Analysis of power ramp rate and minimum power controllability of the MMS model for a plant dynamics analysis of a Prototype SFR

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1. Introduction

A full plant dynamic model was developed for a prototype SFR using the Modular Modeling System (MMS). It includes the modeling of various subsystems such as the neutronics, primary and intermediate sodium systems of the NSSS, steam and water systems of the BOP, BOP controls, and the supervisory plant controls. The NSSS model is subdivided into component models, such as a CORE, IHXs, Pumps, SGs, and the rest of the NSSS loop model. The BOP model is subdivided into a steam subsystem, feedwater subsystem, and preheater subsystem. Plant transient tests were performed to study the operational considerations. It includes varying the power ramp rate and studying the controllability at minimum power.

2. Models and Results

2.1 NSSS and BOP Models

The NSSS model is subdivided into component models, such as a CORE, IHXs, Pumps, SGs, and the rest of the NSSS loop model. The FUEL module of the CORE model calculates the reactor thermal power using the point kinetics model. The calculated thermal power is distributed into the fuel nodes and the connected moderator nodes according to the user-provided fraction of the energy deposition. There are four IHXs and two SGs in the prototype SFR, but all of them are lumped into one model for simplicity. The IHXs are modeled with five axial control volumes for the PHTS-side, IHTS-side using PIPEHX modules, and the tube metal. The SGs are modeled using the PIPEHX modules. The SG model represents only the active heat transfer part of the once-through steam generator, which corresponds to the steam-water part from just after the tube inlet orifice to the steam outlet of the active tube. The active part is modeled with twenty axial control volumes for the steam-water-side, IHTS-side using PIPEHX modules, and the tube metal. The axial tube lengths of the 20 control volumes are equal.

Coolant flows in the hot and cold pools are substituted into the PIPE modules with adequate flow resistance and volumes. The flow path or connecting pipe has volume, mass, and flow resistance.

The major components in the BOP are included in the MMS mode. The BOP model can be broadly subdivided into a steam sub-subsystem, feedwater sub-system, and preheater sub-system. The BOP model also includes an electronic generator. The condenser is treated as boundary conditions. The seawater sub-system will be modeled in future work. The model for the steam sub-system consists of a turbine model and desuperheater model. The condensed feedwater from the condenser goes through the condenser pump, low-pressure preheater, deaerator, the main feedwater pumps, the main feedwater control valve, and two high-pressure preheaters, sequentially. Finally, it enters the steam generators. Figures 1 and 2 show the NSSS and BOP models.

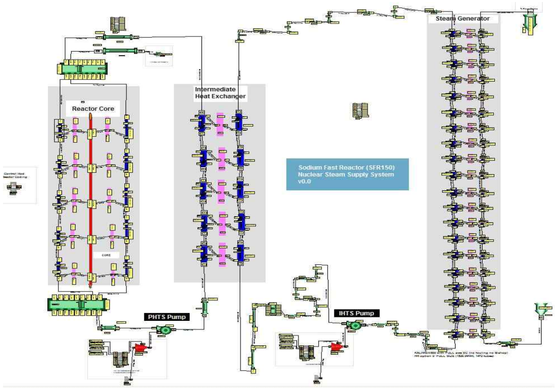

Figure 1. NSSS model

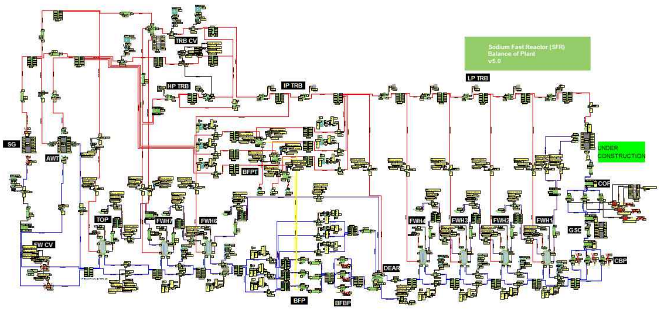

Figure 2. BOP model

2.2 Maximum Power Ramp Rate

One requirement for the prototype SFR is to have a power change capability at some percentage rate per minute. It is necessary to study the plant transient after the plant suffers from an unexpected fault for further design and operational considerations. To determine the maximum power ramp rate, a power reduction to 30% is performed at varying ramp rates of 2%, 5%, 10%, and 20%. The simulation runs for 10,000 seconds to reach a steady state, and a power reduction is performed for over 5,000 seconds. The two variables, rector power and steam temperature, were observed as a function of ramp rates during the power reduction. Figures 3 and 4 show the reactor power and steam temperature versus ramp rates. The control rods eventually stabilize even at a high ramp of 20% per minute. At the power ramp rate of higher than 2%, the steam temperature has a large deviation from the target.

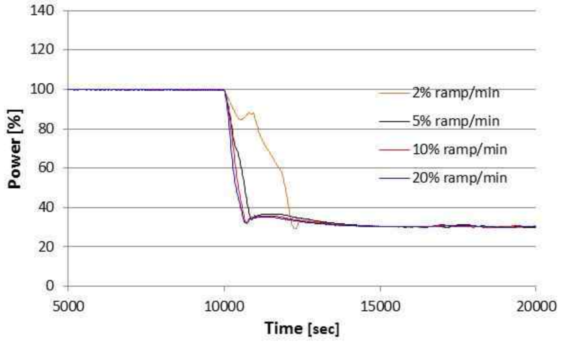

Figure 3. Reactor power vs. Ramp rates

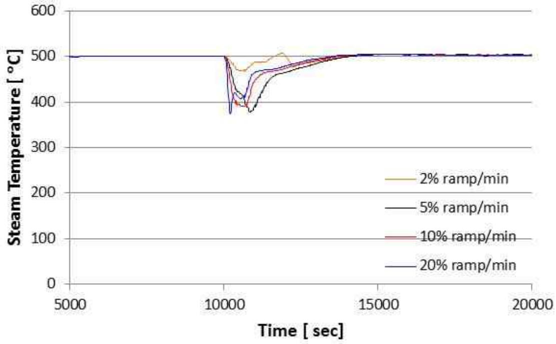

Figure 4. Steam Temperature vs. Ramp rates

2.3 Minimum Controllable Power

Normal power operation range for the prototype SFR is from 30% to 100%. However, it is interesting to determine the minimum controllable power (MCP). This could be useful for studying a very low power phenomenon as well as establishing limits to the model.

The simulation runs for 10,000 seconds to reach a steady state, and a power reduction is performed for over 5,000 seconds. Power reduction to 30%, 25%, 20%, and 15% is performed at a ramp rate of 2% per minute. The two variables, PHTS hot leg temperature and steam temperature, are observed as a function of minimum power set points. MCP analysis focuses on controllability after the transient. Figures 5 and 6 show the PHTS hot leg temperature and steam temperature versus the power set points. They have difficulty in reaching the proper temperature. As the power set point decreases, they tend to have higher deviations.

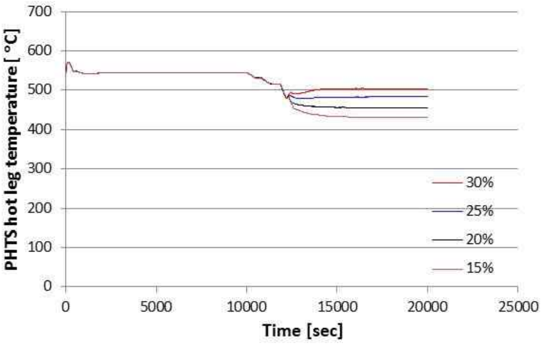

Figure 5. PHTS Hot Leg Temperature vs. Minimum Power Set Points

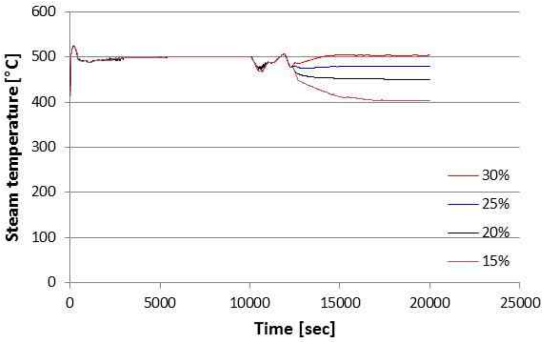

Figure 6. Steam Temperature vs. Minimum Power Set Points

3. Conclusions

Plant transient tests were performed to study operational considerations by using the MMS model for a prototype SFR. It includes varying the power ramp rate, studying the controllability at the minimum power set point. At a power ramp rate of higher than 2%, the steam temperature has a large deviation from the target. As the power set point decreases, the PHTS hot leg temperature and steam temperature tend to have higher deviations. After further refinement of the MMS model, it can be useful for developing the plant operation logics of the prototype SFR.

ACKNOWLEDGEMENT

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