Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-27, 2017

Verification of SPACE Capability using Plant Test Data

Sang Jin Kim*, Jeong Ju Kim, Chan Eok Park, Jong Ho Choi, Gyu Cheon Lee
Safety Analysis Group, KEPCO-E&C, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Rep. of KOREA
**Corresponding author:sangjin@kepco-enc.com*

1. Introduction

The Safety and Performance Analysis Code 3.0 (SPACE 3.0) which is a best-estimate thermal-hydraulic analysis code for nuclear power plants has been licensed for safety analyses in 2017.[1][2] During the development period, a comprehensive code capability assessment has been performed against a numerous conceptual problems and experimental data. As the final assessment stage, the thermal-hydraulic behaviors of the operating power plant are analyzed to verify the best-estimate capability of the SPACE code.

Two test cases performed during the Shinkori unit 3 Power Ascension Test (PAT) period were selected; the turbine load rejection to house load test and the turbine trip & Natural Circulation Cooldown (NCC) test. In order to analyze these test cases, the as-built the plant control system models are developed using the SPACE input model. Finally, the code predictions are directly compared with the measured test data, and the verification results are presented in this paper.

2. Event Description

The turbine load rejection to house load test is initiated by disconnecting the turbine generator from the electrical grid system.[3] As a result, the turbine control system rapidly closes the turbine control valve and the steam flow to turbine decreases to about 5% which corresponds to the house load level.

This sudden decrease in steam flow results in a sharp steam pressure rise, which is controlled by the Steam Bypass Control System (SBCS). The Reactor Power Cutback System (RPCS) and the Reactor Regulating System (RRS) control the increased discrepancy between the core power and the heat removal to turbine by reducing the core power.

The turbine trip & NCC test starts with tripping turbine and, when the system stabilizes at hot stand-by condition, all Reactor Coolant Pumps (RCPs) are tripped to test the capability of NCC. Reactor trips on turbine trip and, therefore, the RPCS and the RRS are not actuated. The SBCS controls the secondary pressure throughout the test.

3. Analysis Methodology

3.1 Control System Modeling

The NSSS control system of APR1400 is composed of the Power Control System (PCS) and the Process-Component Control System (P-CCS). The PCS includes the RRS, the RPCS and the DRCS. The P-CCS includes the PPCS, the PLCS, the FWCS and the SBCS.

These control systems are modelled with SPACE input modellings to simulate the thermal-hydraulic behaviors of the actual plant without any conservative assumptions.

3.2 Initial Conditions

Table 1 and 2 compare the measured initial plant conditions with those used in SPACE analyses for both test cases.

Table 1. Initial Conditions for Turbine Load Rejection to House load Analysis

Parameter	PAT results	SPACE
Core Power, MWt	3983	3983
Pressurizer pressure, MPa(a)	15.51	15.51
RCS average temperature, K	579.87	579.87
Secondary pressure, MPa(a)	6.92	6.61
Pressurizer level, %	49.28	49.30
Steam Generator level, % NR	48.44	50.00

Table 2. Initial Conditions for Turbine Trip & NCC Analysis

Parameter	PAT results	SPACE
Core Power, MWt	3983	3983
Pressurizer pressure, MPa(a)	15.51	15.51
RCS average temperature, K	579.48	579.04
Secondary pressure, MPa(a)	6.94	6.96
Pressurizer level, %	48.90	48.05
Steam Generator level, % NR	49.95	50.06

4. Analysis Results

4.1 Turbine Load Rejection to House Load

Figures 1 and 2 compare the SPACE predictions with the plant test data for the turbine and reactor powers, respectively. As the turbine power drops from 100% to 5% (see Fig. 1), the reactor power reduces rapidly due to RPCS actuation (see Fig. 2). After the RPCS actuation, the reactor power stabilizes to a constant value below the Automatic Motion Inhibit (AMI) setpoint by the RRS. The excessive core power is controlled by the SBCS. As these results show, the SPACE code results agree well with the plant test data demonstrating its best-estimate analysis capability.

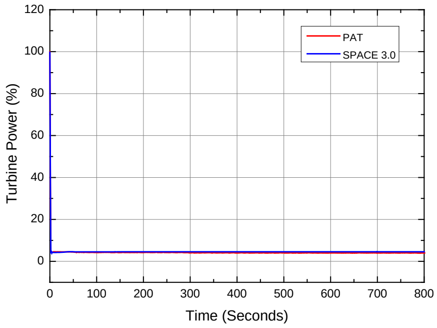

Fig. 1. Turbine Power (Turbine Load Rejection)

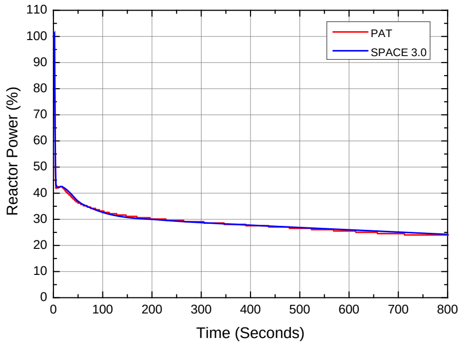

Fig. 2. Reactor Power (Turbine Load Rejection)

After the initiation of the turbine load rejection, the steam generator pressure increases rapidly and reaches the quick open setpoint of TBVs. When the quick open mode ends, the steam generator pressure is stabilized by the actuation of TBVs in modulation mode as shown Fig. 3.

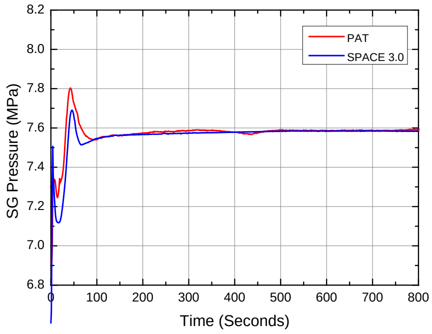

Fig 3. Steam Generator Pressure (Turbine Load Rejection)

Figures 4 and 5 show the steam generator and the pressurizer water levels, respectively. The steam generator water level is controlled by the FWCS and the stabilization of water level requires a longer time than the reactor power. The pressurizer level decreases initially due to the decrease in RCS temperature and stabilizes by the PLCS control actions. As compared in Figures 3 through 5, the SPACE code predictions on the major system parameters also agree well with the plant data within acceptable range.

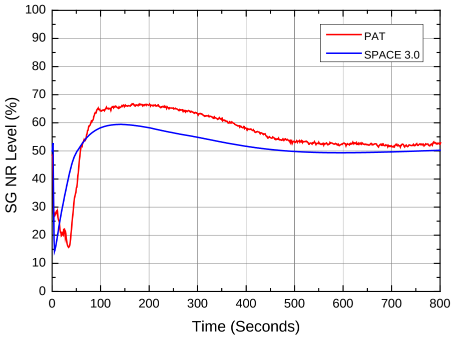

Fig. 4. SG NR Level (Turbine Load Rejection)

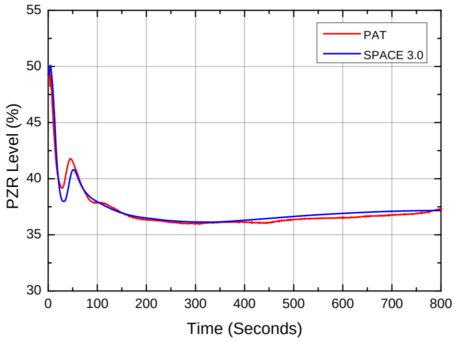

Fig. 5. Pressurizer Water Level (Turbine Load Rejection)

4.2 Turbine Trip & NCC

Fig. 6 compares the measured reactor power and the SPACE thermal reactor power. The measured reactor power represents the ex-core neutron detector signal which drops to 0% at the reactor trip while the SPACE calculated power includes core decay power.

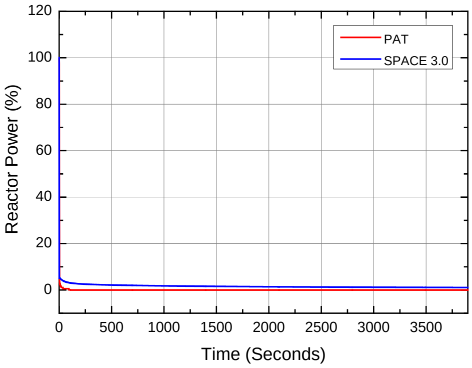

Fig. 6. Reactor Power (Turbine Trip & NCC)

Figures 7 and 8 show the RCP speed and the RCS temperatures. After the reactor trip, RCS is maintained at hot stand-by condition by the SBCS until the time of RCP trip. When the RCPs are tripped, the cold leg, hot leg, and average temperatures are separated with each other due to the reduced RCS flow and NCC starts. As shown in Fig. 8, the SPACE results matches well with the test data.

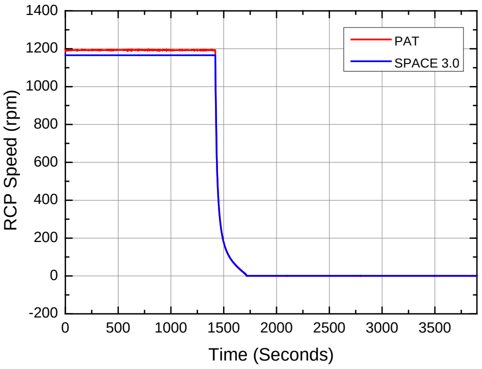

Fig. 7. RCP speed (Turbine Trip & NCC)

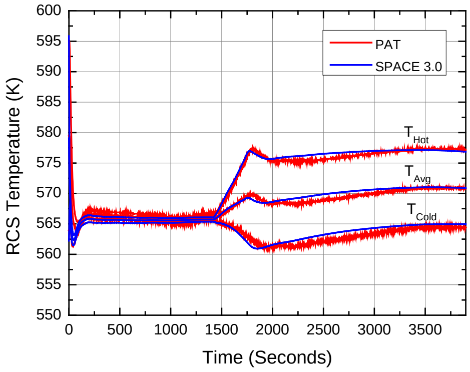

Fig. 8. RCS Temperatures (Turbine Trip & NCC)

Figures 9 and 10 show the steam generator pressure and the pressurizer pressure. Both drop initially and recover by the PPCS and the SBCS. During the period of RCPs coastdown, the heat transfer rate between primary and secondary side decreases and, as a result, the pressure of primary side goes up and that of secondary side goes down. As compared in these figures, the SPACE simulation results also agree well with the measured test data.

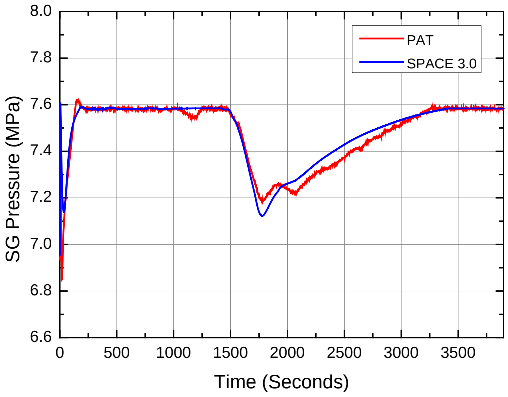

Fig. 9. SG Pressure (Turbine Trip & NCC)

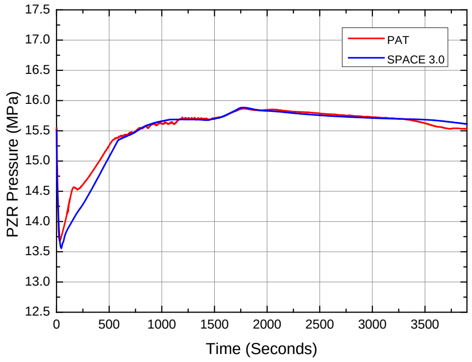

Fig. 10. Pressurizer Pressure
(Turbine Trip & NCC)

5. Conclusions

The load rejection to house load and the turbine trip & NCC test cases have been analyzed with the SPACE code in order to verify its best-estimate simulating capability. The analysis results showed a good agreement with the measured plant test data demonstrating the capability of the SPACE code.

ACKNOWLEDGEMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry and Energy (MOTIE) of the Republic of Korea (No. 20161510101840).

REFERENCES

[1] Korea Hydro & Nuclear Power Co., KEPCO Engineering & Construction, Korea Atomic Energy Research Institute, “SPACE manual, Volume 2, Input manual”, 2017.
[2] S. J. Ha, C. E. Park, K. D. Kim, and C. H. Ban, “Development of the SPACE Code for Nuclear Power Plants, Nuclear Technology”, Vol.43, No. 1, 2011.
[3] Korea Hydro & Nuclear Power Co., “Final Safety Analysis Report of Shinkori 3&4”.
[4] S. J. Kim, C. E. Park, J. H. Choi and G. C. Lee, “Analysis of Turbine Load Rejection for APR1400 using SPACE, Transactions of the Korean Nuclear Society Autumn Meeting” 2016.