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Research Paper

Mechanism modelling on the coordinated control system of a coal-fired subcritical circulating fluidized bed unit

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HIGHLIGHTS

- A mechanism-based control model of CCS for subcritical CFB units is established.
- The model can well describe the dynamic characteristics with high accuracy.
- The model is validated by a 300 MW CFB unit.
- A transfer function matrix of CCS is derived to design the control algorithm.

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ABSTRACT

To improve the load following capacity of a coal-fired circulating fluidized bed (CFB) power generation unit, it is necessary to build a model for the design of the load control system, e.g. the coordinated control system (CCS). In this paper, a mechanism-based control model of the CCS with the balance between model complexity and prediction accuracy applicable for controller design is established based on the dynamic characteristics of a subcritical coal-fired CFB unit. The proposed model was applied on a 300 MW coal-fired subcritical CFB unit with the existing control system. The results showed that the model can reflect the main dynamic characteristic of power plant project with 300 MW CFB unit with the existing control system, has high precision, and can be used to design the controller of load control system. Moreover, the transfer function of coordinated control systems is derived to design the control algorithm.

1. Introduction

In China, the forced curtailment of wind and solar energy reached at a high level of 41.9 B kWh and 7.3 B kWh in 2017, greatly reducing the scale of renewable energy power connected into grid. Since the power grid requires that generation and load closely balance moment by moment, frequent adjustments to the output of power plants are necessary. The traditional coal-fired thermal power plants need to raise the load change speed to accommodate the increasing amount of renewable energy [1,2]. More than 12% of the total coal-fired power plants installed capacity in China employs the CFB boiler, which has been commercialized in power generation owing to the advantages in fuel flexibility [3–5] and low cost of emission control [6]. The requirement for the speed of load change in CFB plants is 1% of rated power output per minute, i.e. 1% Pe/min, less than that of the pulverized coal boilers as 1.5–2% Pe/min in China.

Different from that in a pulverized coal-fired furnace, the combustion heat released in CFB furnace mainly comes from the combustion of residue carbon in the bed material. The relatively low temperature of the combustion [7] and the huge amount of bed material circulating in the circulation loop result in a large thermal inertia in the CFB unit [8,9]. Aiming at utilizing the stored energy of boiler effectively, people often use CCS in the load control system of power plants [10]. Because of the strong coupling and nonlinearity of the controlled parameters [11], and the short period in development, the design and control of the CCS in CFB units are still immature. As a result, many CFB units largely fluctuate during the dynamic process with poor automatic operation performance, resulting in the safety and economic issues. Development a proper control strategy of CCS is critical to enhance the load change capacity of a coal-fired CFB power plant [12].

In the previous studies, some classical load control models were developed for drum boiler units with acceptable performance [13–16]. However, the models are only suitable for pulverized coal-fired units. For a CFB unit, few control models with differential equations with

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Nomenclature

A_{ir}	total air flow rate, N m^3/s
B	amount of burning carbon, kg
C_b	coefficient of drum heat storage, kJ/MPa
C_{O2}	oxygen concentration, kmol/m^3
d_c	average particle diameter, m
H_c	unit calorific value of carbon, MJ/kg
H_i	heating value of component, MJ/kg
K_1	overall coefficient of the model
K_3	gain of turbine, MW/(MPa%)
K_2	resistance fitting coefficient
k_c	burning rate constant, m/s
K_t	dynamic time of the turbine, s
k_g	fuel amount coefficient, kg/(s·MW)
ko_2	oxygen concentration fitting coefficient
M_V	mass fraction of the volatile, %
M_C	molar mass of carbon, kg/kmol
n	a fitting coefficient
N_E	output power of the unit, MW
p_1	turbine regulating pressure, MPa
p_d	drum pressure, MPa
p_t	main steam pressure, MPa
Q_B	burning carbon released heat, MJ/S
Qr	total combustion heat, MJ/s
Q_V	volatile combustion heat, MJ/s
R_c	combustion reaction rate, kg/s
s	Laplace transformation equation
T_b	bed temperature, K
W_c	fuel amount into the furnace, kg/s
W_c'	fuel instruction, kg/s
W_{pz}	quantity rate of slag, kg/s
W_{FL}	quantity rate of fly ash, kg/s
X_c	net carbon as received basis, %
$X_{c,f}$	carbon content of fly ash, %
$X_{c,p}$	carbon content of discharge, %

Greeks

τ	delay time, s
ρ_c	density of carbon particles, kg/m^3
u_B	boiler main control instruction, MW
u_T	turbine position instruction, %
η	efficiency factor, %

Abbreviations

AEB	advanced energy balance
CCS	coordinated control system
CFB	circulating fluidized bed
PSO	particle swarm optimization
RMSE	root mean squared errors

description on the plant design, fluidization and heat transfer were developed [17,18], and they are too complicate to be implemented in practical controller design. That is, a new model is expected to balance complexity and accuracy. To do so, it is of first importance to find out the dominative process inputs, outputs and internal state variables, and to capture the dynamic characteristics of the unit. Accordingly, we developed an energy storage model with the advanced energy balance (AEB) forward control scheme of subcritical CFB units.

Though our previous model was validated in the improvement of the load change speed [19], it still can hardly eliminates the influence generated by feedback loop commendably. Optimal design of the control strategy for closed-loop control system and parameter tuning of controller are needed to solve this problem. This requires more research on the mechanisms of the load control system and development of a mechanism-based control model. Only with such a model, the application of control algorithms, such as predictive control, adaptive control, fuzzy control could be improved.

In this regard, the objective of this study is to establish a mechanism-based control model of the CCS for subcritical CFB units, with simple form and a general structure. The model is applicable in

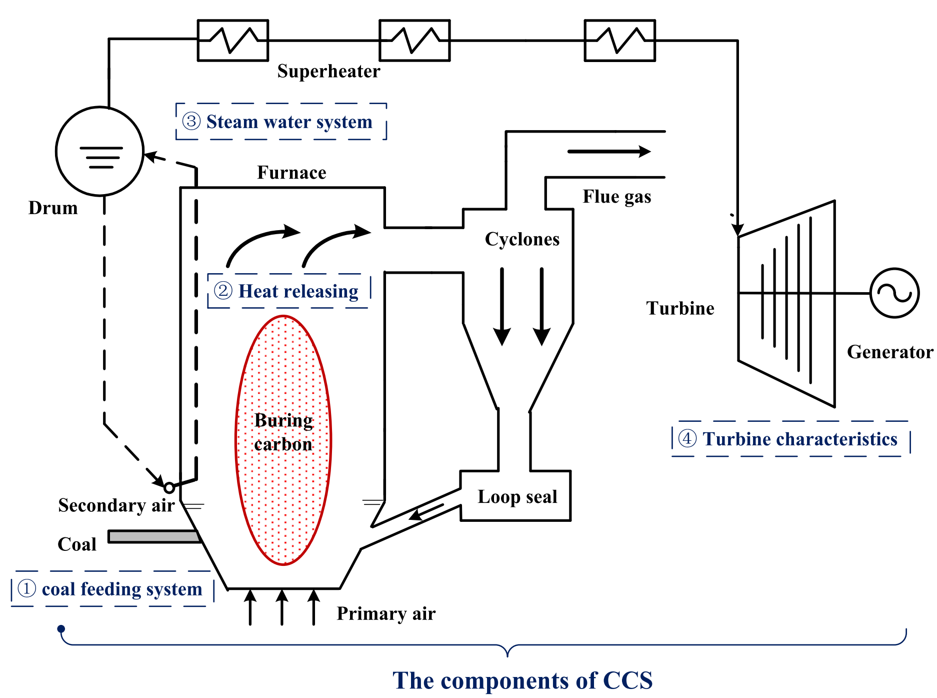

Fig. 1. The process of the CCS for a subcritical CFB power generation.