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Development of Primary-Secondary system integrated MARS-KS input model for V-SMR

Jehee Lee [a*], Jungjin Bang [a], Bub Dong Chung
[a] *FNC Tech., Heungdeok IT Valley, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 446-908, Korea*
**Corresponding author: capable91@fnctech.com*

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1. Introduction

Virtual reactor technology is being actively researched around the world for the development and demonstration of Small Modular Reactors (SMR). Together with the Korea Institute of Science and Technology Information (KISTI) and the Electronics and Telecommunications Research Institute (ETRI), the Korea Atomic Energy Research Institute (KAERI) is developing a virtual reactor platform for SMRs to solve problems that may arise before SMR construction and reduce uncertainties to ensure safety.

In this study, we are developing a nuclear power plant primary and secondary system integration model using MARS-KS[1] as part of the development of a high-reliability/high-speed analysis model for supercomputing-based virtual SMR (V-SMR) platform technology development. The V-SMR platform should be able to simulate the load-following operation that will be applied in actual SMR deployments in the future, which requires the ability to simulate changes in core power and feedwater depending on the amount of power produced by the turbine. It should also be able to simultaneously simulate the resulting changes in the behavior of the primary and secondary systems.

In this paper, the MARS-KS input model, which was previously developed for BOP analysis of secondary systems[2], was modified to be suitable for V-SMR analysis. In addition, the primary system input model of the conceptual SMR was developed and the integration with the secondary system input model was performed.

2. Description of Secondary System Modeling

The secondary system of a V-SMR typically includes helical-coiled Steam Generator(SG), High-Pressure Turbine(HP-Turbine), Low-Pressure turbine(LP-Turbine), and Condenser as shown in Fig. 1. In addition, there are Moisture Separators and Reheaters (MSR), HP/LP Feed water Heaters (HPFH/LPFH), Steam Packing Exhauster, and Deaerator to increase the efficiency of energy conversion. Each component was modeled through MARS-KS 2.0's component model or PIPE, and the flow distribution and pressure in the system were controlled through servo valves and pumps.

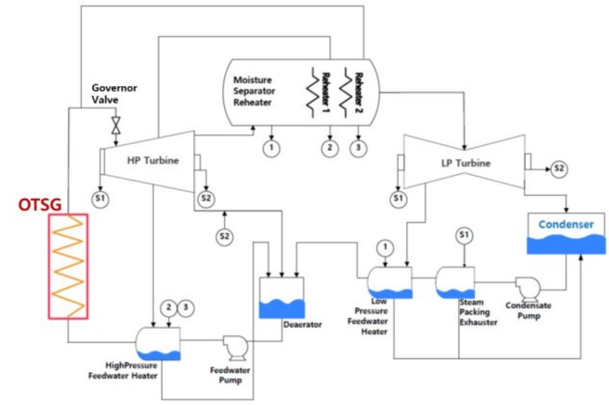

Fig. 1. Schematics of Steam and Power Conversion System of V-SMR

2.1 One-Through Steam Generator Model

The steam generator of the V-SMR is a One-Through Steam Generator (OTSG) utilizing a helical coil. For the heat transfer model in the steam generator tube, the Mori-Nakayama model[3] was used, and the Zukauskas model[4] was applied to the heat transfer model on the shell side. A model of two-phase flow pressure drop inside a helical coil steam generator tube is currently in need of development, and this study simulated the pressure drop with an arbitrary form loss factor.

2.2 Turbine Model

In the turbine of a steam generator secondary system, high-pressure steam is rapidly decompressed to generate power. During this process, the pressure of the vapor is quickly depressurized from about 50 bar to 0.05 bar. Therefore, to properly simulate the rapid steam decompression within the turbine, the turbine model in MARS-KS was used in this study. In previous work, MARS-KS did not adequately predict the energy reduction due to turbine shaft work and proposed to improve the turbine component model [5]. Therefore, the V-SMR secondary system modeling also used a turbine component model that takes into account the effect of shaft work on the enthalpy changes in the turbine.

2.3 Feedwater Heater Model

The V-SMR's feedwater heater utilizes a shell-and-tube type heat exchanger. The internal geometry of the feedwater heater makes it difficult to adequately predict pressure drop and heat transfer using traditional modeling methods with PIPE component. Therefore, previous studies have used MARS-KS MULTID component to improve the prediction performance of Feedwater Heater[6], but the analysis speed was too slow and numerically unstable. Therefore, the Feedwater Heater was modeled using the Tank component and verified with SMART 100 Feedwater Heater date. As shown in Fig. 2, the ability to predict the temperature behavior of the Feedwater Heater was found to be good. Therefore, in V-SMR modeling, the Tank component was used to simulate the Feedwater Heater.

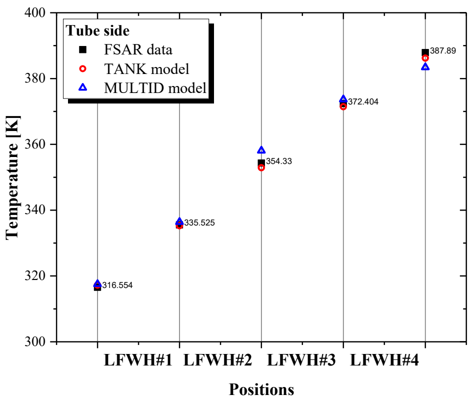

Fig. 2. Feedwater Heater tube side temperature of SMART100

3. Description of Integrated System Modeling

The integrated input model of V-SMR primary and secondary systems using MARS-KS 2.0 is shown in Fig. 3. The primary system is composed similarly to a typical SMR. The coolant heated in the core rises, passes through the reactor coolant pump, and is cooled in the steam generator. The pressure in the primary system is controlled by a pressurizer located on top of the reactor vessel. The heat from the primary system is transferred to the secondary system via a helical coil steam generator, and superheated steam is produced at the outlet of the secondary steam generator. The pressure of the secondary system is controlled by the governor valve (V807) and the flow rate of the secondary system is controlled by the feed water pump (C874).

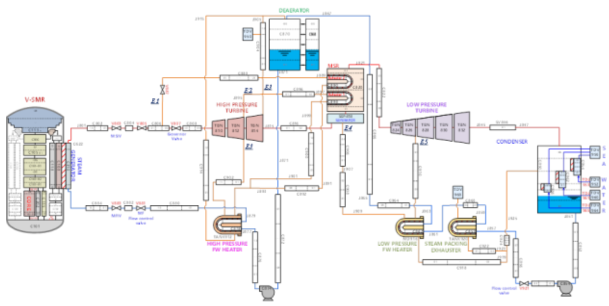

Fig. 3. MARS-KS Nodalization for V-SMR

The preliminary results of the integrated model using MARS-KS 2.0 are shown in Fig. 4~10.

As shown in the Fig. 4, the power of the reactor is equal to the target value, and the steam generator reliably removes all the power from the core. Figs. 5 and 6 show the core inlet and outlet temperature results. As shown in the figure, the core inlet and outlet temperatures were also very close to the target values, confirming the predictive performance of the primary.

For the secondary system, the steam generator feedwater temperature decreased continuously and was slightly lower than the target value (Fig. 7), and the flow rate decreased slightly after about 5,000 seconds and was also lower than the target value (Fig. 8). This is due to the lack of proper heat balance in the secondary system, which will be improved by modifying the heat balance and modifying the control system. The pressure of the steam generator (Fig. 9) was found to be similar to the target value by adjusting the governor valve as shown in Fig. 10.

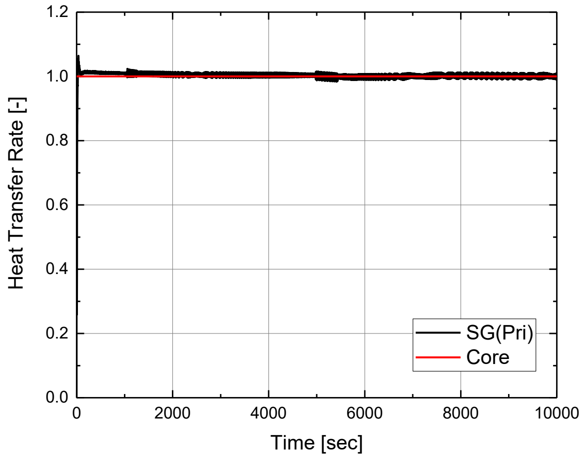

Fig. 4. SG and Core Heat transfer rate of V-SMR

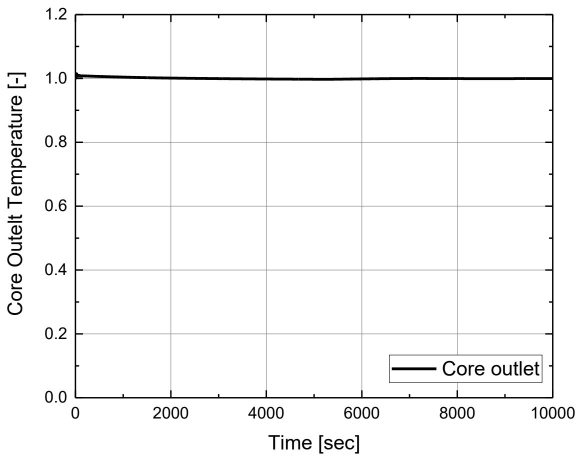

Fig. 5. Core outlet temperature of V-SMR

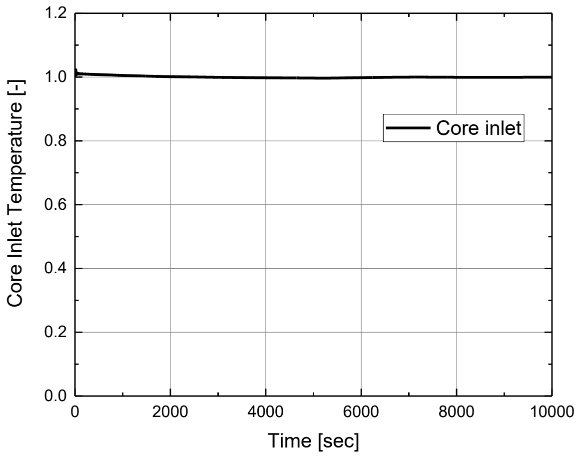

Fig. 6. Core inlet temperature of V-SMR

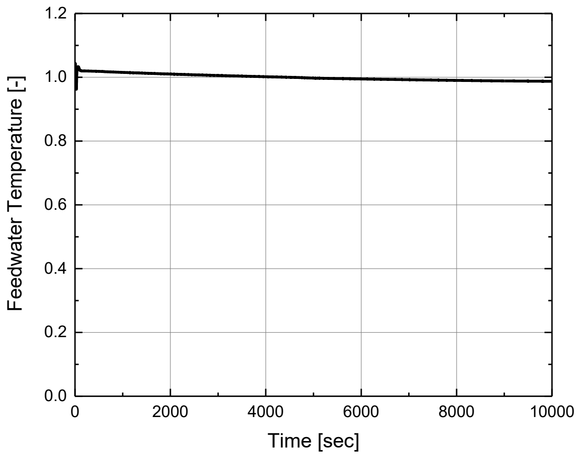

Fig. 7. Feedwater temperature of V-SMR

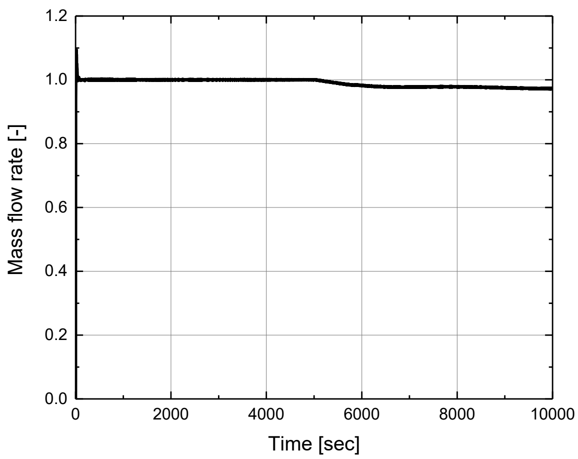

Fig. 8. Core outlet temperature of V-SMR

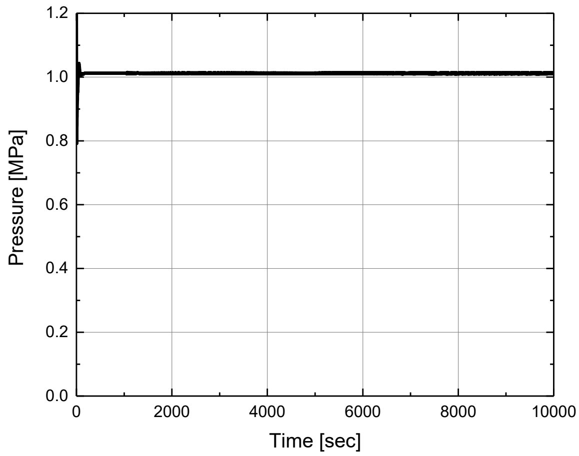

Fig. 9. SG Pressure of V-SMR

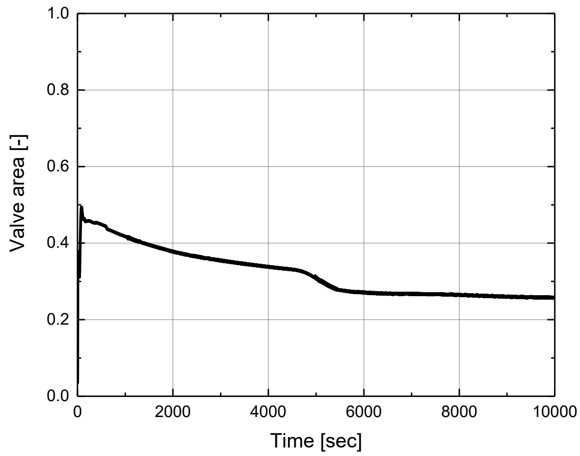

Fig. 10. Governor valve area of V-SMR

3. Conclusions

In this study, we developed and preliminarily evaluated the MARS-KS primary and secondary system integrated input model as a preliminary step in the development of the V-SMR platform. The V-SMR integrated input model was developed by coupling Conceptual SMR to the previously developed secondary system input model, and will be utilized for load following analysis in the future. The V-SMR platform being developed in this study will be integrated with CUPID and various reactor physics codes in the future to perform precise simulations. In particular, MARS-KS 2.0 will be used for V-SMR secondary system analysis, and for this purpose, we will focus on developing secondary system component models.

ACKNOWLEDGEMENT

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