Closed-loop Design and Simulation Analysis for Condenser Pressure Control on Direct Air-cooled Units

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Abstract. Variable-speed fans are employed to support cold source for direct air-cooled units, and their speed regulation can ensure continuous control of condenser pressure and turbine power. The condenser pressure closed-loop control system is, on the basis of safe regulation, designed to ensure the unit changing its load with a rapid speed when it is in a load-change condition. The dynamic model of fan speed to condenser pressure is set up by identification method and a novel load-change strategy based on the condenser pressure regulation is proposed. The simulation on a 300 MW unit has proved it improves the load-change capability significantly.

1. Introduction

China's current new energy power has developed rapidly and in order to achieve large-scale consumption better, enhance the safety and stability of power system operation, thermal power unit, occupies the dominant position of energy, is required to continuously improve their rapid depth variable load capacity, with faster response speed and stronger peaking capacity [1]. In July 2016, the National Energy Board issued "notice on the power flexibility modification pilot project" to determine the Dandong and other 16 power plants as pilot project to tap the potential of peak coal-fired units and enhance the flexibility so as to improve the ability of system peaking and new energy consumption.

Compared with wet cooling unit, direct air-cooled unit, air as the cooling medium, can save a large amount of water resources and big production in the north. For condenser pressure, the existing research only considers its contribution to operating efficient performance, but to a certain extent, it ignores the potential to variable load performance. Study shows that the power deviation can reach 0.5%-1.5% of the rated power when condenser pressure is 1 kPa deviating from the design value, and the higher initial condenser pressure, the greater change of the output [2]. The time required from changes of cooling air to condenser pressure to unit output is only about 30s [3]. Therefore, both from the aspects of range and speed, fan speed (condenser pressure), the control variables of unit variable load control, has well-content effect. Especially the response speed, the effect is far better than fuel volume control. However, considering the unsustainability of its control effect, this paper designs it as the auxiliary strategy of traditional coordinated control, mainly used to improve the response rate of initial load.

In summary, the effect of condenser pressure on the load response rate was significant. In this paper, the closed-loop optimization control system is designed, the unit is operating under the premise of safe back pressure range, to realize fast load tracking under variable load conditions.

2. Closed-loop design for condenser pressure control

Condenser pressure quickly responds to unit output and it can significantly improve load response rate at the initial stage of the variable load, but its ability to respond to large range is weak. And the effect and advantages of traditional coordinated control are exactly opposite to it [4-5]. Therefore, the union of the two could realize the predominance. Based on the above analysis, a new load change control strategy, the combination of the traditional coordinated control and condenser pressure regulation, should have the following functions. (1) The condenser pressure control circuit should operate quickly, reduce or even eliminate the deviation when the power deviation is up to the requirement; (2) as the heat signal tracking, condenser pressure should gradually return, until to the original value in the final state; (3) the load deviation input of coordinated control strategy in the whole control process should not contain the part caused by condenser pressure adjustment to reduce the influence of load during the correction of condenser pressure and ensure that all load changes are borne by fuel flow in the final control state simultaneously. The variable load control strategy according to this design is shown in Figure 1.

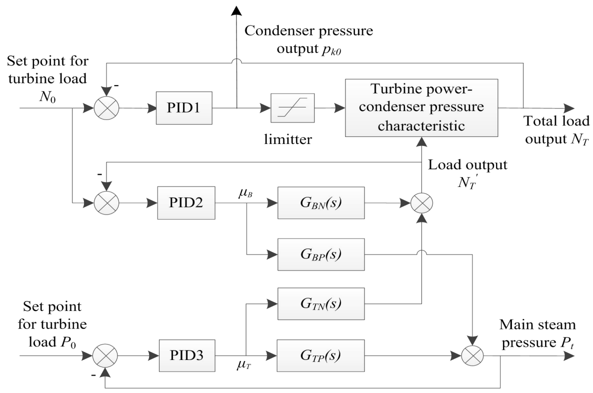

Figure 1. Novel load change control strategy combining CCS with condenser pressure control

The strategy contains two load control loops, and the control variables are the condenser pressure and the fuel flow respectively, in which the former circuit is single loop control. Once the input, the deviation between the target load and the actual load, changes, it can use the characteristic that the fast response rate of the condenser pressure to the load to move quickly. As for the latter control circuit, the input is the deviation between the target load and the coordinated load output so that the fuel flow command is consistent with the target load. It ensures that load change of the unit is entirely borne by the fuel flow in the final state, meanwhile the unit load fluctuation is avoided during the callback of condenser pressure. It can be predicted that the load will be the first time to achieve the target load is the critical point of the callback with the combined control of fuel flow and condenser pressure. For Fuel flow instruction under the fuel flow control circuit corresponding to the target load, it will continue to be regulated towards target load, here the load deviation, received by condenser pressure control loop, will be reversed, and the condenser pressure begin to callback, and eventually return to its initial state. In the novel load change control strategy, the coordinated control strategy adopts the traditional "turbine follow boiler" mode, and the main steam pressure is mainly controlled by the turbine control valve to ensure that the vapour pressure does not fluctuate greatly.

3. Simulation and performance analysis of variable load control

The linearized control model of a 300 MW unit under rated operation at 100% turbine power is expressed as [6]:

$$\begin{bmatrix} N_T \\ P_t \end{bmatrix} = \begin{bmatrix} \dfrac{2.069(311s+1)}{(149s+1)^2(22.4s+1)} & \dfrac{4.665s(99s+1)}{(58^2s^2+50s+1)(4.1s+1)} \\ \dfrac{12.65(205s+1)}{(128s+1)^2(11.7s+1)} & -14.2\left(0.04+\dfrac{0.96}{70s+1}\right) \end{bmatrix} \begin{bmatrix} \mu_B \\ \mu_t \end{bmatrix} \tag{1}$$

where P_t is the main steam pressure, MPa; μ_B is the fuel flow, t/h; μ_t is the turbine valve position.

We build the Simulink simulation model according to the variable load control strategy proposed in the above section (shown in Figure 1), as well as the traditional coordinated control strategy, then carry out a simulation comparison. The process is as follows: the initial set value of unit load command and steam turbine main steam pressure is 300 MW and 17.5 MPa. In the 200 s (model has been in steady condition) the load instruction input step increases 10 MW and the main steam pressure input remains unchanged. The response curve of load command is shown in Figure 2, which can be seen that the control strategy of adjusting load response time in this paper of is about 18 s and greatly reduced, compared with the traditional coordinated control strategy (about 52 s). At the same time, the overshoot of the load response (0.65%) is significantly smaller than that of the traditional coordinated control strategy (1.29%). The response curve comparison result of main steam pressure is shown in Figure 3. The control strategy in this paper is superior to the traditional coordination control strategy in both the adjustment time and the overshoot.

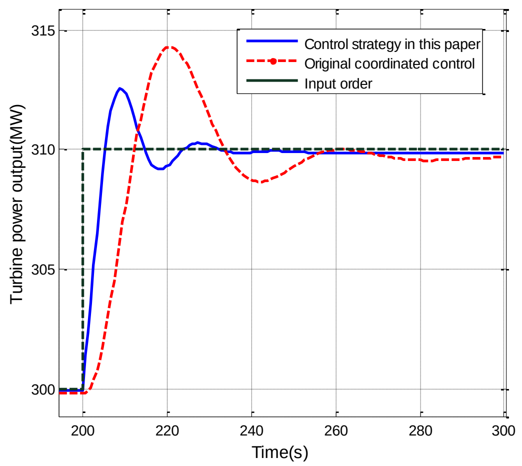

Figure 2. Response curves comparison of turbine power output

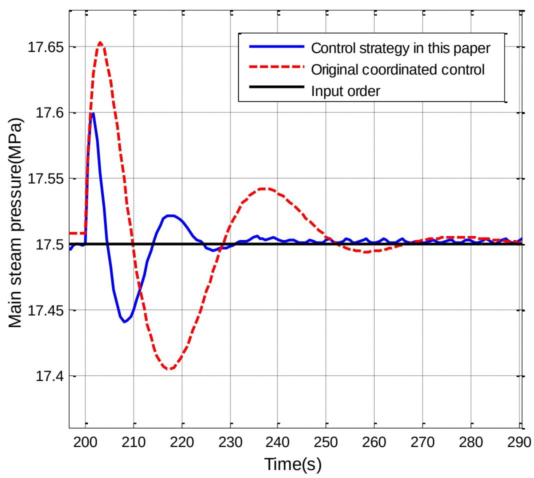

Figure 3. Response curves comparison of main steam pressure

Further calculation of the ITAE index of the two strategies [7]:

$$ITAE = \int_0^t t|e(t)|dt \tag{2}$$

The calculation results are shown in Table 1, which can be seen obviously that the ITAE index of the control strategy in this paper is significantly better than the traditional coordinated control strategy.

Table 1. Control index comparison of ITAE

	Control strategy in this paper	Original coordinated control strategy
$ITAE\_N_T$	7308	28926
$ITAE\_P_t$	96.55	536.8

Summary

In this paper, the dynamic model of fan speed to condenser pressure is set up by identification method and a novel load-change strategy based on the combination of condenser pressure regulation and coordinated control strategy is obtained. Taking a unit as an example, compare the control strategy effect of this paper with the original coordinated control strategy and the results prove that the novel strategy can shorten the accommodation time and reduce the overshoot and accelerates the load change rate greatly.

Acknowledgement

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References

[1]LIU Jizhen, Basic issues of the utilization of large-scale renewable power with high security and efficiency, Proceedings of the CSEE. 33 (2013) 1-8.

[2]Xu Damao, Ke Yan, Wang Shiyong Universal method for calculating the power/back-pressure characteristics of a steam turbine and its applications, Journal of Engineering for Thermal Energy and Power. 25 (2010) 605-608.

[3] Ren Guohua, The optimization of condenser pressure control system direct air cooled condenser based on NNPC, Shanxi University. 2012, Taiyuan.

[4] GUO Minchen, XIE Jinglan, LI Peng. Analysis on Optimum Vacuum of Direct Air-cooled Unit Under Variable Working Conditions [J]. Journal of Chinese Society of Power Engineering, 2012,32(7): 542-546.

[5] SHI Yan. The Determination Method of the Optimal Back Pressure in Direct Air-cooled Condenser[J]. Northeast Electric Power Technology, 2014, 35(1): 44-47.

[6]Wu Guoyuan, Li Donghai, Xue Yali, et al, Tuning of decentralized PID controllers for coordinated boiler-turbine control, JOURNAL-TSINGHUA UNIVERSITY. 44 (2004) 262-265.

[7]Xu Feng, Li Donghai, Xue Yali, Comparing and Optimum Seeking of PID Tuning Methods Base on ITAE Index , Proceedings of the Csee. 23 (2003) 206-210.