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Modeling of Protection System and Control System for the APR1400 Using RELAP5 R/T

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1. Introduction

The NSSS thermal hydraulic model of the APR1400 Simulator has been developed using RELAP5 R/T code which is a real-time version of RELAP5 Mod3.2 [1]. To evaluate the model performance, the Non-Integrated Standalone Test(NIST) is needed without using the simulation environment.

In this study, the models of reactor protection system and NSSS control system for the APR1400 were developed to simulate various NPP transient conditions provided by ANSI/ANS-3.5 [2]. And the manual reactor trip test was performed from an initial condition of approximately 100 % power, steady-state xenon and decay heat, with no operator follow-up action.

The steady-state initial thermal hydraulic parameters of full power were converged on designed ones in the auto-actuation conditions of all NSSS control systems, and the thermal hydraulic parameters after the manual reactor trip were stabilized to designed setpoints by auto-actuation of control systems.

2. Modeling of Protection System and Control System

The reactor protection systems shutdown the reactor promptly and surely to prevent exceeding safety limits when the anticipated transient events occur, and the NSSS control systems perform automatic mitigation of transient events which can occur during power operation of NPP. However, the APR1400 Simulator uses those models made by simulation tools. Thus the modeling of those systems using RELAP5 R/T code is required for the NIST.

2.1 Modeling of Reactor Protection System

The reactor protection systems include reactor trip system, turbine trip system and steam generator(SG) isolation system. These systems are composed of detailed trip signals respectively as follows, and time delay was considered in the modeling.

- Reactor trip system
  The reactor trip signals are generated in the conditions of overpower, pressurizer high pressure, pressurizer low pressure, SG high pressure, SG low pressure, SG low level, RCS low flow rate and manual reactor trip. Table 1 shows the setpoints and the time delays of reactor trip signals.
- Turbine trip system
  The turbine trip signals are composed of reactor trip and manual turbine trip. The turbine trip is modeled by closing the turbine stop valve.
- SG isolation system
  The SG isolation is performed by closing the main feedwater isolation valves or the main steam isolation valves. The main feedwater isolation signals are generated in the conditions of SG low pressure, SG high level, loss of offsite power and manual isolation. And, the main steam isolation signals are generated in the conditions of SG low pressure, SG high level and manual isolation.

Table 1. Reactor trip signals

Reactor trip signals	Setpoint	Delayed Time(s)
(1) Pressurizer high pressure	2373 psia	1.15
(2) Pressurizer low pressure	1807 psia	1.15
(3) Reactor overpower	109.4%	0.55
(4) SG low pressure	885 psia	1.15
(5) SG high level	91%(NR)	1.15
(6) SG low level	45%(WR)	1.25
(7) RCS low flow rate	80%	-
(8) Manual trip	On	-

2.2 Modeling of NSSS Control System

The NSSS control systems include Pressurizer Pressure Control System(PPCS), Pressurizer Level Control System(PLCS), Reactor Regulating System (RRS), FeedWater Control System(FWCS), Steam Bypass Control System(SBCS) and Reactor Power Cutback System(RPCS). The Control Element Deriving Mechanism Control System(CEDMCS) was modeled as the same system to RRS.

- PPCS
  The PPCS provides auto and manual control methods to required pressure setpoint using the proportional heaters, the backup heaters and the pressurizer spray valves.
- PLCS
  The PLCS provides auto and manual control methods to pressurizer level by controlling the charging and letdown flow rate of Chemical and Volume Control System.
- RRS

The RRS adjusts the reactor power to the turbine load variation by correcting the RCS average temperature to the programmed turbine reference temperature using the CEDMCS.

- FWCS

The FWCS regulates the SG level by controlling the feedwater flow rate. At the lower power range of 20 %, the FWCS uses the single parameter of SG level, and at the upper power range of 20 %, the FWCS uses three parameters of SG level, feedwater flow rate and steam flow rate. After the reactor shutdown, the main feedwater flow rate is regulated by the RCS average temperature.

- SBCS

The SBCS regulates the primary and secondary heat balance using eight turbine bypass valves at the condition of desired reactor power.

- RPCS

The RPCS prevents reactor trip in such events as turbine trip or single trip of main feedwater by abruptly reducing the reactor power.

Figure 1 shows the RELAP5 R/T nodalization for the APR1400 which has included all the above control systems.

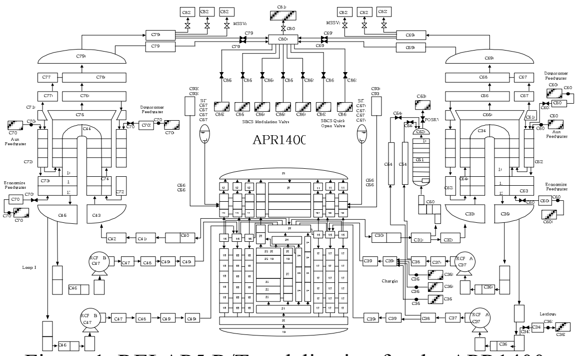

Figure 1. RELAP5 R/T nodalization for the APR1400

3. Transient Performance Test

The steady-state of full power was calculated in the auto-actuating conditions of protection and control systems. The initial thermal hydraulic conditions were in good agreement with design ones. And the manual reactor trip test was performed with no delayed time. Figure 2 shows the calculation results. The thermal hydraulic parameters after the manual reactor trip were stabilized to designed setpoints by auto-actuation of control systems.

4. Conclusion

The models of reactor protection system and NSSS control system for the APR1400 were developed using RELAP5 R/T code. The transient performance test of the model by manual reactor trip shows reasonable plant thermal hydraulic responses to reactor protection systems and NSSS control systems. Several transient performance tests provided by ANSI/ANS-3.5 are in progress. By developing the models of reactor protection system and NSSS control system for the APR1400 using RELAP5R/T, the NIST environment of the APR1400 Simulator thermal hydraulic model can be provided.

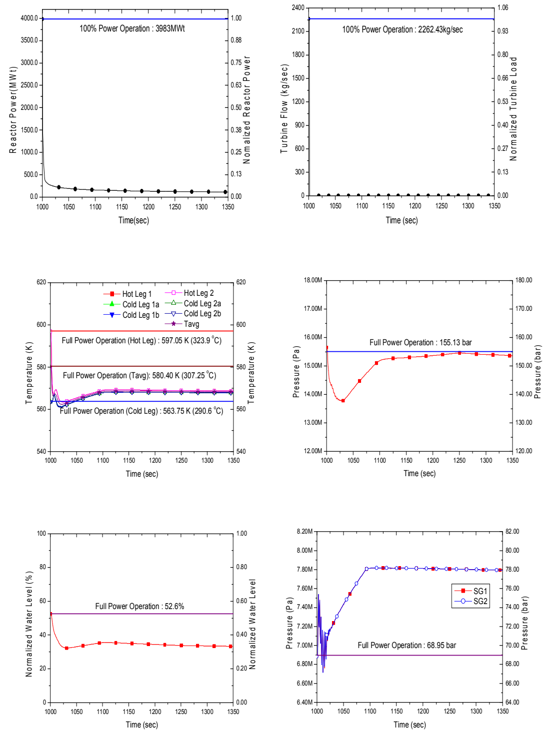

Figure 2. Results of manual reactor trip test

ACKNOWLEDGMENT

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