International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0212

FLEXIBILITY OPTIMIZATION OF COAL-FIRED POWER UNITS BY REGULATING OF HIGH-PRESSURE EXTRACTION STEAM DURING PEAK SHAVING PROCESSES

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ABSTRACT

The operational flexibility of coal-fired power plants during peak shaving processes becomes an urgent problem with the penetration of intermittent renewable power in the power grid. However, the original control systems for the power units have some deficiency during rapid peak shaving processes. In this paper, a revised control system by regulating high-pressure extraction steam was added to improve the operational flexibility during load change processes. Based on the transient models of a 660 MW supercritical coal-fired power unit, comparison on the original and revised control systems for the main parameters were proposed. It turns out that when compared with the original control system, the revised control system exhibits a better control performance during peak shaving processes, especially for the loading down process. The differences of the output power, live steam pressure, live steam pressure and reheat steam temperature between the original and revised control systems during load down process are −1006.41 MW·s, 21.26 MPa·s, 256.17 °C·s, and 680.17 °C·s, respectively. The study can provide a guidance for the control optimization and flexibility improvement of coal-fired power plants during peak shaving processes.

Keywords: operational flexibility, coal-fired power plant, peak shaving process, control system optimization, dynamic simulation.

1. INTRODUCTION

The high penetration of intermittent renewable sources poses a considerable challenge to the safety and stability of a current electric system [1]. Although methods at the demand [2] and network [3] sides, and energy storage technologies [4] all can be served as flexibility options, the demand and network-side options are immature due to their low-efficiency and operation instability, and commercially available and cost-effective large-scale energy storage technologies remain lacking [5]. The conventional thermal power units are still a critical method to improve the power system flexibility [6]. Therefore, the operational flexibility of thermal power plants has aroused much attention.

The enhancement on operational flexibility of coal-fired power plants contains the following aspects: short-term primary frequency control, operation optimization of peak shaving processes, and reduction of time and cost of start-up and shut-down processes. Zhao et al. [7, 8] compared the dynamic characteristics of six measures by regulating thermal system configuration and evaluated their short-term operational flexibility. Wang et al. [9] proposed peak shaving operational optimization of supercritical coal-fired power plants by revising control strategy for water-fuel ratio. Hübel et al. [10] developed dynamic models of a coal-fired power plant and focused on start-up restrictions.

In summary, the previous studies have proposed some methods for evaluating and enhancing the short-term flexibility and limitation of start-up and shut-down processes involving material thermal and mechanical stresses, while with respect to the flexibility of peak shaving processes, the power ramp rate is still limited owing to the safety restriction of heated material, complication of heat transfer, and substantial thermal inertia in coal-fired power plant system. In this paper, a revised control system by regulating high-pressure (HP) extraction steam was added in the original coordinate control system to control reheat steam temperature quickly and finally improve the flexibility during peak shaving processes. The dynamic characteristics of key thermal parameters, output power, and coal consumption rate are studied based on the transient models of a 660 MW supercritical coal-fired power unit. The accumulation deviations of these parameters between the revised and original control systems were compared. The research can provide a guidance for the control optimization and flexibility improvement of coal-fired power plants during peak shaving processes.

2. MODELS AND SIMULATION DETAILS

2.1 Reference case and transient models

A 660 MW supercritical coal-fired power unit is selected as a reference case and the thermal system is shown in Fig 1. The main parameters at the boiler outlet is 25.40 MPa/571 °C/569 °C under the rated working condition. Primary reheat units include three turbines, seven preheaters, a deaerator, and a condenser. The valves at the extraction steam pipelines of 2# and 3# HP heaters are called valves 1 and 2, respectively, which are all applied in the following revised control system.

On the basis of the selected power unit, the design thermal data and structural parameters for every key device are obtained, and then the transient models of the entire thermal system are developed by using the GSE Systems which generates a several of codes to simulate two-phase thermal parameters from the fundamental principles of mass, momentum, and energy balances. The mass and thermal energy storages in all devices are calculated by considering the space sizes and characteristic parameters of working fluids and metal heating surfaces. The detailed numerical solutions and assumptions for the dynamic models have been introduced in our previous study [8].

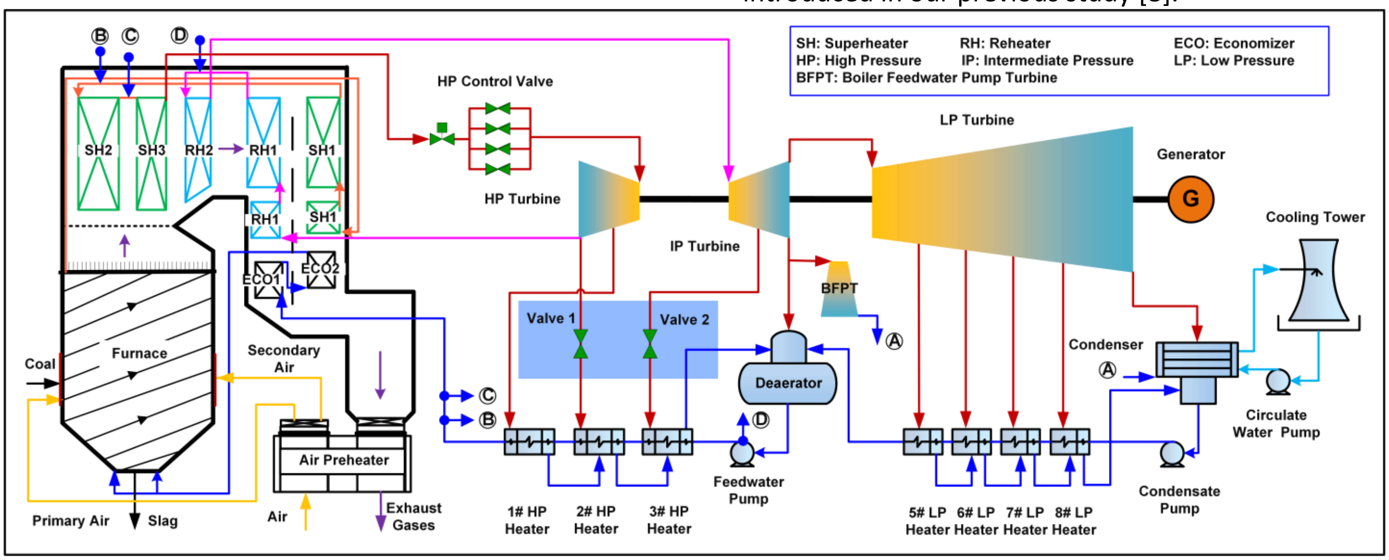

Fig 1. Schematic thermal system of a 660 MW supercritical coal-fired power plant.

2.2 Revised control system models

There are several control systems designed in the present supercritical coal-fired power plants, including coordinate control, combustion, feedwater, steam temperature, auxiliary control systems, and so on. However, owing to the safety restriction of heated material, complexity of heat transfer, and huge thermal inertia in the supercritical unit, the power ramp rate is still restricted and the over-temperature phenomena of live and reheat steam happen easily. Here, a revised control system by regulating HP extraction steam was added in the original coordinate control system. As shown in Fig 2(a), the control model of HP extraction steam valve 2 is added in the coordinate control system to regulate the output power, which is ascribed to that the steam can be rapidly returned to the turbine and produce output power. Moreover, at original control system, the flue gas baffles were used to regulate the reheat steam temperature, but the response rate was slowly and had a significant influence of the live steam temperature. Therefore, as shown in Fig 2(b), the control model of HP extraction steam valve 1 is added to regulate the reheat steam temperature because its rapid regulating rate and slight influence to the live steam temperature.

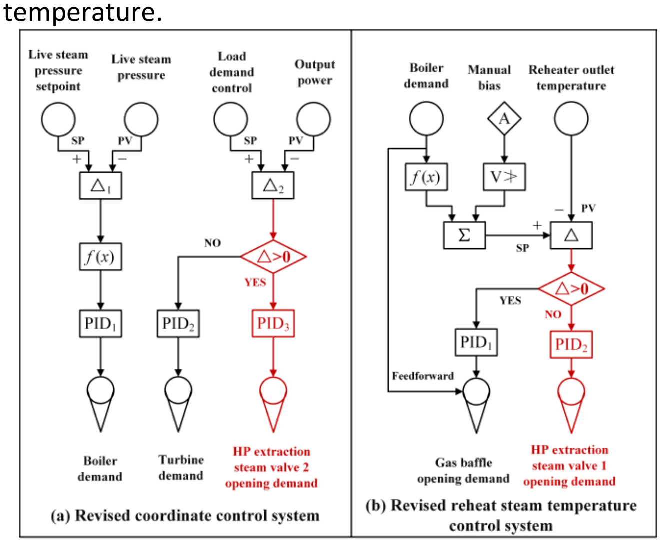

Fig 2. Revised control system models by adding the regulation of HP extraction steam.

2.3 Performance indexes

In our study, to assess the quality of the control system between the original and revised control system, four key parameters of coal-fired power units are selected, including the output power, live steam pressure, and live and reheat steam temperatures. The accumulation deviation during the total control processes is a general index to reflect the control quality. The smaller the value of accumulation deviation is, the better the quality of control system is. Therefore, the accumulation deviations of these four parameters between the revised and original control systems are defined as follows.

$$A_i = \int_{t_1}^{t_2} \left| a_{i,\mathrm{SP}} - a_{i,\mathrm{PV}} \right| \mathrm{d}t, (i = \mathrm{OP}, \mathrm{LSP}, \mathrm{LST}, \mathrm{RST}), \quad (1)$$

where t_1 and t_2 are the initial and end times of peak shaving processes, s; OP, LSP, LST, and RST represent the output power (MW), live steam pressure (MPa), live and reheat steam temperatures (℃), respectively. a_{SP} and a_{PV} donote the set point and present values of these parameters.

3. RESULTS AND DISCUSSION

3.1 Tendency of the main parameters during loading up processes

There is substantial thermal inertia existing in the thermal system, which brings the complexity and coupled-effects of flow, heat transfer, and power conversion processes during transients; That is why that the original control systems are insufficient for the parameters control, especially for the rapid peak shaving processes. In this study, the regulation of HP extraction steam which activates the thermal storage rapidly in the turbine subsystem, named as the revised control system, was added to participate the control of output power and reheat team temperature. When the load change rate is 15 MW·min^{-1} during loading up process from 75% to 100% turbine heat acceptance (THA) working condition, the dynamic characteristics of the main parameters at original and revised control systems are shown in Fig 3.

The results reveal that when operating in the original control system, the output power is bigger than its set point during loading up process (100-760 s), and then has some slight variation during stable process (761-2400 s). The live steam pressure, live steam and reheat steam temperature have more obvious fluctuations than their set point, which illustrates the deficiency of original control system. On the contrary, by adding the regulation of HP extraction steam in the control system, the maximum deviation between the present and set values for four parameters are all smaller than in the original control system. Overall, the revised control system has an obvious quality during loading up process.

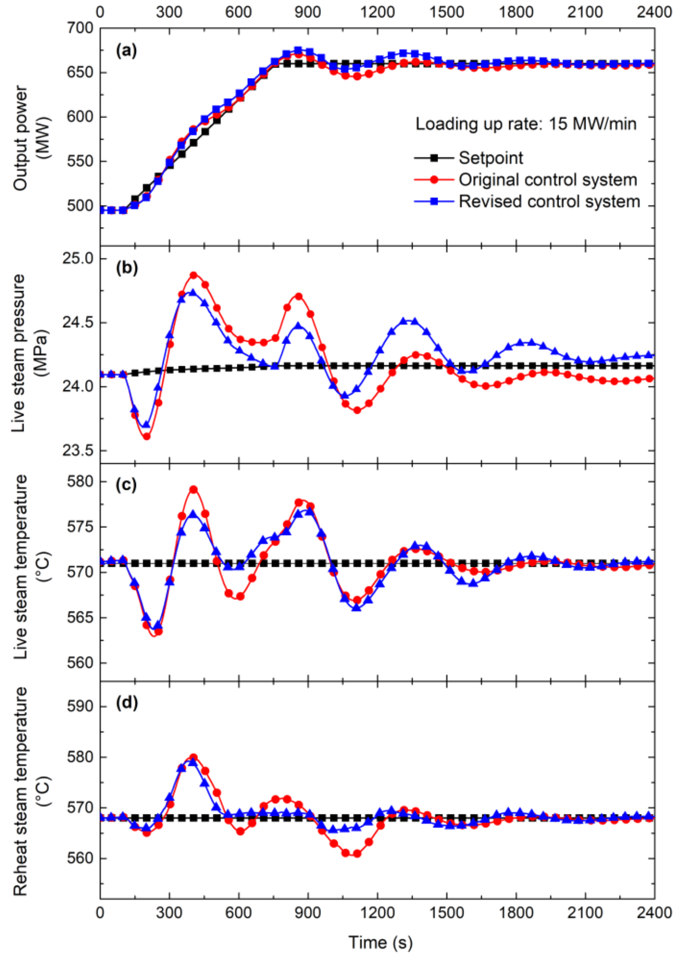

Fig 3. Dynamic characteristics of the main parameters at original and revised control systems during loading up process from 75% to 100% THA working condition.

3.2 Tendency of the main parameters during loading down processes

When the load change rate is 15 MW·min^{-1} during loading down process from 100% to 75% THA condition, the dynamic characteristics of the main parameters at original and revised control systems are shown in Fig 4. The results show that comparing with original control system, the maximum deviation between the present and set values for four parameters in the revised control system all smaller, which illustrates the revised control system has a remarkably positive effect, especially for the control of reheat steam temperature. In addition, the positive control effect of loading down process is more apparent than that of loading up process.

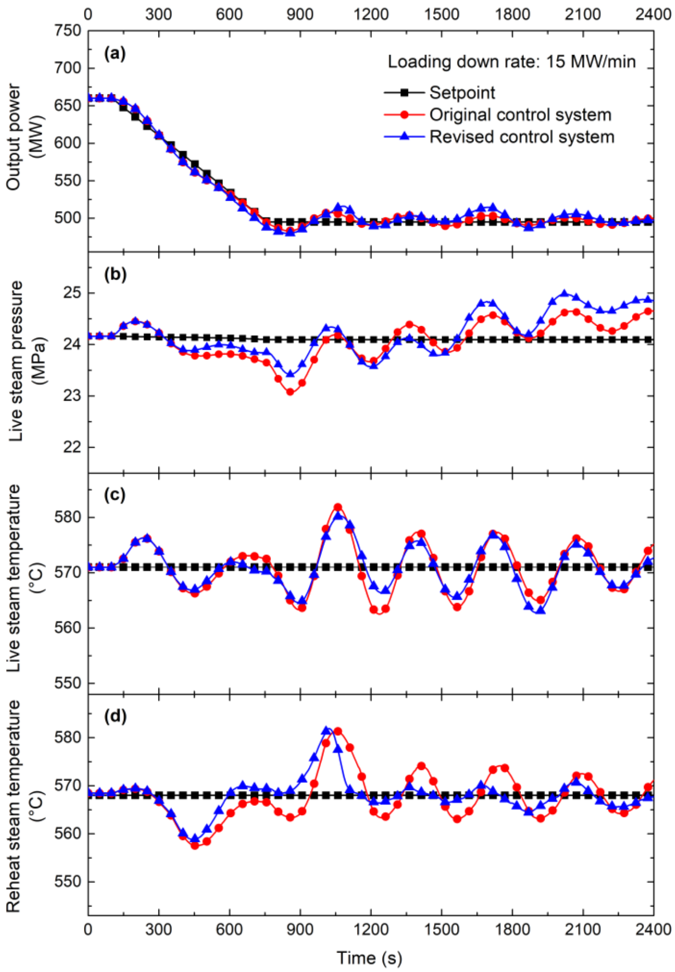

Fig 4. Dynamic characteristics of the main parameters at original and revised control systems during loading down process from 75% to 100% THA working condition.

3.3 Performance evaluation of revised control system

Accumulation deviation can reflect the control effect during the entire control processes. Therefore, the accumulation deviations of four parameters during loading up and down processes are listed in Table 1 and 2, respectively. The results show that accumulation deviation for the live steam pressure, and live and reheat steam temperatures in revised control systems are smaller than that in original control system, which means that the revised control system is better than the original control system. During loading up processes, the differences of accumulation deviation between original and revised control systems for the output power, live steam pressure, and live and reheat steam temperatures are −344.14 MW·s, 18.93 MPa·s, 57.47 °C·s, and 331.00 °C·s. During loading down process, the differences of accumulation deviation between original and revised control systems for these four parameters are −1006.41 MW·s, 21.26 MPa·s, 256.17 °C·s, and 680.17 °C·s, respectively. Compared with the loading up process, the differences of accumulation deviation between original and revised control systems for the live steam pressure, and live and reheat steam temperatures are larger during load down process, which means based on the same revised control system, the control performance for the steam temperatures of loading down process is better than that of loading up process.

Table 1. Accumulation deviation of the main parameters at original and revised control systems during loading up processes.

Accumulation deviation	Unit	Loading up process	
		Original	Revised
Output power	MW·s	2046.93	2391.07
Live steam pressure	MPa·s	96.70	77.77
Live steam temperature	°C·s	947.92	890.45
Reheat steam temperature	°C·s	1021.49	690.49

Table 2. Accumulation deviation of the main parameters at original and revised control systems during loading down processes.

Accumulation deviation	Unit	Loading down process	
		Original	Revised
Output power	MW·s	2260.01	3266.42
Live steam pressure	MPa·s	161.91	140.65
Live steam temperature	°C·s	1721.34	1465.17
Reheat steam temperature	°C·s	1791.11	1110.94

4. CONCLUSION

The conventional thermal power plants have become a critical method to improve the operational flexibility of the current power system. In this study, a revised control system by regulating high-pressure extraction steam was added to improve the flexibility during peak shaving processes. In this study, a revised control system by regulating high-pressure extraction steam was added to improve the flexibility during peak shaving processes. Comparison for the main parameters between the original and revised control systems was proposed based on the transient models of a 660 MW supercritical coal-fired power units. The main conclusions are as follows.

The revised control system has a more positive effect than the original control system during peak shaving processes.

Based on the revised control system, the control of output power during load up process is more effective than that during load down process.

The differences of accumulation deviation for live steam pressure, live steam and reheat steam temperature between the original and revised control system during load down process are 21.26 MPa·s, 256.17 °C·s, and 680.17 °C·s, respectively, which means the control performance for the steam temperatures during loading down process is better than that during loading up process.

ACKNOWLEDGEMENTS

This work was supported by National Basic Research Program of China (973 Program, Grant Number 2015CB251504) and National Natural Science Foundation of China (51776146).

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