Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1995

Study on The Development of Basic Simulation Network for Operational Transient Analysis of The CANDU Power Plant

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Abstract

Simulation models have been developed to predict the overall behavior of the CANDU plant systems during normal operational transients. For real time simulation purpose, simplified thermal hydraulic models are applied with appropriate system control logics, which include primary heat transport system solver with its component models and secondary side system models. The secondary side models are mainly used to provide boundary conditions for primary system calculation and to accomodate plant power control logics. Also, for the effective use of simulation package, hardware oriented basic simulation network has been established with appropriate graphic display system. Through validation with typical plant power maneuvering cases using proven plant performance analysis computer code, the present simulation package shows reasonable capability in the prediction of the dynamic behavior of plant variables during operational transients of CANDU plant, which means that this simulation tool can be utilized as a basic framework for full scope simulation network through further improvements.

1. Introduction

The simulation techniques for nuclear power plant have been greatly improved with the computer technology developments over last decade, and, in addition to operator training simulator, their applicability has been expanded. In CANDU plant, the simulation techniques are relatively not in mature stage and it is needed to develope more physically based simulation package and its utilization technique, which could be used as a basic tool for improvements in operation and design of CANDU plant. The present study is to develope an basic simulation network for use in operational transient analysis of overall CANDU plant.

The CANDU version of DSNP (Dynamic Simulator for Nuclear Power Plant)[1,2] has been adopted as a basic reference simulation program and each mathematical model has been improved and refined with addition of secondary system models and appropriate plant /component control logics for overall plant simulation. For efficient use of simulation package, hardware oriented simulation network is devised through application of graphic-user interface technique.

2. Model Description

2.1 Process System Model

1) Primary Heat Transport System

To predict thermal-hydraulic behavior in the heat transport system in transient process economically, simplified linearized one dimensional homogeneous two phase flow model is applied.[3] The mass, momentum and energy conservation equations are discretized using staggered mesh and linearized with simplifying assumptions, which are applied to the nodalized flow network.(Fig.1) Considering symmetry of the loops, only one primary heat transport loop is simulated with appropriate adjustments for shared components and it is assumed that no heat transfer occurs except in core and steam generator.

A lumped parameter approach is used for the evaluation of the fuel average temperature, fuel centerline temperature,and clad temperatures with temperature dependency of thermal conductivities[4] The reactor core is modeled as two representative bidirectional fuel channels(figure of 8 characteristics of CANDU primary loop)

2) Pressurizer

Transient thermal hydraulic model of pressurizer is simplified with several assumptions; Heavy water in the pressurizer exists in two homogeneous phase only, with no thermal interaction except through condensation and flashing. A single pressure applies to both the steam and water phase in pressurizer.

The operational modes include five parts; one for insurge and one for each of the four outsurge cases as determined by the status of the liquid and vapor phases. The mass and energy balances for each mode are set up with the conditions of liquid phase and vapor condition.[5] The balance equations are solved for mass and enthalpy for each phase and the pressurizer pressure with the boundary condition that the total volume of the pressurizer is fixed.

3) Steam generator

U-tube steam generator model is based on a macroscopic analysis of the control volume.[6] The secondary side is divided into five main control volumes: the downcomer, tube bundle region, dryer/separators, vapor dome, and saturated liquid region. The tube bundle region is further subdivided into a subcooled volume and a saturated volume in order to accommodate the heat transfer modeling.

For simplicity, significant assumptions made in the secondary side modeling include; thermodynamic equilibrium, uniform pressure, homogeneous flow, linear fluid quality profile up through the tube bundle region, negligible vapour production in the downcomer and the subcooled portion of the tube bundle region, and complete vapour/liquid separation by the dryers and separators. Transient behavior of steam generator is predicted by imposing macroscopic mass and energy balances on the indicated control volumes..The primary-to-wall and the wall-to-subcooled secondary heat transfer rates are calculated using approate heat transfer correlations depending on the flow conditions.

4) Steam line

To provide boundary condition for the prediction of steam generator behavior, transient thermal hydraulic model of steam line is needed in addition to related control logics. For the calculational simplicity, steam line which extends from each steam generator exit to turbine governor valve is treated as a single volume, and mass and energy balance equations are applied. The connected discharge valves for steam flow rate control are modeled, but the break flow from steam line is not considered.

2.2 Plant Control Model

The control system models used in this work represents the logic from Wolsong nuclear power plant. The systems modeled include: (1) the important elements of the overall plant control program - boiler pressure (digital) control including atmospheric and condenser steam discharge valve controls, unit power (digital) regulator, and electrohydraulic governor (analog) control; (2) the reactor regulating system including demand power, setback and stepback routines and SDS1 shutdown system; (3) the normal mode of the primary heat transport system(PHT) (digital) pressure and inventory control; (4) the steam generator (boiler) (digital) level control. In the reactor regulating system models, liquid zone level dynamics are modeled as first order linear system. Each control system model is executed by an interface program between process and control modules.

2.3 Configuration of Simulation Display System Network

The overall configuration of the simulation display system network is shown in Fig. 1. The developed simulation program provides virtual dynamic information of the CANDU plant. The virtual graphic environment of the control panels and console display of the CANDU control room are made using the commercial graphic editor DV-Draw. For the display of the plant status/schematics, 3 units of 67" retrovision have been utilized.

The communication between the simulation program and the display units were made by user-writen interface program so that synchronized display of multiple plant status/schematics and run-time monitoring and supervisory control of the plant dynamic behavior are possible.

3. Results and Discussion

The thermal hydraulic model for primary heat transport network solver was examined and it was proved that the present model is stable theoretically and numerically for the prediction of slow transients.. To evaluate the predictive capability of the present integrated simulation package, integral test was performed by applying to typical CANDU6 plant simulation. Also, the test results were compared with the output data from SOPHT computer code, which has been used for performance analysis of CANDU type plants. For this validation test, reactor power calculation was done using point kinetics model without reactivity feedback.

Operational transient due to setback was taken as a test case. In the 100% full power condition, the reactor power was decreased with a ramp rate of -1%/sec to 60% and the turbine was tripped at time zero. The predicted variation of reactor outlet header pressure, pressurizer pressure and steam generator pressure with time are shown Fig.2, Fig.3 and Fig.4, respectively with the SOPHT results.[7]

As can be seen in Fig.2 and Fig.3, the time dependent response of main parameters such ast outlet header pressures and pressurizer pressure are in good agreement with the SOPHT prediction. However, in the case of SG pressure the predicted values show discrepancy with the SOPHT prediction especially in early stage. This disagreement occurs because the present SG thermal hydraulic model does not account for SG water level shrink caused by turbine trip and also incomplete CSDV control logic in turbine trip. In addition to these comparisons, it was noted that the mass flow rate at the steady state 100% full power condition was a little bit lower than the SOPHT result and this seems due to use of incomplete form loss in the flow network, which shall be resolved.

4. Conclusion

A simulation package for transient behavior of CANDU power plant has been developed and its preliminary usability in the operational transient simulation has been shown through validation against proven computer program. Also, hardware oriented basic simulation network has been established, through which simulating process is managed efficiently by applying appropriate graphic-user interface technique. Even if integral test for typical case indicates that the time dependent behavior of the major parameters shows good agreement against reference output result, validation effort with model improvements should be made for more transient cases to establish sound basis for more sophisticated engineering simulator. To overcome the limitation in its applicability, the present simulation model is also needed to be extended to handle abnormal transients.

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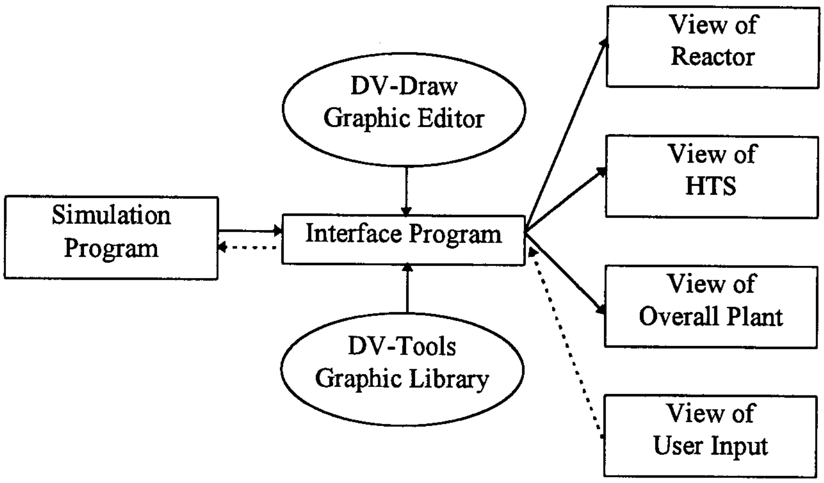

Fig. 1 Simulation network system

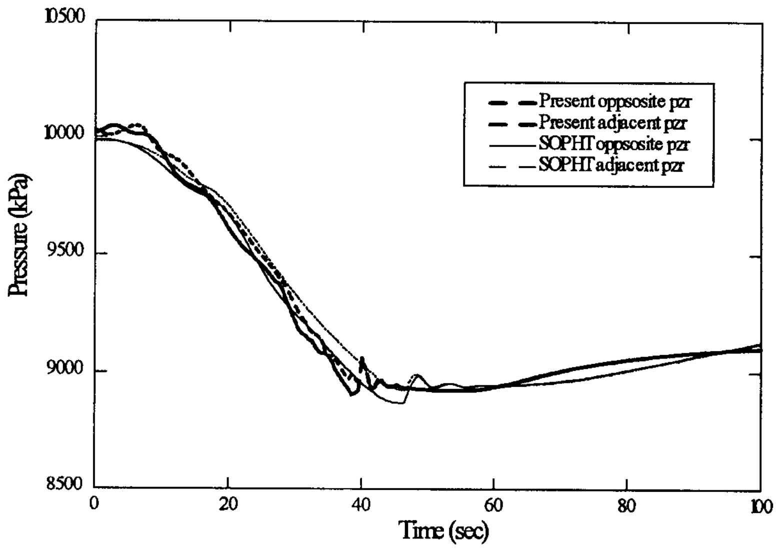

Fig. 2 Reactor outlet header pressure

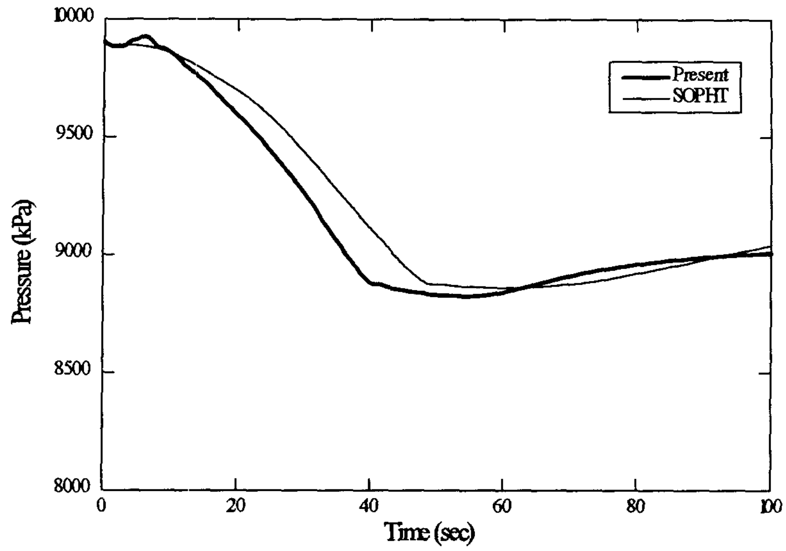

Fig. 3 Pressurizer pressure

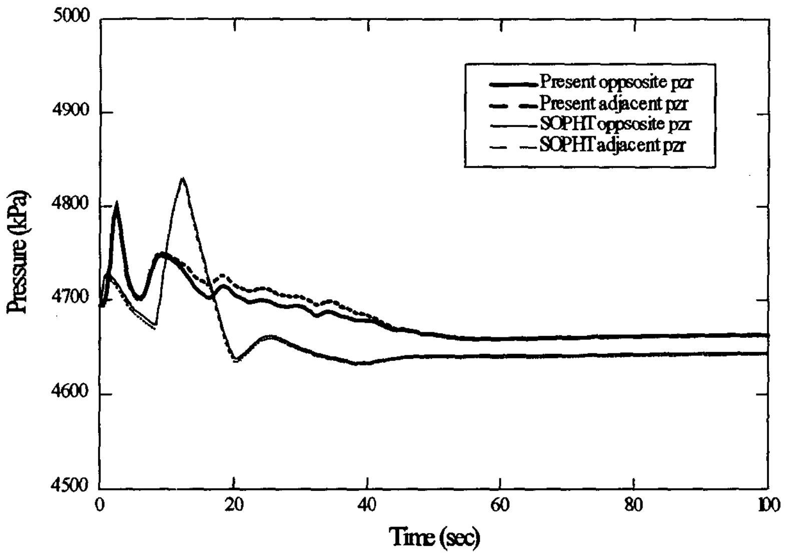

Fig. 4 Steam generator pressure