Numerical Simulation and Optimization of Coal-fired Boiler System based on Dynamic Grid Technology

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Abstract: Coal-fired power generation will remain the most important power generation mode in China for a long time to come, and the changes of resources, environment and climate have brought severe challenges to the sustainable development of coal-fired power generation. In the electricity market, with the increasingly prominent energy crisis and people's awareness of the importance of the environment, energy conservation and environmental protection are the eternal issues faced by the coal-fired power station industry. At present, thermal power generation still occupies a strong position in China, accounting for about 70% of the national power generation. A series of reform measures and environmental protection requirements are put forward for national thermal power plants, which require large-scale utility boilers to limit pollutant emissions into the atmosphere while improving combustion economic benefits. Coal-fired utility boiler is not only a huge power source, but also a huge pollution source, so it is of great significance to optimize its combustion operation. With the increasing capacity of coal-fired thermal power units, increasing parameters and increasing complexity of the system, the research on optimal control and state diagnosis of coal-fired boiler system based on furnace parameter measurement will provide an effective solution for coal-fired thermal power units to achieve high efficiency, pollution emission, safe and stable operation.

1. Introduction

Energy is the material basic resource of social development and a necessary condition for national economic development. The quantity and consumption of energy are related to a country's economic and social construction. With the development of world economy, the growth of population and the improvement of human living standard, the global energy demand continues to increase [1]. With the continuous improvement of people's living standard and the call of our country to build an all-round and economical society, high efficiency, energy saving and environmental protection have become the top priority of power generation enterprises, especially in thermal power generation. In recent years, the Development and Reform Commission has implemented the open policy on the price of thermal coal, the domestic demand has been expanding, the coal production cost has been increasing year by year, the international energy price has been rising rapidly, and the domestic price of power coal has been rising [2]. Electric power industry is the forerunner of economic development. Since the end of 1990s, China's economy has shown steady and rapid growth, and the demand for electric power is increasing day by day [3]. Any problem can't exist independently from the other two aspects. With the progress of society, the breakthrough of science and technology, the change of natural environment, and the continuous improvement of people's material and spiritual needs, the understanding of energy, economy and environmental problems has been deepened. As two indispensable factors for human survival and development, environment and energy have been paid attention by governments and the international community [4]. Therefore, the state has put forward a series of reform measures and environmental protection requirements for thermal power generation enterprises, requiring thermal power generation enterprises to limit the emission of pollutants into the atmosphere while improving the economic benefits of boiler combustion [5]. On the one hand, power generation enterprises are faced with the shortage of energy, which leads to the price increase of thermal coal, thus increasing the production cost, forming the competition of electricity market in which the

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production is separated from the network and the bidding is on the internet. In addition, they are faced with multiple pressure requirements such as reducing pollutant emissions and improving thermal efficiency. In this paper, it is of great significance to optimize the coal-fired boiler system based on the numerical simulation of dynamic grid technology [6].

2. Necessity and feasibility of boiler system optimization

2.1. The necessity of boiler system optimization

Reducing the coal consumption of power generation and the emission of environmental pollutants are the outstanding problems faced by the operation and development of thermal power enterprises in China at present, and they are also the only way to respond to and implement the national energy saving and emission reduction strategy [7]. The quality of boiler combustion has a significant impact on the operation economy and safety of the whole generator set. The key task of regulating combustion is to comply with the demand of external load and ensure the economy and safety of boiler operation while providing qualified steam [8]. As one of the three main equipments of coal-fired units, the boiler's thermal efficiency directly affects the efficiency of the whole unit. Its safety and stability determine the safety and reliability of the whole power production process; Its combustion products are the main source of air pollution, and the control of its pollutant emissions is a powerful means to solve environmental problems [9]. For ordinary pulverized coal boiler with solid slag discharge, the objectives of regulating combustion include: ensuring normal steam temperature, steam pressure and evaporation, stable combustion, even flame, no damage to the burner, avoiding slagging, and ensuring high combustion efficiency and low pollutant generation of the boiler [10].

Due to the instability of coal quality and the variability of load, large coal-fired units run under non-optimal conditions [11]. Therefore, it is particularly necessary to implement the combustion optimization of utility boilers, which is one of the most effective and fundamental means to improve the safe, economic and environmental protection operation of boilers [12]. The boiler system control technology and its optimization are of great significance to improve boiler efficiency, reduce power generation cost and pollutant emission level. Electric power industry is an energy processing industry, and it is an energy conversion industry that converts primary energy such as fossil energy into electric energy, which is a secondary clean energy. China's power supply structure is dominated by coal electricity, and a large number of environmental pollutants, including soot, sulfur dioxide and nitrogen oxides, will inevitably be produced in the process of electric power production. These pollutants affect the visibility of the atmosphere, form acid rain, and lead to haze and haze in urban agglomerations and regions, which are important factors leading to environmental pollution in China [13]. The purpose of system optimization control is to ensure the safety, stability, economy and environmental protection of combustion.

2.2. Feasibility of boiler system optimization

With the rapid development of utility boiler technology in China, the boiler system tends to be large-scale and high-parametric, so as to improve the overall efficiency of boilers and units. However, for units with certain capacity and parameters, it is necessary to improve the efficiency of boilers and units through system optimization. China is rich in coal resources. Although China attaches great importance to the optimization and adjustment of power structure, from the point of view that coal-fired power generation has been kept at about 75%, coal-fired power will remain the most important power generation form in China for a long time to come. With the acceleration of modernization, according to the experience of developed countries, the proportion of coal converted into electricity will be further increased, and the coal consumption in other industries will gradually decrease, which will also play a positive role in environmental protection. Coal for power generation accounts for about 80% of coal consumption in major industrial countries in the world. For China's primary energy structure dominated by coal, increasing the proportion of coal converted into electricity is also one of the major measures to promote the sustainable development of energy

industry. Therefore, under the background that the proportion of coal used for power generation continues to increase, the thermal power industry can achieve the national goal of energy saving and emission reduction through combustion optimization technology.

Due to the differences in coal quality, auxiliary equipment configuration and operating conditions of different power plants, and the widespread coal blending and burning and equipment wear and aging, it brings many challenges to the optimization research of unit efficiency, and also leaves much room for improvement. In recent years, furnace parameter detection means and detection technology have developed rapidly, and some advanced analysis and measurement instruments have entered the practical stage of engineering. Many important process parameters affecting boiler combustion can be obtained relatively accurately. These important parameters closely related to furnace combustion can provide reference for boiler combustion optimization, guide operators to adjust boiler combustion, ensure the balanced combustion of pulverized coal in furnace, improve boiler thermal efficiency and reduce the emission of pollutants such as NOx. The flexible operation of thermal power units requires deep peak shaving, fast climbing and fast start-stop ability, etc., and requires the units to adjust the load at a faster rate and in a wider range, and to track the load with higher accuracy. Therefore, flexible operation requires higher load response ability and safe and stable operation under fast and wide load changing conditions.

3. Numerical Simulation and Optimization of Coal-fired Boiler System Based on 3 Dynamic Grid Technology

3.1. Dynamic network technology

With the development of computer equipment and computing technology, CFD is often used in various disciplines, such as optimization design, aeroelasticity, thermal analysis and aeroelasticity. These problems can be well solved by linear method under the condition of small disturbance, but for complex flow fields (vibration induced vortex, transonic flutter, large control surface motion), nonlinear methods are required, and large-scale parallel computing platform technology is needed. The application of CFD in various disciplines also includes structural load calculation, surface motion analysis and regional deformation technology of optimal design, that is, dynamic mesh generation technology. In the field of computational fluid dynamics, there are many numerical simulations that need to use dynamic grid technology. At present, the dynamic grid methods developed at home and abroad mainly include algebraic method, iterative method and analytical method. Algebraic method and analytical method are relatively time-consuming, but they are only limited to small-amplitude motions. For large-displacement motions, using these two methods may lead to grid crossing or merging. Iterative method can handle large motions, but it takes more calculation time. In aerodynamic shape design and aeroelastic optimization, To evaluate the aeroelastic performance and flying quality of an aircraft, it is necessary to constantly adjust the grid according to the change of the aircraft shape. For example, in flutter analysis, the structure is deformed at every time step. We need to provide this information to CFD calculation in time, so we need to use the dynamic grid to adapt to the moving object surface. Therefore, we must study the effectiveness and efficiency of grid regeneration.

In the structured grid area, the dynamic layering method can be used to dynamically increase or decrease the number of grid layers near the moving boundary according to the law of movement, so as to update the grid in the deformed area. The standard for increasing or decreasing the grid is the height of the grid adjacent to the moving boundary. For the algorithm of moving grid, the biggest difficulty lies in preventing the repeated interlacing and loss of grid points at the boundary. One of the simplest methods is to regenerate the computational grid according to the new object surface, but it takes a lot of time. The feasible way is to redistribute the grid according to the distance ratio from the boundary or the original sparse ratio by using interpolation or iteration method with the help of the initial grid data, which not only generates the grid quickly, but also ensures that the grid can reflect the change of the object surface in time. The number of grids will affect the accuracy of calculation results and the size of calculation scale, so more accurate numerical simulation of

furnace can be done by correspondingly increasing the number of grids.

3.2. System optimization

Boiler combustion optimization is an important means to improve unit efficiency, involving problems in many fields, and it is a complex system engineering. In the process of pulverized coal combustion in the furnace, there are many disturbance factors, and the boiler combustion system shows the characteristics of fast and time-varying parameters with the change of unit load. During the operation of a power station, with the change of equipment performance (the working efficiency of coal pulverizer), the accumulation of furnace ash and the change of the proportion of fuel components, the corresponding boiler operation performance will also change accordingly. The model established by the initial training data can't accurately reflect the actual operation law of the boiler, so intelligent algorithms are needed to make adaptive changes with the changes of various factors. The key to realize the combustion optimization of coal-fired boiler in power station lies in establishing a mathematical model of combustion optimization with accurate prediction.

Because the combustion mechanism of pulverized coal in boiler furnace is quite complex, it is impossible to establish a combustion model by theoretical method at present. However, the combustion characteristics of the boiler must be reflected in the combustion process data of the boiler, that is, the actual combustion operation data of the boiler contains the combustion operation characteristics of the boiler. At present, the research on the combustion mechanism of boiler is not mature enough, and the research on its characteristics is generally based on the mechanism models of partial differential equations or algebraic equations. The establishment of these models is obtained under many assumptions and simplified conditions, which are different from the real actual process to some extent, and the results obtained are not very accurate. When the parameters of the actual boiler combustion system change, it is necessary to find the optimal parameters again to meet the changing needs, which requires that the learning and training algorithm should be fast to meet the actual engineering requirements. The combustion optimization system of coal-fired boiler is shown in Figure 1.

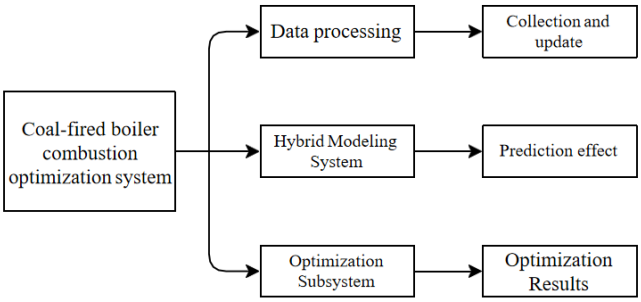

Figure 1 Combustion Optimization System of Coal-fired Boiler

When a new problem arises, the problem will be generated into a target case which is consistent with the form of the source case according to the corresponding preservation rules. Then, according to the corresponding retrieval conditions and retrieval methods, similar cases which are consistent with the current target case will be found from the historical case database, and the similar cases will be used to solve the current problem. Sometimes, due to the coupling of variables, it is difficult to get completely consistent similar cases, so it is necessary to revise the similar cases and finally get the correct solution of the current problem.

4. Conclusions

Boiler combustion optimization system is a very complex system, which is a multi-objective optimization system with large inertia, many variables, strong coupling and uncertainty. Nowadays, the domestic energy sources are still mainly electric energy, and thermal power generation plays an extremely important role in electric energy. However, there are many problems in thermal power generation industry, such as large pollutant discharge and low boiler thermal efficiency. With the

increasing proportion of new energy installed capacity and power generation in China, flexible operation has become a new trend in the development of thermal power industry, which also puts forward higher requirements for the economy and environmental protection of unit operation. Coal-fired power generation will remain the most important form of power generation in China for a long time to come. The requirements of resources, environment and economic benefits have brought severe challenges to the sustainable development of coal-fired power generation, and effective boiler combustion optimization control technology is one of the important means to improve boiler efficiency, reduce pollutant emissions and ensure safe and stable operation of boilers.

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