Transient Analysis in the APR1400 CVCS Using the CARD1400 Code

Hong Sik Park*, Do Hyun Kim, Jong Seob Park, and Se Jin Baik
NSSS Division, KEPCO Engineering & Construction Company, Inc,
**Corresponding author: siksik@kepco-enc.com*

1. Introduction

The APR1400 chemical and volume control system (CVCS) design had been considerably changed from that of OPR1000. Thus it was necessary to develop a computer code for a detailed simulation of the APR-1400 CVCS. The CARD1400 computer code has been developed to evaluate the performance of the APR1400 CVCS, by using the same mathematical models as the CARD code which had been developed and validated for simulation of the OPR1000 CVCS [1, 2].

In this study, the transient analysis in the APR1400 CVCS was performed using the CARD1400 code and the results were evaluated to verify the appropriateness of the code.

2. Computer Code Development

2.1 General Descriptions on the Code

The CARD1400 code is written in FORTRAN computer programming language and runs on Personal Computer using Windows XP Operating System. It is a stand-alone code which can simulate CVCS in detail whenever correct system boundary conditions are provided. The code consists of two modules, i.e. control and process modules. The control module includes the models for the Pressurizer Level Control System (PLCS), the Letdown Backpressure Control System (LBCS), the Charging Differential Pressure Control System (CDPCS), and the Seal Injection Flow Control System (SIFCS). Thermal-hydraulic responses of the system are simulated by the process module. The modeling of the system is based on a node and flow path network. The thermal-hydraulic model is based on the assumption of homogeneous equilibrium mixture. The major system components such as valves, orifices, pumps, heat exchangers and the volume control tank are explicitly modeled in the code

2.2 CVCS Design Changes Incorporated into the Code

In comparison with the existing CARD code, the APR1400 CVCS design changes incorporated in the CARD1400 code are as follows:

a. Changed arrangement of the letdown orifices and the letdown heat exchanger,
b. Removed the warm-up line bypassing the letdown orifices,
c. Added the containment isolation valve in the letdown line inside the containment,
d. Changed location and interlock of the temperature instruments,
e. Adopted two charging restricting orifices in series,
f. Removed the RCP seal injection heat exchanger,
g. Removed the path to the HPSI header,
h. Added the path to the RDT and renamed the RWT to the BAST, and so on.

3. Transient Analysis for Code Test

3.1 Selection of Analysis Cases

Three analysis cases that render severe transient in CVCS among the performance-related design basis events (PRDBE) were selected as follows [3]:

- Turbine Power Step Decrease from 100% to 90%
- Loss of Load at 100%
- Reactor Trip at 100%

These cases are the RCS induced transients in CVCS.

3.2 Initial Conditions

- RCS & CVCS: Normal condition
  - RCS Pressure: 2250 psia, Temperature: 585˚F
  - Letdown flow: 80 gpm, Charging flow: 93 gpm
- Reactor power & turbine power : 100%
- PLCS : Automatic controlled by programmed level program
- LBCS : Automatic control (setpoint : 400 psig)
- CDPCS : Automatic control (setpoint : 124 psig)
- SIFCS : Automatic control (setpoint : 6.6 gpm)

3.3 Boundary Conditions

The pressurizer pressure and level, the RCS average temperature, the RCP seal pressure, and letdown and charging nozzle pressures were the parameters to be set as the boundary conditions. The time dependent boundary conditions could be obtained from the results of plant performance analysis code: KISPAC [4].

3.4 Calculation Results

Among the above PRDBEs, the loss of load gives the most severe transient in CVCS and the results of this case only are shown in this paper. The boundary conditions used for this event are shown in Fig. 1. At the beginning the loss of load results in the sudden rise of RCS average temperature (Tavg), then Tavg slowly goes down by the reactor power cutback system in about 100 seconds.

Based on the above boundary conditions, the following transients in CVCS are expected: As the pressurizer level increases initially as Tavg rises, the PLCS will reduce the charging flow rate, then the seal injection flow rate and charging back-pressure will decrease and the exit temperatures of regenerative heat exchanger tube and shell sides will increase. After 250 seconds the pressurizer level is lower than the setpoint. At that time the PLCS will increase the charging flow rate. Thus the system will behave in the opposite way to the above. During transient the letdown flow rate and back-pressure will be maintained constantly because the pressurizer level error does not exceed the actuation setpoints of letdown orifice isolation valves.

The code-predicted transient of letdown, charging, and RCP seal injection flows is shown in Fig. 2. The charging flow is decreased to 46 gpm at first, but increased to 131 gpm due to pressurizer pressure and level changes during this event. The RCP seal injection flow rate increases to 8.1 gpm/RCP (total 32.3 gpm) and a high flow alarm is actuated (alarm setpoint is 7.5 gpm). The letdown flow is maintained almost constant. The transient of charging backpressure is shown in Fig. 3. For the charging backpressure, no alarm is actuated. The transient of exit temperatures of regenerative heat exchanger (RHX) and letdown heat exchanger (LHX) is shown in Fig. 4. The RHX temperature varies due to charging flow change.

As shown in the figures, the transient in the CVCS is controllable and the code predictions are consistent with the expected system responses.

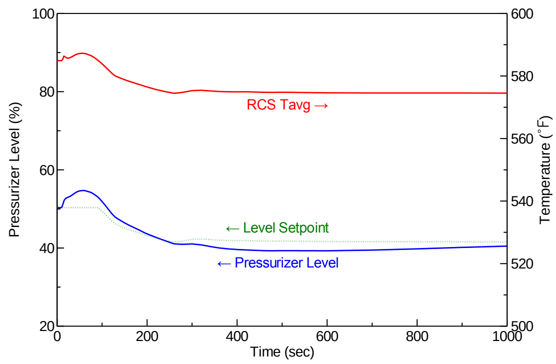

Fig. 1. RCS Boundary Conditions during Loss of Load

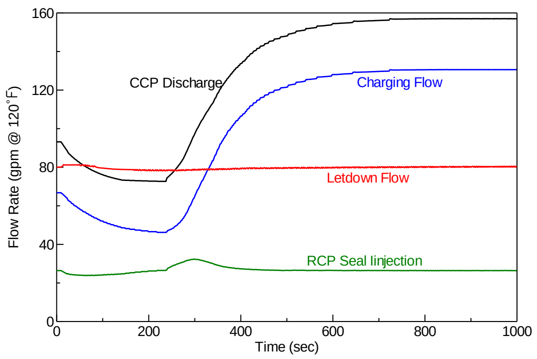

Fig. 2. Flow Rates during Loss of Load

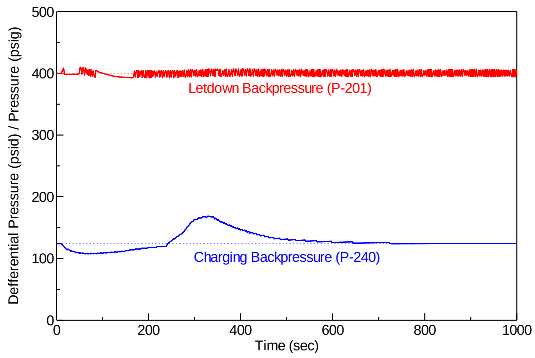

Fig. 3. Back-Pressures during Loss of Load

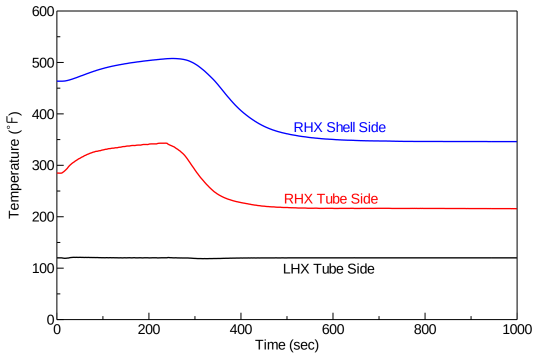

Fig. 4. Heat Exchanger Exit Temperatures during Loss of Load

4. Conclusions

In this study, the transient performance of the APR1400 CVCS integrated with RCS transients has been evaluated for the severe transient cases among the PRDBEs using the CARD1400 code. The evaluation results have shown that the transient in the CVCS is controllable and the code predictions are consistent with the expected system responses. Therefore, it is concluded that the CARD1400 code has been validated and can be used in the simulation of the APR1400 CVCS. With more extensive validation of the code against test data from startup of the first APR1400 plant in the future, the CARD1400 code can be used as an engineering tool in simulation of the APR1400 CVCS and other similar applications.

REFERENCES

[1] S. W. Kim and J. S. Ahn, "Development of the CARD Computer Code for the Application to the Design of the CVCS in YGN 5&6", KOPEC, Feb. 1998.
[2] H. S. Park, et al, "CVCS Transient Analysis during Pressurizer Level Step Change", Proceedings of the 13th PBNC, Oct. 2002.
[3] SKN 3&4 Final Safety Analysis Report, Section 9.3.4, KHNP
[4] Software Verification and Validation Report for KISPAC-PC Code, Rev. 00