

# Study on Control Algorithms for Union Regulating with Different Strength Multiply Actuators

WAN Wen-jun, CHEN Wen, HU Kang-tao, Liu Zhe

Electric Power Research Institute of Guangdong Power Grid Co., Ltd, Guangzhou  
510080, China

**Abstract.** The deaerator control system with multiple actuators of main and vice valves was described. An improved control strategy was proposed in order to solve the problems occurred in this type control systems. Especially, the newly tacking loop was designed to satisfy no disturbance switching of the control system. Furthermore, the control algorithm expressed in this paper was confirmed by the rigorous verification of three hypotheses. Thus the no disturbance switching and system stability could be achieved by this control algorithm proposed in this paper. Finally, the control algorithm was applied in the deaerator level control system and condensation water head pressure control system. Fluctuation of the main/assistant regulating valve command was resolved thoroughly. The operation results indicate that the no disturbance switching and superior control performance are achieved after the application of the control algorithm.

## 1. Introduction

In process control, concerned with energy conservation, cost, and industrial process, different strength multiple actuators were installed to accomplish specified functions. In coal-fired power plant, there are several systems equipped with different strength multiple actuators, such as the electricity/steam driven feed pump in the water feeding control system, high/low pressure regulating valves in the speed control system of small turbine, big/small regulating valves in the water feeding system of deaerator. Several problems including balanced output, non-disturbance switching need to be solved in the design of the control system.

Currently, researchers mainly focus on intelligent and advanced control algorithms, multiple variable control system and its decoupling, while less attention was paid to the design of industrial control loop and its realization. Disturbances caused by the switching of operation mode in the control loop of different strength multiple actuators were pointed out<sup>[10]</sup>. Wan et al<sup>[2]</sup> proposed the control algorithms for different strength multiple actuators system, which provided a direction for the industrial realization of this type of control loop. However, the realization method was not provided. In this paper, the control of main/assistant regulating valves in the deaerator was used as an example to discuss the theory basis and realization method of the control system for different strength multiple actuators.

## 2. The inlet flow control system of deaerator

The water level of deaerator, which is controlled by main, assistant regulating valves, is a typical different strength multiple actuators system. The control diagram is shown in Fig.1.



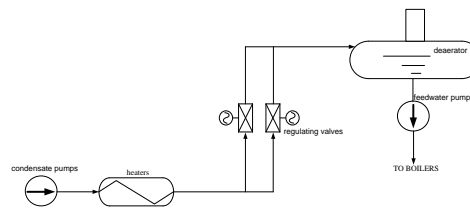


Fig.1 The control diagram of water level of deaerator

As shown in Fig.1, water from the condensate was pumped to low pressure heater by condensate pump, then it was fed to the deaerator through regulating valves. The deaerated water was fed to the furnace by the feeding pump, which was installed at the outlet of deaerator. During this process, main/assistant regulating valves are acted as the actuator for water level adjustment. The valve was turned up while the water level of deaerator was lower than the set point. Contrarily, it was turned down. During the operation process, the operation mode of main/assistant regulating valves including: both manually, both automatically, and only one automatically. It is required that manually operated valve can be in any opening degree and no disturbance between operation mode switch.

There are two traditional methods to design deaerator water level control systems. The first method is to design independent control loop for main/assistant regulating valves, while the second method unify the two regulating valves in one control loop and open these two regulating valves in sequential. Obviously, the former method utilizes two control loops to adjust one object, which is in violation of basic control principles. Besides, these two actuators are unable to simultaneously operate in automatic mode. There is no feedback for the second method, which leads to disturbance during the switch of operation mode. Therefore, a design method that realizes non-disturbance switching and superior control performance is required to improve the automatic level of the control loop.

### 3. designing of control strategies and analysing of control algorithms

#### 3.1 Control strategies

The reason for main/assistant regulating valves is as follows: assistant regulator was used to feed water at low load period, after the assistant regulator was totally opened, the main regulator was turned on. Therefore, the main and the assistant regulating valves receive the same command and they are turned on sequentially. As shown in Fig.2, with the increase of control command, the assistant regulator is turned on firstly. While the control command reaches  $X_0$ , the assistant regulating valve turns to its highest position. Simultaneously, the main regulating valve is turned on. The main regulating valve is totally opened at 100 of the control command.

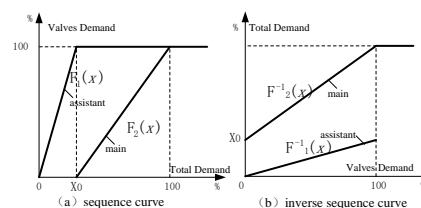


Fig.2 main and assistant valve sequential open function and its inverse-function

Except for the opening sequence of regulating valves, the control system needs to adjust the operation mode of the two regulating valves, which realizes non-disturbance switch between the switch of operation mode and turn on/off. Thus, the corresponding command balance and loop tracking need to be designed. Inspired by Wan et al, bias block and related tracking algorithms were introduced to the system.

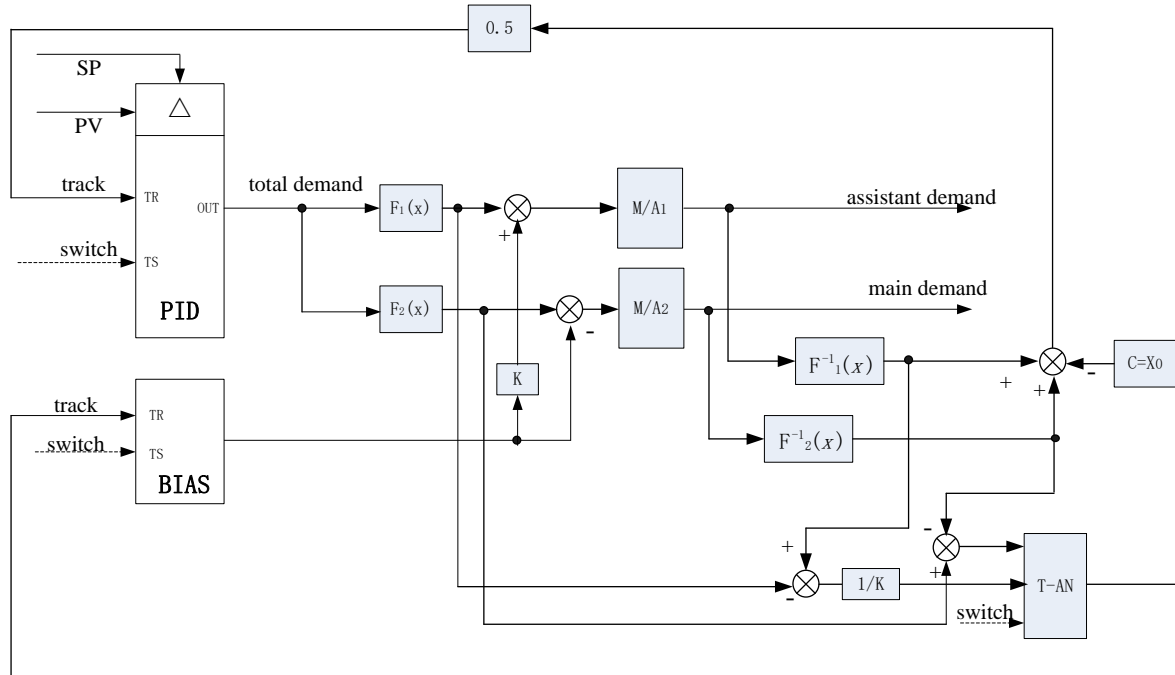


Fig.3 SAMA diagram of control system with main and assistant valves

As shown in Fig.3, output from PID controller is distributed to main/assistant regulating valves by sequential functions  $F_1(x)$  and  $F_2(x)$ . The bias block multiplied by output coefficient is added to the distribution command to modify the command of regulating valves. The calculation diagram of PID command tracker and bias, which guarantee non-disturbance switching are also provided in Fig.3.

Distribution function  $F_1(x)$ ,  $F_2(x)$  and their inverse functions  $F^{-1}_1(x)$ ,  $F^{-1}_2(x)$  are provided in Fig.2 and they are linear functions. With the increase of controller output  $P_{out}$  from 0 to  $X_0$ , the corresponding output of  $F_1(x)$  increases from 0 to 100. With the further increase of  $P_{out}$  from  $X_0$  to 100,  $F_1(x)$  remains unchanged at 100 while  $F_2(x)$  increases linearly from 0 to 100. The bias block is in tracking mode while any regulating valve is in manual mode. The controller is in tracking mode while both regulating valves are in manual mode. To study the immanent mechanism of non-disturbance switching, the tracking algorithms of PID and Bias will be analyzed as follows.

### 3.2 Analyzing of algorithms and proving of theories

#### 3.2.1 Proposal

The distribution function of main/assistant regulator  $F_1(x)$ ,  $F_2(x)$  is shown in Fig.1. When  $P_{out}$  equals to  $X_0$ , the output of  $F_1(x)$  is 100 and the output of  $F_2(x)$  is 0. With the further increase of  $P_{out}$ ,  $F_1(x)$  remains unchanged at 100,  $F_2(x)$  increases with a certain slope. The ratio of the slope of  $F_1(x)$  and  $F_2(x)$  is  $K$ , namely,  $K = \frac{100 - X_0}{X_0}$ . The ratio of the slope of  $F^{-1}_1(x)$  and  $F^{-1}_2(x)$  is  $1/K$ . To verify the

stability of algorithm and non-disturbance switching of operation mode, three hypotheses are given.

Hypothesis 1: while the assistant regulator operates is in manual mode and its command is  $Y_1$ , to satisfy the request of non-disturbance switching between different operation modes, the algorithm of control loop should be:

$$B = (Y_1 - F_1(P_{out})) / K \quad (1)$$

Hypothesis 2: while the main regulator is in manual mode and its command is  $Y_2$ , to satisfy the request of non-disturbance switching between different operation modes, the algorithm of control loop should be:

$$B = F_2(P_{out}) - Y_2 \quad (2)$$

Hypothesis 3: while both the main and assistant regulating valves are in manual mode and their

command are respective  $Y_2$  and  $Y_1$ , the PID controller is in tracking mode. To satisfy the request of non-disturbance switching between different operation modes, the output of PID and the tracking value of PID should be:

$$P_{TR} = P_{OUT} = (F_1^{-1}(Y_1) + F_2^{-1}(Y_2) - X_0) / 2 \quad (3)$$

### 3.2.2 Verification of hypotheses

#### (1) Verification of Hypothesis 1:

While the assistant regulator is in manual mode, the input of M/A1 ( $Y_{A1}$ ) block should be:

$$Y_{A1} = Y_1 \quad (4)$$

As

$$Y_{A1} = F_1(P_{OUT}) + K * B \quad (5)$$

Then

$$B = (Y_{A1} - F_1(P_{OUT})) / K = (Y_1 - F_1(P_{OUT})) / K \quad (6)$$

Hypothesis 1 is verified.

The previous equations can be reverse deduced. In other words, once the assistant regulator is in manual mode and equation 1 is founded, equation 4 can be verified, i.e. non-disturbance between the switching of assistant regulating valve operation modes.

#### (2) Verification of Hypothesis 2:

While the main regulator is in manual mode, the input of M/A2 ( $Y_{A2}$ ) block should be:

$$Y_{A2} = Y_2 \quad (7)$$

As,

$$Y_{A2} = F_2(P_{OUT}) - B \quad (8)$$

Then

$$B = F_2(P_{OUT}) - Y_{A2} = F_2(P_{OUT}) - Y_2 \quad (9)$$

Hypothesis 2 is verified.

The previous equations can be reverse deduced. In other words, once the main regulator is in manual mode and equation 2 is founded, equation 7 can be verified, i.e. non-disturbance between the switching of main regulator operation modes.

#### (3) Verification of Hypothesis 3:

The basis of hypothesis 3 is both the main and assistant regulating valves are in manual mode, which means the basis of both hypothesis 1 and 2 are founded. Thus both equation 1 and 2 are founded. Combining equation 1 and 2, we can get:

$$(Y_1 - F_1(P_{OUT})) / K = F_2(P_{OUT}) - Y_2 \quad (10)$$

Linear transformation was conducted for Equation 10:

$$F_1^{-1}[Y_1 - F_1(P_{OUT})] = K * F_1^{-1}[F_2(P_{OUT}) - Y_2] \quad (11)$$

Expand the function and inverse function in Equation 11 according to Fig.3:

$$F_1^{-1}(Y_1) - F_1^{-1}[F_1(P_{OUT})] = K * F_1^{-1}[F_2(P_{OUT})] - K * F_1^{-1}(Y_2) \quad (12)$$

As the distribution functions  $F_1(x)$  and  $F_2(x)$  are linear function and the ratio of the slope of their inverse function is  $1/K$ , equation 12 can be transformed into:

$$F_1^{-1}(Y_1) - P_{OUT} = K * P_{OUT} / K - K * F_2^{-1}(Y_2) / K + X_0 \quad (13)$$

Simplification of Equation 13:

$$P_{OUT} = (F_1^{-1}(Y_1) + F_2^{-1}(Y_2) - X_0) / 2 \quad (14)$$

In any operation mode, the control system should guarantee:

$$P_{TR} = P_{OUT} \quad (15)$$

Thus, hypothesis 3 is verified.

According to the main/assistant regulator control system shown in Fig.3, while both regulating valves are in manual mode, the switching block of Bias block choose the value from the lower pin in Fig.3, i.e. equation 1 and 3 are founded. Equation 10 derived from linear transformation is verified. In other words, the tracking of PID and BIAS block guaranteed the correctness of equation 1 and 2. Thus,

non-disturbance switching can be assured.

In summary, the control SAMA diagram and algorithm have rigorous theory support, which guarantee the stability of the control system and non-disturbance switching between different operation modes.

#### 4. Applications

According to the analysis discussed above, the SAMA diagram is applied to the control system of union regulating with different strength multiply actuators. In industrial practice, anti-integral saturation loop is required to add to the control loop designed according to the SAMA diagram. PID block in the distributed control system can be employed as the anti-integral saturation loop in single control loop system. However, the anti-integral saturation loop needs to be re-designed for the control system shown in Fig.3. In this paper, the increase/decrease lock function in PID controller is adopted in the anti-integral saturation loop. In automatic mode, the PID increase lock command will be generated if the valve opening degree is higher than 99%. Similarly, the PID decrease lock command will be generated if the valve opening degree is lower than 1%.

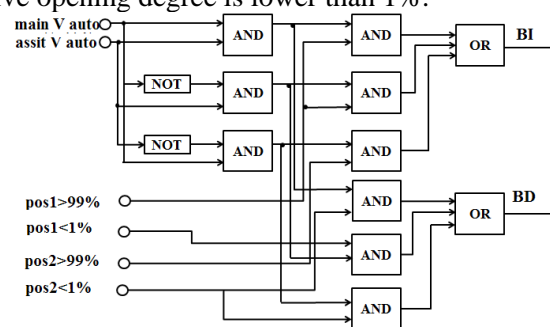


Fig.4 logic blocks of anti-windup for main valve and assistant valve control system

The control algorithm was applied to the control of deaerator with main/assistant regulating valve in a 1000 MW power plant. Non-disturbance was observed between the switching of manual/automatic mode regardless of the system in single impulse, three impulses water level control or condensation water head pressure control. In the process of step disturbance and load change, the performance of the control loop achieved the requirements of operation.

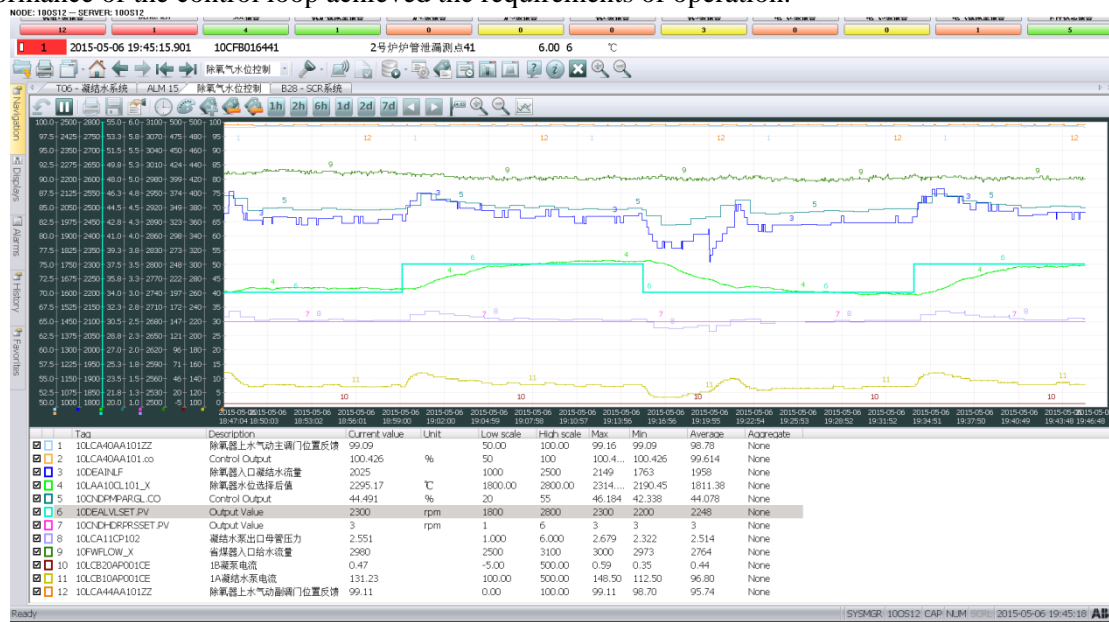


Fig.5 Step response of main/assistant regulating valve control system

In operation, the valves can be in any modes. And there is no need to rigorously open the two valves sequentially. The two valves can operate under automatic mode in any opening degree. No

sudden change was observed. Thus the operation steps can be greatly simplified.

## 5. Conclusions

(1) According to the analysis of union control with different strength multiple actuators, a control strategy that satisfies the operation conditions is proposed.

(2) According to the analysis of control algorithm, three hypotheses for the stability of control loop are proposed and verified.

(3) The control algorithms was applied to the control of water level of deaerator and condensation water head pressure control. The fluctuation between the switching of operation mode was solved. Therefore, this algorithm provides the theory support for the design of union control with different strength multiple actuators.

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