CANDU 시뮬레이션을 위한 증기발생기 모델링

Steam Generator Modeling for CANDU Transient Simulation

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Abstract

A simplified steam generator model has been developed for the simulation of the operational transients of CANDU nuclear power plant. For the analysis of the secondary side, a control volume approach is used and the flow conservation equations are applied for each control volume. The typical steam generator control logic such as the level control and the pressure control are incorporated into the steam generator model with appropriate interface conditions. The steam line including ASDV, CSDV, and governor valve also has been modeled. Test results for typical operational transient case show reasonable transient behavior of steam generator in a real time basis, which is promising for a CANDU engineering simulator.

1. Introduction

A nuclear power plant simulator is an essential tool for plant operator training. Recently, the application of the simulator is being extended to an engineering tool for plant system design. Therefore, by developing a more physically based simulation techniques, the operator training and the overall plant system analysis can be performed. The purpose of this study is to develop an analytical steam generator(S/G) model, , which does an important role in the simulator, applicable to operational transients in the CANDU primary heat transport system. In the following discussions, the theoretical modeling and example simulation results are presented.

2. Model Description

2-1. Thermal-Hydraulic Model

The thermal hydraulic simulation of the U-tube steam generator is based on a macroscopic analysis of the control volume. (Fig.1) As indicated, the primary side, the tube wall, and the secondary side are coupled by heat transfer. The secondary side is divided into five control volumes: the downcomer, the tube bundle region, the dryer/separators, the vapor dome, and the saturated liquid region. The tube bundle region is further subdivided in order to treat separately the subcooled and the bulk boiling regimes. The saturated liquid region represents a fixed volume of recirculated saturated liquid that is yet to be mixed with the downcomer inventory. The downcomer is a variable volume mixing control volume.

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 vapor production in the downcomer and the subcooled portion of the tube bundle region, and complete vapor/liquid separation by the dryers and separators. The secondary side variables considered may be obtained 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 the Dittus-Boelter correlation and the wall-to-saturated secondary heat transfer rates are calculated using the Thom correlation.

2-2. Steam Generator Control

S/G control logics are essential for stable plant operation by eliminating possible plant trips due to upset conditions of S/G such as excessive deviations of steam generator level and pressure. The steam generator control logics include level control logic and pressure control logic.

The S/G level control is performed by adjusting feedwater valve lift. The demand feedwater valve lift is a sum of five terms; bias lift, swell of inventory, proportional level error, integral level error, and mass balance. The bias lift term is a function of S/G power and the swell term is a function of the rate of change in power. To evaluate level error term, level set point and the actual level are calculated and compared. The proportional level error is defined as a product of level error and gain, and the integral error term is obtained with proportional level error term. The mass balance term is defined by comparing the feedwater flow rate and steam flow rate. The actual valve lift at any given time is updated with calculated demand valve lift, but it is limited by the maximum rate of change in valve position.

The S/G pressure control routine calculates the demand governor valve position through determine steam flow to the turbine, and the valve lifts for ASDV and CSDV to relieve S/G over pressure. The governor valve position is controlled by the pressure error between the S/G pressure and its setpoint, and it is also a function of S/G and reactor power. Valve lifts for both ASDVs and CSDVs are calculated in response to rising boiler pressure, and they are calculated with S/G pressure error and power mismatch between reactor power and turbine power.

For interfacing the S/G thermal-hydraulic model with control logic, the steam flow from S/G and the feedwater flow to S/G are required. The feedwater flow is obtained as a function of feedwater valve lift, S/G pressure, and pressure at the feed pump discharge. The mass and energy equations are solved for the steam line to evaluate steamline pressure. The pressure difference between S/G and steamline induces steam flow. Also, the feedwater temperature required for S/G thermal-hydraulic calculation is obtained as a function of turbine power.

2. Application and Results

To evaluate the functional capability of the present models, transient behavior of typical CANDU6 steam generator has been analyzed. For the transient simulation, the present S/G model has been applied to the DSNP program, which is a simplified simulation code for nuclear power plants. Available data from Point Lepreau nuclear power plant were used for the required plant geometrical data and the plant specific control data. Setback case was taken for the test simulation, i.e., in the 100% full power condition, reactor power is decreased with a ramp rate of 0.4%/sec down to 60%. (Fig. 2)

In Fig. 3, the time dependent response of the level setpoint and the actual S/G level are shown with time, in which the predicted S/G level follows the setpoint value, which is a function of power. Also, in Fig. 4, the time dependent behavior of S/G pressure shows pressure approaches the setpoint value (4.69 MPa). With these simulation results, the present

S/G model is thought to function reasonably for the prediction of transient S/G behavior in the operational power maneuvering case.

3. Conclusion

A simplified steam generator model for transient simulation of the CANDU power plant has been developed and its preliminary functional capability has been shown by applying to the typical case. However, only one simple transient case was chosen for model validation, which means that it is needed to test the present model for more cases. Also, it is required to extend applicable operating range in parallel with model improvements by comparing calculational results against plant specific data.

References

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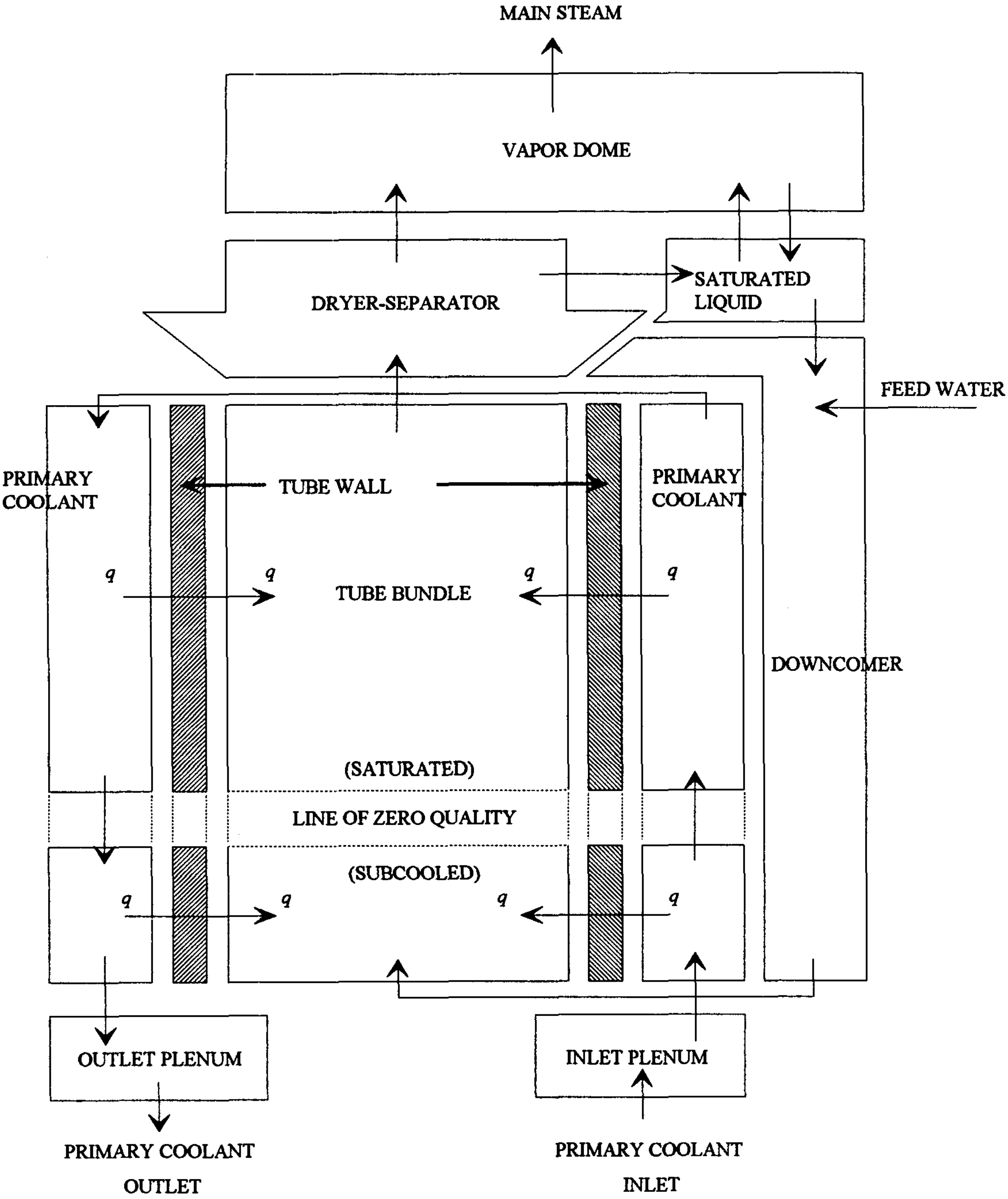

Figure 1. Steam Generator Overall Control Volume Schematic.

Fig. 2. Reactor power

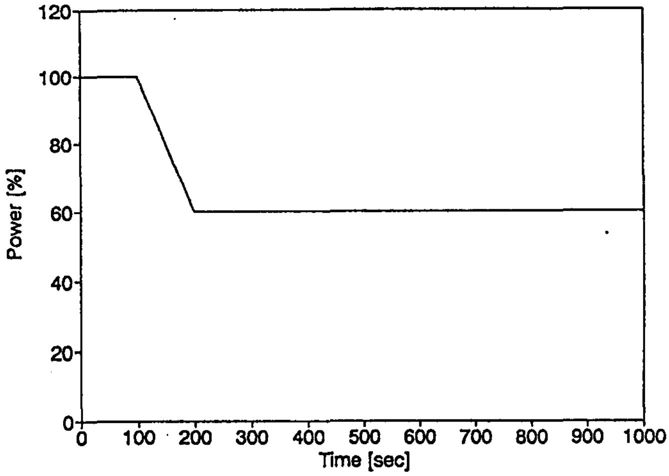

Fig. 3. S/G water level

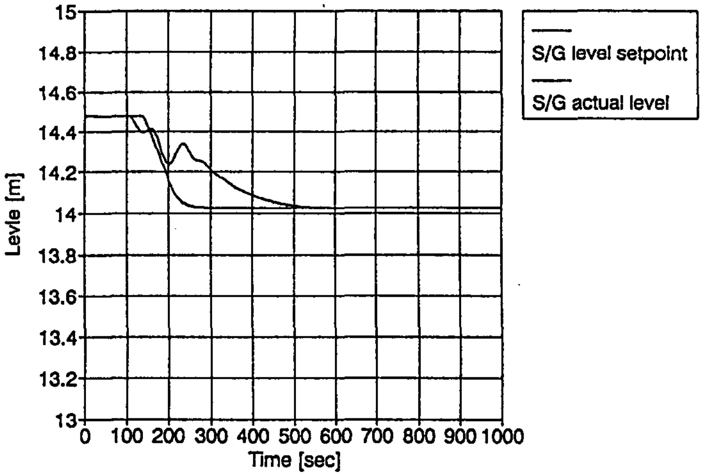

Fig. 4. S/G pressure