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Upgrade of KNPEC#2 Simulator for Kori Unit 3 Power Uprating

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1. Introduction

Kori-Unit 3&4 is preparing the operation of the power-uprating (2900MWt), and therefore the Korea regulatory body(KINS) requested the operator training with the simulator reflecting the power-uprating.

As a result of the intensive research and expertise of KEPRI on the simulators, KEPRI accomplished the upgrade project of KNPEC#2 simulator for Kori-Unit 3 power-uprating. This project includes various high-tech methods incorporating

- realtime neutronics model based on MASTER[1] (Multi-purpose Analyzer for Static and Transient Effects of Reactors) code, best-estimate neutronics code by the KINS, (By using the RMASTER, the precision of the simulation of the neutron behaviors in the core is highly improved.)
- betterment of the reactor coolant system and the balance-of-plant system
- modification of the corresponding setpoints due to the power-uprating

And the acceptance test procedure (ATP) was successfully carried out through the integration of system models and its performance tests.

Through the success of this project, the operator training for the power uprating of the Kori-Unit 3 will be accomplished before its power operation and, after all, this simulator will contribute to the safe operation for the power-uprating of the Kori-Unit 3&4.

2. Plant System Modeling

2.1.Neutronics Model

As mentioned above, the neutronics model was developed based on the RMASTER[2], the realtime MASTER code. The power-uprating of the Kori-unit 3 is applied from 18th cycle of the fuel, and its power increases from 2775MWt to 2900MWt. At its power operation, the inlet temperature of the core decreases from 291.4°C to 289.3°C. The loading pattern is shown in Fig.1, which is the preliminary loading pattern applied for the safety analysis for the power-uprating.

2.2.Thermal-Hydraulic Model (ARTS) [3]

The NSSS TH model adopted in KNPEC(Korea Nuclear Plant Education Center)-2 simulator was provided in the early 1980s. Due to the limited computational capability at that time, it uses overly simplified physical models and assumptions for a real-time simulation of NSSS thermal-hydraulic transients. This may entail inaccurate results and thus, the possibility of so-called “negative training”, especially for complicated two-phase flows in the reactor coolant system. To resolve the problem, we developed a realistic NSSS TH program (“ARTS” code) based on the best-estimate codes, RETRAN-3D. The systematic assessment of ARTS has been conducted by both a standalone test and an integrated test in the simulator environment.

2.3.Reactor Protection and Control Systems

2.3.1. OTΔ T/OPΔ T Setpoint

From the 18th fuel cycle of the Kori-unit 3&4, its rating power of the primary system increases 4.56% and the average temperature (T_{avg}) of the RCS decreases. Therefore, changes on setpoints for the reactor trip are required.

2.3.2. Setpoint of RCS High-Temp Alarm

According to the design change proposal for the Kori-unit 3&4 power uprating, the alarm of the RCS high temperature is requested to decrease 3°F.

2.3.3. Axial Flux Difference Limits

According to the design change proposal for the Kori-unit 3&4 power uprating, the allowable axial flux difference limits are changed from [-16~+8%] to [-14~+8%] at the rated power and from [-42~+26%] to [-24~+22%] at the 50% power.

2.4. RCS Protection System

2.4.1. Setpoints of Low-Temp Alarm for PZR Spray and PRT Water-Level

(a) Setpoint of Low-Temp Alarm for PZR Spray : 277°C → 271°C

(b) Setpoint of PRT Water-Level (Hi/Lo) : 83/64(%) → 85/69(%)

2.4.2. Setpoints of RWST Low-Level Alarm

In the event of the low-level alarm of the RWST, the setpoint of the low-level alarm for the RWST was changed higher than the limit of the technical specification (50%→60%) so that operators can perceive the status, refill the water into the RWST, grasp the leakage point and swiftly take measures.

2.5.BOP System Model

2.5.1. Main Turbine Model

As for the main turbine system, the turbine model installed in the current KNPEC#2 simulator references that of Yongkwang-unit 1, and it's very hard to change the turbine model in the short period. So, instead of the change of its reference, its steam flow, pressure and power were modulated to the balanced state, and the model would be upgraded in the later project.

2.5.2. Main Feedwater Model

Like the turbine system, the main feedwater system references that of Yongkwang-unit 1, so its feed flow and pressure were modulated to the balanced state with the turbine system, and the model would be upgraded in the later project.

3. Realtime Synchronization of Neutronics Model

In order to implement the realtime distributed system as the simulation module driver, the distributed system must communicate with the other simulator modules and should be synchronized under the control of the simulator host computer. KEPRI developed the KSIM-RD (KEPRI Simulation Environment - Realtime Distributor) program to communicate and synchronize with others running on the host computer. The host computer sends data necessary to execute the distributed module and waits for the notification whether receiving the calculated outputs of the distributed module. The distributed module calculates the phenomena of its modeling system based on boundary conditions received from the other simulator modules on the host computer. After the calculation, the distributed system sends to the host computer the needed data in other modules and then the simulator terminates the waiting for the notification to advance all simulator modules to next time frame.

4. Acceptance Test Procedure

To verity and validate the performance and the quality of the simulator reflecting the power-uprating, KEPRI developed and amended the acceptance test procedure including power-uprating items based on the modified dynamic models.

- 10 normal operation tests including the operation from 100% power to 75% power
- 4 steady state tests, (100%/75%/50%/25% steady power level at Xenon Eq. BOL)
- 11 transient tests including the manual trip of the reactor
- 57 virtual transients including the rupture of the main steam pipe inside the containment

5. Verification

To accurately evaluate the performance of the simulator models, lots of data and tests are indispensible. For this, we compared the results of transient tests for the simulator with those of accident analysis based on the RETRAN-3D/RELAP with the same condition as tests in the simulator. As for LBLOCA, the reference results are calculated based on the RELAP, and as for Non-LOCA, based on the RETRAN.

Variables which could best represent the characteristics of the tested transients, that is, reactor power, coolant temp, PZR pressure, PZR level, SG pressure/level, are adopted as the comparatitive points. To conclude, the developed Kori-unit 3 simulator reflecting power-uprating can simulate very much like the results of best-estimated codes like RETRAN/RELAP.

6. Conclusions

The objective of this project is to develop and amend the dynamic models of the KNPEC#2 simulator, and reflect the power-uprating of the Kori-Unit 3&4. To evaluate the performance of the overall dynamic models, 10 normal operations, 4 steady-state tests, 11 transients and 57 virtual transient tests were carried out successfully. Especially, for the comparison with results of codes for the accident analysis (RETRAN/RELAP), 11 test items were chosen and variables which could best represent the characteristics of the tested transients, that is, reactor power, coolant temp, PZR pressure, PZR level, SG pressure/level, are adopted as the comparatitive points. The comparison is much satisfactory.

As a result, the KNPEC#2 simulator can simulate the main characteristics of the power-uprating of the Kori-unit 3 and enables operators to take training before the power operation of the Kori-unit3. So, this system will contribute to the safe operation of Kori-3 and finally to meeting the requirements of the review criteria of the regulatory body and the performance standard [4] of simulators for the training of operators.

REFERENCES

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