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Integrated Model for Secondary and Primary Systems using MARS-KS Code

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1. Introduction

Recently, due to the increasing use of small modular reactors (SMRs) and the carbon neutrality policy, there has been active research into expanding nuclear power plants into non-electric application field. One such concept is the Nuclear-Renewable Hybrid Energy System (NRHES), which involves combining a secondary system of a nuclear power plant (NPP) with renewable energy to enhance the efficiency and economy of energy systems [1].While most NPPs primarily use the steam generated by the steam generator for electricity generation, in NRHES, a portion of the steam can be extracted from the secondary system and the thermal energy for later use.

Therefore, it is important to understand the impact of steam extraction on NPPs when operating NRHES. For this reason, we developed the secondary system of NPPs using the MARS-KS code so far [2-5]. However, the thermal-hydraulic conditions of the secondary and primary sides affect each other. For example, a decrease in the feedwater temperature reduces the reactor coolant temperature, which can cause an increase in core power due to the feedback effect. As the core power increases, the thermal-hydraulic conditions of steam generators change, thus affecting the amount of steam generated in the secondary side.

In order to analyze the effect of steam extraction on the NPPs, it is essential to develop an integrated model that considers both a primary and secondary side. In this paper, we will develop an integrated input model using the MARS-KS code and verify that it predicts well.

2. Integrated model for secondary and primary systems

Fig. 1 shows the nodalization of integrated modeling of secondary and primary systems. An integrated model was developed by referring to the standard design of SMART100 [6], all major components were connected through pipes, and modeling was performed without any boundary conditions. The core modeling was divided into two volumes: fuel assemblies (004) and core bypass region (008). The reactivity coefficient was use to consider the temperature feedback effect (e.g., moderator temperature and Doppler feedback.) of the core. The upper plenum (024) and pressurizer (026), which are the downstream of the core were modeled as PIPE components. 4 Reactor Coolant Pumps (RCP) and 8 Steam Generators (SGs) were integrated into one each considering symmetry configurations and efficiency calculation time. Finally, the Flow Mixing Header Assembly (022) and Low plenum (001) flowing into the core from the steam generator outlet were modeled as PIPE components.

The secondary side is consists of the high and low pressure turbines, Moisture Separator and Re-heater (MSR), condenser, feedwater heaters, and a deaerator, Condenser Pump (COP) and Feedwater Pump (FW). To consider the appropriate turbine work according to the rapid enthalpy change of steam in turbine, the momentum and vapor energy equations for turbine were modified. The condenser was modeled as a vertical pipe. In the case of the MSR, the area (250) where moisture is separated used the SEPARATR component provides by MARS-KS, and the area (252) where steam was heated to superheated steam condition was modeled by a vertical pipe. For modeling the COP and FW, MARS-KS built-in homologous curve table for the Westinghouse pump was used. Also, the pump speed was considered as constant condition.

Finally, feedwater heaters include complex geometrics, such as partition plat and supporting baffle, to increase the efficiency of heater. Therefore, when modeling the phenomenon as a simple pipe model, there is a limit to simulating the appropriate pressure drop and heat transfer performance. As shown in Figure 3, to consider the complex configuration of feedwater heater, we used for MULTID component in MARS-KS. A detailed modeling guide for feedwater heaters and other components can be found in the referenced documents [5,7].

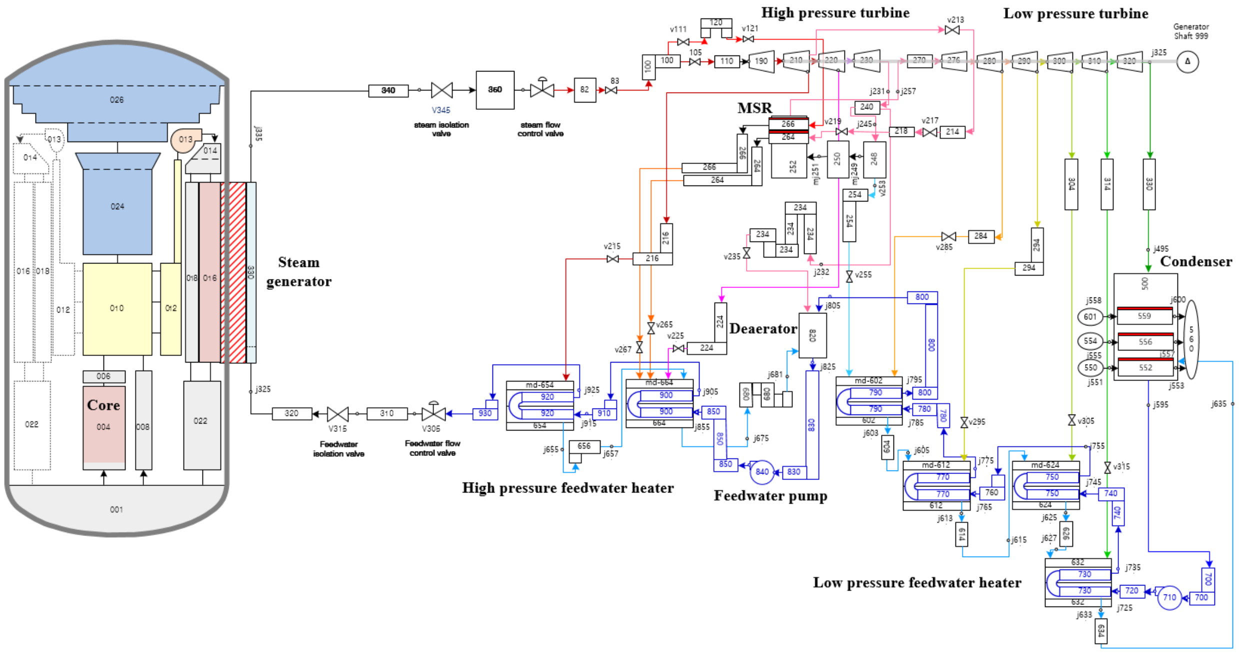

Fig. 1. MARS-KS nodalization of primary and secondary systems

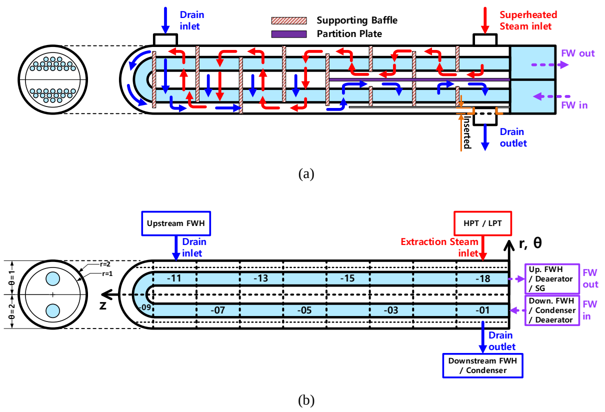

Fig. 2. Feedwater heater modeling using MULTID component

3. Integrated model verification

To verify the integrated model, we compared to the calculated results and design data for secondary system of SMART100.

Fig. 3 shows the distribution of temperature and vapor fraction in a low-pressure feedwater heater. In general, a feedwater heater into which superheated steam flows can be divided into a desuperheating zone, where superheated steam is reduced to saturation temperature condition, a condensing zone, where phase change heat transfer occurs, and a drain cooling zone, where condensate is cooled [8]. As shown in Figure 3(a), it was confirmed that the heat exchanger model using MULTID physically reasonably calculated the target value and three zones of the feedwater heater. In addition, as shown in Figure 4(b), the vapor void fraction indicates '1' in the area where superheated steam is introduced (1-4). Also, it was confirmed that the steam fraction was decreased at lower part (10-18) of heat exchanger because the condensed water was accumulated.

Fig. 4 shows a comparison of the pressure, temperature and mass flow rate according to major components. As a result, it was confirmed that the developed model well predicted the thermal-hydraulic behavior. The turbine work was properly simulated under the relative error of 2 %.

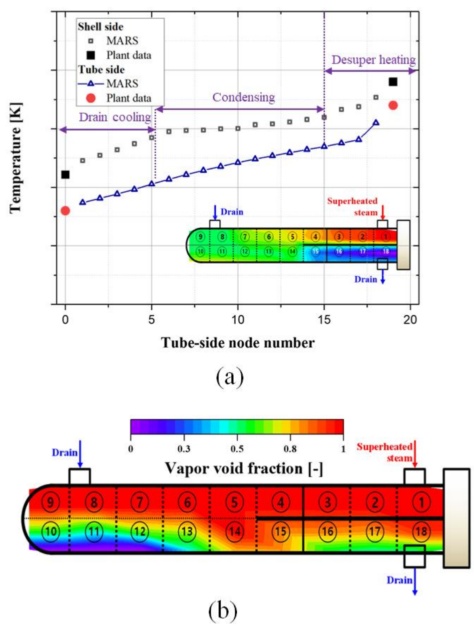

Fig. 4. Calculated pressure and vapor void fraction distribution in feedwater heater

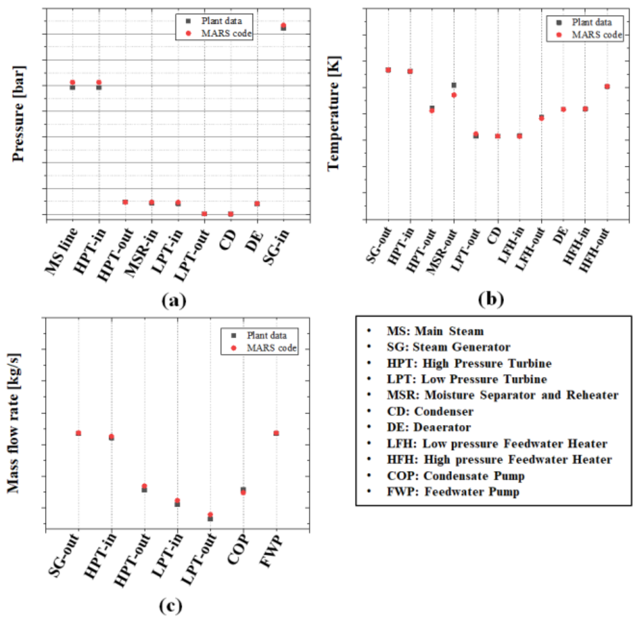

Fig. 3. Verification results according to major compartments: (a) pressure, (b) temperature, (c) mass flow rate

4. Conclusions

In this study, based on MARS-KS, and NPP analysis model was developed that can simulate the behavior of major thermal hydraulic variables in the primary and secondary systems simultaneously. As a result of comparing the developed model with the design data of plant, the overall thermal hydraulic behaviors of main compartments were properly simulated. In the future, the integrated model will be used to derive operating strategies that can extract appropriate thermal energy while maintaining the integrity of nuclear power plants.

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