Analysis on energy consumption index system of thermal power plant

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Abstract. Currently, the increasingly tense situation in the context of resources, energy conservation is a realistic choice to ease the energy constraint contradictions, reduce energy consumption thermal power plants has become an inevitable development direction. And combined with computer network technology to build thermal power "small index" to monitor and optimize the management system, the power plant is the application of information technology and to meet the power requirements of the product market competition. This paper, first described the research status of thermal power saving the ory, then attempted to establish the small index system and build "small index" monitoring and optimization management system in thermal power plant. Finally elaborated key issues in the field of small thermal power plant technical and economic indicators to be further studied and resolved.

1. Introduction
With the implement of the policy of “power plants separated from electric network, competing electric price” in China power industry, the power generation enterprises make efforts to reduce cost and improve efficiency of power generation to succeed in the competition. Meanwhile, along with the increasing emphasis on environmental protection, as the primary energy guzzler and pollution emitters, thermal power plants has to consider how to achieve high efficiency and low emissions on the basis of providing reliable power for the sustained and healthy development of national economy[1]. Therefore, under the premise of safe and reliable operation, it is of great significance to reduce the coal consumption rate of thermal power units, and to improve the thermal economy of the thermal power units [2]. The operation and management of thermal power plants is mainly to control the main indicators of thermal power system, if these indicators are controlled, the unit can run safely and economically.

In this article, we reviewed and discussed the monitoring and optimizing management of small index of thermal power unit from following aspects: First, development status of performance monitoring of power plant thermodynamic system at home and abroad, and construction method of small index system are introduced. Then, sorting out the meaning and algorithm of all the small indexes involved and pointing out the problems existing in the research work and the key problems to be studied in the next step, in order to provide a scientific basis for the establishment of small index monitoring and optimization management system for thermal power units.
2. Research Status

2.1. Abroad Research Status
In early 1970, The United States, Britain, France and other countries have been pumping money for the research into performance monitoring of power plant thermodynamic system, and lay a foundation for the operation optimization of thermal power unit. In the beginning, the performance monitoring of the unit is mainly used as an additional part of the data acquisition and data processing system [3]. From the beginning of 80s, the performance monitoring of power plants is gradually developing in the direction of guiding the on-site operation and completing the performance and overall performance analysis and diagnosis[4]. After years of development, a large number of software of thermal power plant operating optimization management are constantly emerging at abroad. Among them, the function of some software package, which has been applied in a number of foreign plants, is outstanding and complete, such as the Synergy system of German Siemens company and the Optima system of Swiss ABB company, which can be supplied as a whole and divided into different needs as well[5].

2.2. Domestic Research Status
Because of the implementation of the reform and opening policy in 1980s, the automatic information technology of thermal power plant in China has entered a period of rapid development on the basis of large-scale electric power construction. At present, many researches have been done on the performance monitoring of thermal power plant, and some research institutes and universities have done a lot of research in the field of operation management software. In order to make the performance analysis and optimization of the operation of the unit reach the international advanced level, such as Tsinghua University, Wuhan university, North China Electric Power University and Southeast University. Some thermal power plants in China have put the real time optimization management software in actual production activities, for example, the on line energy loss analysis and optimization system for thermal power plant, which was developed by the Institute of thermal power and automation in Zhejiang university, has put into use in the 300MW unit of Guangdong Shajiao Power Plant [6].

3. Construction of small index system
At present, DCS, MIS, SIS and other intelligent optimization software in China's thermal power enterprises, which can supervise and manage the operation index value of the unit in real-time or post-processing, have entered the stage of mature application. Thus, the control level of the unit has been more precise and reduced the cost of power generation. For the monitoring software, whether the evaluation index is scientific or not has great influence on its accuracy and practicability[7]. Therefore, the study of the technical and economic indexes of thermal power plant is quite necessary. In this paper, the small index system of thermal power plant is constructed based on the coal-saving index and electricity-saving index. As shown in Table 1.

3.1. Coal-saving index

3.1.1. The main boiler performance index (1) Boiler thermal efficiency (anti-balance method):

$$\eta_{b1}=100-\left(q_2+q_3+q_4+q_5+q_6\right)$$

Where, $q_2$ is boiler exhaust heat loss, $q_3$ is heat loss of chemical incomplete combustion, $q_4$ is heat loss of mechanical incomplete combustion, $q_5$ is heat loss of dispelling heat of boiler, $q_6$ is physical heat loss of ash.
Table 1. The small index system of thermal power plant

| Target layer               | First-class index | Second-class index                                                                 |
|----------------------------|-------------------|-------------------------------------------------------------------------------------|
| Coal-saving index          | The boiler performance index | Boiler thermal efficiency, Boiler exhaust heat loss, Heat losses of chemistry incomplete combustion, Heat loss of mechanical incomplete combustion, Heat radiation loss, Heat loss due to sensible heat in slag, Excessive air coefficient, Superheated steam pressure, Superheated steam temperature, Reheat steam pressure, Reheat steam temperature, Leakage rate of air preheater |
| Electricity-saving index   | The steam turbine performance index | Steam turbine heat rate, Steam turbine thermal efficiency, Turbine steam rate, Turbine back pressure, Heater’s upper terminal temperature difference, Heater’s bottom terminal temperature difference, Feed water temperature of high pressure heater outlet, The vacuum of the steam condenser, Inlet temperature of circulating water, Temperature rise of circulating water, Terminal temperature difference of steam condenser, Exhaust steam temperature |
|                           | The unit consumption and electricity consumption rate of auxiliary machine | The unit consumption and electricity consumption rate of coal mill, The unit consumption and electricity consumption rate of powder evacuation machine, The unit consumption and electricity consumption rate of air feeder, The unit consumption and electricity consumption rate of induced draft fan, The unit consumption and electricity consumption rate of water feed pump, Electricity consumption rate of circulating water pump, Electricity consumption rate of condensate pump, Electricity consumption rate of coal handling system, Electricity consumption rate of dashing device, Electricity consumption rate of desulphurization equipment system, |

(2) Superheated steam pressure and temperature
The superheated steam pressure and temperature refer to superheated steam pressure and temperature of boiler final superheated outlet, if the final superheated outlet of the boiler is provided with a plurality of main stream pipes, we should take its arithmetic mean value.
(3) Excessive air coefficient
The ratio of the actual air supply to the theoretical air volume is called the excess air coefficient. In order to make the coal can complete combustion in the furnace, reduce loss of incomplete combustion, the actual amount of air into the furnace is higher than the theoretical air volume, so that the combustion reaction can be carried out in the presence of excess oxygen.

(4) Leakage rate of air preheater

\[ A_L = \frac{RO_2 - RO_2'}{RO_2} \times 90\% \]  

Where, \( RO_2 \) is the volume percentage of three atomic gases in the inlet of air preheater, the unit is \( \% \); \( RO_2' \) is the volume percentage of three atomic gases in the outlet of air preheater, the unit is \( \% \).

3.1.2. The main steam turbine performance index

(1) Steam turbine heat rate
For reheat steam turbine, the calculating formula as follow:

\[ q = d \left( h_{ms} - h_{fw} \right) + \frac{G_{ms}}{G_{r}} \left( h_{rhr} - h_{rhl} \right) \]  

Where, \( q \) is heat rate, the unit is \( \text{kJ/kW} \cdot \text{h} \); \( h_{rhr} \) is the enthalpy of reheater outlet steam, \( h_{rhl} \) is the enthalpy of reheater inlet steam, \( h_{ms} \) is the enthalpy of live steam, \( h_{fw} \) is the enthalpy of boiler feedwater, the unit is \( \text{kJ/kg} \); \( G_{ms} \) is main stream flow, \( G_{r} \) is reheated steam flow, the unit is \( \text{kg/h} \); \( d \) is steam rate, the unit is \( \text{kJ/kW} \cdot \text{h} \).

(2) Steam turbine thermal efficiency

\[ \eta = \eta_c \eta_i \eta_m \eta_g = \frac{3600}{q} \times 100\% \]  

Where, \( \eta_c \) is cycle thermal efficiency of steam turbine, the general value is 36\%-54\%; \( \eta_i \) is relative internal efficiency of steam turbine; \( \eta_m \) is mechanical efficiency of steam turbine; \( \eta_g \) is generator efficiency, high-power generator efficiency is generally 98\%-99.5\% .

(3) Turbine steam rate

\[ d = \frac{D_{eq}}{P_{eq}} \]  

Where, \( d \) is turbine steam rate, the unit is \( \text{kg/kWh} \); \( D_{eq} \) is the main stream flow entering the turbine, the unit is \( \text{kg/h} \) or \( t/h \); \( P_{eq} \) is the generation load of steam turboset, the unit is kW.

(4) Heater’s terminal temperature difference
Heater’s upper terminal temperature difference is the difference between the saturation temperature under heater inlet steam pressure and the outlet temperature of the heater heating, the unit is \( ^\circ \text{C} \). Heater’s bottom terminal temperature difference is the difference between the drainage temperature of the working fluid into the drain cooler and out the drain cooler, the unit is \( ^\circ \text{C} \).

(5) The vacuum of the steam condenser

\[ V_{zkd} = 1 - \frac{P_{zk} \cdot D_{zk}}{98.1} \times 100 \]
Where, \( V_{zkd} \) is the vacuum of the steam condenser, the unit is \( \% \); \( P_{dq} \) is the atmospheric pressure, the unit is mmHg; \( P_{zk} \) is the absolute value of condenser vacuum, the unit is mmHg.

(6) Exhaust steam temperature

Exhaust steam temperature is the temperature when steam worked in the steam turbine and discharged into the condenser, which also named saturation temperature, is an important indirect index which is often ignored but important in steam turbine operation. There is a one-to-one relationship between exhaust temperature and exhaust pressure, when the exhaust temperature changes 1 ℃, the coal consumption changes about 1.1 g/(kW·h).

\[
\frac{t_{pq}}{t_{sh}} = t_{sh}^{wk} + t_{sh}^{ws} + t_{pq}^{dc}
\]  

(7)

Where, \( t_{pq} \) is the exhaust steam temperature, the unit is ℃; \( t_{sh}^{wk} \) is the inlet temperature of circulating water, the unit is ℃; \( t_{sh}^{ws} \) is the exhaust steam temperature of condenser, the unit is ℃; \( t_{pq}^{dc} \) is the terminal temperature difference of condenser, the unit is ℃.

3.2. The main electricity-saving index

(1) The unit consumption and electricity consumption rate of coal mill

\[
L_{nm} = \frac{W_{nm}}{W_{fd}} \times 100\%
\]  

(8)

Where, \( L_{nm} \) is the electricity consumption rate of coal mill, the unit is \( \% \); \( W_{nm} \) is the amount of electricity consumed during the grinding of pulverized coal, the unit is kWh; \( W_{fd} \) is the generating capacity during given period, the unit is kWh.

\[
Dh_{nm} = \frac{W_{nm}^{yd}}{M_{mf}}
\]  

(9)

Where, \( Dh_{nm} \) is the unit consumption of coal mill, the unit is kWh/t; \( W_{nm}^{yd} \) is the amount of electricity consumed during the grinding of pulverized coal, the unit is kWh; \( M_{mf} \) is the amount of pulverized coal produced by coal mill during given period, the unit is t.

(2) The unit consumption and electricity consumption rate of powder evacuation machine

The electricity consumption rate of powder evacuation machine refers to the percentage of electricity consumption of powder evacuation machine out of the generating capacity during given period. The unit consumption of powder evacuation machine is the electricity consumption while powder evacuation machine exhausting the mixture of air and dust produced by per ton pulverized coal, characterizing the operation economy of powder evacuation machine.

(3) The unit consumption and electricity consumption rate of air feeder

The electricity consumption rate of air feeder is the percentage of the amount of electricity that the air feeder consumed by producing steam in the boiler out of the generating capacity during given period. The unit consumption of air feeder refers to the amount of electricity consumed by the air feeder producing per ton steam in the boiler.

(4) Electricity consumption rate of coal handling system

\[
L_{sm} = \frac{W_{sm}}{W_{fd}} \times 100\%
\]  

(10)
Where, $L_{sm}$ is the electricity consumption rate of coal handling system, the unit is %; $W_{sm}$ is the amount of electricity consumed by coal handling system, the unit is k·Wh.

(5) Electricity consumption rate of desulphurization equipment system

$$L_d = \frac{W_d}{W_{du}} \times 100\%$$

(11)

Where, $L_d$ is the electricity consumption rate of desulphurization equipment system, the unit is %; $W_d$ is the amount of electricity consumed by desulphurization equipment system, the unit is k·Wh.

4. Conclusions

The main work and important conclusions of this paper are as follows:

With the gradual implementation of energy saving and emission reduction policies and the construction of energy-saving society, the development of China's thermal power will tend to be more efficient, more energy saving, and more environmentally friendly.

In this paper, the small index system of thermal power plant is constructed based on the boiler performance index, the steam turbine performance index, and the unit consumption and electricity consumption rate of auxiliary machine. It has a certain reference value for the establishment of "small index" monitoring and optimization management system to further regulate the energy conservation management and tap the energy saving potential of the thermal power plant.

The future direction of this paper: The following research will be based on the small index system established in this paper, and combined with usual operation experience, establishing a comprehensive small finger library, covering all the systems and equipment involved in the operation of the thermal power plant, including turbine, boiler and others. Then according to the requirements of the user and the actual operation of the unit, select all or some of the small indicators, to complete the small index monitoring and optimization management system implementation case based on the DCS and SIS system of operation unit. To realize the real-time monitoring, operation optimization and statistical management of unit operation small index, provide guidance for the operator to implement the "small index" energy-saving operation, help the technicians and managerial personnel control the "small index" running state of the unit, provide guidance and suggestions for the development of energy saving technical innovation and operation management system for power plant.

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References

[1] Yuan G L, Zhang J H, Wang T H, et al. Comprehensive energy-saving evaluation of thermal power plants based on TOPSIS gray relational Projection and the Weight Sensitivity Analysis[J]. Journal of Chinese Society of Power Engineering, 2015, 35(5): 404-11

[2] Hu Y, Liu J ZH, Zeng D L, et al. Thermo-economic analysis for water make-up system of power plant condensers[J]. Journal of Chinese Society of Power Engineering, 2013, 33(5): 370-74

[3] Xu X B. On-Line Calculation on Thermo-economic indicators for a large fire power generating unit[D]. Taiyuan: Taiyuan University of Technology, 2008:1-2

[4] Sun L W. Investigation of energy-saving emission reduction and optimization real-time system for power plants[D]. Taiyuan: Shanxi University, 2010:1-3

[5] Shi B. The research on operation performance appraisal system of large-scale thermal power plant[D]. Harbin: Harbin Engineering University, 2007: 5-7

[6] Li B, Ren R, Ren H R, et al. Online energy-loss analysis & optimization system for fossil-fuel power plants[J]. Energy Engineering, 2001, 28(6):34-36

[7] Zhou Y B, Hu X L, He T, et al. Index management system and its implementation for thermal power station[J]. Electronic Power, 2002, 35(10): 77-80

[8] Jiang M C. Handbook of energy consumption index analysis of thermal power plant [M]. Beijing: China power press, 2011

[9] Li Q, Gong W P. Energy saving and index management technology of thermal power plant M. Beijing: China power press, 2006