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Cascade control of superheated steam temperature with neuro-PID controller

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ABSTRACT

In this paper, an improved cascade control methodology for superheated processes is developed, in which the primary PID controller is implemented by neural networks trained by minimizing error entropy criterion. The entropy of the tracking error can be estimated recursively by utilizing receding horizon window technique. The measurable disturbances in superheated processes are input to the neuro-PID controller besides the sequences of tracking error in outer loop control system, hence, feedback control is combined with feedforward control in the proposed neuro-PID controller. The convergent condition of the neural networks is analyzed. The implementation procedures of the proposed cascade control approach are summarized. Compared with the neuro-PID controller using minimizing squared error criterion, the proposed neuro-PID controller using minimizing error entropy criterion may decrease fluctuations of the superheated steam temperature. A simulation example shows the advantages of the proposed method.

1. Introduction

Superheated steam temperature plays an important role in the security and economy of power plants. Control of superheated steam temperature is not only economically essential in terms of improving lifetime and efficiency, but also technically challenging because of the complex superheater process characterized by nonlinearity, uncertainty and load disturbance.

A lot of efforts have been made to develop advanced control algorithms for controlling superheated steam temperatures in power plants. Generic model control (GMC) algorithm was developed to control steam temperature and compared with a state feedback controller in [1], however, both control algorithms cannot deal with variant operating condition adaptively.

Predictive control theory has been spread in process industry [2–9]. Generalized predictive control strategy has been applied to control the steam temperature in a 265 MW unit [2]. Dynamic Matrix Control algorithm was implemented in a simulator to control the superheated and reheated steam temperature respectively in [3]. A neuro-fuzzy generalized predictive controller was proposed to regulate superheated steam temperature of a 200 MW power plant [4]. A nonlinear predictive controller based on neural networks was presented to control the superheated steam temperature, reheated steam temperature and pressure in a power plant [5]. Though some linear predictive controllers have been applied by the field, however, the nonlinear predictive control law is encountering some challenges to improve its efficiency and robustness [6–9].

In addition, some other adaptive control algorithms were also developed for regulating steam temperature in power plants. Based on the estimated parameters, an adaptive control system was applied to control the superheated and reheated steam temperature of a 375 MW power plant [10]. An adaptive optimal control method was developed for steam temperature control of a once-through coal fired boiler in [11].

Intelligent control strategies were also applied to control superheated steam temperatures. Fuzzy logic control algorithm was used to control the steam temperature in [3]. An effective neuro-fuzzy model of the de-superheating process was developed, the genetic algorithm based PI controller was proposed to regulate steam temperature of four 325 MW power plants in [4,12]. Neural networks were applied to control temperature in a thermal power plant with once-through boilers [5,13].

Cascade controllers are still most popular and commonly available in steam temperature control systems, because cascade control system has three advantages [14]: (1) reject disturbances arising in the inner loop; (2) improve the speed and accuracy of system response and (3) reduce the effect of parameter variations in the inner loop. In order to improve control performance of superheated steam temperature control systems in power plants, the conventional primary PID controller can be replaced by other advanced controller, moreover, feedforward controller can also be combined with cascade controller. Hence, some improved cascade control strategies have been designed to regulate superheated steam temperature of power plants [2–4,15–17]. A PT_x model which adapts with operating point was incorporated with a

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cascade control strategy in order to compensate high-order and load-dependent dynamics of the superheater. In addition, both generalized predictive controller and fuzzy controller acted as the primary controller in the superheated steam temperature cascade control system in [2]. Combining feed-forward control and cascade control algorithm, a three-element controller was presented to control superheated steam temperature in [15], in which the feedforward controller compensates for load changes. In [16], an LQ self-tuning controller minimizing a multi-step quadratic control performance index was applied to replace the primary PI controller in the cascade control structure for superheated steam temperature control in a 200 MW coal-fueled power plant. The MUSMAR predictive adaptive controller was served as primary controller in the cascade control scheme for regulating superheated steam temperature in an industrial boiler [17]. A neuro-fuzzy generalized predictive controller was proposed to be primary controller in the cascade control system for regulating superheated steam temperature of a 200 MW power plant [4].

In this study, cascade control structure is still used to control superheated steam temperature due to its advantages. However, the conventional cascade PID system may be unsatisfactory when dealing with stochastic disturbances and variable operation conditions. Consequently, it calls for an advanced approach to control superheated steam temperature under the framework of cascade control and stochastic control.

The fluctuations of superheated steam temperature under different control schemes are shown in Fig. 1. y_{max} is the allowable limit of superheated steam temperature according to the thermal stress of the plant. Compared with the control scheme B, the control scheme A can reduce the fluctuations of the superheated steam temperature. The shape of the probability density function of the temperature under scheme A is narrower and sharper than that under the scheme B. As a result, the set-point of temperature y_{Asp} can be set to a higher value because the controlled superheated steam temperature does not violate the upper bound y_{max} under the control scheme A. Hence, the scheme A not only prevents from mechanical stress causing micro-cracks but also provides high efficiency of the turbine.

Disturbances in the superheater process, such as steam mass flow, flue gas and attemporator water mass flow, can cause fluctuations of superheated steam temperature besides variations of load. Not only these disturbances are not necessarily Gaussian, but also the dynamics of the real superheated process is nonlinear, hence, the entropy of tracking error is used to characterize the performance of the closed-loop control systems rather than variance of tracking error.

Following the advancement in dynamic stochastic distribution controller [18–24] and neuro-PID controller [13,25,26], a neural networks assisted PID controller using minimizing error entropy (MEE) criterion is presented to act as a primary controller in superheated steam temperature cascade control systems. The entropy of tracking error is obtained by receding horizon technique. The inputs of the neuro-PID controller include not only the sequences of tracking error but also the measurable disturbances in superheated processes so as to deal with disturbances quickly. The proposed neuro-PID controller can reduce the dispersion of tracking error rather than the existed neuro-PID controller under minimizing squared error (MSE) criterion [13,25–27]. In general, the proposed neuro-PID controller not only overcomes the tedious tuning for the PID controller, but also makes the control system adaptive and robust. Similarly, predictive controller also uses the "receding horizon" idea, the optimal controller inputs can be solved under MSE criterion. Although predictive controller is able to take into account of constraints, however, it is still necessary to do further research on nonlinear predictive control algorithm to improve its efficiency and robustness [6–9].

The rest of this paper is organized as follows: Section 2 describes the superheater process and introduces the basic structure of the proposed cascade controller for regulating superheated steam temperature of power plants. Section 3 presents the primary neuro PID controller using MEE criterion, and analyzes the convergent condition of the neuro-PID controller. Section 4 addresses the problems related to the implementation of the proposed control scheme. Section 5 verifies the efficiency and feasibility of the proposed approach to regulate superheated steam temperature by comparing with a cascade control system whose primary controller is a neuro-PID controller under MSE criterion. Section 6 concludes this paper.

2. Plant description and control scheme

The boiler process usually includes several steam superheating processes shown in Fig. 2: low temperature superheater, platen superheater and high temperature superheater. Each of these processes serves as an energy transferring system, in which energy is transferred from the flue gas to the steam. Each superheater is equipped with an attemperator, water is injected at the inlet of attemperator for control of the steam outlet temperature.

The steam is generated from the boiler drum and passes through the low-temperature superheater before entering the platen superheater where it receives a spray water injection to control the temperature of steam. Similarly, there is a spray water

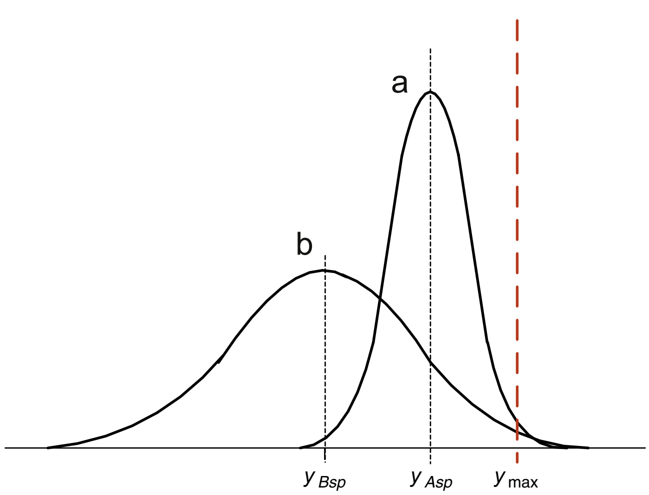

Fig. 1. Control fluctuations of superheated steam temperature.

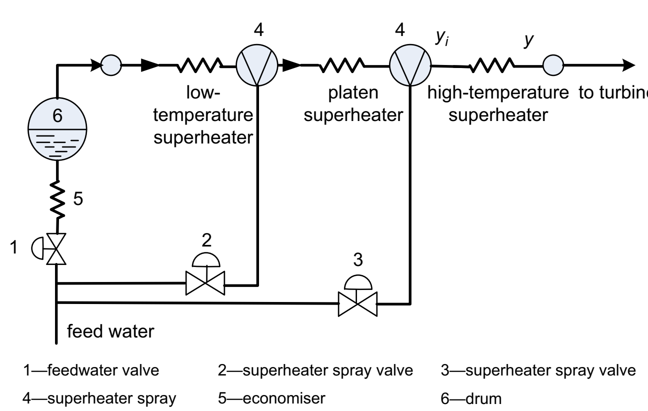

Fig. 2. Superheater process.