Research on selection optimization technology of air fan for ultra-supercritical circulating fluidized bed boiler

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Abstract. In recent years, with the improvement of the capacity and parameters of domestic CFB boiler units and the potential of technology from design, operation adjustment and equipment transformation, the CFB technology has been relatively mature, and economic indicators are significantly improved. The successful application of new technologies in project provides good conditions for the development of selection optimization technology of air fan. Combined with the application and project practice of the energy-saving technology of air fan for supercritical CFB boiler in service, the energy distribution of air fan after design and energy-saving transformation is quantitatively analyzed through the experiment. Based on this, the energy-saving technology of air fan is researched. From the low bed pressure design, selection optimization of air fan parameter and frequency conversion energy-saving, the selection optimization technology of air fan for ultra-supercritical CFB boiler is proposed, which provides a technical basis for the lower energy consumption technology of ultra-supercritical CFB boiler design in the future.

1. Introduction
Circulating fluidized bed (CFB) power generation technology has been rapidly developed in China and abroad for nearly three decades due to its extensive coal quality adaptability and excellent environmental performance[1]. China's CFB boilers have reached the world's leading level in terms of stand-alone capacity, installed scale and technological advancement. By 2018, China's large-capacity CFB boilers of 410 t/h above have been put into operation in more than 440 units, and the total installed capacity has exceeded 82.3 GW[2]. The supercritical CFB boiler units with independent intellectual property rights have been put into operation in more than 30 units, and the maximum capacity of single unit has reached 600MW. According to a large number of practical research results, the indicators of supercritical CFB boiler are running well, and advanced CFB technologies have also been applied and popularized[3]. The 350MW supercritical CFB boiler unit of Shenhua Hequ is designed according to the the state specification design theory technology, and the energy consumption indicators are in a good level of similar units. The supercritical CFB boiler unit of Xuzhou Huamei adopts high-efficiency secondary air technology to strengthen the reducing NOX atmosphere through the gas-solid flow characteristics in the furnace, which reduces the formation of raw NOX and achieve lower energy consumption of NOX ultra-low emission. For the first time, the supercritical CFB boiler unit of Shanxi Shuguang replaced the electric air fans with steam-driven fans,
reducing the service plant rate of the unit to less than 4%. On January 30, 2019, the National Energy Administration has included the Shaanxi Binchang 660MW CFB boiler unit project in the National Power Demonstration Project. The high-efficiency ultra-supercritical 660MW CFB power generation project will soon be transferred to the engineering construction stage, which indicates that China's ultra-supercritical CFB technology will realize engineering application and further lead the development direction of international CFB technology. It will build the world's first CFB boiler with the lowest emission and energy consumption levels, the highest capacity and efficiency. Through the preliminary research results[4], in the aspect of low energy consumption technology, the selection optimization technology of air fan for ultra-supercritical CFB boiler still needs a lot of research work.

In the early day, the matching degree between air fan and the system of CFB boiler units in China was not reasonable. The air fan margin is too large to result in a small opening of the baffle and a large throttling loss, the operating efficiency of which is low, and the economy is poor. In recent years, the utilization hours of CFB boiler units have been decreasing year by year, and the units have been in low-load operation for a long time. Therefore, most power plants have modified the primary air fan, secondary air fan and induced-draft fan, the fixed speed adjustment mode has been changed to the frequency conversion speed regulation, which has greatly reduced the service plant rate of air fan. At the same time, a large number of research and engineering verification practice work have been carried out by research institutes[5-6]. The energy-saving technology of air fan has been successfully applied in the design, operation and modification, which provides technical conditions for selection optimization technology of air fan. This work will be combined with the application of energy-saving technology of air fan that adopted by supercritical CFB boiler unit, the energy saving effect of air fan after energy-saving technology was quantitatively analyzed, and the research proposes the low energy consumption technology of air fan that can be used in the design of ultra-supercritical CFB boiler.

2. The application of energy-saving technology of air fan for supercritical CFB boiler

2.1. The application of design optimization technology of air fan
At the beginning of the design of a supercritical CFB boiler unit, the implementation of the low bed pressure technology was demonstrated. Under the condition of ensuring the ash volume of the boiler, the low bed pressure operation should be maintained as much as possible. According to the characteristics of the boiler air distribution plate and the position of the boiler bed pressure point, the boiler bed pressure under different loads is controlled to be about 4-5.5 kPa. Combining the low bed pressure technology with frequency conversion adjustment of air fan, it reduces the service plant rate by about 1% according to the calculation.

According to the regulations and research on the operating experience of power plants, reasonable choice of air fan output margin for a supercritical CFB boiler is shown in Figure 1. Due to a significant reduction of the margin coefficient in wind pressure and air volume of the primary air fan, it can effectively reduce the wear of the heating surface in the furnace of the boiler and improve the reliability of the unit equipment. Because the fluidized wind speed is reduced, the residence time of the coal in the furnace is increased, which can effectively improve the combustion environment and efficiency of the boiler. For the first time, based on the standard recommendation coefficient, the wind pressure coefficient of the primary air fan is reduced by 5%, reducing the service plant rate calculated about 0.8%. The increase of margin coefficient in wind pressure and air volume of secondary air fan is to improve the penetration of secondary air, strengthen the mixing of gas-solid phase and promote the concentration distribution of materials in the furnace. The increase of wind pressure of high-pressure fluidized fan is mainly to ensure the continuous balance of external circulation materials. Optimizing the selection of air fan equipment, reasonably selecting the auxiliary coefficient and motor capacity of the auxiliary machine can perfectly match the output of air fan to meet the normal operation requirements of the unit.
2.2. The application of transformation technology of air fan

After a supercritical CFB boiler unit putting into production, there is a problem that the margin coefficient of the primary and secondary air fan is too large. According to the analysis of the design parameters and the actual operation of the project, the main reasons are that the selection of the air fan parameters is higher than the design requirements, resulting in a large difference between the design value and actual value. Under the low load, the actual operating wind pressure is higher than the design value, which also results in a large difference. The valve of air fan operates at a low opening for a long time, the efficiency of which is lower, resulting in higher service plant rate. Therefore, the energy-saving technical transformation of air fan is carried out, mainly includes the selection of the air fan parameters and the transformation of the frequency conversion. After air fan modified, the parameters of primary air fan, secondary air fan and high-pressure fluidized fan are reduced, and the frequency conversion of the primary air fan and secondary air fan are configured to adjust the operation. The operating current of air fan under the same working conditions is lower than before.

In order to compare the effect of energy-saving transformation technology of air fan, the reduction percentage of the air fan parameter after the transformation is shown in Figure 2, and the changes in energy consumption indicators before and after the transformation are shown in Figure 3. The percentage of air fan parameter decreases significantly, resulting in a significant reduction in the power consumption. It can be seen from the figure that the power consumption of air fan is reduced by 8.4% compared with that before the transformation. The reduction percentage of air volume and motor power of primary air fan is by more than 20%, and wind pressure of primary air fan by about 6%, the proportion of the power consumption of primary air fan decreases significantly by 11%. The reduction percentage of air volume, wind pressure and motor power of secondary air fan is the value of between 10% and 15%, which causes the proportion of the power consumption of secondary air fan to decrease by 4.4%. The reduction percentage of wind pressure of high-pressure fluidized fan decreases by 10%, and air volume by 5%. The power consumption of high-pressure fluidized fan increases by 2.3%, mainly because the power consumption of high-pressure fluidized fans decreases less than that of the power plant. The test result shows that compared with the transformation, the service plant rate of the unit from 6.9% before to 5.5% after the transformation is reduced by 1.4%.

Figure 1. Margin coefficient of air fan selection for the supercritical boiler unit.
In summary, the ultra-supercritical CFB boiler can propose the optimization technology of air fan including the low bed pressure design, the selection optimization of air fan parameter and frequency conversion energy-saving.

3. Selection optimization technology of air fan for ultra-supercritical CFB boiler

3.1. The low bed pressure design technology

The ultra-supercritical CFB boiler adopts a single furnace and single air distribution structure, The boiler will not have the phenomenon of double-furnace turn-over, which can effectively reduce the operating wind pressure of the primary air fan. It also adopts the low bed pressure design technology. Though studying low-energy CFB boiler technology for the State Specification Design theory[7], it can improve the quality of the bed material in the furnace, reduce the stock of bed material, and increase the amount of circulating material by means of optimizing the reduction of boiler feed size and the use of high efficiency cyclones. It can maintain enough fine particle bed material and the bed pressure in the furnace to ensure enough circulating material to participate in the heat exchange. The low bed pressure design technology is based on this theory. The amount of the material in the furnace decreases, and the operating bed wind pressure of the boiler is reduced, which effectively reduces the
operating wind pressure and power consumption of primary air fan. As the bed pressure decreases, the ability of the ash to remove heat decreases, and the carbon content of the fly ash and the bottom slag also decreases, which leads to an increase in the boiler efficiency. Compared with the double-air distribution structure of the 600MW supercritical CFB boiler in service, the wind pressure of the primary air fan is reduced by more than 5 kPa, the wind pressure of the secondary air is reduced by about 1kPa.

At present, some 300MW subcritical and 350MW supercritical CFB boiler units have achieved low bed pressure operation. The operating bed pressure of the boiler is reduced from the original design of 11 kPa to 5~7 kPa, and the system resistance is also reduced accordingly. The primary and secondary air fan currents are significantly reduced.

3.2. Selection optimization technology of air fan parameter
When selecting air fan parameters for the ultra-supercritical CFB boiler, margin coefficient of air fan can break the recommended margin coefficient of the existing specification. Air fans are one of the most important auxiliary equipments of the power plant. The choice of air volume and wind pressure affects the operation of the entire power plant and the service plant rate, which in turn affects the economic benefits. Therefore, it is very important to choose the appropriate margin coefficient of air fan. The design reference point of air fan can be based on the TMCR working condition. The wind pressure margin only considers the resistance of the smoke or air road, and the equipment resistance does not repeatedly consider the margin. The resistance of the smoke or air road is multiplied by the margin plus the resistance of the equipment as the parameter of the TB point of air fan. The margin coefficient of air fans is selected according to the specified lower limit. This can avoid the situation that the actual operating condition of air fan deviates from the design working condition, it can reduce the selection of the air fan parameters and the capacity of the supporting motor, thereby saving the initial investment. In addition, the high-pressure fluidized fan adopts a multi-stage centrifugal air fan, and the induced-draft fan adopts two-stage moving blade adjustable axial flow fan, which of the efficiency is higher, and the service plant rate is further reduced.

3.3. Frequency conversion energy-saving technology
Air fan of ultra-supercritical CFB boiler is equipped with a variable frequency speed control device, which can effectively reduce the operating power consumption. The primary and secondary air fan are large consumers of CFB boiler units. Due to the relative high pressure of the primary and secondary air fan, only centrifugal air fans can be used, but the centrifugal fans are inefficient, especially at a low load. Therefore, the primary and secondary air fans of the ultra-supercritical CFB boiler unit are equipped with variable frequency speed control devices, and air fan can still ensure higher efficiency during partial load. The axial fan of the cooling unit of air fan adopts frequency conversion control, and the output of the axial flow fan is adjusted according to the cooling water temperature of the auxiliary machine.

4. Conclusions
From the aspect of design optimization and technical transformation, the application of energy-saving technology of air fan for supercritical CFB boiler in service is demonstrated. Through the test, the influence of the energy-saving technology of air fan is quantitatively analyzed. A supercritical CFB boiler in design comprehensively with the low bed pressure, optimization selection of air fan parameter and frequency conversion energy saving technology, reduces the service plant rate by about 1.8%. A supercritical CFB boiler after the transformation of optimization selection of air fan parameter and frequency conversion reduces the service plant rate by 1.4%. Based on this study, this work presents a summary of energy-saving technologies of air fan from three aspects for ultra-supercritical CFB boiler. In the low bed pressure technology, the boiler with single air panel is designed with 5 kPa bed pressure, which can effectively reduce the operating wind pressure of the primary air fan and improve the efficiency of the boiler. From the aspect of optimization selection of
air fan parameter, it is proposed that the design reference point of air fan selection is based on TMCR working conditions, and the margin coefficient of air volume and wind pressure of air fan is selected according to the specified lower limit or breaking the existing specifications. About the frequency conversion energy-saving technology, it is recommended that air fan of the boiler set the frequency converter to effectively reduce the running power consumption.

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References
[1] Nowak W 2012 Polish activities in circulating fluidized bed combustion VGB Power Tech. 70-76
[2] Zhong Huang 2019 Application and development of large-scale circulating fluidized bed boiler Thermal Power Generation 48(06) 1-8
[3] Song C et al 2018 Proceedings of the CSEE 38(02) 338-347,663
[4] Jiayu L, Hong W, Feng M 2013 Compressor, Blower & Fan Technology 55(05) 61-68
[5] Guowei Xie et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 227 032032
[6] Shi Liu, Chu Zhang, QingShui Gao 2017 59(03) 65-69
[7] Shi Yang et al 2009 Chinese Journal of Power Engineering 29(8) 728-732,788