Study on Efficiency Enhancing and Energy Saving of High Voltage Power Supply of EP

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Abstract: It was analyzed that theoretical and practical watt consumption needed in flue gas cleaning in electrostatic precipitator in this paper to find that they were quite different from each other. Actually, the operating electrical energy consumption of EP should be classified as effective, minus effective, ineffective and natural energy consumption. The effective electrical energy is very little, but the proportion of the others is big. The proportion of effective electrical energy can be enhanced and the others can be reduced via techno-measure. Based on the White's theory about EP power supply, the operating status quo of EP and the successful study and extension of high voltage power supply facility of EP with efficiency enhancing and energy saving, the working manner of electrostatic precipitator power supply should be transferred from the single spark setting of high current, high power and high consumption to the scientific track of high efficiency and energy saving in coal-fired power plants in China.

Keywords: electro-precipitator, high voltage power supply, efficiency-enhancing, energy-saving, electric corona power, intelligence optimization

1 INTRODUCTION

With the high spread of electric power industry, electrostatic precipitator (EP) has become the absolutely necessary equipment for the safe power generation in coal-fired power plants and environmental protection. The EP is used to clean the gas mostly whether in the new, the reconstructed and rebuilt, or the old coal-fired power plants as the number of the EP and amount of the flue gas increasing rapidly in power system. The EP in the coal-fired plants is faced three rigorous situations. First, the emission standard of the smoke dust is more and more strict that is reduced from 200 mg/Nm^3 to 50mg/Nm^3 in new-built unit boilers and is advanced greatly in old unit boilers in different times, while the dust content consistency is required strictly by the technological process of desulfurization equipment. Second, the coals used in power plants are inferior coal mostly with high ash content, low sulfur content and more kinds leads to the ash in the flue gas up to 40%-50% and even more. Third, the limitations of the site and the space which is finite in new-built units and which is extremely scarce in old power plants as the technical reform of EP make EP face severe challenge. This is a challenge, as well as an opportunity to exploit potentialities of EP by technological innovations.

EP goes along the way of innovation for science and technology how to exploit the potential and enhance the performance of EP furtherly to adapt the requirement of the new situation. The main factors impacting EP performance are the entity structure, the power supply control and the running condition. The running condition mainly includes the properties of flue gas and dust among which the influence of flow rate and specific resistance are relatively outstanding. Power supply control of EP has an important effect on adopting the request of running condition and enhancing the whole performance of EP. For many years, the power supply control facilities have worked mostly under the working mode of large power (the spark automatic tracking or the spark setting). These are all important subjects that we have to face whether this working mode is reasonable, whether the power supply control facility of EP can play a more important role furtherly, whether the availability of electrical energy can be enhanced and the energy consumption can be lowed while the collection efficiency can be improved and the dust emission concentration can be reduced.

2 THEORETICAL ENERGY CONSUMPTION OF EP

The charged dust particles in the flue gas move to the collecting plate under the electrostatic force. Based on Stokes's law, the fraction resistance worked on a spherical dust particle was calculated using

$$F_D = 6\pi\eta a\omega \tag{1}$$

where η is the medium viscosity, a is the dust particle radius, ω is the reaching rate.

The work consumed when the charged dust particle moves to the collecting plate at a range s was calculated using

$$W = F_D \times s = 6\pi\eta a\omega s \tag{2}$$

The medical particle size of fly ash is always between 10 and 25μm. It is assumed that the dust particle diameter is 10μm, the travel distance s toward to collecting plate is 5 cm, the reaching rate ω of the charged dust particle is 30cm/s. The work consumed can be calculated using formula [2]

$$\begin{aligned} W &= 6\pi\eta a\omega s \\ &= 6\pi \times 1.8\times10^{-5} \times 5\times10^{-6} \times 30\times10^{-2} \times 5\times10^{-2} \\ &= 2.54\times10^{-11}(\mathrm{J}) \end{aligned}$$

The dust content consistency is 10 g/m^3-40 g/m^3

generally produced by coal-fired plant boiler. It is assumed fatherly that the dust content consistency C is 20 g/m^3, the density of dust particle is 1 g/m^3. The amount N_0 of dust particle in per flue gas is

$$N_0 = \frac{C}{4/3 \times \pi a^3 \rho} = \frac{20\text{g}/\text{m}^3}{4/3 \times \pi \times \left(5 \times 10^{-6}\text{m}^3\right) \times 1\text{g}/\left(10^{-2}\text{m}^3\right)}$$

=3.82×10^{10} (particles/m^3)

So, the work consumed to separate all dust particles in 1 m^3 flue gas is

$$W_0 = W \times N_0 = 2.54 \times 10^{-11} \times 3.82 \times 10^{10} = 0.970(\text{J})$$

The amount of flue gas produced by 600MW unit boiler is 3.4×10^6 m^3/h. The power W_S needed to separate all dust particles is

$$W_s = W_0 \times Q = 0.97 \times 10^6 \times 3.4 \times 10^6 / 3600 = 918\ (\text{W}) \qquad (3)$$

So, 918 W is a small data when separate the dust particles produced by 600 MW unit boiler. The powers needed change with the particles size. The particle size is larger, the power is smaller, while the particle size is smaller, the power is larger. Under above conditions, the power needed is 230 W when the particle size is 20 μm and the power needed is 3.6 kW when the particle size is 5 μm. The consumed power is insignificant in spite of the particle size. These are theoretical power consumption and the practical power consumption is bigger. Small energy consumption is an important characteristic of EP. The main reason is the electric power acts on dust particles directly. The electric power acts on dust particles indirectly in the mechanical cleaner. For example, most energy is used to produce centrifugal force by high speed rotating to separate dust particles, while the energy used to separate dust particles is small in cyclone separators.

The power consumption during operation is bigger than the above power calculated in ideal state because of the secondary blowing dust, non-uniform flow distribution, the ash-deposition on plate and line, the bad vibration effect on plate and line, the ash-deposition and condensation on high voltage insulator, the spacing between discharge and collecting electrodes exceeding the error criterion, the properties of EP power supply, the reverse corona, and so on. In any case, the theoretical power consumed in flue gas cleaning is an important reference.

3 PRACTICAL SECONDARY ENERGY CONSUMPTION OF EP HIGH VOLTAGE POWER SUPPLY

With the example of $3.4 \times 10^6 \text{m}^3/\text{h}$ flue gas, EP is always designed to double- chamber four electric fields (or five) with the spacing between discharge and collecting electrodes should satisfy the expression 2b≥400 mm in order to reach the emission standard and meet the requirement of desulfurization process. Giving an example to show the double- chamber- four-electric field, the average output power rating is $W_e = 72 \times 10^3 \times 2.0 = 144(\text{kW})$ when the collection area of every electric field is 5000 m^2-5600 m^2, the output voltage rating of every high voltage power supply is 72KV, and the output current rating is 1800 mA-2200 mA. The secondary voltage is 50 kV-65 kV and the secondary current is 1200 mA-1600 mA usually when EP is running. The running average power is $W_e' = 57.6 \times 10^3 \times 1.4 = 80.64(\text{k W})$ when the secondary voltage occupies 80% of the secondary rated voltage, 72 kV×80%=57.6 kV, and the secondary current occupies 70% of the secondary rated current, 2000 mA×70%=1400 mA. The total energy consumed by 16 high voltage power supply facilities is 80.64 kW×16=1290 kW, and this is a big data. The data in practice is smaller or bigger because of multiple factors and they are in the same magnitude. Power consumption 1290 kW, equivalent to 1400 times comparing with the theoretical power consumption 918 W, is a quite big data which need to be analysed and discussed.

4 THE CATEGORIES OF HIGH VOLTAGE POWER SUPPLY ENERGY CONSUMPTION

For the conventional high voltage power supply facilities which always run under the working mode of spark setting(spark automatic tracking), the running voltage U_2 approaches the spark flashover voltage and the secondary current is big enough in order to enhance the collection efficiency and reduce the dust emission concentration. This is high parameter operating named high power and high energy consumption temporarily. The status that high voltage power supply facilities of EP almost run under the working mode of spark without considering the properties of coal and the different conditions among cement industry, metallurgical industry and so on deserves our reflection and discussion.

In fact, the high voltage power consumption should be classified into four categories: ①the energy used to charge and trap the dust is effective energy; ②the energy which play destructive effect on charging and trapping dust is minus effective, e.g., reverse corona, secondary blowing dust; ③the ineffective energy which is between ① and ② has no effect; □ the energy used to transform the 380 VAC dynamical power to the pulse DC negative high voltage output is natural energy. During collecting process, the effective, the minus effective, the ineffective and the natural energy all exist and in fact, the effective energy occupies small proportion and the others occupy the most proportion in total energy consumption. We can enhance the collection efficiency, reduce the dust emission concentration and in the meantime achieve the goal of reducing energy consumption by advanced technical measures to increase the proportion of the effective energy consumption and reduce the proportion of the others.

5 THE STUDY AND ANALYSIS ON WHITE POWER SUPPLY THEORY OF EP

In the development of international electrostatic precipitation technology, the predecessors such as White have made great contribution to the theory and the technology of electrostatic precipitation. White had discussed the importance of the power supply technology and the relation between power supply energy and collection efficiency penetratingly as early as in 1962. The main arguments are as follows:

(1) power supply is the most basic and important factor for the high collection efficiency. The good mechanical body can't replace excellent power supply even though it is necessary.

(2) The corona discharge and the electric field are produced by high voltage power in dust collecting area.

(3) The theoretical power needed when the dust in the flue gas were collected by EP.

(4) The reaching rate ω is the basic link between collection efficiency and electric factors.

(5) The reaching rate can connect with power supply in several ways:

a. the peak and the average voltage of the power;

b. The average current of EP;

c. The useful corona power.

(6) the pulse power supply with the peak voltage produce higher collection efficiency in many applications.

As we all known, White had gotten the equation on the basis of the relation between collection efficiency and corona power:

$$P_2 = I_2 \times \frac{U_P + U_m}{2} \tag{4}$$

where P_2 is corona power of EP, I_2 is the total corona current, U_p, U_m is the peak and the minimum voltage respectively.

$$\omega = K_1 \frac{P_2}{A} \tag{5}$$

where ω is the effective reaching rate, A is the total dust collection area of EP, $\frac{P_2}{A}$ is the corona power consumed by per unit dust collection area, which can be simply described specific power, K_1 is a parameter, $K_1 = \frac{\omega}{P_2 / A}$, which means that the reaching rate per specific power , and the value is related to gas, dust and the design of EP.

Equations (4) (5) are substituted into the Deutsh equation, and the equation is stated as

$$\eta = 1 - e^{-K_1 \frac{P_2}{Q}} \tag{6}$$

where η is the collection efficiency of EP, Q is the amount of flue gas.

Equations (5) (6) indicate clearly that the corona power is in the direct ratio to the reaching rate and the collection efficiency. In the development of international electrostatic precipitation technology, we found that the applicability of equations (5) and (6) is conditional by studying White′ theory comprehensively and systematically and analyzing seriously combined with the running status quo of EP. The conditions are: ① It is suitable for the working mode of spark setting(spark automatic tracking); ② It is suitable when the running voltage is different from the flashover voltage; ③ It is suitable for low specific resistance and some medium specific resistance particles. It is not suitable for the working modes of intermittent power supply, simple pulse and pulse power supply and for the comparison between these working modes and spark setting.

In addition, White had made unique discussion on pulse power supply which was at the primary stage before 1962. White indicated that pulse power supply was a new power supply mode which was completely different from other high voltage power supply system of EP and the advantage of pulse power supply was that it can supply peak voltage for EP to obtain higher collection efficiency in many applications.

In summary, White theory should be studied and analysed comprehensively and systematically and should be connected with the operation status quo of EP of national coal-fired power plants in order to better inherit and develop the theory.

6 THE ENERGY SAVING AND EMISSION REDUCTION OF EP

There are some achievements on efficiency enhancing and energy saving (energy saving and emission reduction) of EP in electric and entity plants, colleges and scientific research institutions. There are two concepts, ways and means to improve the collection efficiency of EP by high power supply control technology of EP: first, enhancing running power of EP, in other words, pursuing high voltage and large current. The working mode with guide of this concept is spark automatic tracking; second, enhancing the running voltage of EP and optimizing voltage waveform. The voltage is peak voltage rather than secondary average voltage. The voltage waveform includes peak-voltage-value, average-voltage -value, valley-voltage-value and the pulsatile frequency, etc. The working mode with guide of this concept is simple pulse whose duty ratio and amplitude ratio are adjustable. In this ways, we can reduce emission concentration and power consumption simultaneously, in the other words, we can reach the effect of efficiency enhancing and energy saving. We are gratified that Nanjing Automation National Power plant have researched the new generation conventional(50 Hz) power supply control equipment of EP with efficiency enhancing, energy saving and intelligence optimization control. The most outstanding characteristics of this equipment is four functions: ① efficiency enhancing, energy saving and pulse power supply function; ② efficiency enhancing, energy saving and dynamic intelligence optimization control function; ③ power reducing strike optimization; ④ dynamic test technology of dust specific resistance in single electric field. With the four functions, EP can run in a winning state which achieves the goal of efficiency enhancing and energy saving because EP can be adjustable to different coals and conditions. With this equipment, collection efficiency can be further enhanced, dust emission concentration can be reduced by more than 30% and even 60%, and energy can be saved by more than 70% and even 80% and can be saved by more than 90% in some electric field based on former fundament. The reverse corona is more serious, the effect of efficiency enhancing and energy saving is better. This technology has practical significance.

In order to further enhance collection efficiency, reduce dust emission concentration and decrease greatly energy consumption, the working mode of electrostatic precipitator power supply should be transferred from the single spark setting of high current, high power and high consumption to the scientific track of high efficiency and energy saving in national coal-fired power plants, which accord with White' theory and running status quo of EP in China. Specific effect of efficiency enhancing and energy saving and the suitable working mode relate directly to coal, condition and entity of EP.

7 CONCLUSIONS

(1) In present, the practical energy consumption is near to 1400 times of the theoretical energy consumption because the power is consumed greatly and the performance is bad when the EP operates in the working mode of spark automatic tracking.

(2) The applicability of White' equation about the power, the reaching rate and the collection efficiency is conditional, the conditions are: ①It is suitable for working mode of spark setting (spark automatic tracking); ② It is suitable when the running voltage is different from flashover voltage; ③ It is suitable for low specific resistance and some medium specific resistance particles. In addition, White indicated that efficiency enhancing and energy saving of EP is potential.

(3) The power consumed by the high voltage power supply should be classified into four categories, the effective energy, the minus effective energy, ineffective energy, the natural energy. In fact, the effective energy consumption occupies small proportion and other three energy consumptions occupy large proportion in total energy consumption. So, we should increase the proportion of the effective energy consumption and reduce the proportion of the others greatly.

(4) There are two concepts, ways and means to improve the collection efficiency of EP by the high power supply control technology of EP: first, enhancing running power of EP; second, enhancing the running voltage of EP, especially the peak voltage, and optimizing secondary voltage waveform and pulsatile frequency. The latter can reach a better effect of efficiency enhancing and energy saving and accord with running status quo of EP and national conditions.

(5) have researched the new generation conventional (50 Hz) power supply control equipment of EP with efficiency enhancing, energy saving and intelligence optimization control. The outstanding characteristic of this equipment is that the collection efficiency can be further enhanced, the dust emission concentration can be reduced by more than 30% and even 60%, and the energy can be saved by more than 70%-80% and even 905 and can be saved by more than 90% in single electric field based on former fundament. The reverse corona is more serious, the effect of efficiency enhancing and energy saving is better. This technology has practical significance.

(6) In order to further enhance collection efficiency, reduce dust emission concentration and decrease greatly energy consumption, the working mode of electrostatic precipitator power supply should be transferred from the single spark setting of high current, high power and high consumption to the scientific track of high efficiency and energy saving in national coal-fired power plants, which accord with White′ theory, running status quo of EP and energy saving and the strategic target of emission reduction in China.

If the high voltage power supply control technology with efficiency enhancing and energy saving would be used, the energy will be saved by more than 80% and the emission will be reduced by more than 30% and these data are considerable. If the popularity of this technology will bring great economic, environment and social benefits.

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