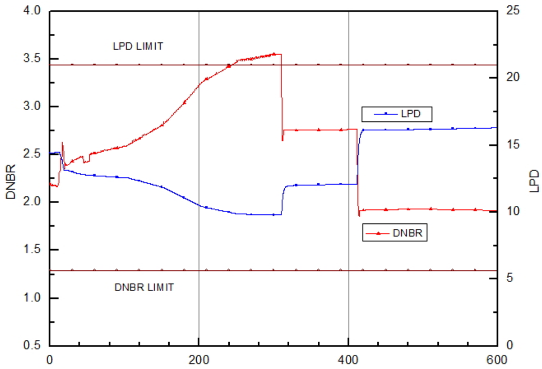

Fig. 9. DNBR and LPD vs. Time

3. Conclusions

The SHN 1&2 reflects the improved system design to prevent the reactor trip from a 12-Finger CEA drop. In order to verify the adequacy of design modifications, the single 12-Finger CEA drop test will be performed during the PAT of the SHN 1. The system performance analysis was performed by using the KISPAC, the ROCS and the CPC Fortran. In accordance with the results of the NSSS system and the RCOPS performance analysis, it is expected that the reactor trip signals will not be generated and the trip margins will be sufficient during the single 12-Finger CEA drop test in PAT of the SHN 1 unit.

REFERENCES

[1] EPRI URD, Advanced Nuclear Technology: Advanced Light Water Reactor Utility Requirements Document, Rev.13, Chapter 4, 2014.
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