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Fuzzy Modeling and Predictive Control of Power plant Steam Temperature System

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Abstract: This paper develops a data-driven modeling strategy and predictive controller for the superheater steam temperature (SST) system in the power plant. First, a data-driven Takagi–Sugeno (T-S) fuzzy model is developed to approximate the behavior of the SST control system using the subspace identification (SID) method. Then, a fuzzy model predictive controller is designed based on the TS-fuzzy model to regulate the SST under the input constraints. Simulation results on a 600MW power plant demonstrate the feasibility and effectiveness of the proposed approach

Keywords: Superheater steam temperature system, power plant, subspace identification, TS-fuzzy model, model predictive control.

1. INTRODUCTION

Superheater steam temperature (SST) is one of the most critical variables to be controlled in a steam power plant. It must be tightly controlled within a small variation range for the security and economy reasons.

However, control of the SST is challenging due to its large thermal inertia. In addition, to meet the unit load demand at all times, most of the power plants have to change power generation frequently over a wide range, and thus the nonlinear behaviour becomes significant. Consequently, the conventional proportional-integral-derivative (PID) controllers with fixed gains cannot satisfy the control requirement. Thus, the SST system has been studied widely in the literatures using various control techniques.

In Ghaffari et al. (2007) a genetic-algorithm (GA) based PI controller is developed on the basis of adaptive neuro-fuzzy inference model. A neural-network (NN) model is built in Zhang et al. (2012) for online tuning of the PID parameters. In Sanchez-Lopez et al. (2004), a fuzzy logic controller is applied to the SST system of a 300MW plant and an inverse dynamic neuro-controller is designed in Ma et al. (2010), where the results show that the computational intelligence techniques achieve a much better performance than the fixed parameter PID controllers and linear model based controllers. However, none of these controllers have dealt with the input constraints in the controller design stage, therefore, model predictive controller (MPC) has been employed in recent years.

In Sanchez-Lopez et al. (2004) and Kim et al. (2010) dynamic matrix controllers (DMC) are employed for the SST system based on the step-response model, but the performance of these linear controllers is degraded for a wide range operation. Nonlinear MPCs are designed in Ma et al. (2012) on the basis of dynamic NN models. Although the control performance is improved, the nonlinear optimization lacks in robustness and suffers from computational requirement.

For these reasons, we propose an MPC based on the fuzzy model to solve the SST control problem. Firstly, a Takagi–Sugeno (TS) fuzzy model (Takagi & Sugeno, 1985) is developed to approximate the behavior of the SST system. Compared with the usual method which linearizes the nonlinear analytical model around different operating points, we utilize the subspace method (Qin, 2006) to identify the local state-space models using input-output data. However, the state variables of the identified model do not have physical meanings, which makes the interpretation of the model difficult. Moreover, for different local models, the state-variables do not share a common basis such that the models cannot be algebraically combined to form a fuzzy model. To overcome this problem in the subspace identification method, similarity transformations are devised to give the state variables common fictitious physical meanings, so that all local models can be transformed into the common basis. A nonlinearity analysis is performed to determine the number of fuzzy rules and the corresponding local linear models, which are then connected by the fuzzy membership functions to form an integrated fuzzy model. The resulting model is shown to represent the SST system very closely, and thus a fuzzy model predictive controller (FMPC) is designed on it to achieve a satisfactory steam temperature performance, while satisfying the input constraints. The proposed modeling and control approaches are applied to the SST system in a 600MW large-scale power plant simulator.

2. SYSTEM DESCRIPTION

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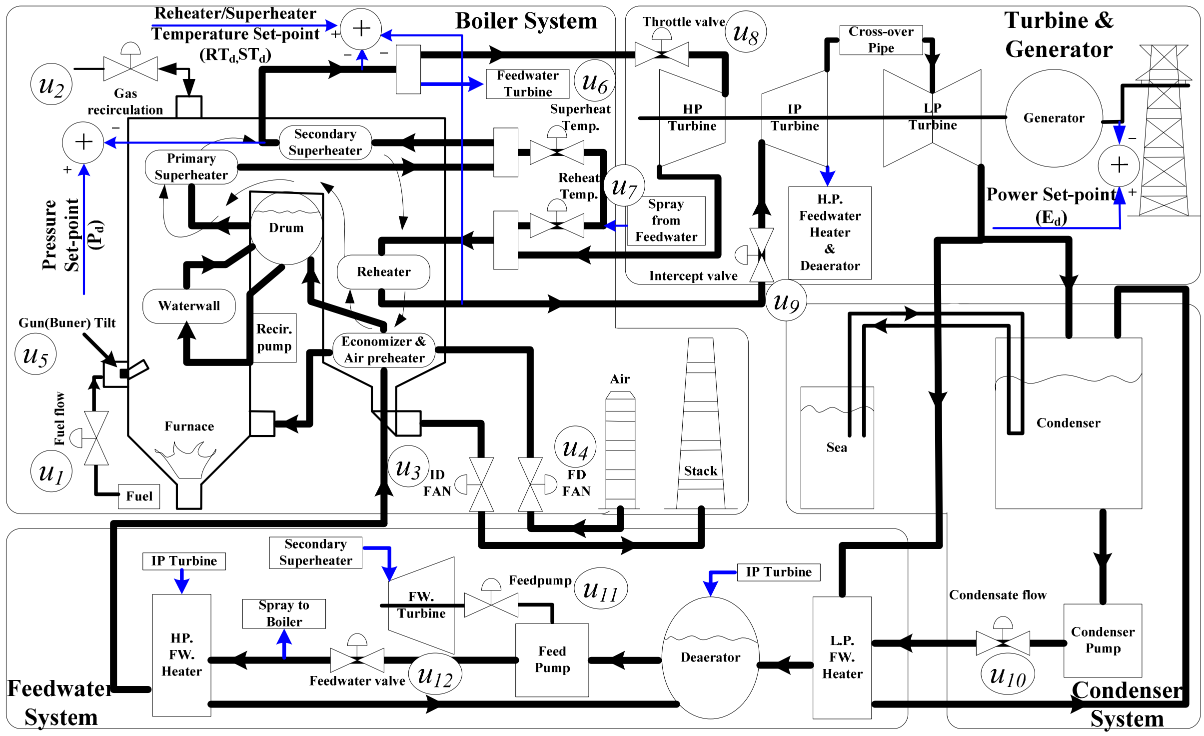

Fig. 1. Large-scale 600 MW power plant model (Heo et al., 2006).

The power plant under consideration is a 600MW oil-fired drum-type boiler-turbine-generator unit shown in Fig. 1. The model of this plant is developed from the first-principles as used in a power plant simulator and is validated in the MATLAB environment. The model is grouped into boiler, turbine, feedwater, and condenser modules and composed of 31 subsystems and 12 control valves associated with physical processes as shown in Fig. 1 (Heo et al., 2006).

The Superheater system of this plant is mainly composed by three parts: primary superheater, secondary superheater and water-spray attemperator between the two superheaters. Its task is to regulate the saturated steam out of the drum to a rated temperature (1005℉, 540.6℃) before delivering it to the turbine.

During the operation of the power plant, there are many factors that will influence the superheater steam temperature; mostly the rate of the steam flow, the heat transfer from flue gas and the rate of spray water flow. For this power plant, three valves can be manipulated to regulate the SST, which are: gas recirculation u_2, combustion gun (burner) tilt u_5 and superheater spray flow u_6. In general, since u_2 and u_5 will greatly influence the plant power output and burning security of the boiler, they are fixed at a given level and superheater spray flow u_6 becomes the only variable to control the SST.

However, the influence of spray flow to the SST has a relatively large thermal inertia property. Moreover, the frequent unit load demand change calls for the change of steam flow rate and flue gas heat transfer, which will influence the SST more quickly. Therefore, advanced control techniques are needed to improve the conventional PI/PID controllers.

3. DATA-DRIVEN MODELING OF SUPERHEATER STEAM TEMPERATURE SYSTEM

Fuzzy model strategy which utilizes the combination of several linear models to approximate the behavior of nonlinear plant has been widely used in power plant modeling and control recently, and the state-space model has been adopted as a local model because of the availability of advanced control theories for linear systems (Wu et al., 2012). In these works, an approximation or transformation of the nonlinear system has been used to obtain the state-space model. However, for complex systems such as SST system, it is a challenge to develop an accurate analytical model without the knowledge of thermodynamics and design specifications of many components. This has become one of the main limitations for designing controllers for real power plants.

Subspace identification (SID) method provides an alternative way to develop the state-space model directly from the input-output data of the plant (Qin, 2006). Based on computational tools such as QR factorization and singular value decomposition (SVD), the SID extracts the model from subspaces of data Hankel matrices. Thus comparing with the conventional optimization based identification, the SID has several distinct advantages, such as: 1) computationally efficient; 2) avoid local minima and convergence problems; 3) no initial condition requirement; and 4) the system order can be easily chosen.

However, the SID is only suitable for linear system identification, while the SST system has severe nonlinearity due to the load change of power plant (Ghaffari et al., 2007). Therefore, the fuzzy modeling strategy is taken in this paper to break the nonlinear system down into a number of linear