Transactions of the Korean Nuclear Society Autumn Meeting
Pyeong Chang, Korea, October 30-31, 2008

The Development and Evaluation of Inherent RPCS for the APR1400

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1. Introduction

The APR1400 RPCS (Reactor Power Cutback System) is designed to rapidly reduce the core power to eliminate the need for a reactor trip following a large load rejection or a loss of two main feedwater pumps at high power.

GDC (General Design Criteria) 25 says "Protection system requirements for reactivity control malfunctions. The protection system shall be designed to assure that SAFDL (Specified Acceptable Fuel Design Limits) are not exceeded for any single malfunction of the reactivity control systems, such as accidental withdrawal (not ejection or dropout) of control rods." In order to comply GDC 25, CPCS (Core Protection Calculator System) will apply a big power penalty(~ 1.3) to determine the minimum DNBR (Departure from Nucleate Boiling Ratio), the maximum LPD(Local Power Density) and reactor may immediately trip by CPCS low DNBR and high LPD during high power operation for 12-finger CEA drop.

The purpose of this study is to develop the inherent RPCS to avoid unwanted reactor trips due to a 12-finger CEA drop. In order to accomplish this purpose, the CPCS should be modified to send RPCS actuation signal and not to apply power penalty due to 12-finger CEA drop for a shot period. During this period which is determined by assessment of safety, the SAFDL will not be violated without any CPCS trip function. The system and CPCS performance is evaluated to verify that CPCS trip does not occurred during 12-finger CEA drop event.

2. CPCS Algorithm Improvement

The CPCS is composed of four CPCs (Core Protection Calculators) and two CEACs (CEA Calculators). CPCS is designed to provide DNBR and LPD protection for AOOs (Anticipated Operational Occurrences). If there is a fast reduction in power during 12-finger CEA drop event, the increased safety margin generated by lower power could be maintained plant operation without reactor trip. In order to prevent CPCS trip due to 12-finger CEA drop, CPCS algorithm is improved to initiate RPCS operation and not to apply power penalty factor for short periods. The improved CPCS algorithm is summarized in Figure 1.

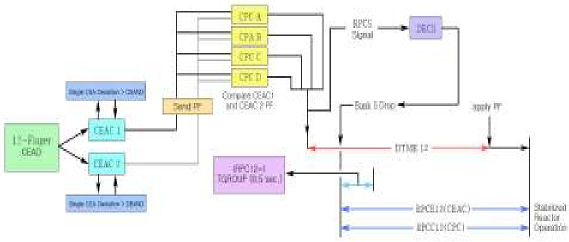

Figure 1. APR1400 CPCS Algorithm Improvement

In according to CPCS algorithm improvements, CEAC generates 12-finger CEA drop mode flag to each channel CPC when the CEAC detects the occurrence of a 12-finger CEA insertion deviation in the subgroup larger than the deviation deadband. After each channel CPC receives the flag from CEAC, each CPC sends RPCS actuation signal to reduce core power. Also each CPC does not apply the power penalty due to 12-finger CEA drop to calculate the minimum DNBR and maximum LPD for some time and then the core power is reduced. The duration of this time period is added to CPCS algorithm as DTME12 constant.

Because of RPCS signal by CPCS during 12-finger CEA drop, the preselected RPC group CEAs are dropped into the core to reduce the core power. If the present and previous positions of RPC group CEAs are changed at freely dropping speed, CEAC sends the 12-finger CEA RPCS mode flag to each channel CPC. During the 12-finger CEA RPCS mode, the each channel CPC calculate the minimum DNBR and the maximum LPD without using RPF (Radial Peaking Factor) increase and RSF (Rod Shadowing Factor) due to RPC group CEAs drop until the plant condition is stabilized in enough lower power condition not to occur reactor trip. The duration of this time period is added to CPCS as RPCE12 constant.

3. Safety and Performance Evaluation

Since the CPCS was modified to initiate RPCS and not to apply penalty factor due to 12-finger CEA drop for a short period, it is necessary to determine DTME12 and RPCE12 CPCS constants by performing safety analysis. The DTME12 and RPCE12 constants are determined to achieve two objectives. First, the 12-finger CEA drop mode or 12-finger RPCS mode should maintain long enough to prevent reactor trip due to power penalty. Second, the 12-finger CEA drop mode or 12-finger RPCS mode must end soon enough to prevent SAFDL violation due to 12-finger CEA drop event and RPCS operation. This former objective is related to CPCS performance and the latter objective is related to safety analysis.

DTME12 is calculated with analyzing 12-finger CEA drop event. In order to determine the most limiting DTME12 and RPCE12 constants for APR1400 plant, all possible 12-finger CEA drop cases are examined. The CESEC-III code[1] and CETOP-D code[2] are used to determine DTME12 and RPCE12 constants. The safety analysis results show that the maximum DTME12 and RPCE12 constants are 40.0 seconds and 50.0 seconds respectively.

To verify that reactor trip does not occur by analogue RPS(Reactor Protection System) or CPCS during 12-finger CEA drop, performance evaluations of all possible cases are carried out. The various CEA configurations, burnups, locations of dropped 12-finger CEA including spurious 12-finger CEA drop case are considered to accomplish performance evaluations. Table 1 shows cases analyzed to evaluate performance.

Table 1. Performance Evaluation Case Summary

Cases	Burnup	12-finger Rod(*)	Condition
Case01	BOC	Spurious (#33)	Maximum PF
Case02	EOC	Spurious (#33)	
Case03	BOC	CEA Drop (#46)	Maximum Asymmetry
Case04	EOC	CEA Drop (#46)	
Case05	BOC	CEA Drop (#09)	Maximum CEA Worth
Case06	EOC	CEA Drop (#33)	
Case07	BOC	CEA Drop (#65)	Minimum CEA Worth
Case08	EOC	CEA Drop (#65)	

* : CEA number

Performance analyses for above 8 cases of analogue RPS are evaluated with using KISPAC code[3]. As a result of performance analysis for analogue RPS, none of reactor trip is occurred. The CPCFORTRAN code[4] is used for CPCS performance evaluation. The initial conditions are selected conservatively to consider plant operating experiences and margin for future cycle variation of core. During RPCS operation after 12-finger CEA drop, system behavior from KISPAC code calculation results and excore detector signals from ROCS[5] code calculation results are used to evaluate CPCS performance for 8 cases in Table 1. Based on the CPCS performance results, the CPCS trip is not occurred for all possible 12-finger drop cases. Figure 2 shows the CPCS performance calculation results for the most limiting case(Case06). As shown in Figure 2, the DNBR decrease and LPD increase had occurred twice after DTME12 and RPCE12 time because of penalty factor.

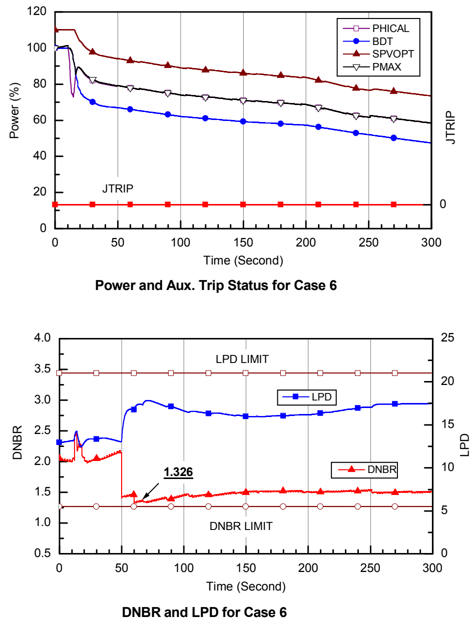

Figure 2. CPCS Performance Results for Case06

4. Conclusions

To prevent unexpected reactor trip due to 12-finger CEA drop for APR1400, the CPCS is modified to initiate RPCS and delay 12-finger CEA drop penalty factor, and the safety and performance evaluations are performed. Safety and performance evaluation results show that the reactor trip by analogue or CPCS is not occurred during RPCS operation after a 12-finger CEA drop. Therefore, APR14000 plant with the modified CPCS can safely prevent the reactor trip due to 12-finger CEA drop.

Acknowledgements

This work was carried out under KHNP R&D program. The authors would like to express thanks to KHNP for their support of this work.

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