

## Multivariable Predictive Control of the Main Steam Temperature in Power Plant

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### Abstract

*This paper aims at the problems existing in the cascade Proportional Integration Differential (PID) control of the main steam temperature system in power plants nowadays, such as large dynamic deviation, poor load adaptability etc. The two multivariable model predictive controllers are designed and applied to control the second stage desuperheater inlet temperature and the main steam temperature, respectively, which is aimed by the simulation platform for 200 MW unit. The controlled object of the main steam temperature is simulated, and both predictive control and cascade PID control strategies are designed to control the object. The results of the stimulation experiments have shown that the predictive controller is superior to the traditional cascade PID controller in dynamic deviation and load adaptability of main steam temperature in power plant.*

**Keywords:** main steam temperature, multivariable predictive control, PID, dynamic deviation, load adaptability

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### 1. Introduction

Main Steam Temperature (MST) is an important indicator of the quality of the boiler operation, so it will significantly affect safety and economical efficiency of power plants when it is too high or too low. If MST is too high, it will cause damages to the superheater, steam pipes and metals in the high pressure part of steam turbine; if MST is too low, it will cause heat consumption to raise, thermal efficiency to become lower, and the corrosion of the turbine blades to aggravate. Therefore, MST must be maintained steadily near the specified value in the operating process of boilers. That is to say that the temporary deviation does not exceed  $\pm 10$  °C and the long-term deviation does not exceed  $\pm 5$  °C [1].

The method of SURF feature point detection which is based on SIFT algorithm, use the integral image instead of the input image convolution operation, change the size of the square filters instead of scaling the image and detect the eigenvalue using the mathematical properties of the Hessian matrix. The extraction quality of the feature points may be affected to some extent, but the algorithm speed can be greatly improved, avoiding the problems of calculating large amount of data and consuming long time when using the SIFT algorithm, which is good for achieving real-time video mosaicing.

At present, the unit plants are gradually upsized so the capacities of them have been continuously increased. Thus the controlled objects of MST become more complicated than ever before. Furthermore, frequent fluctuation of the load in electricity grid leads to large change of the unit plant load. As a result, the fluctuation of MST is frequent. The cascade PID control strategy is mostly adopted to control the MST in plants nowadays. These results in larger dynamic deviation, longer response time, the poorer load adaptability and all these cannot meet the requirement of automatic control, which has a serious impact on the reliability and economy of unit operation. Predictive control is an advanced control algorithms of computer that combines the predictive model, rolling optimization and feedback correction together, which has the advantages of better control effect, stronger robustness and lower demanding of model accuracy. Compared with classical control methods, such as PID control and modern control theories, predictive control is able to get better control performance [2-7].

In order to solve the problems mentioned above, the method of multi-variable model predictive control is adopted in this paper to design reasonable control system according to the characteristics of controlled object of MST in 200MW thermal power unit, and used to solve the problems of the MST fluctuation in a large range that are caused by load change and other unknown factors. That ensures that the MST control system can operate within the prescribed scope in the long term, and also improve the safety and economy of power plants.

## 2. Predictive Controller

### 2.1. The Main Steam Temperature System

Three factors influence the main steam temperature (MST), namely the steam flow, flue gas heat and desuperheating water flow. There are also many different regulation methods adopted according to the different types of regulation mechanism. Among them, the spray desuperheating one is the widely used in power plants currently because of its flexibility, simplicity and high controllability. Due to the superheater's long pipes and complex structure, moreover, hysteretic nature and large inertia, the mode of two stage spray desuperheating is used. The first stage desuperheater is set at the entrance of the platen superheater, mainly used to protect platen superheater from tube-wall over-temperature, at the same time to adjust MST coarsely. The second stage desuperheater is set at the entrance of final superheater to adjust MST elaborately. The typical regulation setup of MST is shown below in Figure 1. In this paper, by the simulation platform for 200MW thermal power unit, the controlled object of the MST is simulated.

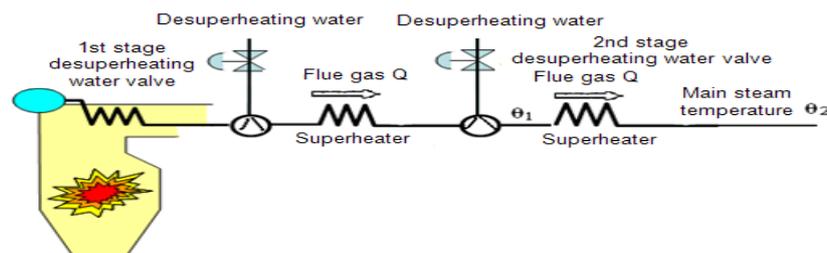


Figure 1. The Schematic Regulation Setup of MST

### 2.2. Design of the Control Strategy

In this section, based on the dynamic characteristics of the MST analysis, two predictive controllers are designed to control two desuperheaters, respectively. The design of predictive control strategy is shown below in Figure 2. For the first stage predictive controller, the controlled variable is the temperature of the second desuperheater inlet, the operating variables is valve opening of the first stage desuperheating water, and the feedforward variables are the main steam flow, main steam pressure and the temperature of the first stage desuperheater inlet. For the second stage predictive controller, the controlled variable is the main steam temperature, the operating variable is the valve opening of the second desuperheating water, and the feedforward variables are the main steam flow, main steam pressure and the temperature of the second desuperheater inlet steam.

### 2.3. Design of the Predictive Controller

In this section, the FRONT-Sutie software, which is innovated independently by Zhejiang University, is applied to design the predictive controller of MST. The functions of FRONT-Sutie software include the dynamic test, model identification, multiple variables and the constrained predictive control. Using the FRONT-Sutie software, the unrelated testing signal sequences are automatically generated and input into MST object, and the testing signals including the operating variables like the valve openings of the first and second stage desuperheating water, the feedforward variables like the main steam flow, the main steam pressure, and the temperatures of the first and second stage desuperheater inlet are saved. Based on the dynamic testing results, the models are identified by the software as shown in

Figure 3. And then, the obtained models are introduced into the predictive controllers. The parameters are set as follows: the sampling period is 1s, the prediction horizon is 300 and the control horizon is 1. Through the OPC (Object Linking and Embedding for Process Control) interface, the predictive controller can communicate with the simulation platform. Finally, the predictive controllers are put into operation.

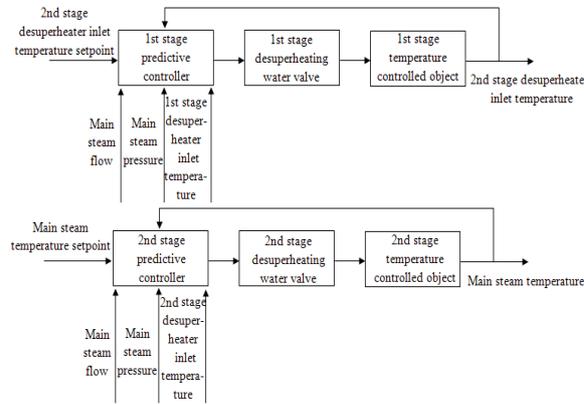


Figure 2. The Block Diagram of the Predictive Controller

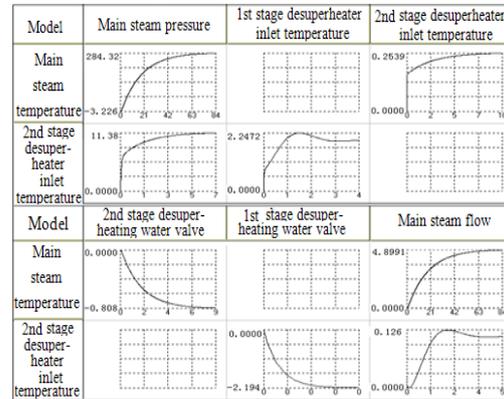


Figure 3. The Obtained Models by Identification

### 3. Results and Analysis

According to the practical operation of power plants, the experiments are determined in three different operating conditions, which include load increasing in a large range, load reducing in a large range and load swing. The controlled object of MST adopts predictive control and cascade PID control strategy, respectively. And then simulation experiments are conducted under the above operating conditions. Finally, the control performance of the two control strategies is compared.

#### 3.1. Load Increasing from 120MW to 200MW

In the experiment, the set values of the MST and the second stage desuperheater inlet temperature are set to 540°C and 515°C, respectively. After the unit plant operates steadily in 120MW, the load increases from 120MW to 200MW gradually, during this process, the predictive controller and cascade PID controller are applied to control the MST object, respectively.

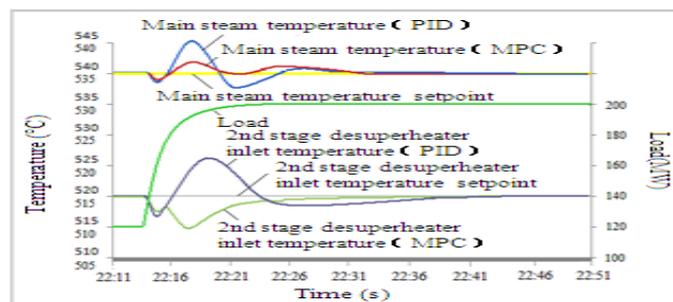


Figure 4. The Comparing Curves when the Load Increases from 120MW to 200MW

The Figure 4 shows that comparing curves of the MST and the second stage desuperheater inlet temperature for these two kinds of controllers. In the initial stage of the experiment, the coal quantity increases and the oxygen content in furnace decreases when the load increases. Therefore, the MST appears a slight decline because of that the coals can not be fully burned in a short time. In both cases, the MSTs appear the same kind of variation

trend. The predictive controller can sostenuto modify the output value on line and accurately calculate the output value of manipulated variable, so the predicted output value is closer to the actual output value compared with the cascade PID control strategy. For the predictive controller, the maximum deviation of the MST is 2.1°C and the maximum deviation of the second stage desuperheater inlet temperature is 5.2°C. For the cascade PID controller, the maximum deviation of MST is 4.5°C and the maximum deviation of the second stage desuperheater inlet temperature is 6.9°C. Obviously, the fluctuation amplitude of the MST under the predictive control strategy is less than the one under the cascade PID control strategy for the same operating condition of that the load increases from 120MW to 200MW gradually.

### 3.2. Load Reducing from 200MW to 120MW

In the experiment, the set points are as the same above. After the unit plant operates steadily in 200MW, the load reduces from 200MW to 120MW gradually, during this process, the predictive controller and cascade PID controller are applied to control the MST object, respectively. The experiment results are shown in Figure 5. For the predictive controller, the maximum deviation of the MST is 2.4°C and the maximum deviation of the second stage desuperheater inlet temperature is 6.1°C. For the cascade PID controller, the maximum deviation of MST is 4.9°C and the maximum deviation of the second stage desuperheater inlet temperature is 7.3°C. Obviously, the fluctuation amplitude of the MST under the predictive controller is less than the one under the cascade PID controller for the same operating condition of that the load reduces from 200MW to 120MW.

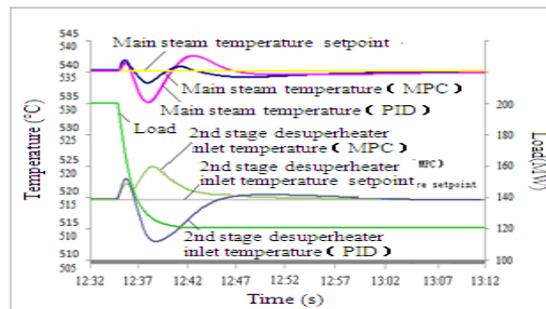


Figure 5. The Comparing Curves when the Load Reduces from 200MW to 120MW

### 3.3. Load Swing

In order to simulate the practical operation of the power plants and compare the control performance of the predictive controller strategy and cascade PID control strategy, the simulation experiments are carried out under the same operating conditions of the load swing. The comparing results are shown in Figure 6 and 7.

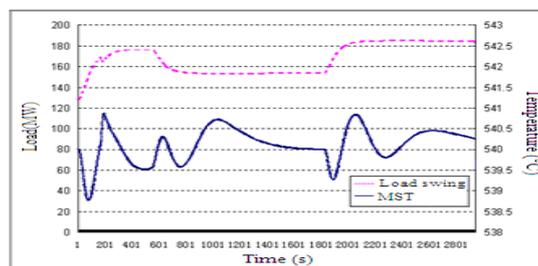


Figure 6. The MPC Ccurves under the Load Swing Conditions

The curves in Figure 6 are obtained using the predictive controller when the load swings from 127MW to 179MW, from 179MW to 156MW and from 156MW to 183MW. According to the curves, we can see that the maximum deviation of the MST is 1.2°C. When the load changes from 127MW to 179MW, the maximum deviation of the MST is 1.2°C. When the load variation

range is smaller than the above, namely changing from 179MW to 156MW, the corresponding maximum deviation of MST is 0.75°C. And when the load changes from 156MW to 183MW, the maximum deviation of MST is 0.8°C. Therefore, if the load variation range increases, the fluctuation amplitude of the MST will become larger.

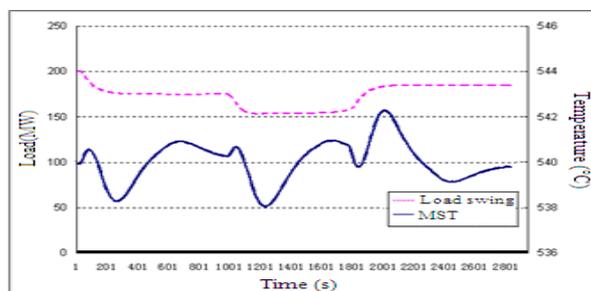


Figure 7. The PID Curves under the Load Swing Conditions

The curves in Figure 7 are obtained using the cascade PID controller when the load swings from 200MW to 175MW, from 175MW to 156MW, from 156MW to 183MW. According to the curves, we can see that the maximum deviation of MST is 2.3°C. When the load changes from 200MW to 175MW, the maximum deviation of MST is 1.8°C. When the load changes from 175MW to 156MW, the load variation range is almost the same, and the corresponding maximum deviation of the MST is 1.9°C. When the load changes from 156MW to 183MW, the maximum deviation of MST is 2.3°C. Therefore, if the load variation range increases, the fluctuation amplitude of MST will become larger.

Table 1. The Maximum Dynamic Deviations for Different Controllers under Different Conditions

	Load increasing	Load reducing	Load swing
Predictive controller	2.1 °C	2.4 °C	1.2°C
Cascade PID controller	4.5 °C	4.9 °C	2.3°C

To sum up, in all experiment conditions, the performance of the predictive controller is better than the one cascade PID controller for the control of MST.

#### 4. Conclusion

The results of the experiments in this paper show that the predictive controller can reduce the maximum dynamic deviation of the main steam temperature, the response time and have better load adaptability than the cascade PID controller. Because the predictive controller can improve the control performance of the main steam temperature system, it has the practical value in power plant control.

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