The Automatic Control Design and Simulation of Reactor Control System in Small Modular Reactor

Nuclear Power Institute of China

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Introduction

1.1 The status of the SMRs in the world

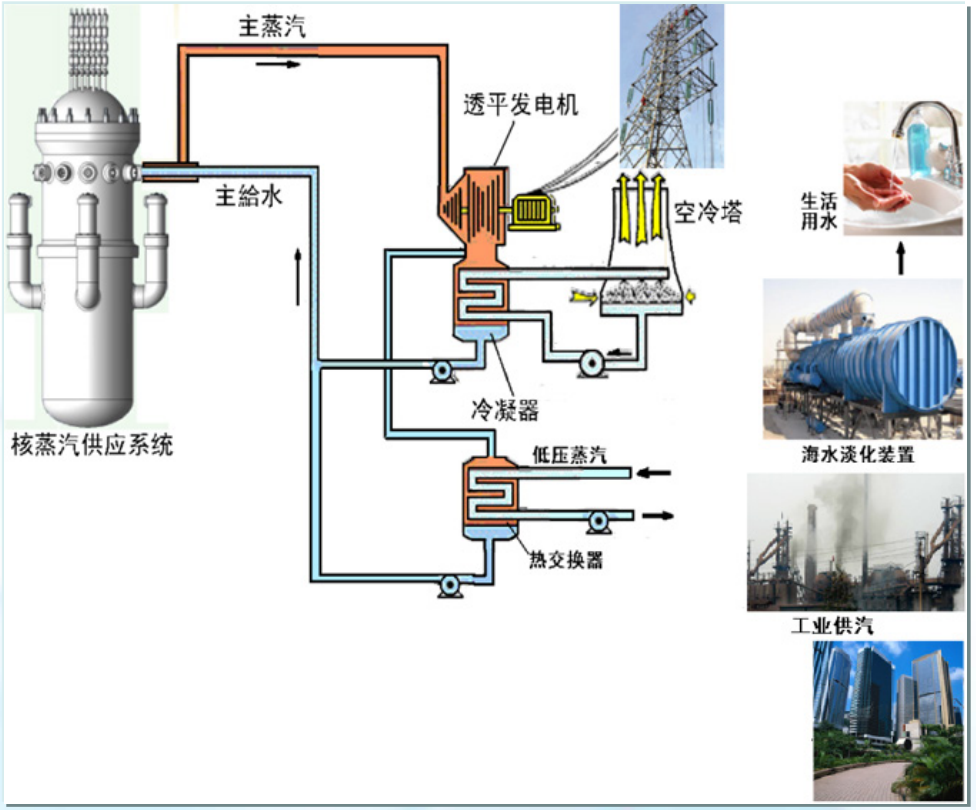
- *The demands and applications of Nuclear Power Plant (NPP) are not only concentrated at the electricity generation but also some large-scale and enormous power consumption non-electricity applications.*

- *More and more countries are developing the advanced Small Modular Reactor to meet the more extensive and diverse demands.*

- *13 SMRs are under construction in six countries and the approximately 45 innovative SMR concepts research for electricity generation and other applications is being carried out.*

1.2 The demands for the SMRs in China

- In electricity generation domain
- In city heat supply domain
- In industrial and process heat supply domain
- In seawater desalination domain



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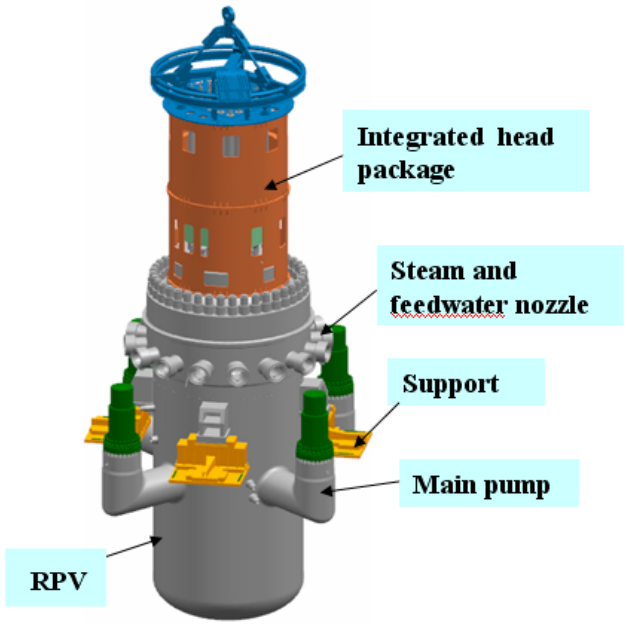
Introduction

2.1 What does the SMR in China look like?

It is an innovative PWR based on existing PWR technology, adapting "integrated" and "modular" reactor design technology.



- Integrated head package
- eliminate the primary pipeline
- integrate the One-Through Steam Generator (OTSG) into the RPV

➡ *influence the characteristic of the control process of the reactor power and steam generator feed water flow*

⬇

the automatic control design of the RPC and FWC is mostly affected by this integrated layout and the OTSG

SMR System Description

2.2 Main configuration of the SMR

- forced circulation by 4 coolant pumps
- much shorter length of the coolant loops
- 4 groups of OTSG produces superheated steam
- few water inventory and the thermal-hydraulic process is rather adverse and rapid

SMR System Description

2.3 The general control scheme

The general control scheme for NSSS of the SMR

- automatic control combined with the manual control
- The whole reactor control systems have an automatic control range from 0 to 100% full power (FP)
- the RPC and FWC use the manual scheme instead of automatic scheme below 20%FP
- automatic control within ±10%FP step variations of the load and ±5%FP/min ramp variations of the load

The primary control principle is to maintain the main steam pressure at a constant and the reactor coolant average temperature at a constant

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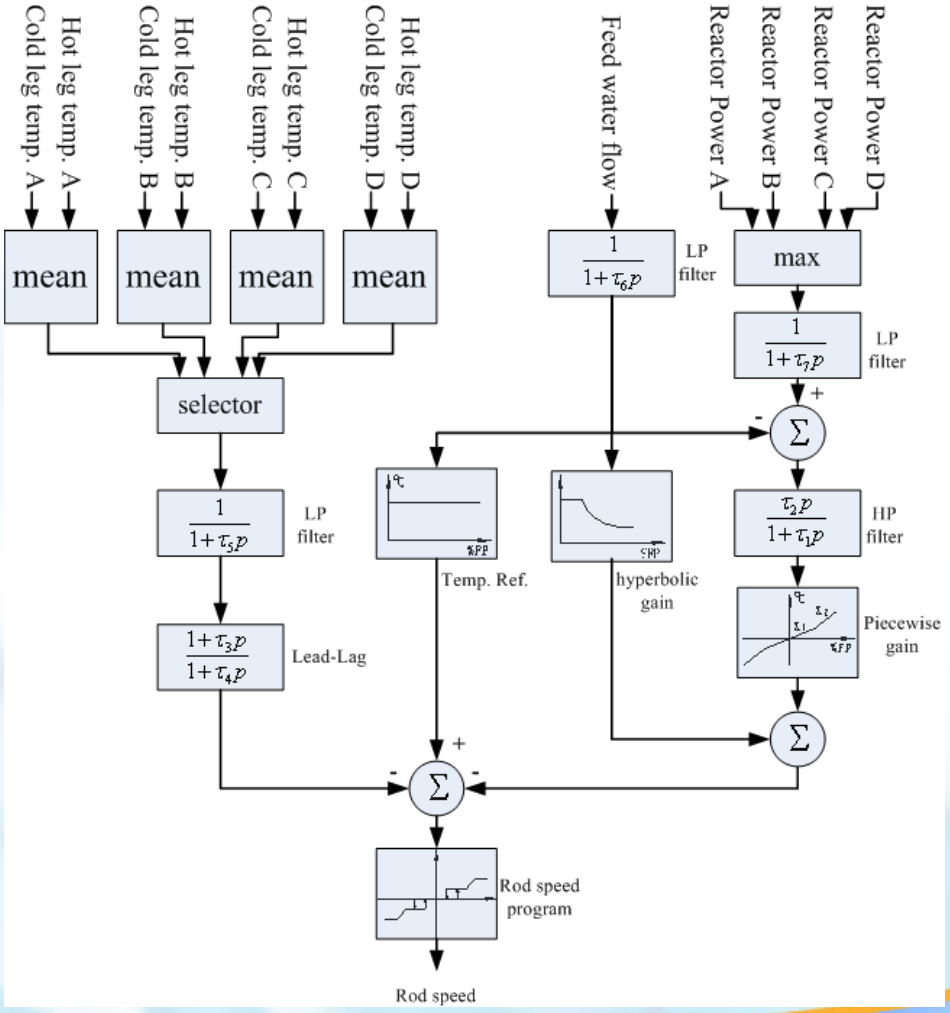
The Automatic Control Design

3.1 The automatic control scheme of the RPC

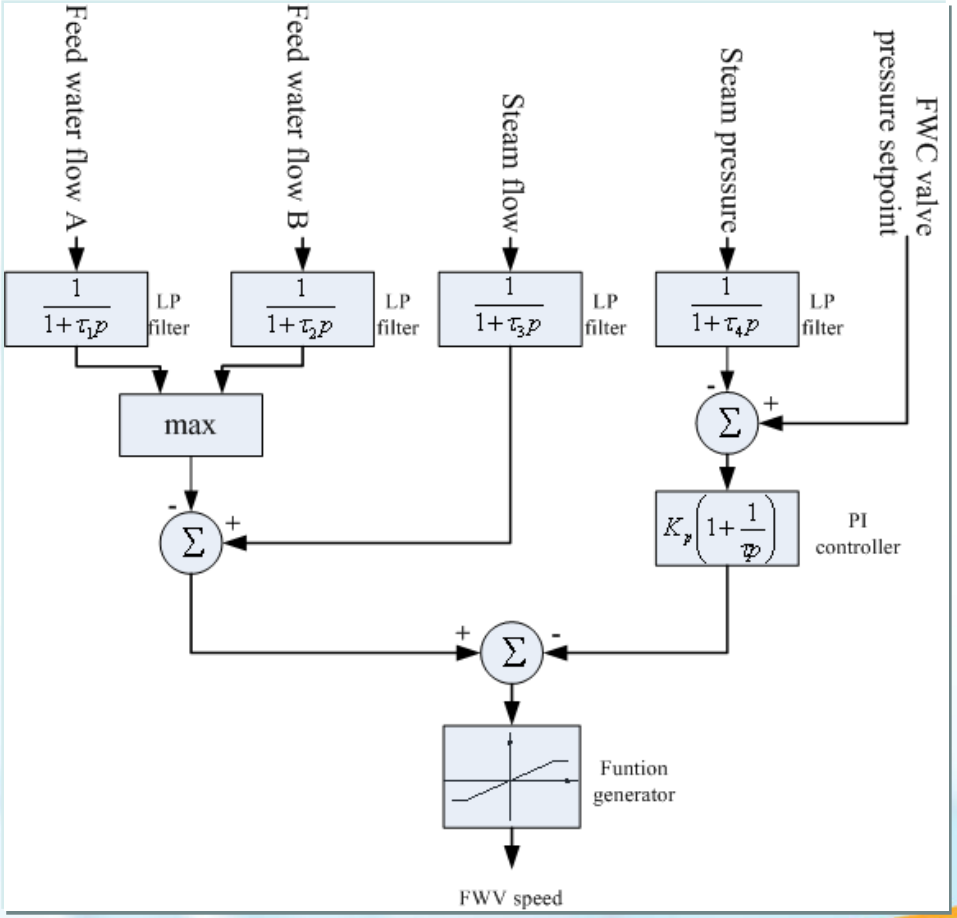
- The temperature control channel and the power mismatch control channel
- Introduce the feed water flow of the secondary side as the load signal



The Automatic Control Design

3.2 The automatic control scheme of the FWC (the feed water valve control scheme)

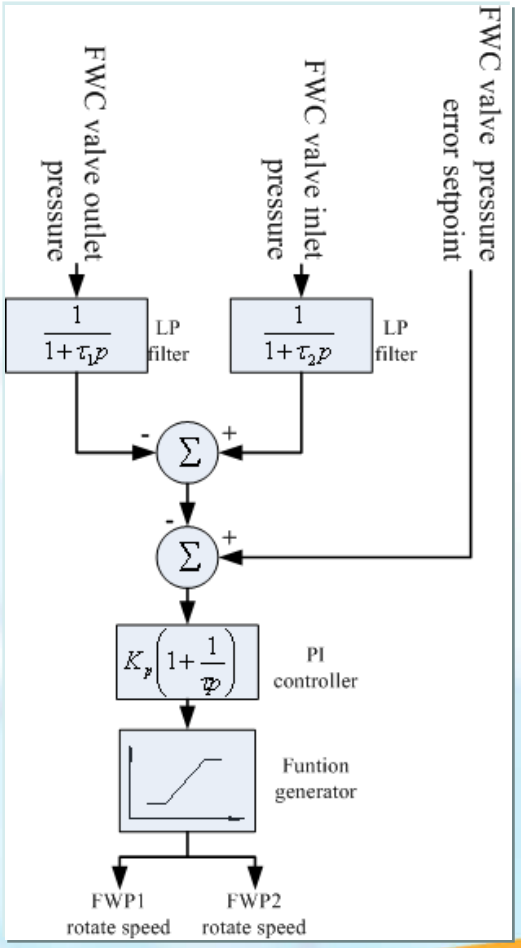
- The steam pressure control channel and the flow mismatch control channel
- Fast follow the mass demand of steam flow
- Delicately regulate the steam pressure with a PI controller



The Automatic Control Design

3.3 The automatic control scheme of the FWC (the feed water pump control scheme)

- Keep a linear mapping relation between the feed water flow and the FWV opening position
- Act fast enough to change the feed water heading and lead the feed water flow change



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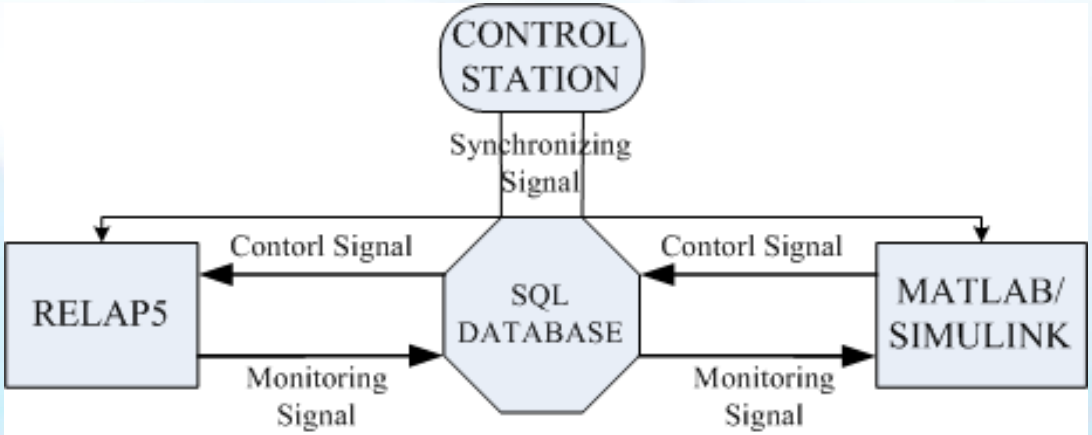
Simulation Study

4.1 The test bench and modeling

- The control process model is built in RELAP5
- The control system model is built in Simulink
- Data exchange via SQL Database
- Synchronized by Control Station



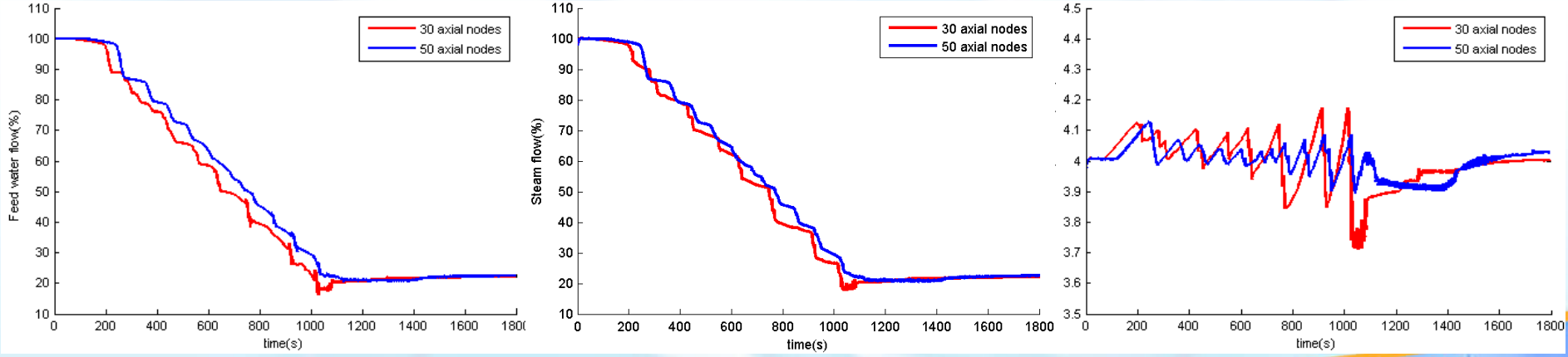
Simulation Study

4.1 The test bench and modeling

- The model includes:
  - Reactor
  - 4 Integrated OTSG groups
  - 4 Coolant pumps
  - Feed water and steam piplines
  - 2 Feed water pumps
  - Feed water and steam boundaries

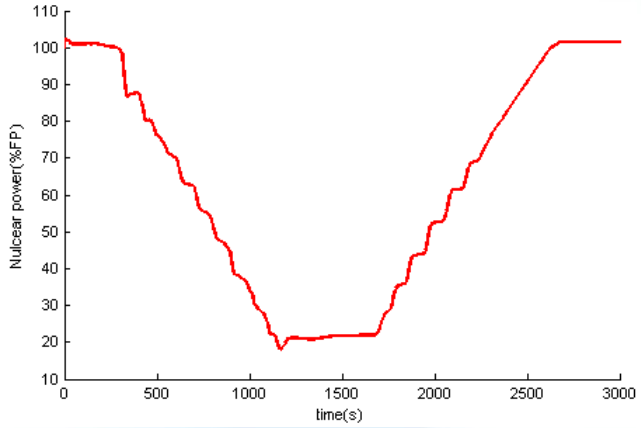
4.2 The key factors of modeling for control simulation

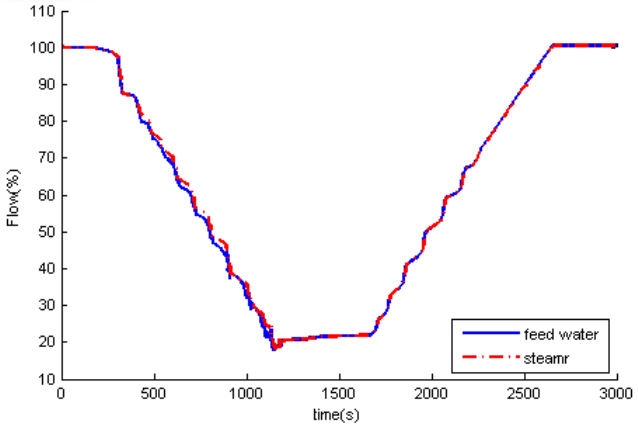
- The reactor core is densely nodalized in order to calculate the temperature of the moderator fluid more precisely in the simulation
- The OTSG also needs a dense nodalization in order to catch the possible two-phase phenomenon in every node by using the correct flow regime and heat transfer formula in the simulation

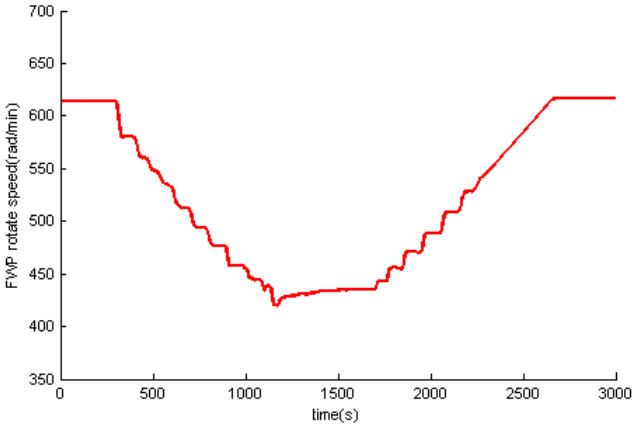


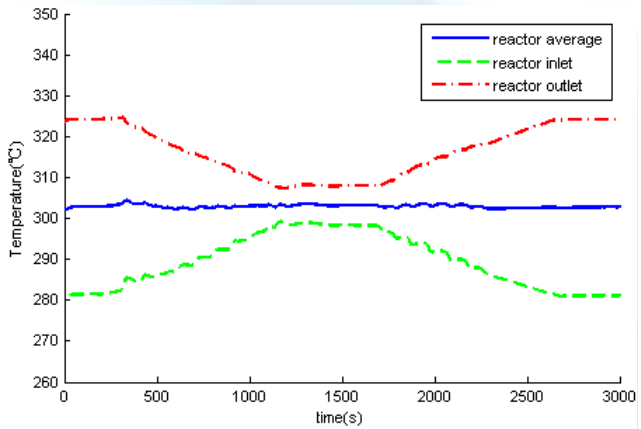
4.3 Specified transient simulation

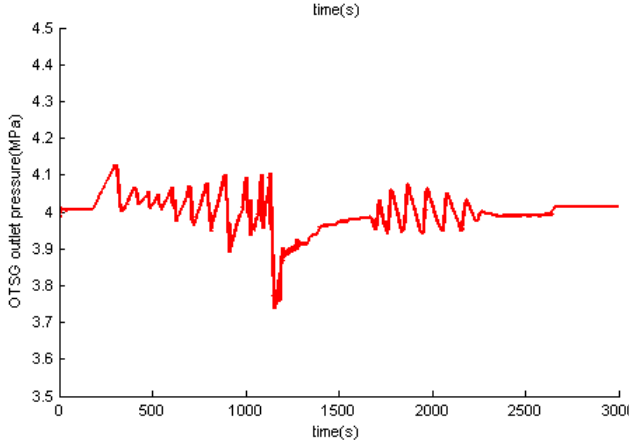
- The large-scale ramp load change within 20%FP and 100%FP

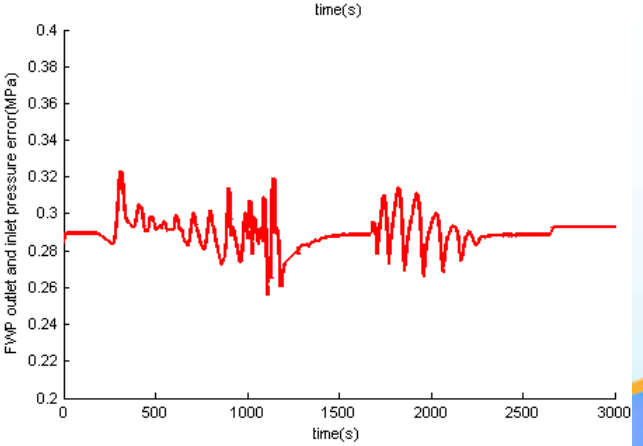






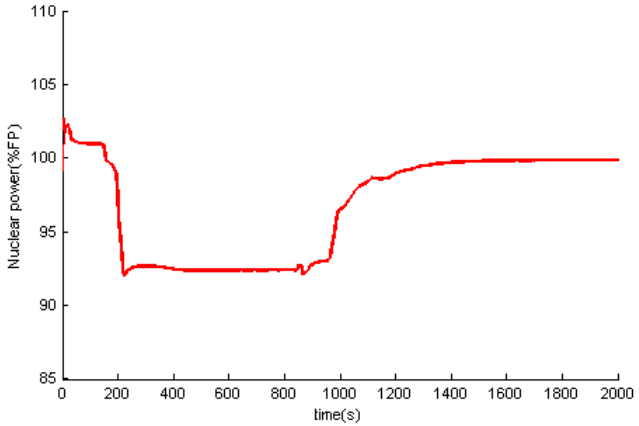


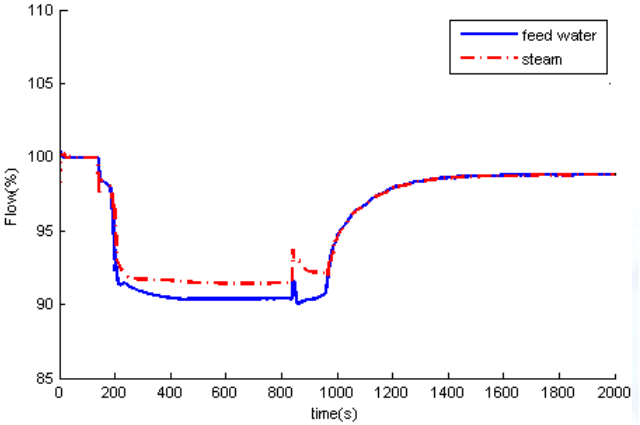


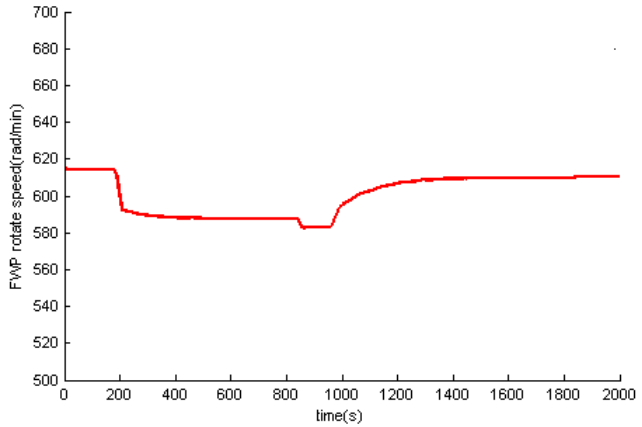


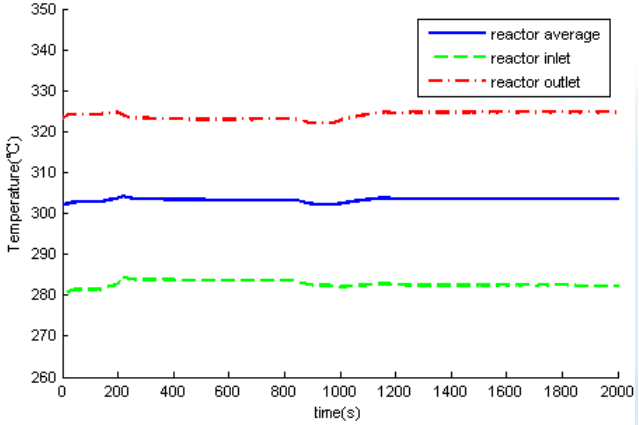
4.3 Specified transient simulation

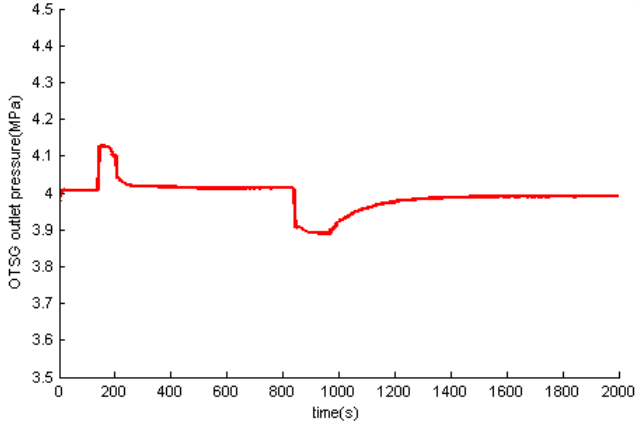
- The step load change within 90%FP and 100%FP

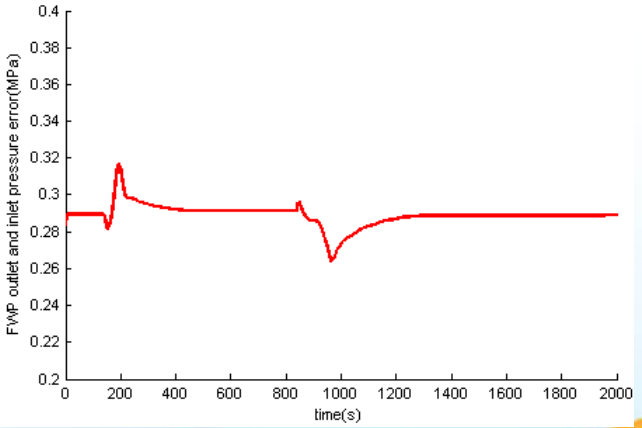












Conclusion

- *The automatic control schemes are tested to be feasible within the simulation including large-scale ramp and step load change specified*
- *The reactor power control is related to the feed water control through the feed water flow considered as the load signal*
- *The control performance of both the primary and secondary loop is sensitive and closely coupled due to the transient of the integrated OTSG*

Thanks for your attention!