Study on Coordinated Control Concepts for i-SMR Power Regulation

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1. Introduction

The innovative Small Modular Reactor (i-SMR) applied with a Helical-type steam generator, which exhibits characteristics that are significantly different from those of conventional nuclear power plants as APR1400. And i-SMR is required that can provide load following operation and high-level automation controls.

One-through type boilers in coal-fired power plants has characteristics similar to those of the i-SMR steam generator. Through extensive operational experience, coal-fired plants have developed the turbine-boiler coordinated control concept, which has proven to be an effective method for stable power regulation. Therefore, this study examines the coordinated control strategies of coal-fired power plants and proposes their application to the power control of i-SMRs.

2. Helical Type Steam Generator

There are characteristics that shape of the helical type steam generator as follows

1) Limited feedwater inventory
In i-SMRs, feedwater (secondary coolant) flows inside the helical tube and is converted to steam by receiving heat from the primary coolant. As a result, feedwater inventory in the steam generator is smaller than APR1400. This limited inventory makes the system highly sensitive to load changes.

2) Inability to measure water level
Due to the helical configuration of the tubes, the point of the feedwater level cannot be directly measured. When the supplied feedwater is insufficient, evaporation point will be changed to upside and the vapor will be superheated steam. Degrading steam quality makes stable control and will potentially affecting equipment.

For stable operation of SMRs requires a precise control strategy that maintains the energy balance between the primary side and the secondary side.

3. Coordinated Control in one-through type boiler

Coal-fired power plants are generally classified into one-through and drum-type boilers. Among these, the one-through boiler exhibits operational characteristics similar to the i-SMR steam generator, as feedwater flows continuously through the tubes and is converted into steam. This configuration allows for continuous steam production and it's similar SMR operation.

Table I : Comparison between one through and Drum Type

	One through type	Drum type
Drum	Nothing	Exist
Tube inside	Secondary Coolant	Primary Coolant
Tube Outside	Primary Coolant	Secondary Coolant
Features	Rapid Vaporization	Stable steam production
	Miniaturization	Enlargement
Similar type with NPP	i-SMR	APR1400(PWR)

In coal-fired plants, power regulation is implemented in Distributed Control System (DCS), which coordinates boiler and turbine controllers to achieve stable power regulation. There are three types major control modes can be summarized as follows

3.1 Boiler Follows Turbine

When load demand changes, the turbine control valve is controlled firstly to turbine load. Turbine throttle pressure will be changed and the boiler fuel and feedwater supply are subsequently controlled. This approach provides fast load response but may reduce overall system stability. It is primarily used in drum-type boilers where sufficient feedwater inventory is available.

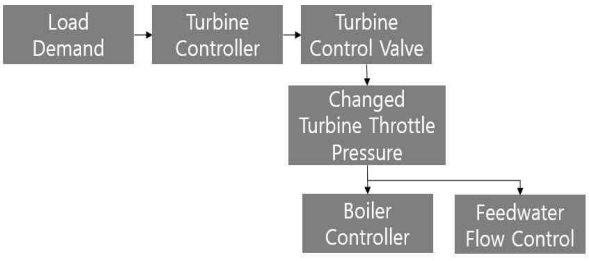

Fig. 1 Boiler Follows Turbine Diagrams

3.2 Turbine Follows Boiler

In this mode, When load demand changes, boiler output is controlled firstly through changes in combustion and feedwater supply. The turbine control valve is then controlled to accommodate the resulting steam pressure and flow. Although this approach offers slower response to load demand, it minimizes steam pressure and temperature fluctuations.

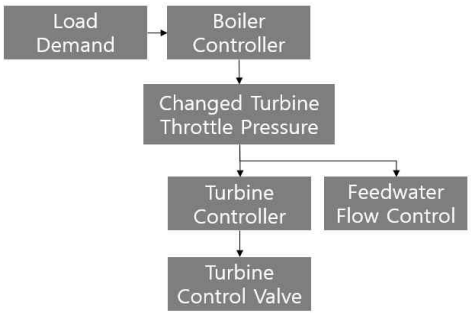

Fig. 2 Turbine Follows Boiler Diagrams

3.3 Turbine-boiler Coordinated Control

To overcome the disadvantage of the above two methods, coordinated control has been developed. The load demand signal is simultaneously transmitted to both the boiler and the turbine controller, not sequentially to achieve minimizing control delay and ensure fast and stable power regulation. Each controller refers to turbine throttle pressure for adjust to rate of change and it makes control feedwater flow and turbine control valve.

The coordinated control has become the advanced method in one-through boiler plant controls. And the plant has improved load variability and load followability. While coordinated control has disadvantage that become more complex.

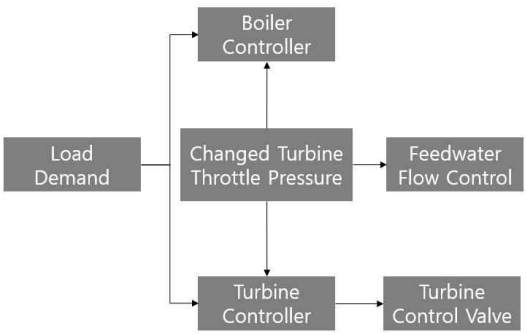

Fig.3 Turbine Follows Boiler Diagrams

4. Consideration of Reactor-Turbine Coordinated Control Structure of i-SMR

Turbine-boiler coordinated control concept of coal-fired power plant can be motivated to i-SMR control concept.

The coordinated control will be needed to i-SMR to get fast and stable power regulation control. The load demand signal is simultaneously transmitted to Power Control System (PCS), NSSS Process Control System (NPCS), and the Turbine Control System (TCS) to coordinated control between the reactor and turbine. And each controller will refer to turbine throttle pressure to adjust rate of change.

5. Conclusion

The i-SMR requires different power control strategy from that conventional nuclear power plants, due to the structural characteristics of helical type steam generator. This study analyzed control method of power regulation in coal-fired power plants, focusing on the turbine–boiler coordinated control concept and it will be considered for application to i-SMR.

Although there is disadvantage that control system becomes more complex, it will be necessary to develop coordinated control concept for high automation, stability and fast load response.

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