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Multivariable constrained predictive control of main steam temperature in ultra-supercritical coal-fired power unit

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A B S T R A C T

Ultra-Supercritical (USC) unit is more and more popular in coal-fired power industry. In this paper, a multivariable constrained predictive control (MCPC) method is introduced for superheated steam temperature control of USC unit. The four levels of superheated temperature including division superheater outlet temperature, platen superheater outlet temperature, finish superheater inlet temperature and finish superheater outlet temperature, i.e. main steam temperature, are selected as outputs. The three levels of attemperators spray are selected as inputs. Step responses of the superheater temperature are recorded as the predictive model used in multivariable constrained predictive control algorithm. In simulation, the superheated steam temperature can be controlled around the setpoint closely in load changing. And the proposed method keep the main steam temperature more stable than conventional PID controller.

1. Introduction

In recent years, USC unit is more and more popular in coal-fired power industry [1]. Ultra-Supercritical (USC) unit has the higher value of parameters in boiler and turbine than conventional unit. The pressure and temperature are higher than 25 MPa and 580 °C respectively. Comparing to traditional coal-fired power generation, USC coal-fired power generation units has good promising application for its higher efficiency and less harmful emission [1]. The high parameters of once-through type boiler in USC unit bring the advantages for tracking the load demand in large range, and also propose the tough requirements of USC unit control system, especially the steam temperature control task. As there is no phase distinction between water and steam when units operate at supercritical or ultra-supercritical condition, strong non-linearity and coupling exist in the USC unit operation. The temperature and density of steam in heating section, evaporation section and superheating section changes with the disturbance of manipulated variable, e.g. combustion rate, feedwater flow and main steam valve opening. This brings coupling and complicated relationship among steam temperature, output power and steam pressure. Meanwhile, the steam temperature is important to safe and efficient operation of USC unit, which works in large operation ranges from load demand [2].

The main tasks in the USC unit temperature control are the temperature control of superheat steam and reheat steam temperature. For once-through boiler of USC unit, superheated steam temperature is regulated by ratio of feed coal flow and feedwater flow basically, and tuned by the attemperators sprays of desuperheater around setpoint. Superheated steam temperature is more important to the efficiency of the unit, especially. Currently, the unit is usually based on the classic cascade PID control and feedforward control etc. to achieve the superheated steam temperature regulation [3].

Predictive control, which has been also widely used in other fields [4,5], arose in process industry with advantages to handle the problem of delay, coupling and multi-input multi-output system [6]. Nakamura firstly proposed optimal control based on state space for supercritical thermal power unit [7]. Rovnak et al. discuss the application of Dynamic Matrix Control (DMC) for power unit on theoretical and practical

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aspects, which used output power, the main steam pressure and main steam temperature as outputs, and feedwater flow, the fuel flow and the main steam governor valve opening as inputs [8]. Sanchez et al. used DMC method for controlling the steam temperature of power unit, which considered as single input and single output. The results show that the control effect is better than conventional PID method [9]. Hua et al. applied DMC method combined with state feedback control for steam temperature [10]. Moon et al. given an adaptive DMC for drum boiler type power unit which considered as a simplified third-order model [11]. Moon and Kim control superheat steam temperature and reheat steam temperature together by establishing 4 by 4 input–output dynamic step response model which gives the satisfied simulation [12]. In this paper, the superheated steam temperature control of a 1000 MW USC unit is studied. The valve opening of three levels of attemperators spray are used as manipulated variables (MVs) and the four outlets and inlets of superheater temperature are used as controlled variables (CVs). The superheater temperature are controlled in steady load condition and varying load condition. The proposed method is compared with the traditional casacade PID controller employed in DCS system.

The rest of this paper is organized as follows. In Section 2, the desuperheater section of USC unit is analyzed. A multivariable constrained predictive control scheme for superheated steam temperature control is presented in Section 3. In Section 4, the simulation and discussion based on a thermal-power simulation system is conducted. Finally, conclusions are given in Section 5.

2. Desuperheater section of USC unit

The superheated steam temperature is a key parameter for safe and efficient operation of USC unit. When the output power is smaller than 30% MCR (Maximum Continuous Rating), the unit is operated in Wet State. The characteristic of USC unit under wet state is similar as drum boiler power unit. The superheater temperature is mainly regulated by attemperators spray. When the output power is bigger than 30% MCR, the unit is operated in Dry State. The superheater temperature is basically regulated by tuning water-coal ratio and kept at setpoint accurately by attemperators spray. The schematic diagram of superheater temperature control based on MCPC is shown as in Fig. 1, where DS, PS and FS are abbreviations of Division Superheater, Platen Superheater and Finish Superheater respectively. The first attemperator spray is located between primary superheater and division superheater. The second attemperator spray is located between division superheater and platen superheater. The third attemperator spray is located between platen superheater and finish superheater. The atomized cold water, from feedwater turbo pump or storage tank, is sprayed into superheated steam through attemperator to drop the steam temperature to the setpoint. The valves opening of three attemperators spray are regulated to control the corresponding superheated steam temperature. And the finish superheater outlet temperature is the final temperature of steam, i.e. temperature of main steam which is fed into HP turbine. In this paper, the superheater section of USC unit in dry state is considered.

Meanwhile, the disturbances in USC unit can bring the challenges of controlling the superheated temperature. When the load demand changes, the coordinated coal flow and feedwater flow need to follow the load changes, which cause the fluctuations in steam temperature. The temperature of feedwater influence the steam temperature too. The coal quality is another factor influencing the steam temperature. When the coal quality is falling, the coal flow will increase to keep the intermediate point temperature, in which case the superheated and reheated steam temperature will also increase. These disturbances bring the difficulty in controlling the superheated steam temperature.

Through the analysis of superheater section of USC unit, the valve opening of attemperators spray are chosen as MVs and Division Superheater Outlet Temperature (DSOT), Platen Superheater Outlet Temperature (PSOT), Finish Superheater Inlet Temperature (FSIT) and Finish Superheater Outlet Temperature (main team temperature) (FSOT) are chosen as CVs. Considering the disturbances, the Finish Superheater Outlet Temperature are controlled along with other levels superheated temperature. The details of proposed method are shown in next sections.

3. Mcpc for steam temperature of superheater in USC unit

3.1. Fundamental of model predictive control

MPC is arisen from chemical process control. Based on the thoughts of predictive model, online optimization and feedback correction, MPC has been successfully applied to many industry fields with satisfied results [4–6]. In this paper, MCPC means multivariable constrained predictive control, which is used in control of main steam temperature of USC unit control and based on Dynamic Matrix Control (DMC) taking the algorithm as following:

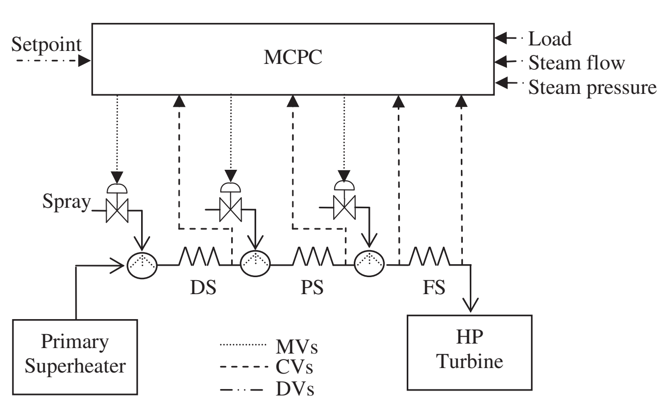

Fig. 1. The schematic diagram of superheater temperature control based on MCPC (DS = Division Superheater, PS = Platen Superheater, FS = Finish Superheater).