Research on the Application of Operational Optimization Expert Analysis System Technology

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Abstract. At present, the national power system is gradually achieving separation of government and enterprise, and corporate restructuring; Implement the separation of network factories and bidding for online access, and gradually establish a modern enterprise system. Effectively carrying out energy conservation and consumption reduction work, reducing the cost of power generation and supply, is an inevitable requirement for the survival and development of power enterprises themselves.To effectively carry out energy-saving and consumption reduction work, as a group power generation company and power plant, it is necessary to solve the following problems: how to evaluate the actual and expected level of unit performance, how to quantitatively determine the impact of various factors on unit performance, how to improve operational level to reduce energy consumption, how to assess and evaluate the implementation of energy-saving work from a management perspective, and so on. Therefore, it is necessary to have a complete and scientific expert analysis system for optimizing power plant operation.

key word: Operational optimization；Expert analysis system；power plant

1. Introduction

Using the basic theory and principles of energy loss analysis, a large number of factors affecting the economic efficiency of the unit were analyzed, compared, and judged. 21 main influencing factors were identified as the basic optimization elements. The relationship between each optimization element was analyzed, and the characteristics of the unit were analyzed. Through dimensional analysis, the overlapping relationship between the optimization elements was briefly analyzed using the superposition method and item by item approximation method.According to the second law of thermodynamics; Improving the initial parameters of the working fluid in a thermal cycle and reducing the final parameters can both improve the thermal efficiency of the cycle. The changes in initial and final parameters during operation will inevitably have a significant impact on the economic performance of the unit. Whether using the heat method or the energy loss method to analyze the thermal economy of a unit, the same conclusion can be drawn: the key to affecting the thermal economy of a turbogenerator unit is the cold source heat loss. The exhaust pressure of the low-pressure cylinder determines the magnitude of the cold source loss. Therefore, the exhaust pressure of the low-pressure cylinder has the most significant impact on thermal efficiency.[1].

2. Thermal economic impact indicators

2.1 Impact of Main Steam and Reheat Steam Temperature on Thermal Economy

The decrease in temperature of main steam and reheat steam, whether it is the absolute ideal efficiency of the cycle or the relative efficiency of the steam turbine, must be reduced.[2]. This is because they reduce the average temperature of the heat absorption process, and at the same time, the decrease in temperature also reduces the specific volume and expansion final dryness of the steam. The former leads to a decrease in absolute ideal efficiency, while the latter leads to steam leakage loss and an increase in wet steam in the flow parts of the high-pressure and low-pressure cylinders of the steam turbine, resulting in a decrease in the relative efficiency of the high-pressure and low-pressure cylinders.

2.2 Impact of Main Steam Pressure on Thermal Economy

When the main steam temperature and exhaust pressure are the same, the change in main steam pressure causes a change in the ideal enthalpy drop of 1 kilogram of steam, which affects the efficiency of the cycle. On the other hand, the change in main steam pressure causes a change in the specific volume of steam and the final dryness of

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expansion, which affects the internal efficiency of the steam turbine.[3]. The specific direction of change should be determined by the specific parameters and range of change.

2.3 Effects of smoke exhaust temperature, oxygen content, air leakage, and environmental temperature

These parameters are the main factors that determine the heat loss of exhaust gas. When the exhaust temperature, oxygen content in the exhaust gas, and air leakage rate (which determine the magnitude of the excess air coefficient) change, the heat loss of exhaust gas and boiler efficiency will correspondingly change.

2.4 Impact of combustible materials in ash and slag

The main parameters that affect the heat loss of incomplete combustion of machinery are fly ash combustibles and slag combustibles, and the latter changes very little during operation, so only the influence of the former can be considered. The increase of combustible materials in fly ash will result in incomplete combustion heat loss of machinery and a decrease in boiler efficiency.

2.5 Impact of Coal Types

It mainly refers to the impact of changes in the calorific value, volatile matter, ash content, and moisture of coal on the economic performance of the unit. In general, the decrease in calorific value and volatile matter makes it difficult for coal to burn completely, increases heat loss during incomplete combustion, and reduces boiler economy. The increase in ash and moisture will make the coal less flammable.

2.6 Impact of water spray desuperheating amount on reheater

The reheater uses water spray to reduce temperature, which completes heat absorption and evaporation at low temperatures, and then completes thermal processes such as expansion and work in the middle and low pressure cylinders of the steam turbine. Compared with the main steam work under subcritical high parameters, the economy is much lower.

2.7 Impact of Boiler Blowdown

The continuous sewage discharge from the boiler is hot water with high temperature, high pressure, and high energy levels. It is gradually absorbed by the supplementary water, heated up, and discharged after reaching saturation temperature in the boiler. It inevitably carries away a lot of heat, resulting in a relatively low thermal economy of the unit.

2.8 Effect of heater terminal difference

The end difference given in the design is determined through economic and technological comparison. Due to various reasons during operation, insufficient heating of the feedwater may increase the end difference, which will increase the irreversibility of heating exchange, generate additional cold source losses, and reduce the thermal economy of the unit. Its impact on economy mainly depends on the size of the end difference and the difference in extraction efficiency between adjacent heaters, as well as the proportion of drainage from the previous heaters.

2.9 Impact of feedwater temperature

The change in feedwater temperature has a significant impact on the economic performance of the unit. It causes changes in the amount of reheated steam extracted, affects the power output, and also changes the heat transfer temperature difference and exhaust gas temperature of the boiler, affecting the efficiency of the boiler. The influence of feedwater temperature on boiler exhaust temperature also leads to changes in boiler efficiency.

2.10 Impact of supplementary water

When supplementary water enters the condenser, without considering the changes in vacuum, regardless of the temperature of the supplementary water, it will not increase work or increase work loss, but it reflects the tightness of the system.

2.11 Impact of condenser subcooling

The subcooling of the condenser increases the loss of cold source and reduces the power output.

2.12 Impact of Efficiency on High and Low Pressure Cylinders of Steam Turbines

The changes in parameters and steam leakage during operation cause changes in the efficiency of the high-pressure and low-pressure cylinders of the steam turbine.

2.13 ower consumption of forced draft and induced draft fans and power consumption of pulverizing system

The power consumption of the forced draft fan and induced draft fan, as well as the power consumption of the pulverizing system, directly reduces the net efficiency of the unit.

Based on theoretical analysis and practical experience, factors have been selected to optimize the economic factors of unit operation. The main parameters that vary independently include: main steam temperature, main steam pressure, reheat temperature, oxygen content in flue gas, carbon content in fly ash, air preheater leakage, environmental temperature, coal type, reheater spray desuperheating, boiler discharge, condensate subcooling, and power consumption of the pulverizing system. Among these parameters, those related to load include: main steam pressure (during sliding pressure operation), air preheater leakage rate, power consumption of forced and induced draft fans, and power consumption of the pulverizing system. The factors affected by other parameters (hereinafter referred to as non independent variation factors) include reheat pressure loss, exhaust

pressure, feedwater temperature, make-up water volume, heater end difference, turbine high and intermediate pressure cylinder efficiency, and exhaust gas temperature.[5].

The mutual influence of unit steam parameter deviations includes two meanings: firstly, there is a connection between parameter deviations, such as the main steam temperature deviation causing changes in exhaust flow rate and resulting in exhaust pressure deviation; The second is that the degree to which a certain parameter deviation affects the economic performance of the unit is related to other parameter deviations. Similarly, the heat rate changes caused by the main steam temperature deviation at different exhaust pressures are different. For non independent elements, on the one hand, they can change randomly due to changes in load and environmental temperature, and on the other hand, they are also influenced by multiple factors. Therefore, the superposition method and itemized approximation method are used to solve the influence between parameters (elements).

3. Research on Operational Optimization Theory

3.1 Principle of parameter optimization

3.1.1 Principle of optimizing main steam temperature

The main factor affecting the main steam temperature is boiler combustion adjustment, and the main means of adjusting the main steam temperature include adjusting the boiler combustion and superheater desuperheating water. In theory, the higher the main steam temperature, the more advantageous the economic efficiency of the unit. Therefore, keeping the main steam temperature as high as possible within the safety range specified in the unit regulations is beneficial for the thermal economy of the unit. During the test, the operator first reduces the superheater desuperheating water to the minimum, and then adjusts the boiler combustion. Under the condition of maintaining the main steam temperature stable, the main steam temperature should be as close as possible to the rated temperature. The maximum value that can be reached under this condition is the optimization reference value of the main steam temperature under this condition. From the concept of consumption difference, it is the main steam temperature when the main steam temperature consumption difference+boiler efficiency consumption difference=the minimum value. This experiment needs to be conducted simultaneously with the boiler test due to its involvement in combustion adjustment[6].

3.1.2 Principle of optimizing main steam pressure

The optimization of main steam pressure mainly involves optimizing the opening and throttling loss of the turbine governing valve, as well as the energy consumption of the feedwater pump group. The main influencing factors of main steam pressure are the outlet pressure of the feedwater pump and the opening of the turbine regulating valve. The main measure is to adjust the opening of the regulating valve during constant pressure operation by the operating personnel. When the main steam pressure is close to or equal to the rated value, the efficiency of the high-pressure cylinder of the unit is the highest. When the unit is partially loaded, the main steam pressure is high, which not only increases the throttling loss of the control valve, but also increases the steam consumption of the small unit of the feedwater pump group, and reduces the exhaust temperature of the high-pressure cylinder, thereby affecting the reheat temperature and reducing the thermal efficiency of the unit as in table 1.

Table 1 Determination of optimized main steam pressure values for 135MW units

load	Optimization value of main steam pressure	load	Optimization value of main steam pressure
MW	MPa	MW	MPa
135	13.24	80	7.8
130	13.24	70	7.74
120	13.24	60	7.68

When the unit operates under sliding pressure and the main steam pressure is too low, the thermal cycle efficiency decreases, causing significant economic losses. From the perspective of consumption difference analysis, when the consumption difference of main steam pressure+efficiency difference of high-pressure cylinder+consumption difference of feedwater pump group=minimum, the optimal value of main steam pressure is obtained.

This time, on-site testing was used to make the problem resolution relatively easy.

3.1.3 Principle of reheat temperature optimization

The main factor affecting reheat temperature is boiler combustion adjustment, and the main means of adjusting reheat temperature include adjusting boiler combustion and reheater desuperheating water. Due to the large temperature difference between the desuperheating water of the reheater and the mixture of reheated steam, the irreversible heat transfer loss is significant, and it is equivalent to adding a thermodynamic cycle with medium and low pressure parameters. The impact on the thermal economy of the unit is much greater than that of the desuperheating water of the superheater. Therefore, the control of the desuperheating water of the reheater should be stricter, and theoretically, the smaller the better. Maintaining a high reheat temperature within the safety range specified in the unit regulations is beneficial for the thermal economy of the unit. During the test, the operator first reduces the reheater desuperheating water to the

minimum, and then adjusts the boiler combustion. Under the condition of keeping the reheat temperature stable, the reheat temperature should be as close as possible to the rated temperature. The maximum value that can be reached under this condition is the optimal reference value of the reheat temperature under this condition when the reheat temperature difference+the boiler efficiency difference caused by the reheat temperature adjustment=the minimum value.

3.1.4 Principle of reheat pressure optimization

The reheat pressure mainly depends on the pressure loss of the reheat circuit, and the pressure loss depends on the steam flow rate of the unit. For units operating under sliding pressure, when the optimized value of the main steam pressure is determined and the environmental conditions are determined, the reheat pressure and reheat pressure loss are also determined. When the main steam pressure of the unit is adjusted to the optimal value, the corresponding reheat pressure is considered the optimal reheat pressure.

3.1.5 Optimization principle of superheater desuperheating water

The minimum value of the desuperheating water volume of the superheater while maintaining the stability of the main steam temperature and being the optimization reference value is the optimization reference value of the desuperheating water of the superheater. The desuperheating water of the superheater is taken from the outlet of the high-pressure heater, and from the perspective of thermal cycle theory, it has little impact on the economic efficiency of the unit. However, the theoretical application of equivalent heat drop is based on the fact that the expansion process line of the steam turbine remains unchanged. Due to the presence of desuperheating water, the process line will change, and it will also have a certain impact on the economy. At the same time, the temperature difference between the feedwater temperature and the steam temperature of the superheater is very large, resulting in a large heat exchange temperature difference and a large strain force on the equipment. Therefore, efforts should also be made to minimize it.

3.1.6 Optimization principle of reheater desuperheating water

The desuperheating water volume of the reheater, while maintaining a stable reheating temperature and being the optimal reference value, is the optimal reference value for the desuperheating water of the reheater. Due to design reasons, the reheat temperature is relatively low under various operating conditions, and the desuperheating water of the reheater is basically zero throughout the entire test process. From the perspective of thermal cycle, the presence of reheated desuperheating water is equivalent to adding a low-parameter thermal cycle process, which has a significant impact on the economic performance of the unit.

3.1.7 Optimization principle of exhaust pressure

The vacuum of the condenser has a significant impact on the economic performance of the unit, and is the largest of all influencing factors. The determination of the optimal vacuum is influenced by many factors. In theory, the optimal vacuum is the minimum sum of the economic benefits brought about by the increase in vacuum caused by the input of the circulating water pump and the work consumed by the input of the pump, which is the optimal vacuum. At the same time, there are many factors that affect the vacuum of the condenser in the unit. Firstly, it is the heat exchange of the condenser. For the operating unit, the thermal resistance, which refers to the cleanliness of the condenser and the tightness of the negative pressure system, mainly depends on the quality of steam, the quality of circulating water, and the amount of air leakage, and is a gradual process; Next is the environmental conditions, which are the inlet water temperature of the circulating water; Once again, the steam flow rate discharged by the turbine into the condenser corresponds to the load of the unit.

When optimizing the test, the first step is to conduct a tightness test to determine the external working conditions of the condenser, the leakage situation on the negative pressure side, and eliminate all possible leakage points. This is to determine the operating influencing factors of the K value and the operating combination mode of the circulating water pump, as shown in the subsequent circulating pump test. On this basis, conduct tests on condenser back pressure and circulating water temperature, as well as the relationship between condenser back pressure and unit load.

3.1.8 Optimization principle of heater end difference

The main factors affecting the heater include the end difference of the heater, extraction pressure loss, and heat dissipation loss, with the most important being the end difference of the heater. The main factors affecting the end difference of the heater include the size of the heat transfer tube inside the heater, the convective heat transfer coefficient inside the tube, the condensation heat transfer coefficient outside the tube, and the temperature of the medium inside and outside the tube. Calculating the end difference of the heater using heat transfer methods is very cumbersome. For the operating heater, as it has been designed, the factors that affect the end difference are actually the feed water flow rate, the temperature at which the feed water enters the heater, and the steam side temperature at which it enters the heater. Optimize the use of on-site testing methods, adjust the water level of high and low pressure heaters, and check the drain valves of the heaters. For the low-pressure heater, adjust the air extraction pipe and check the temperature rise of the heater. If the terminal difference of the heater is normal,

the maximum temperature rise that the heater can achieve is the optimized reference value of the heater.

3.1.9 Optimization principle of exhaust gas temperature

Higher exhaust temperature than the optimized value can lead to a decrease in boiler efficiency. Every 10 ℃ increase in exhaust temperature can reduce boiler efficiency by 0.5% and increase coal consumption by 1.7g/kWh.

The optimization principle of exhaust gas temperature is to comprehensively consider the influence of various factors, and the minimum temperature that can be reached under the optimal operating state of the boiler is the optimization value. The factors that affect the exhaust temperature include: 1) fouling of the heating surface, coking in the furnace, and ash on the convective heating area at the tail can all cause an increase in exhaust temperature. The boiler should undergo combustion adjustment and timely soot blowing on the heating surface. 2) Boiler combustion. The deviation of the furnace flame, unreasonable coordination of primary and secondary air, high primary air speed, and excessive air volume may cause the flame center to shift upwards and the exhaust temperature to rise. 3) Operation mode of the pulverizing system. Check if the pulverizing system is functioning properly. Focus on checking whether the fineness of coal powder is too coarse, whether the pulverizing air volume is too high, and whether the pulverizing system uses too much cold air. Add steel balls in a timely manner according to the current of the coal mill.

The influence of air supply temperature and air leakage rate of the air preheater. 4) As the supply air temperature increases, the exhaust gas temperature also increases, so the exhaust gas temperature needs to be corrected to 20 degrees below the design ambient temperature.

3.1.10 Optimization principle of oxygen content at the inlet of air preheater

The oxygen content at the inlet of the preheater is one of the important indicators that should be controlled during operation, and it is also the easiest parameter to control and adjust during operation. Other indicators it affects include the carbon content of fly ash and large slag, the total power consumption of the forced draft fan and induced draft fan, the exhaust temperature, and the temperature of the main steam and reheat steam. The analysis and selection of this indicator should be based on the calculation of the power supply coal consumption of the unit before making a comprehensive judgment. The method is to use the power supply coal consumption as the final optimization indicator to determine the optimal oxygen level operating condition that can maintain the economic performance of the entire unit. The ideal oxygen control curve was obtained.

3.1.11 Optimization principle of carbon content in ash and slag

Mechanical incomplete combustion heat loss is one of the main heat losses in boilers, second only to exhaust heat loss. For solid state slag removal coal powder boilers, it is within the range of 0.5-5%. The main factors affecting the heat loss of incomplete combustion of boiler machinery are fly ash combustibles and slag combustibles. In a coal powder furnace, the ash that falls into the cold ash hopper only accounts for a small portion of the total ash amount entering the furnace, and the proportion of ash in the ash in the total ash amount entering the furnace varies very little. Therefore, the mechanical incomplete combustion heat loss caused by combustible substances in the ash is usually only 0.5-1%. The vast majority are caused by combustible materials in fly ash. Therefore, only the impact of the former can be considered. It is generally believed that the residual combustibles in fly ash and ash residue are pure carbon, and mechanical incomplete combustion heat loss can be calculated by measuring the carbon content of fly ash.

The optimal operating condition for a single indicator may not necessarily be the optimal operating condition for the entire unit. Optimization experiments have shown that using low oxygen operation mode can reduce smoke exhaust losses and fan power consumption, and the overall economic efficiency of the unit is the best. However, the carbon content of combustible materials in fly ash and large slag will increase. Therefore, the optimized value of carbon content in ash and slag may not necessarily be the lowest value that can be achieved, but rather the value that maximizes the economic efficiency of the unit.

3.1.12 Optimization principle of total power consumption of forced draft fan

The main factor determining the power consumption of the supply and induced draft fans is the amount of oxygen used during operation. Under the same load, there is a significant difference in total power consumption between the supply and induced draft fans due to the use of different oxygen levels. With the increase of oxygen content, the power consumption of the forced draft fan and induced draft fan significantly increases, leading to an increase in auxiliary power consumption and directly affecting the power supply coal consumption of the unit. The lower total power consumption (rate) of the supply and induced draft fans that can be achieved when operating with lower oxygen levels. Therefore, the optimization value of power consumption for the forced draft fan is determined based on the final optimization index of power supply coal consumption.

3.1.13 Optimization principle of total power consumption in the milling system

The total power consumption of the pulverizing system is mainly determined by: a) the operating characteristics of a single pulverizing system, and b) the operating mode of

the pulverizing system under different loads. For the monthly electricity consumption data of the power plant's daily statistics, it is also related to the load curve of the unit this month. When the steel ball loading capacity of the coal mill is constant, the main factor affecting the unit consumption of a single pulverizing system is the output of the pulverizing system. When the pulverizing system operates at high output, the unit consumption of the pulverizing system is significantly reduced. Improving the output of the pulverizing system is an effective measure to reduce the power consumption of the pulverizing system.

3.2 Optimization principle of operation mode

3.2.1 Principle of optimizing the constant sliding pressure operation mode of the main engine

The influence of main steam pressure on the relative internal efficiency of steam turbine units is opposite to that of main steam temperature. When the main steam temperature is constant, as it increases, the specific volume of the steam decreases, and the leakage loss of the steam turbine correspondingly increases and decreases; When the reheating parameters and exhaust pressure remain unchanged, increasing also increases the exhaust humidity, causing an increase in exhaust moisture loss and a decrease. According to the formula, the decrease in relative internal efficiency reduces the effect of increasing. However, due to the increase caused by the increase exceeding the decrease, the overall result is that the actual cycle efficiency of the steam turbine unit is still improved. The existing units of Zhanhua Power Plant are designed with basic load, and 135MW has been operating at constant pressure for a long time. In recent years, with the continuous expansion of power grid capacity and the continuous decrease of unit load rate, it is inevitable for large units to participate in peak shaving of the power grid. In addition, in recent years, there have been renovations to optimize the operation mode of the units, which is to determine the load range of variable voltage operation of the units and the optimal constant and sliding voltage operation parameters. This is extremely urgent. Although increasing the initial parameters can help improve economic efficiency for high parameter and large capacity units, as the main steam pressure increases and the load decreases, the throttling loss of the control valve will increase. Therefore, there will be an optimal value for the main steam pressure under different loads. This optimal value is mainly determined through experimentation. By conducting experiments under different loads and operating modes of constant sliding pressure, the conversion load points of constant sliding pressure are calculated and analyzed.

3.2.2 Principle of power consumption operation mode of circulating water pump

By determining the efficiency of circulating water pumps under different loads; Determine the relationship between circulating water flow rate and power consumption of circulating water pumps under different loads; Determine the relationship between circulating water flow rate and vacuum under different loads; Determine a reasonable operating mode of the circulating water pump to determine the optimal vacuum.

When the inlet temperature of the circulating water is a constant value and the unit load is a constant value, the main factor affecting the pressure of the existing condenser is the circulating water flow rate. In this case, increasing the flow rate of circulating water can reduce the pressure of the condenser, but when the flow rate of the circulating water pump increases, the power of the circulating water pump also increases. Therefore, increasing the flow rate of the circulating water pump is beneficial for the economic efficiency of the unit only when the increased power of the turbine is greater than that of the electric power of the circulating water pump due to the increase in the flow rate of the circulating water. That is to say, when the power generated by the decrease in condenser pressure - the power consumption increased by the increase in circulating water flow=the maximum value, it is the most economical for the unit, and the vacuum at this time is the optimal operating vacuum.

The determination of the optimal vacuum is determined through experiments. The experimental design was conducted separately in different seasons and at different environmental temperatures.

3.2.3 The impact of coal mill operation mode on the overall unit economy

The total power consumption of the pulverizing system is mainly determined by: a) the operating characteristics of a single pulverizing system, and b) the operating mode of the pulverizing system under different loads. The optimization experiment requires comprehensive testing of the operating characteristics of two pulverizing systems. When the steel ball loading capacity of the coal mill is constant, the main factor affecting the unit consumption of a single pulverizing system is the output of the pulverizing system. When the pulverizing system operates at high output, the unit consumption of the pulverizing system is significantly reduced, but for multiple pulverizing systems, the operating characteristics are not the same. Similarly, for the operation mode of the pulverizing system under different loads, increasing the output of the pulverizing system is an effective measure to reduce the power consumption of the pulverizing system.

4. Conclusion

The operation of power plant units is a very complex system, and there are many factors that affect the economic efficiency of the units. The relationship between the influencing factors is very complex. The factors that simultaneously affect the economic performance of the unit can be divided into controllable and uncontrollable factors. And some factors have an impact on both steam turbines and boilers. The ultimate goal of this project is to reduce the coal consumption rate

of the unit through experimental adjustments and equipment adjustments by operators, based on the basic principle of "practicality and accessibility". The so-called "practical and achievable" refers to the minimum coal consumption rate or minimum unit heat consumption rate and highest boiler efficiency that can be achieved by the unit after various on-site tests and repeated debugging of relevant equipment by operators. That is to say, the total consumption difference of all parameters on the machine or furnace side that affect the thermal economy of the unit on the unit is the smallest. It is the target value that operators can achieve through their efforts in the operation and mode of the system and equipment, rather than the design value of the unit. The experiment takes the power supply coal consumption rate or unit heat consumption rate of the unit as the final optimization target value, and takes controllable and uncontrollable parameters that affect the unit heat consumption rate and boiler efficiency as optimization variables. When considering the impact of individual parameters on the thermal economy of the unit, other parameters and operating states of the unit are corrected to a comparable benchmark state, in order to accurately determine the impact of parameter changes on the thermal economy of the unit.

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References

1. K eravnou E T et al，W hat 15 a D eeP E xPert System A n A nalysis of the A x ch iteetu ralR eq u irem ents of Second ― G en eratio n ExPert System. The Knowledge Engineering Review， 1989(3): 3-6.
2. Hayes RothE，waterman D. A., Lenat D.B.Establish an expert system. Sichuan Science and Technology Publishing Society, 1986.
3. Zhang Lei. Mathematical Model for Online Monitoring of Thermal Power Units. Master's Thesis of Southeast University, 2006
4. Sun Xintian. Research on the Application of Load Optimization and Distribution System in Thermal Power Plants. North China Electric Power University, 2005
5. Li Xiaojin, Analysis of Consumption Difference of 500MW Units and Its Application in Management of Operational Economic Indicators. North China Electric Power University Xue, Baoding, Hebei. 2003
6. Yuan Guili, Wang Tianhong, Shi Guoqing. Application of Operation Optimization System O PT I PR O in Power Plant Operation Management Research. China Electric Power, 2004, Volume 37, Issue 9.