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Development of the MMS model for KALIMER-600 plant dynamics analysis

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1. Introduction

It is important to know the dynamic behavior of the plant during various events to provide transient thermal loads for a structural integrity assessment of the plant and its components, and to demonstrate the operability and safety of the plant.

The MMS (Modular Modeling System) code [1] was used to develop a performance analysis tool for the simulation of various transients and a steady-state operation of the KALIMER-600. For application to the KALIMER-600, a few modules of the MMS code were modified to incorporate the sodium property and related heat transfer correlations.

The purpose of this paper is to present the NSSS and BOP models, as well as the results of a transient analysis during power maneuvering according to power control logic.

2. KALIMER-600 Design Description

The KALIMER-600 [2] is a pool-type reactor. The heat transport and connected systems of the reactors mainly consist of the primary heat transport system (PHTS), intermediate heat transport system (IHTS), and steam generator system. The PHTS is a pool-based system and transports the generated heat from the core to the four IHXs. The heat is transferred to two steam generators through the two IHTS loops. Figure 1 shows the heat balance of the KALIMER-600.

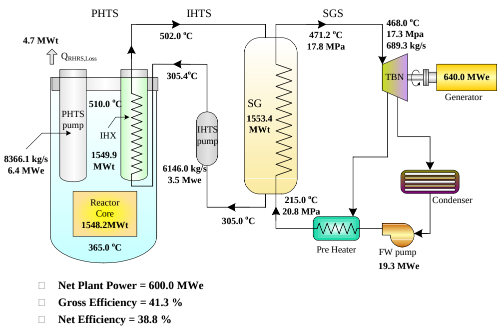

Fig. 1. Heat Balance of KALIMER-600.

3. Analysis Model

3.1 MMS

The MMS (Modular Modeling System) is a Windows NT based visual software system for modeling the dynamics characteristics of power plant systems, and for studying various design, performance, and operation aspects. Software modules were developed to correspond to the plant components, and the interface specifications were defined such that the modules can be interconnected analogously to components in the actual plant. An MMS model is composed of predefined components along with connections that define the interrelationships. The current version of MMS has a real-time capability through an advanced pressure-flow solution technique.

3.2 NSSS Model

The NSSS model is subdivided into component models, such as a CORE, IHXs, Pumps, SGs, and the rest of the NSSS loop model. Figure 2 shows the developed NSSS model. The core model consists of PIPEHX modules, four QMETAL modules, one FUEL module, and one code block. Flow through the core is modeled using two flow paths. The FUEL module of the CORE model calculates the reactor thermal power using the point kinetics model. Control rod reactivity are modeled outside of this model as a Fortran subroutine. The nuclear fuel cladding and moderator are simulated using separate QMETAL and PIPEHX modules, respectively. The control logic for the core power are programmed in the code block RXCB, which generates control rod insertion/withdrawal signals, and calculates the bank location and rod worth. There are four IHXs and two SGs in the KALIMER-600, but all of them are lumped into one model for simplicity. Coolant flows in the hot pool and cold pool are substituted into the PIPE modules with adequate flow resistance and volumes.

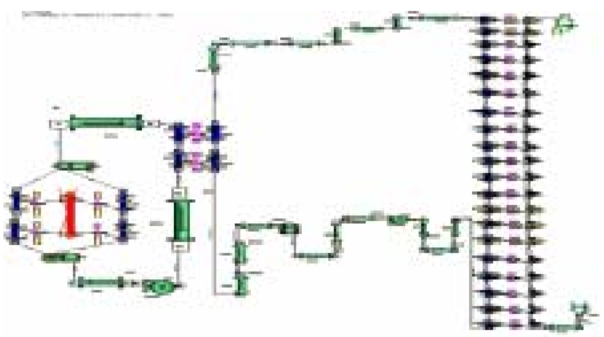

Fig. 2. NSSS model.

3.3 BOP Model

The BOP model is subdivided into a steam subsystem, feedwater subsystem, and preheater subsystem. Figure 3 shows the BOP model.

The model for the steam subsystem consists of a turbine model, desuperheater, and extraction lines for the preheaters.

The preheater subsystem is composed of two high-pressure preheaters, a deaerator, and four low-pressure preheaters. There is a topping heater at the final stage of the preheater subsystem to properly heat the water to the SG.

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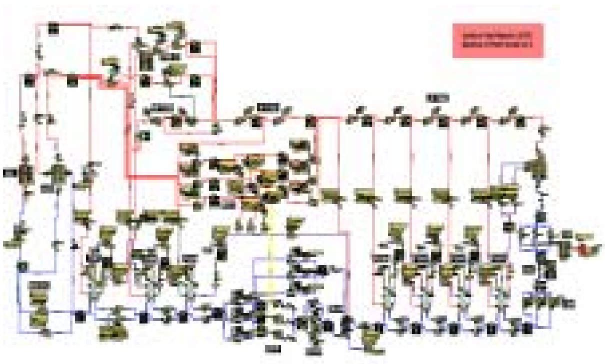

Fig. 3. BOP model.

3.3 Operation mode for power change

The KALIMER-600 has two operation modes for a power change, that is, the reactor leading mode and turbine leading mode to have efficient accommodation of the required plant power and load changes.

In the reactor leading mode, the power set point signal is sent to the primary loop. The reactor adjusts control rods, changing reactivity, which in turn changes reactor power. The remaining plant systems will control to their set points, effectively following the reactor. In turbine leading mode, however, the power set point signal is sent to the BOP. The FCV will maintain flow to provide the desired electrical power. The remaining plant systems will control to their set points, effectively following the turbine.

The reactor leading mode is used for a plant startup, shutdown operation, and rapid power change, while turbine leading mode is used during normal power operation.

The following are steps of the reactor leading mode.

1) Adjust control rods for load. Control rods are inserted or removed to adjust the reactivity in response to load demand.
2) Primary loop pump control is used to maintain primary side hot leg temperature.
3) IHTS loop pump control is used to maintain IHTS cold leg temperature.
4) A throttle control valve controls the steam pressure.
5) A feedwater control valve is used to maintain a constant steam temperature.

3.4 Results

To verify the transient analysis model for KALIMER-600, the model was ramped down from a maximum of 100% power to a minimum of 25%. Maneuvering is performed with a demanded load reduction of 25% at 5% per minute with a total allotted time of 2000 seconds to stabilize. Figure 4 and Figure 5 show the transient results of powers and steam/feedwater conditions of the systems. It is shown that the transient analysis model can calculate the transient for a power change properly without severe oscillations.

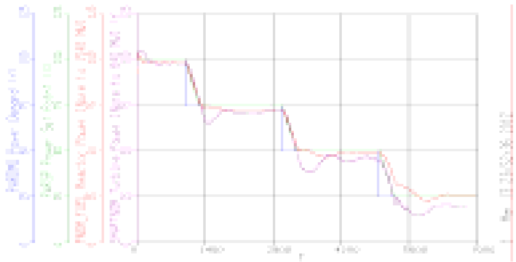

Fig. 4. Demanded and actual powers

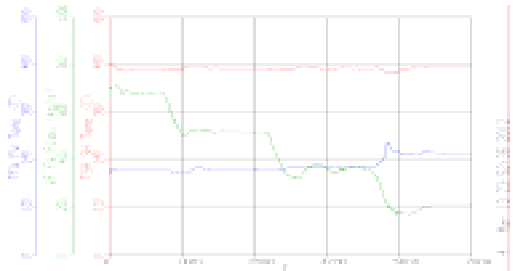

Fig. 5. Steam and feedwater conditions

4. Conclusions

The performance analysis model was developed for the simulation of various transients and a steady-state operation of the KALIMER-600 using the MMS code. The MMS model is composed of several interfacing MMS modules with numerical data, each of which represents a component of the plant and control logic. For the simulation of various operations, the model for the NSSS and BOP are included in the MMS KALIMER-600 model. A transient analysis was performed to assess the power change capability of the model. The analysis results show that the MMS model is considered satisfactory for an evaluation of the system performance.

REFERENCES

[1] nHance, MMS Basics, nHance Technology Inc., 2007.

[2] Hahn, D.H. et al, Conceptual Design Report of SFR Demonstration Reactor of 600MWe Capacity, KAERI/TR-4598/2012, KAERI, 20012.