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The Development of Inherent RPCS for the APR1400

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1. Introduction

The APR1400 is an evolutionary ALWR with the rated thermal power of 4,000MW. The existing RPCS(Reactor Power Cutback System) of APR1400 is designed to avoid the unneeded reactor trips caused by a large turbine load rejection, turbine trip or loss of two of three operating main feed water pumps by step-reduction in the reactor power to below 75% target power. This is accomplished by the drop of preselected CEA group(s). The APR1400 CEAs consist of part-strength, 4-Finger, and 12-Finger rods. At a 4-Finger rod drop event, reactor trip will not happen. But, in case of a 12-finger rod drop event at high power, the reactor trip will happen by applying a penalty factor (~1.3) to DNBR and LPD in CPCS, because core design margin can't afford to accept the distortion of power distribution caused by the 12-finger rod drop event.

The objective of this study is to develop the inherent APR1400 RPCS which prevents unneeded reactor trips by actuating RPCS in case of the 12-Finger Single rod drop event. To achieve this objective, the CPCS should be modified to accommodate the transient by a rod drop and RPCS actuation without applying a penalty factor for a certain duration until the reactor is stabilized under the reduced power. During this period, the reactor must be stayed in safe condition and this is confirmed by safety analysis. The performance of the modified CPCS is evaluated by system performance analysis and CPCS performance analysis.

2. Selection of the analysis cases

When a 12-Finger single rod drops, the inherent APR1400 RPCS inserts preselected CEAs(group 5 or group 5+4). Then system response is affected by the location of the dropped 12-Finger single rod, burnup, NSSS's initial conditions and so on.

Accordingly, we selected 16 test cases which are combinations of below conditions for the sensitivity analysis.

o Burnup
- BOC (Beginning Of Cycle)
- EOC (End Of Cycle)

o 12 Finger single rod drops or not
- Error signal
- Actual single rod drop

o Preselected CEA groups for RPCS
- CEA group 5
- CEA group 5+4

o Position of Dropped 12-Finger single rod
- Maximum radial unsymmetric power distribution
- Maximum rod worth
- Minimum rod worth

3. Evaluation method

The main idea of the inherent APR1400 RPCS is to reduce reactor power to get larger DNB margin to prevent reactor trip although the penalty factor is applied in CPCS by a 12-finger rod drop. To do this, the penalty factor application should be delayed until RPCS is actuated and the reactor power is reduced. This delay time is determined by the safety analysis. The safety analysis is performed as same procedure as the single rod drop accident. According to ROPM(Required Over Power Margin) calculation from the safety analysis, penalty factors for CPCS and penalty factor delay times are needed. Figure 1 shows the scheme of the advanced CPCS functional algorithm. There are two types of penalty factor delay times. The first type is to delay the penalty factor for DNBR and LPD calculations. It applies as soon as 12 finger rod drops. The second is to delay RPF(Radial Peaking Factor) and RSF(Rod Shadowing Factor) calculation. It applies as soon as RPC flag is set. These delay times are calculated in CEA drop accident analysis. The first type is calculated with dropped 12 finger single rod worth. The second type is calculated with dropped 12 finger single rod worth and selected RPCS bank worth.

System performance evaluation is achieved by confirming that the reactor trip does not occurred by CPCS or analogue reactor protection system.

Evaluation for analogue reactor protection system is performed with the same procedure as the APR1400 design procedure with KISPAC code[1] which uses dropped 12-finger CEA worth, RPCS bank and regulating group 3 worth. CPCS performance evaluation is performed with CPCFORTRAN code[2] which uses results of KISPAC code calculation such as reactor powers, cold leg temperatures, hot leg temperatures and pressurizer pressures and the results of ROCS 3D[3] full core calculations such as excore detector signals.

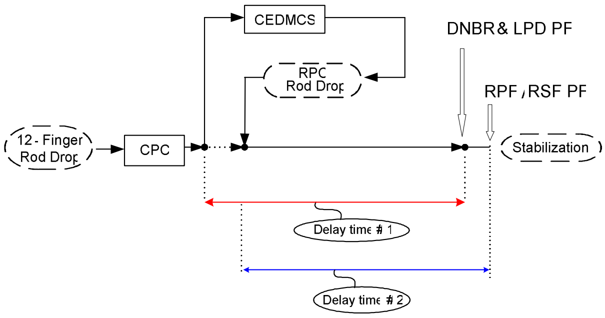

Figure 1. The advanced CPCS functional algorithm

4. Conclusions and further studies

As the results of safety analysis, the delay times are determined as 30sec and 32sec, respectively. According to the results of system performance evaluation so far achieved, the reactor trip by the analogue Reactor Protection System does not happen. As the results of CPCS performance analysis, auxiliary trip(JTRIP) don't happen in every case. But LPD/DNBR trips are occurred in test cases 4 and 12 which are cases of actual 12-Finger single rod drop with RPCS bank2(group 5+4) in EOC.

Figures 2 and 3 show the results of CPCS performance analyses for these two cases.

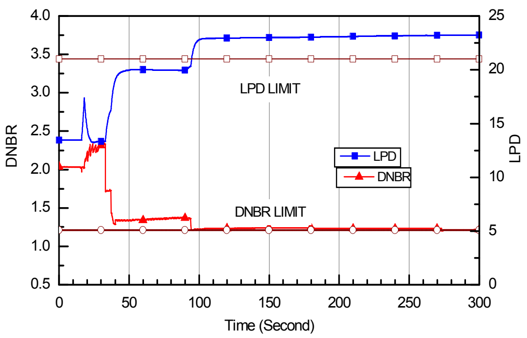

Figure 2. The case 4 of LPD and DNBR reactor trip

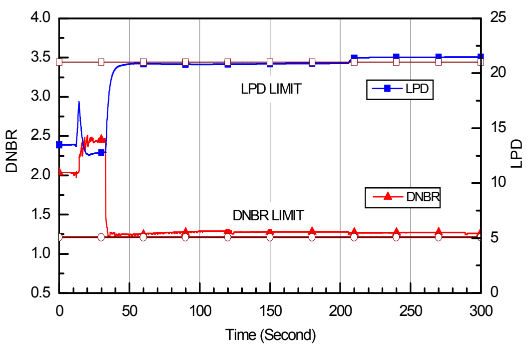

Figure 3. The case 12 of LPD reactor trip

The main reason of these trips is that the axial power distribution is shifted to upper side of core due to insertion of the positive reactivity. When the reactor power is decreased due to RPCS actuation, core exit temperature is decreased. Therefore, positive reactivity is inserted to upper part of reactor core.

To prevent rector trip at the test cases 4 and 12, the following further studies will be performed;

- Under the 12 finger single rod drop event, RPCS selects Group 5 CEA only. In this case, positive reactivity in upper side of reactor core will be minimized.
- Modifications of RSF/RPF and Fr distortion through the detailed analysis of ROCS 3D full core calculations.

In further studies, it is expected that the reactor trip will not occur in every test case of the 12-Finger Single rod drop event by actuating RPCS.

REFERENCES

[1] "Technical Manual for the KISPAC", KOPEC, August, 1999.

[2] KNFC, "CPCFORTRAN User's Manual", KNF-TR-CCD-01005, Rev.00, March 30, 2001.

[3] R. Loretz et. Al., "ROCS User's Manual-Coarse Mesh Diffusion Theory Neutronics Code", CE-CES-4, Rev. 11-P, Ausust 1996.

[4] "Functional Design Requirements for a Core Protection Calculator System", KNF-KSNGEN-03026, Rev.01, September, 2004.