Boiler Modelling and Optimal Control of Steam Temperature in Power Plants

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Abstract: Achieving accurate control of main steam temperature is a very difficult task in Thermal power plants due to the large process lag (8 to 10 minutes) associated with the superheater system. A control oriented boiler model and an appropriate optimal control strategy are the essential tools for improving the accuracy of this control system. This paper offers a comprehensive integrated 8th order mathematical model for the boiler and a Kalman Filter based state predictive controller for effectively controlling the main steam temperature and to enhance the efficiency of the boiler. In order to demonstrate the effectiveness of the control system, three more advanced control methods are experimented with the boiler model - Pole placement controller, Optimal controller with state observer and Optimal controller with Kalman filter. Simulation results have illustrated that the Predictive controller method with Kalman filter state estimator and predictor is the most appropriate one for the optimization of main steam temperature control. At present, we are in the process of implementing this control strategy in running Thermal power plants.

Keywords: Large Process lag, Boiler model, Stochastic model, State observer, Kalman filter, N-step prediction, Process identification, Pole placement controller, Optimal Controller, Adaptive predictive controller

1. INTRODUCTION

A coal-fired thermal power plant in general, consists of a number of complex subsystems characterized by nonlinearity, uncertainty, large process lag and random load disturbances. The boiler furnace, drum, superheaters and reheaters are examples wherein these undesirable characteristics have to be accommodated gracefully to achieve optimum power generation from the plant. Traditionally, plant controller designers have developed control strategies based on Proportional-Integral-Derivative (PID) controllers for such types of processes and systems in the same way they did for simple processes. While the PID controllers have produced very good results in the case of simple deterministic plants, their performance was no closer to the expectation in the complex systems (John N. Wallace and Ray Clarke, 1983; Sato and Nomura, 1994; Xiang and Ji-Zhen, 2006). Therefore, controlling of such complex systems is not only technically challenging but also economically important vis-à-vis the energy crisis throughout the world.

In this background, automation vendors world over have developed advanced control techniques to realize accurate control of process variables and achieve maximum plant and energy efficiencies (Nomura, and Sato 1999; Waddington 1994). Obviously, besides achieving better product quality, the new control schemes seem to be very good energy conservation agents to meet world's energy crisis likely to arise from the diminishing fossil fuels. The most relevant application of the multivariable optimal control techniques is the linear quadratic regulator for the steam temperature in the boiler of a 500 MW unit at the Kyushu Electric Company in Japan. This kind of steam temperature control schemes, including other state space identification, non-linear programming and model reference adaptive control techniques have become a standard feature in Japanese fossil power plants during the last 25 years, allowing them to operate with highest levels of availability and thermal efficiency (Flynn 2003).

In principle, Adaptive Control seems to be well suited for overall power plant control. Recent approaches utilize artificial intelligence techniques with a judicious mix of conventional and advanced control techniques. Fuzzy set algorithms, Neural Network classifiers, Genetic algorithm based tuning mechanisms, State observers and Kalman filter based process state estimators perform fault diagnosis and fault accommodation functions (Oluwante and Wei et al., 2007). In this paper, we make an attempt to illustrate the applications of Kalman filtering, state estimation and prediction in power plant optimization and control.

2. THERMAL POWER PLANT OPERATION AND PROBLEMS IN STEAM TEMPERATURE CONTROL

Fig. 1 illustrates the schematic diagram for water, steam and flue gas flow lines of a drum type boiler. The feed water pressurized by the boiler feed pumps goes through many heat exchangers such as the economizer, drum-evaporator,

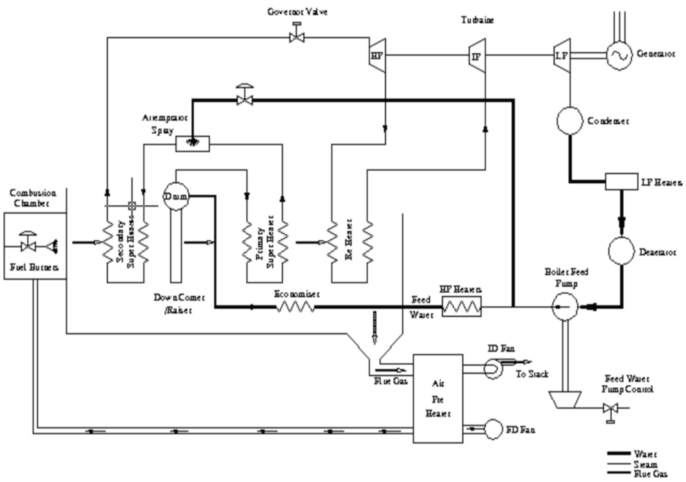

Fig. 1 Schematic Diagram of Steam, water and Flue gas flow lines of a drum type boiler

Primary Superheater (PSH), Secondary Superheater (SSH) etc. and undergoes the phase change to steam. The saturated steam from the drum is superheated to the final required temperature in the PSH and SSH and fed in to the High Pressure (HP) turbine. After isentropic expansion there, the steam is reheated in the reheaters and fed into the Intermediate Pressure (IP) and Low Pressure (LP) turbines.

Fig.2 illustrates the conventional superheater steam temperature control system that aims at the control of the SSH outlet temperature as the final target. This is a cascade control system employing PID Controllers that regulates the spray water flow in the attemperator so that the deviation of the main steam temperature from the set value is zero. Steam temperature at the inlet as well as the outlet are measured with thermocouples and fed to the PID Controllers. Spray water flow is measured using a differential pressure transmitter and a square root extractor. The main steam temperature controller also regulates the fuel flow rate for better control, if required. However, the following problems exist while controlling the steam temperature using the scheme shown in Fig. 2:

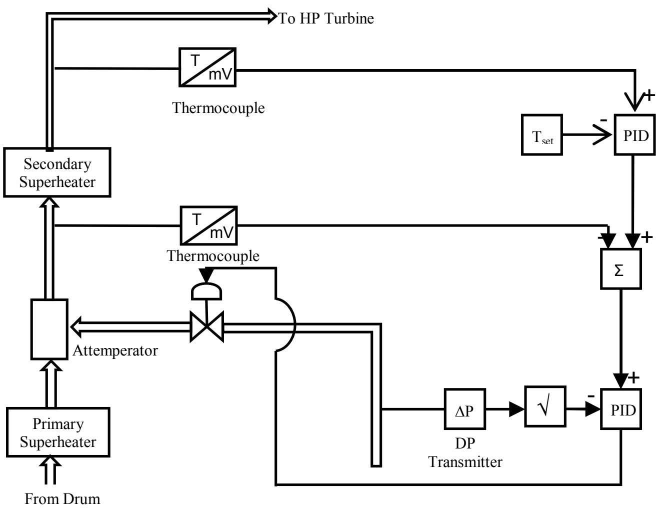

Fig. 2 Conventional steam temperature control system

(a) Owing to the inherent process dynamics, the SSH exhibits a large process lag (τ_p) of the order of 8 to 10 minutes as shown in Fig.3. This is an undesirable feature for the PID controllers.

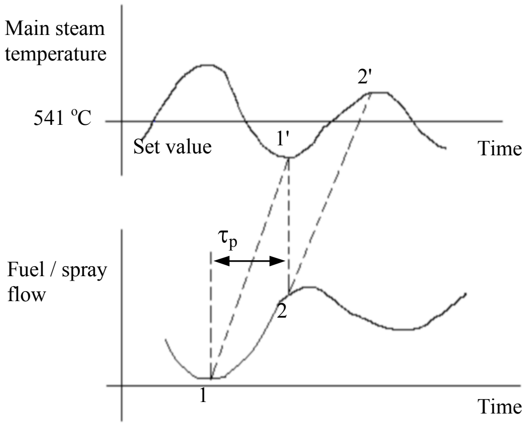

Fig. 3 The SSH exhibits a large process lag (τ_p) of the order of 8 to 10 minutes

(b) In a thermal power station, the highest work efficiency can be achieved by maintaining the highest possible steam temperatures as limited by plant metallurgy. If these temperatures can be controlled with extreme precision, they can be pushed closer to the set point value of 541 °C. With the conventional control method described above, due to the boiler and superheater dynamics and associated large process lag, it takes a long time to estimate whether the amount of spray / fuel provided is proper or not. As a result, correction is delayed and a temperature deviation of minimum ± 10°C occurs during load change as illustrated in Fig. 4. With an advanced control system, it is possible to reduce the temperature deviation and elevate the set point as close as to 539 °C.

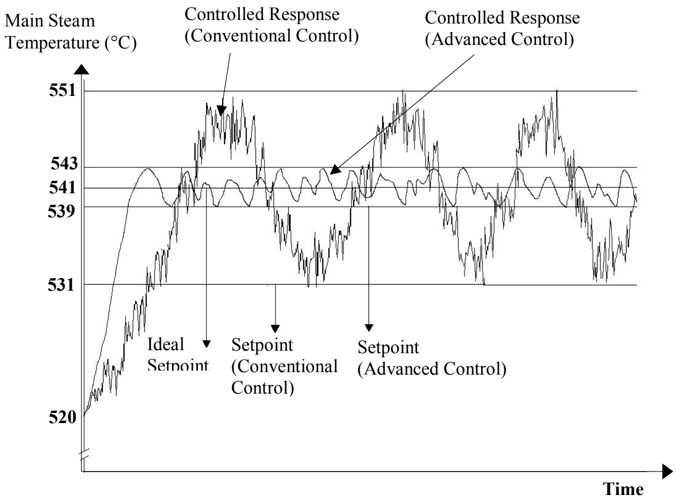

Fig. 4 Advanced Control pushes the practical setpoint very close to the ideal setpoint

(c) The value of τ_p changes heavily according to factors such as main steam flow, heat value of fuel etc.