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ATOM Secondary Side Pump Modeling for Developing Artificial Intelligence Operational Scheme

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1. Introduction

In recent years, researches are being conducted to adapt AI (Artificial Intelligence) into various functions in nuclear power plants. In KAIST, a preliminary research is under way under ERC (Engineering Research Center) project to operate a newly designed small modular nuclear power plant, namely ATOM, through artificial intelligence using reinforcement learning algorithms. To make well-trained AI operator, enough datasets of simulations are needed.

Therefore, in the ERC project, ATOM MARS-KS input is being constructed in which the primary side and the secondary side are simulated at the same time in order to create coherent nuclear power plant operation datasets under various operational modes. Most of nuclear power plants safety analysis in the past do not simulate the secondary side in detail. However, to develop AI for ATOM it is necessary to model all of the primary and secondary system components and each control logic. Until now, the ERC team has constructed a simulation that treat pump and condenser using time dependent volume of MARS-KS, and turbine is modeled as a constant efficiency stage group turbine.

ATOM steady states can be simulated with the existing pump, turbine, and condenser models. However, when the mass flow rate is changed in the transient case, it is confirmed that the continuity equation is not satisfied because the mass flow rate of the front and the rear of pump and condenser changed. Thus, it is not possible to obtain accurate simulation results of the transient case with the existing ATOM simulation platform. Currently, the ERC project team is separately constructing each component of the secondary side including the control logic to improve the accuracy of the simulation results. In this paper, the progress of secondary side pump modeling of ATOM reactor for simulating load following is reported.

2. Methods

2.1. Target Nuclear Power Plant, ATOM

Target Nuclear Power Plant is ATOM. ATOM (Autonomous Transportable On-Demand Reactor Module) is an SMR system that is researched at ERC. It is a virtual SMR operating with AI operator ensuring extreme safety by integrating nanomaterials and ICT technology. ATOM reactor core has 330MWth and has various advantages such as soluble boron free environment, load following and air cooled condenser.

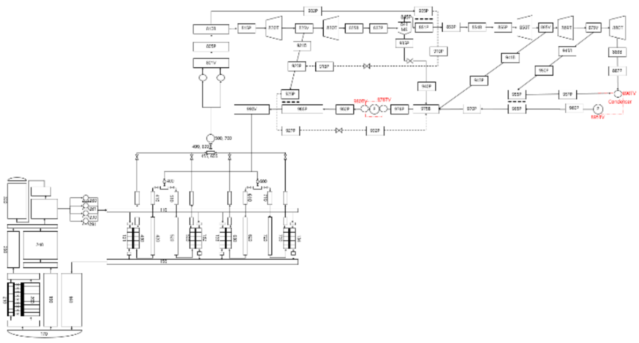

Fig. 1. ATOM nodalization of MARS-KS 1.4 simulation

2.2. Steady State Pump simulation with original input

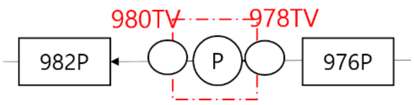

Fig. 2. Original ATOM secondary side pump nodalization

In the original ATOM pump nodalization which is composed of time-dependent volume, the steady state inlet mass flow rate is 145.92kg/s and the outlet mass flow rate is 155.67kg/s. Therefore, before making the pump input, the authors adjusted the mass flow rate of the condenser to obtain more accurate steady state value. As a result, 155.68kg/s at the pump inlet and 155.67kg/s at the pump outlet were achieved. In this case, the pressure before the pump is 0.295MPa and the pressure at the outlet was 6.57MPa.

Modified Original Pump input	Mass flow rate (kg/s)	Pressure (MPa)
Inlet	155.68	0.295
Outlet	155.67	6.57

Table. 1. Mass flow rate and Pressure of simulation input

2.3. New pump input modeling

In the case of a commercially used centrifugal pump, normalized single-phase homologous curves have a similar form. Therefore, pump scaling for secondary side pump is possible by using the built-in-data for Westinghouse pump used in the primary side of the ATOM core.

The head, mass flow rate, and torque of the pump were calculated and input through the previously obtained pump condition. The selected pump velocity was 3600rpm which is commonly used in commercial centrifugal pumps.

	Value
Head [m]	655.4
Mass flow rate [kg/s]	155.67
Torque [N·m]	1011.06
Velocity [rpm]	3600

Table. 2. Pump input value

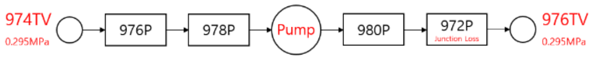

Fig. 3. New pump nodalization for steady state testing

The new pump was placed between two 0.295MPa time dependent volumes to ensure steady state compliance. As a result, it was confirmed that the mass flow rate was generated by the pump. If there are no loss coefficients at all the pipes and junctions, it was confirmed that the pressure does not increase at the pump outlet but increases only the mass flow rate through the pump. Thus, the pressure and mass flow rate of the pump were checked by controlling the junction loss coefficient of pipe 972, one of the outlet pipes.

3. Results

3.1. Pump outlet pressure and mass flowrate

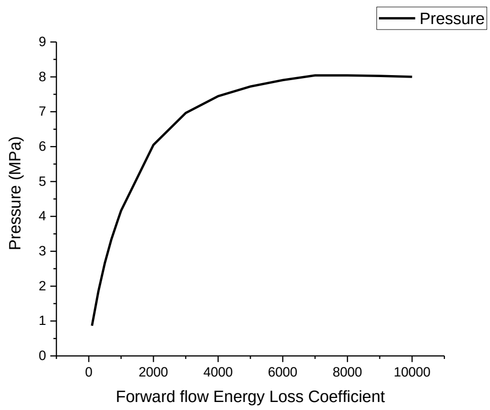

Fig. 4. Pressure due to Junction Loss Coefficient

As the junction loss coefficient of the pipe at the back of the pump increases, the pump load and outlet pressure increases.

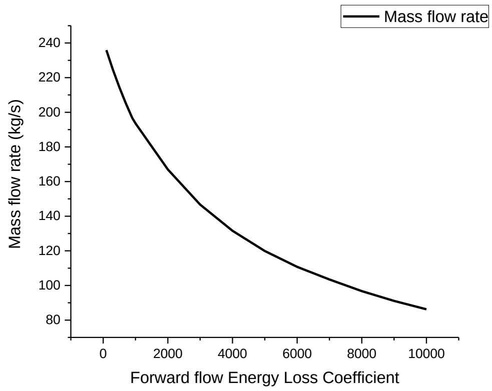

Fig. 5. Mass flow rate due to Junction Loss Coefficient

As the junction loss coefficient of the pipe at the back of the pump increases, mass flow rate of the pump decreases.

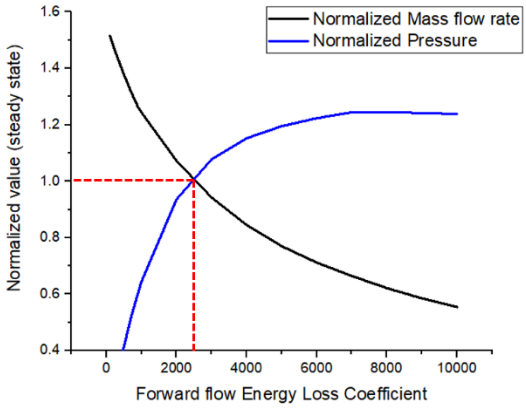

Fig. 6. Normalized Pressure and Mass flow rate

Original steady state values are obtained at the intersection of two graphs when the pump outlet pressure and mass flowrate are normalized to the values of the original steady state. Thus, it can be confirmed that the new pump input satisfies the steady state of the existing cycle. Also, it can be confirmed that the control system such as the throttling valve can be applied later due to the variation of the pump outlet pressure and the mass flowrate as the junction energy loss coefficient changes.

3.2. Combination of new pump input and original input

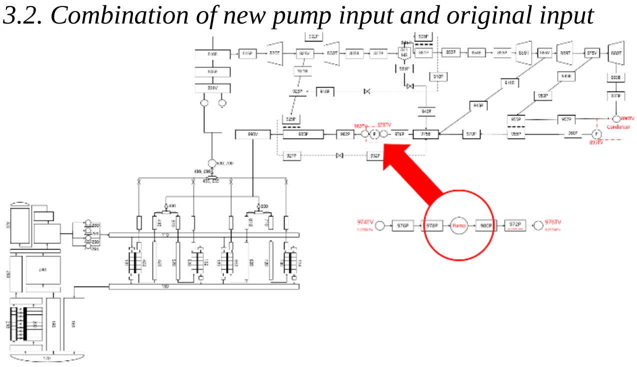

Fig. 6. ATOM nodalization with the new pump input

The mass flowrate and pressure of the front and back of the pump were checked by replacing the pump part of original cycle input with the new pump input. As a result of checking the converged value, it is confirmed that there is some difference between original and new converged steady state values. This is because the loss coefficient of the entire cycle has not yet been adjusted and the condenser has not been fully modeled.

	Original value	New value
Inlet Pressure [MPa]	0.295	0.326
Outlet Pressure [MPa]	6.57	6.37
Mass flowrate [kg/s]	155.67	162.76

Table. 3. Pressure and mass flowrate of original and new input

The authors tried to adjust the loss coefficient of the secondary cycle by pump throttling valve, but it is confirmed that there is some difference between adjusted values and desired values. This is because mass flow rate of water from the condenser is now fixed in the current model. If the condenser is further modeled with more detail later, this problem is expected to be resolved.

4. Conclusions

As a result of the study, it was possible to make the pump input usable for the secondary side control by using scaling and homologous curve of the existing primary side pump. When the pump is separated, it can be seen that the desired value can be accurately adjusted. In case of the combination with original full cycle input, it can be confirmed that it has a convergence value which does not greatly differ from the existing value. If the turbine, condenser, and shaft are fully modeled and then the overall loss coefficient is adjusted, a complete modeling of the controllable secondary side input will be completed.

Acknowledgement

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