Research and Application of Prediction Control Method Based on Automatic Optimization of Coal Volume in AGC

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Abstract. One circulating fluidized bed boiler (CFB) generator set of a thermal power plant in Inner Mongolia power grid planned to put into automatic power generation control (AGC) by transforming the software and hardware of the unit. This can reduce the electricity allocation and punishment by the power grid. In order to overcome the characteristics of large delay and inertia of CFB unit and improve the quality of AGC, a multi-feedforward is added to the boiler master, the prediction section and configuration of coal quantity were designed, and a new objective function was devised to self-optimize the coal quantity. Logic of automatic optimization was made to improve the control indexes of AGC. After the AGC test was finished and AGC was put into operation, the indexes of AGC are excellent, which not only eliminates the AGC power punishment, but also obtains the reward.

Introduction

A power plant of Inner Mongolia power grid has two CFB units, The capacity of each unit is 150MW.The boiler of the unit adopts ultra-high pressure, single furnace, balanced ventilation, primary intermediate reheat, natural circulation and fluidized bed boiler, it was manufactured by Wuxi Huaguang Boiler co.,ltd. The turbine of the unit adopts a single-shaft, double-cylinder, double-exhaust, intermediate reheat and extraction condensing turbine, and it was produced by Wuhan Steam Turbine Factory. The unit's model number is C125/N150-13.24/0.245/535/535. The generator is air-cooled, and AC brushless QF-155-2 generator.

Distributed Control System (DCS) for the unit adopts XDC800 system produced by Shanghai Xinhua Company.

Inner Mongolia Power Grid Company requires that units with a capacity of 200MW and above must have AGC function and must participate in rewards and punishments system according to AGC effects of the unit. However, thermal power units that do not have AGC functions should also be penalty for power allocation. The two units in the factory have a monthly electricity punished 2 million kW.h, this had seriously affected the economic benefits of the factory. Therefore, the plant added AGC signals and designed configuration logic to reconstruct AGC function by using maintenance downtime. After the unit was started, CCS logic was optimized and AGC test has been done. The AGC quality was improved by putting feedforwards such as self-optimizing coal quantity prediction feedforward and other methods. The comprehensive performance index (Kp) of AGC has reached more than 1.6, therefore, the power plant went from electricity penalty to reward.

AGC System Reformed

Hardware Transformed

There are seven communication signals between DCS of the unit and dispatching center of power grid, including five analog signals and two switching signals. Before the joint commissioning test, checked the interface signal with the dispatching central commissioning. After adding measuring signals and setting measuring range of the signals, carried out joint adjustment of signals with the dispatchers of the dispatching center. Dispatcher issued load command, DCS can receive it correctly, the AGC permission and AGC input signals sent by DCS to the electric remote unit (RTU) could be correctly received by the central control unit. AGC related interface signals are shown in Tab.1.

Table 1. AGC related interface signal

Type	Signal Name	Measuring Range
Analog Input(AI)	AGC load command	(75～150) [MW]
Digital Input(DI)	AGC mode permit	Switch
Digital Output(DO)	AGC mode	Switch
Analog Output(AO)	load upper limit	(0～180)[MW]
Analog Output(AO)	load lower limit	(0～180)[MW]
Analog Output(AO)	Load change rate	(0～10)[MW/min]
Analog Output(AO)	Actual load	(0～200)[MW]

Software Tranformed

CCS logic had been improved and optimized ,by designing the control strategy of each main control system of boiler, adding AGC main control unit, designing and writing logic of throwing into AGC and exit AGC conditions, etc.

Simulation test had been done when the unit was not started. Setting up simulation conditions, simulated the input of coordinated control mode, and carried out switching test between the given load of the machine and the AGC load command of dispatching center to check whether the system software function is normal.

AGC Optimization

Optimization of Boiler Main Control Systems

The primary air control system changes the control object from primary air pressure to primary air volume.

The primary air volume and secondary air volume control system were changed to the air volume instruction corresponding to the load instruction (actual load instruction) after the speed limit unit, and the boiler main control instruction differentiation was added. When the unit load was unchanged but the coal volume instruction changed, the air volume could be increased or decreased according to the boiler instruction change, thus realizing the balance of boiler air and coal and improving the response speed of the boiler.

Modified the oxygen correction section and put into the oxygen automatic adjustment system.

The bed temperature correction was added to the wind volume instruction. When the bed temperature deviates from a given value, the appropriate correction will be made by the wind volume.[1]

The system of furnace negative pressure control system, main steam / reheated steam temperature control system and steam drum water level control system are optimized to improve the unit's ability to change load rapidly.

Design and Optimization of CCS

Design of Feedforward for Boiler Master Controller. Boiler master controller is an important part of CCS. It controls the main steam pressure of the unit by coal volume.

Considering that the CFB response speed is slow, it is necessary to increase the amount of coal in advance regardless of the load change or the change of the main steam pressure, in order to increase the boiler's response speed, and ensure that the parameters such as the main steam pressure is quickly adjusted and maintained when the unit is rapidly changing the load[1]. The control scheme therefore used Multiple feedforward, as shown in Fig.1.

In the actual logical configuration and debugging, not only considering the size of feedforward, but also the modifying of the unit variable load rate, and the necessary amplitude and speed limit. Among them, the forecast coal volume G1 is the deviation between the target load(AGC instruction) and the actual load instruction(the target load after the rate-limited instruction), and the corresponding coal volume prediction feedforward is obtained by the predetermined function.

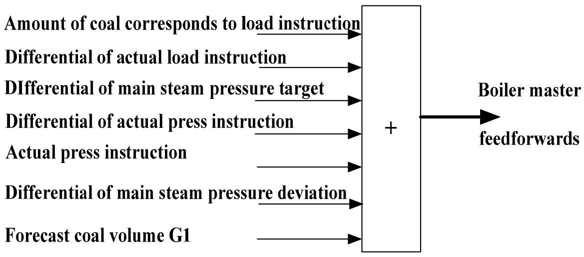

Figure 1. Boiler master feedwards

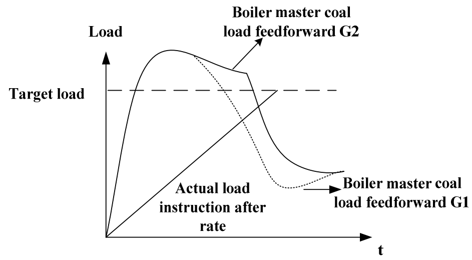

Figure 2. Comparison of curves before and after modification

Design and Application of Feedforward for Forecasting Coal Volume G1. In the process of large-scale load changes, it was found that the predicted coal volume G1 reset in the feedforward coal volume was earlier, making the main steam pressure unable to keep up with the pressure given, and there was a large deviation, resulting in large fluctuations in parameters such as coal volume, and the system was difficult to quickly stabilize. Therefore, the prediction of coal volume G1 was modified by introducing debugging experience and non-linear links. The modified curve G2 and the feedforward G1 before modified curve are shown in Fig.2.

As shown in Figure 2, when the load instruction changes, the load changes from the current instruction to the target instruction, the feedforward immediately invests a large amount of fuel; When the load has not yet changed in place, the original designed coal volume feedforward is recovered prematurely (shown in the dotted line in the figure), and the time for feedforward coal volume action is increased by modifying the predicted coal quantity G1 (shown in the solid line in the figure).

The logic of the predicted coal volume G1 feedforward of the pre-increase part is shown in Fig.3. The logic of the pre-decresse part is similar to that of the pre-increase part. The feedforward has the following characteristics.

(1) The deviation between the target load and the actual load instruction is greater than 1 MW then delay 2 s and the unit instruction is "got", then the feedforward trigger begins to function, and at the same time it is judged that the unit is in the "load instruction increase" state.

(2) The feedforward must not be reset of the first 40s after the feedforward begins to affect.

(3) When the difference between the target load and the actual load is less than 1.2 MW and the deviation between the main steam pressure instruction and the target value is less than a certain value (search optimal reset "F"), reset feedforward and eliminate the "load instruction increase" state.

(4) When the target value of the main steam pressure and the main steam pressure deviation are less than a certain value of -0.3 MPa, the feedforward is reset immediately to ensure that the main steam pressure overshoot volume is not too large.

(5) The main steam pressure of the unit adopts a fixed-pressure-sliding pressure-fixed-pressure operation mode. During the 135MW and above load operation, the unit adopts fixed-pressure operation. Since there is no need to increase the main steam pressure, the coal load feedforward multiplied by 0.5. Halve the operation

(6) In the "load instruction increase" state, the feedforward maintains the initial deviation between the target load and the actual load(the maximum deviation) to meet the demand for coal quantity when the unit increases the load;

(7) The logic of "feedforward coal reduction" and "feedforward coal increase" is similar.

The dynamic test showed that the feedforward could meet the needs of the large range of load changes, and the main steam pressure maintained a small deviation and could be quickly stabilized during the load change process. However, during debugging, it was found that the reset "F" value played a key role in regulating the quality of the control system. When the unit variable load rate changed and the coal quality changed, the reset "F" value needed to be constantly adjusted to achieve the best adjustment effect. As shown in Figure 4, when the absolute value of the reset value was large, the S1 area was large and the S2 area was small, but climbing phenomenon occurred; when the absolute value of the reset value was small, the S2 area was large and the S1 area was small, and the overshoot volume was large.

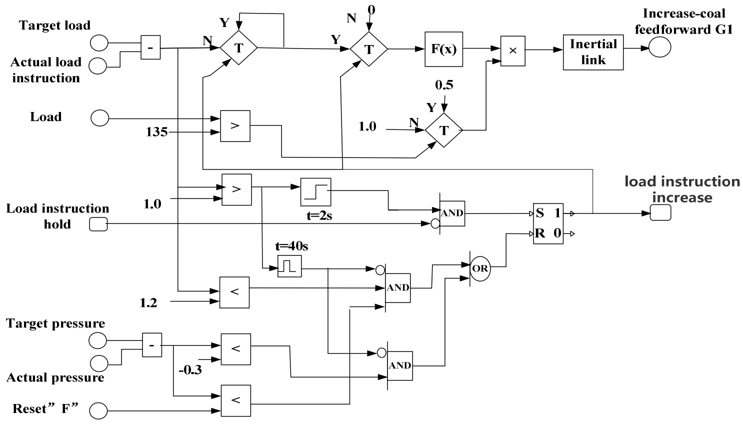

Figure 3. The logic of feedforward G1

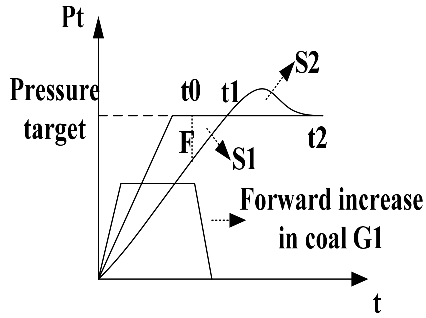

Figure 4. Forecast coal volume regulation on steam pressure

Design and Application of Self-seeking Optimization Reset "F" Value. After considering the above factors, the design objective function is shown in Eq. (1).

$$J_{\text{target}} = \min\left|c_1\int_{t0}^{t1} e(t)dt + c_2\int_{t1}^{t2} e(t)dt\right| \tag{1}$$

In Eq.1, C1 and C2 are the weights of S1 and S2. When setting, considering that excessive overshoot will bring certain dangers, C2 is set greater than C1; the specific logic of load reduction optimization is similar to the logic of load increase optimization, and the logic of load increase optimization is shown in Fig.5.

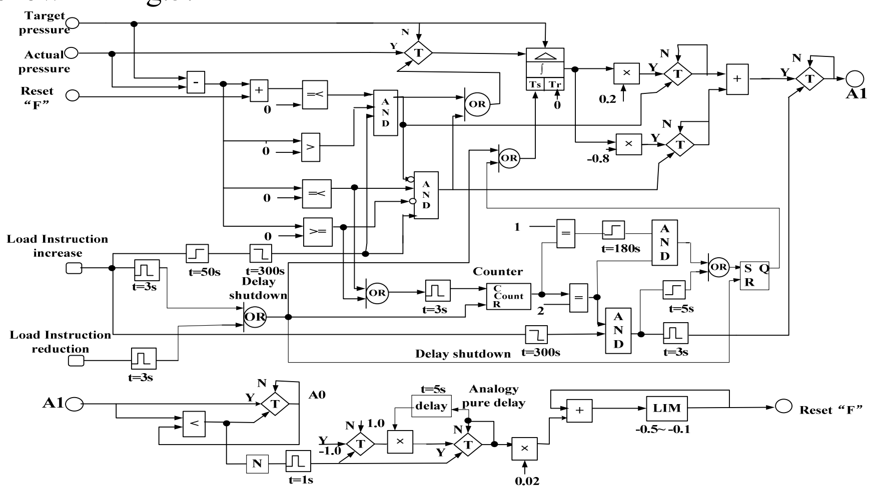

Figure 5. Automatic optimization logic of load increase feedback reset

The optimization logic algorithm of load increase feedback reset self-seeking is specified as follows.

(1) Setting the weight C1 = 0.2, C2 = 0.8 in the logic.

(2) Both S1 and S2 are obtained by integrators.

(3) After the process begins, when the target pressure is the same as the actual pressure, it is t1 moment, the counter begins to record the number of times. When the target pressure and the actual pressure are the same again, that is, t2 moment, the counter begins the second count.

(4) When the "load instruction increase" state disappears for 300 seconds and the two counting processes are not completed, the optimization is invalid, the system is reset, the parameters are cleared or the previous value is retained.

(5) When the second count is not counted within the first count of 180s, the optimization is considered invalid and the system is reset.

(6) In the process time, the load is not changed again, and the two counts are completed, the optimization process is considered valid, and the target function integral value is recorded in A1.

(7) The A1 value recorded after the end of this integral is compared with the A0 value recorded last time. If A1 is greater than A0, the reset "F" value is increased or reduced by a certain value of 0.02; If the last time was an increase of 0.02, then this time the decrease is 0.02.

(8) The A1 value recorded after the end of this integral is compared with the A0 value recorded last time. If A1 is less than A0, the reset "F" value continues to increase or decrease by 0.02; If the last time it was increased by 0.02, this time it will continue to increase by 0.02.

(9) According to debugging experience, the reset "F" value is limited between -0.5 and -0.1.

(10) While the integrator Ts = 1, the integrator tracks the value and sets "0".

(11) The system adopts uninterrupted cycle optimization, which will be optimized as long as the conditions are met.

(12) The optimization logic for load reduction is the same as that for load increase.

Fuel Master Optimization. The feedback value in fuel main control is changed from the coal machine instruction of the sum of the effective operation to the coal machine feedback of the sum of the effective operation. After modified, when the coal machine is blocking, the loss of coal volume can be automatically compensated by the fuel master control to ensure that the main steam pressure is stable. The coal quality correction function is designed. The coal quality of the plant is unstable. Adding this function can be manually or automatically compensated by coal quality operations, which increases the flexibility and stability of the system operation.

Turbine Master Optimization. The turbine master controlling load, directly affects the AGC indexes. Therefore, integration and proportionality of the PID controller are strengthened through testing, and the load instruction differential feedforward was introduced to improve the response speed of the adjustment system. By optimizing the flow characteristics of the valve, the adjustment effect under different opening degrees of the turbine master was improved.

Test Results

Disturbance Test

The unit is in the AGC operating mode to carry out load change tests. The load change test is divided into two sections: the load reduction test between 140MW and 100MW and the load increase test between 100MW and 130MW, respectively. The CFB unit variable load rate requires 1% Pe/min. Setting the unit variable load rate at 1.8 MW/min(1.2 % Pe/min) during the test. The adjustment trend chart of the main parameters during load increase or reduction test is shown in Fig. 6.

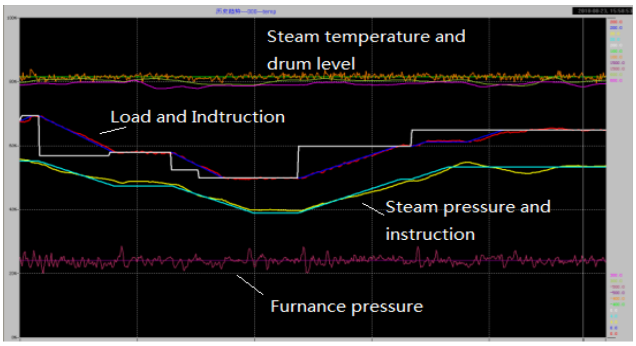

Figure 6. Load disturbance test curve

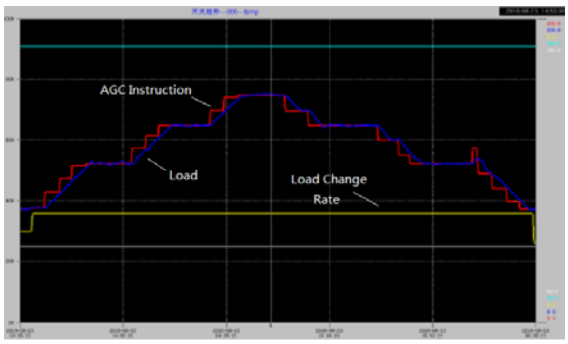

Figure 7. AGC test curve

During the load disturbance test, the data records and comparative analysis of the test results of each parameter of the unit are shown in Tab.2. The indexes fully meet and exceed the requirements of the regulations. The load deviation and main steam pressure deviation achieved good results.

AGC Test

Before the AGC load following test, the coordinated control operation mode is the coordinated control mode (CCBF) of the boiler following the steam turbine, the load change rate is 1.8 MW / min, and the dispatch center instruction range is 50 % Pe to 100 % Pe, that is, 75 MW to 150 MW, sliding pressure mode, The AGC test curve is shown in Fig.7.

During the test period, the maximum dynamic deviation of the main steam pressure was 0.37 MPa and the maximum dynamic deviation of power was 2.2 MW, which achieved a better result.

Table 2. The results of load variation test[2]

Parameters		Dynamic quality indexes of load variation test and AGC load following test	Stable quality indexes
Load instruction change rate [%Pe·min^{-1}]	Allowed value	1	/
	Actual value	1.2	/
Actual load change rate [%Pe·min^{-1}]	Allowed value	≥1	/
	Actual value	1.2	/
Load response delay time [s]	Allowed value	60	/
	Actual value	25	/
Load bias [MW]	Allowed value	±3	±1.5
	Actual value	-2.6～+1.5	-0.5～+0.6
Main steam pressure bias [MPa]	Allowed value	±0.39	±0.26
	Actual value	-0.33～0.25	-0.25～0.23
Main steam temperature [℃]	Allowed value	±8	±3
	Actual value	-5.2～3.4	-2.6～1.9

Conclusion

In the process of AGC logic designed and optimized in the 150MW CFB unit, the self-seek optimization control method was used for the first time, introduced into the CCS coal volume feedforward, and configured in the DCS to achieve the automatic optimization reset function and coal volume prediction function. The idea of the staff was introduced into the electronic equipment, which reduced the workload of the personnel and effectively improved the control quality of the AGC. In the process of changing the load, the main steam pressure can be quickly stabilized and the safety of the boiler can be improved.

Although this control method is not as profound as modern control theory, it also has advantages that modern control theory does not have, such as needless to establish accurate mathematical models, the small calculation online, easy to implement on the spot and so on.

The artificial intelligence (AI) technology is prevalent now, this control method can replace experts to perform calculations. In a certain sense, it can also be called an artificial intelligence. However, the application of this method in DCS is an attempt. It is not yet complete in some aspects and it still needs to be perfected.

References

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