2영역 튜브모델을 고려한 CANDU 시뮬레이션용 DSNP 증기발생기 모델 개선

Improvement of Steam Generator Model for DSNP with Two-Region Tube Bundle Model for CANDU Transient Simulation

임 재천,서재승

고등기술연구원 전력에너지연구실

Abstract

An improved steam generator model has been developed for the DSNP simulation of normal operational transient behavior of CANDU nuclear power plant. For more realistic prediction of steam generator behavior during transient, tube bundle region is divided into two separate control volumes, subcooled region and saturated region, and the variation of thermal hydraulic properties in the control volume is accounted for more realistic estimates of outlet enthalpy of each control volume. Test results for typical CANDU operational transient case show reasonable transient behavior of steam generator with overall CANDU operation and improved operational characteristics of steam generator with power variation.

1. Introduction

The steam generator model does an important role in the prediction of the behavior of plant variable during plant transients,especially in the simulation of normal plant operational transient combined with related control logics,which is because the behavior of primary side is strongly dependent on the thermal-hydraulic condition of steam generator. In the previous steam generator model, which has been used in DSNP-CANDU, the tube bundle region is treated as one control volume and the outlet enthalpy of each control volume is approximated as the average value of that control volume, which is oversimplified approach. Even thouth this simplified model predicts transient behavior of steam generator reasonablly, a more detailed analytical model is desirable for use in the engineering simulator.

The theoretical modeling of improved steam generator model is presented and example simulation results are discussed in comparison with previous model..

2. Model Description

The thermal hydraulic simulation of the U-tube steam generator is based on a macroscopic analysis of the control volume. The primary side, the tube wall, and the secondary side are coupled by heat transfer. The secondary side is divided into six control volumes: the downcomer, subcooled tube bundle region, saturated tube bundle region, dryer/separators, vapor dome, and saturated liquid region. The saturated liquid region represents a fixed volume of recirculated saturated liquid that is yet to be mixed with the downcomer inventory. The downcomer region is a variable control volume, which determines the steam generator level with saturated liquid volume. Each of the tubel bundle region , subcooled and saturated, is also variable control volume and the total volume is fixed.

For any given control volume V_k with i inlets and j oulets , the general governing equations are given as

$$\frac{\partial M_k}{\partial t} = V_k \frac{d\rho_k}{dt} + \rho_k \frac{dV_k}{dt} = \sum_i \dot{m}_i - \sum_j \dot{m}_j$$

$$\rho_k V_k \frac{dh_k}{dt} = q_k + \sum_i \dot{m}_i \left(h_i - h_k\right) - \sum_j \dot{m}_j \left(h_j - h_k\right) + V_k \frac{dP_k}{dt}$$

For subcooled and saturated tube bundle region, the mass and energy balances are expressed as

$$V_{SB}\frac{d\rho_{SB}}{dt}+\rho_{SB}\frac{dV_{SB}}{dt}=\dot{m}_{DC}-\dot{m}_{sub}$$

$$\rho_{SB}V_{SB}\frac{dh_{SB}}{dt}-V_{SB}\frac{dP}{dt}=\dot{m}_{DC}\left(h_{DC}-h_{SB}\right)+\dot{m}_{sub}\left(h_{SB}-h_{f}\right)+Q_{sub}$$

$$\rho_{TB}\frac{dV_{TB}}{dt}+V_{TB}\frac{d\rho_{TB}}{dt}=\dot{m}_{sub}-\dot{m}_{TB}$$

$$\rho_{TB}V_{TB}\frac{dh_{TB}}{dt}-V_{TB}\frac{dP}{dt}=\dot{m}_{sub}(h_{f}-h_{TB})+\dot{m}_{TB}\left(h_{TB}-h'_{TB}\right)+Q_{sat}$$

The downcomer is assumed to have uniform properties and outlet enthalpy of subcooled tube bundle region is saturated liquid enthalpy. Also, the outlet enthalpy of saturated tube bundle region, h'_{TB}, is obtained by assuming linear quality profile through the height of saturated region. For simplicity, several assumptions made include: thermodynamic equilibrium, uniform pressure, homogeneous flow, negligible vapor production in the downcomer and the subcooled tube bundle region, and complete vapour/liquid separation by dryer/separators. The downcomer mass flow rate, which is required for the solution of mass and energy equations, is simply predicted by a macroscopic momentum balance over the flow path in the steam generator.

3. Test Results and Discussion

A transient behavior of typical CANDU6 steam generator has been analyzed using DSNP-CANDU with the previous one tube bundle model and the present steam generator model (two tube bundle model with nonuniform property in a control volume). The avaiable geometrical and control data from Point Lepreau nuclear power plant were used for the simulation. The steam generator in Point Lepreau has integral preheater and the feedwater inlet is located at the bottom of steam generator shell, which is different from present model. However, it is assumed that the present model can be used for this type of steam generator because the preheater and the feedwater inlet location have negligible effect on the overall transient behavior in this simplified model. Setback case were 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 by 60%. (Fig. 1)

The time dependent behaviors of S/G water level for one-tube bundle model and two-tube bundle model are shown in Fig. 2 and Fig. 3, respectively. The predictions indicate that both models show the reasonable results qualitatively in the prediction of general steam generator general behavior,i.e.,the steam generator level approaches the set point values. However, the present model is better in that it shows more consistent behavior. With these simulation results, the present model is thought to function more reasonably for the prediction of transient S/G behavior in the operational power maneuvering case.

4. Conclusion

A simplified steam generator model, physically based two-tube bundle 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, further model improvements are required by examining quantitative predictions results against any plant specific data.

References

1. J. Zhang and D. A. Meneley," DSNP: Dynamic Simulator for Nuclear Power Plants - CANDU",1993

2. G.E.Welch, E.T.Dugan, and W.G. Vernetson,"A Dynamic Model of a U-Tube Steam Generator for the DSNP Simulation", The University of Florida

3. 서재승 외"Steam Generator Modeling for CANDU Transient Simulation", 에너지공학회 춘계학술발표회 , 5.1994

4. 김동수 외," Nuclear Plant Analyzer 개발",KAERI/RR-902/89

Fig. 1. Reactor power

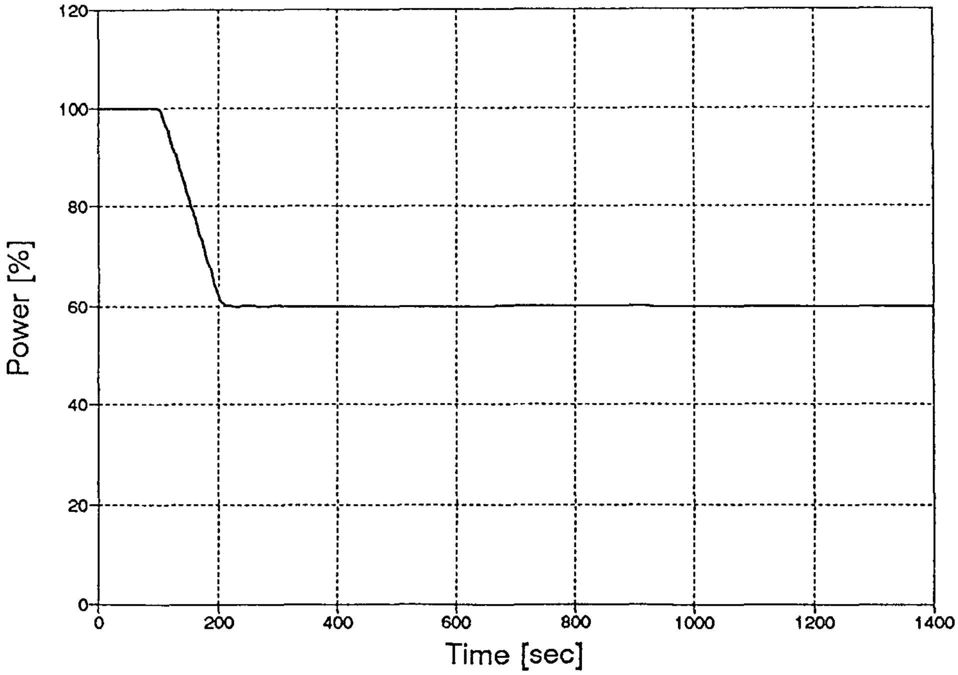

Fig. 2. S/G water level(1 tube bundle)

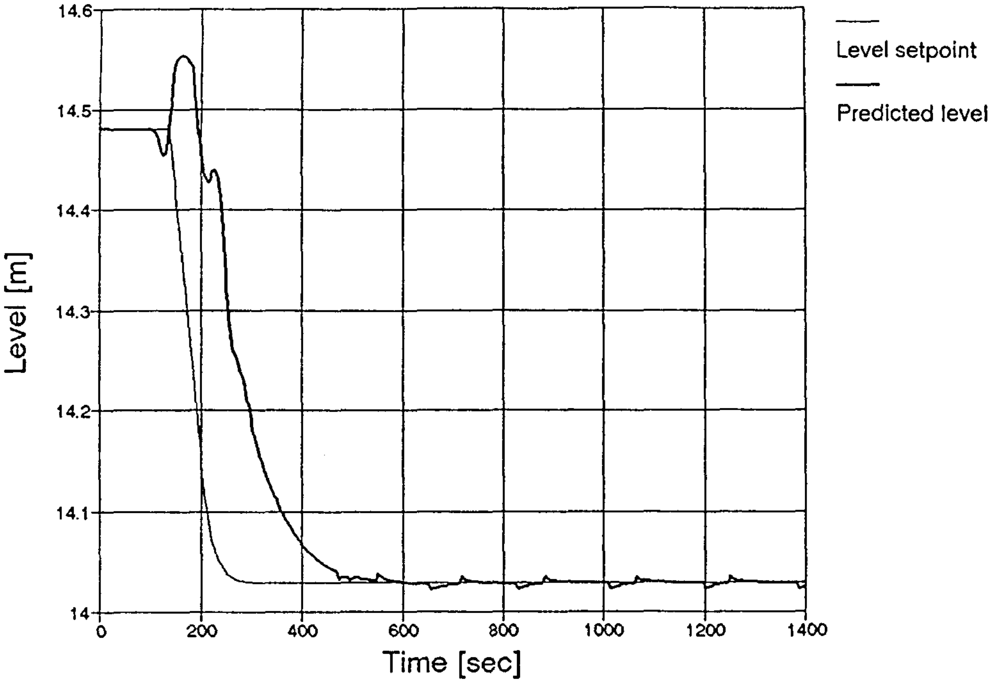

Fig. 3. S/G water level(2 tube bundle)