Study on the Dust Removal Efficiency Formula of EP with Efficiency Enhancing and Energy Saving

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Abstract: Based on theoretical reaching rate, operating status quo of EP and successful study and extension of high voltage power supply facility of EP with efficiency enhancing and energy saving, the dust removal efficiency formula reflecting the characteristics of high voltage power supply, efficiency enhancing and energy saving and intelligent optimization control was studied. It was indicated that the effective reaching rate and the dust removal efficiency were in the direct ratio to the peak and the minimum of the secondary voltage under the working manner of high efficiency and energy saving and the working manner of spark setting through the formula. The basis can be provided for the optimization and the efficiency enhancing and energy saving of high voltage power supply facilities of EP by the formula.

Keywords: Electrostatic precipitator, High voltage power supply, Efficiency enhancing and energy saving, Corona power, Dust removal efficiency, Drift velocity

1 INTRODUCTION

The EP had born for hundred years, the electricity dust removal technology had made contribution to humanity progresses, economic developments, human health and environmental protection. Based on electrostatic precipitation, Dr. Deutsch inferred the Deutsch EP dust removal efficiency formula in 1922[1]. This formula raised electrostatic precipitation to the theoretical level. It was the theory basis for the research and the design, as well as the operation analysis of EP.

By connecting many parameters with the reaching speed, White inferred the White EP dust removal efficiency formula which was in the direct ratio to the corona power[2]. The formula indicated that the high dust removal efficiency could be gained in pursuit of high voltage (average) and large current. The formula plays an instruction role in the design and the operation of the EP high-voltage power supply equipments and in enhancing the dust removal efficiency.

With the development of economy, energy saving and the emission reduction has been the strategic target. The EP high voltage power supply control device with efficiency enhancing and energy saving had been developed in some domestic units[3]. This kind of equipments could overcome the reverse corona. This is a big progress on electrostatic precipitation technology. The urgent need is to raise the technology to the theory to obtain the dust removal efficiency formula reflecting the characteristics of efficiency enhancing, energy saving and intelligence optimization control of high voltage power supply. The theory can be used to guide the design and running of high voltage power supply equipments.

2 DEUTSCH EP DUST REMOVAL EFFICIENCY FORMULA

Deutsch EP dust removal efficiency formula:

$$\eta = 1 - e^{-\frac{A}{Q}\cdot\omega} = 1 - e^{-f\omega} \tag{1}$$

Where η is dust removal efficiency (%), A is total dust collection area (m^2), Q is amount of flue gas (m^3/s), ω is effective drift velocity (m/s), f is specific dust collection area ($m^2/m^3/s$), $f = \frac{A}{Q}$, namely the dust collection area needed in cleaning one cubic meter of flue gas per second.

3 WHITE (H.J. WHITE) CORONA POWER-TYPE DUST REMOVAL EFFICIENCY FORMULA

Based on the relationship between reaching velocity ω and the corona power , dust removal efficiency formula was stated:

$$\eta = 1 - e^{-k_1\frac{p_2}{Q}} \tag{2}$$

Where η is dust removal efficiency (%), P_2 is useful corona power of high voltage power supply(w).

$$p_2 = I_2 \cdot \frac{V_p + V_m}{2} \tag{3}$$

Where I_2 is total corona current (A), V_p, V_m is the peak and the minimum of the secondary voltage, respectively.

$$\omega = k_1 \frac{p_2}{A}\ (\text{m/s}) \tag{4}$$

Where A is total collecting area, k_1 is parameter, which means the drift velocity under unit specific power.

The formulas (2)(4) indicated that the corona power was

in the direct ratio to drift velocity and dust removal efficiency. [2] is suitable in some situations and is not in others. The White theory on high voltage power supply should be studied systematically to get more practical dust removal efficiency formula.

4 STUDY ON EFFICIENCY ENHANCING AND ENERGY SAVING DUST REMOVAL EFFICIENCY FORMULA

4.1 Basis

4.1.1 White theory on EP high voltage power supply

The main body and the high voltage power supply of EP affect the EP performances. In Deutsch dust removal efficiency formula, A and Q reflect the structural parameters of main body, while ω does not. Therefore, White pointed out:

[1] The drift velocity is basic link between the dust removal efficiency and the electrical factor,

[2] The drift velocity can be connected with power supply in several ways:

a. The peak and the average voltage of the power supply,

b. The average current of EP,

c. The useful corona power.

[3] Pulse power supply bigger peak voltage which produces higher removal efficiency.

4.1.2 The running status of EP–the working mode of spark setting

The coals used in plants are high ash, low sulphur, low calorie and variety. The ash is up to 40%-50%and the reverse corona causes difficulty in EP operation and standard discharge. For conventional high voltage power supply facilities, the running voltage V_2 is close to spark flashover voltage and the secondary current is big enough to get higher dust removal efficiency. The high voltage power supply facilities almost run under the working mode of spark setting and are in the status of high power and energy consumption [4].

4.1.3 Efficiency enhancing, energy saving and intelligent optimization control

Some units have developed the new generation of EP conventional (50Hz) power supply equipments with function of efficiency enhancing, energy saving and intelligent optimization control. This kind of equipments can overcome reverse corona and their characteristics are:(1) the pulse power is major, (2) dynamic intelligent optimization control, (3) power control rapper, (4) dynamic dust specific resistance test technology in single electric field. The guiding principle is enhancing the operation voltage and optimizing voltage waveform automatically. The voltage here is the peak voltage but the secondary average voltage. The voltage waveform is mainly peak value, average value, valley value of the voltage, as well as pulsation frequency of the secondary voltage. Supported by above four functions, the dust removal efficiency was enhanced, the dust emission concentration was reduced, and the power energy consumption was reduced simultaneously. The dust emission concentration can be reduced by more than 30%-60% and the energy can be saved by more than 70%-80%, and in some single electric field the energy can be saved by more than 90%. The dust specific resistance is higher, the reverse corona is more obvious, and the effect of effect enhancing and the energy saving is more remarkable. Therefore, the EP dust removal efficiency formula reflecting the efficiency enhancing, energy saving and intelligence optimization control function of EP high-voltage power supply is pressing need.

4.2 Study on EP Dust Removal Efficiency of Formula with Efficiency Enhancing and Energy Saving

4.2.1 The theoretical drift velocity

The theoretical drift velocity expression of charged dust particle is stated as:

$$\omega = \frac{2}{3}\frac{D\varepsilon_0 a E_c E_p}{\mu} \quad \text{(m/s)} \tag{5}$$

$$\omega \propto E_c \cdot E_p \tag{6}$$

Where ω is theoretical drift velocity, E_c is field intensity for dust charging, V/m, E_p is the field intensity for dust collecting,V/m;

From [5] and [6], the theoretical drift velocity is proportional to both field intensities. The former field intensity was proportional to peak of the secondary voltage and the latter was in the direct ratio to minimum voltage.

4.2.2 Effective drift velocity can be connected with the power supply mode of efficiency enhancing and energy saving in the following ways:

[1] the field intensity for dust charging and collecting produced by power supply,

[2] the peak voltage and the minimum voltage of power supply,

[3] the peak voltage ratio and minimum voltage ratio between the working mode of efficiency enhancing and energy saving and in the working mode of spark setting,

[4] the field intensity for dust charging ratio and the field intensity for dust collecting ratio between the working mode of efficiency enhancing and energy saving and in the working mode of spark setting.

4.2.3 Study on drift velocity and the formula of dust removal efficiency with efficiency enhancing and energy saving

There are several considerations:

[1] Compare the working mode of efficiency enhancing and energy saving with the working mode of spark setting. The working mode of efficiency enhancing and energy saving has inherited the advantage and has improved the deficiency in the working mode of spark setting.

[2] Introduce the idea of field intensity for dust charging and collecting

The law that the effective drift velocity is in the direct

ratio to the both field intensities was introduced to the formula.

$$\frac{E_{Tc}}{E_{hc}} \approx \frac{V_{Tf}}{V_{hf}} \tag{7}$$

$$\frac{E_{Tp}}{E_{hp}} \approx \frac{V_{Tm}}{V_{hm}} \tag{8}$$

$$E_{Tc} \propto V_{Tf}, E_{Tp} \propto V_{Tm}, E_{hc} \propto V_{hf}, E_{hp} \propto V_{hm} \tag{9}$$

where V_{Tf}, V_{Tm} is the peak and the minimum of secondary voltage in the working mode of efficiency enhancing and energy saving, respectively, V_{hf}, V_{hm} is the peak and the minimum of secondary voltage in the working mode of spark setting, respectively, E_{Tc}, E_{Tp} is the field intensity for dust charging and collecting in the working mode of efficiency enhancing and energy saving, respectively, E_{hc}, E_{hp} is the field intensity of dust charging and collecting in the working mode of spark setting, respectively.

Peak and minimum of secondary voltage represented the field intensity for dust charging and collecting, peak voltage ratio and minimum voltage ratio represented the field intensity for dust charging ratio and the field intensity for collecting ratio between two working modes.

[1] Without introducing the corona current
The corona current needed in dust removal process is very small.

[2] Without introducing the average voltage
The average voltage can not represent the dust removal efficiency. The peak value, the minimum value, the waveform of voltage and the pulsation frequency affect the dust removal efficiency actually.

[3] the main electrical parameters which had an important effect on efficiency enhancing and energy saving were separated from the effective drift velocity in some form.

The effective drift velocity under the working mode of efficiency enhancing and energy saving can be expressed as follows:

$$\omega_T = \omega_h \cdot K = \omega_h \cdot B\left(\frac{V_{Tf}}{V_{hf}} \cdot \frac{V_{Tm}}{V_{hm}}\right) = \omega_h \cdot D\left(V_{Tf} \cdot V_{Tm}\right) \tag{10}$$

$$K = \frac{\omega_T}{\omega_h} = B\left(\frac{V_{Tf}}{V_{hf}} \cdot \frac{V_{Tm}}{V_{hm}}\right) = D\left(V_{Tf} \cdot V_{Tm}\right) \tag{11}$$

$$K \propto \frac{V_{Tf}}{V_{hf}} \cdot \frac{V_{Tm}}{V_{hm}} \propto V_{Tf} \cdot V_{Tm} \tag{12}$$

Where ω_T and ω_h are the efficiency drift velocity under the working mode of efficiency enhancing, energy saving and intelligent optimization control and under working mode of spark setting, respectively (m/s) ; K is the lifting coefficient for drift velocity.

$K \geq 1$ is due to the increase of $V_{Tf} \cdot V_{Tm}$ in the working mode of efficiency enhancing, energy saving and intelligence optimization control. If K=1, ω does not increase. If K=1.1, ω increases by 10%. K is related to entity structure ,electrical characteristics, the properties of flue gas and dust as well as the operation of EP.

B is the proportional coefficient (dimensionless and the value approaches 1), determined by the effect and the parameters of field operation, D is specific lifting coefficient $(1/(kV)^2)$, determined by the effect and the parameters of field operation.

$$B = \frac{K}{\left(\frac{V_{Tf}}{V_{hf}} \cdot \frac{V_{Tm}}{V_{hm}}\right)} \tag{13}$$

$$D = \frac{K}{V_{Tf} \cdot V_{Tm}} \tag{14}$$

The working mode of efficiency enhancing and energy saving had the characteristics of pulse power supply whose duty ratio and amplitude ratio could be adjusted automatically. The two limits of amplitude ratio correspond to the working mode of spark setting and the working mode of intermittent power supply respectively. Therefore the formula (10) has contained the working mode of spark setting, intermittent power supply, pulse power supply and so on. B=K=1 when high voltage power supply equipment works under the working mode of spark setting.

The formula (11) is substituted to Deutsch dust removal efficiency formula, the expressions is got:

$$\begin{aligned} \eta &= 1 - e^{-\frac{A}{Q}\omega_T} \\ &= 1 - e^{-\frac{A}{Q}K \cdot \omega_h} \\ &= 1 - e^{-\frac{A}{Q}B\left(\frac{V_{Tf}}{V_{hf}} \cdot \frac{V_{Tm}}{V_{hm}}\right)\omega_h} \\ &= 1 - e^{-\frac{A}{Q}D\left(V_{Tf} \cdot V_{Tm}\right)\omega_h} \end{aligned} \tag{15}$$

$$\eta \propto A, \frac{1}{Q}, \omega_T, \omega_h, K, \left(\frac{V_{Tf}}{V_{hf}} \cdot \frac{V_{Tm}}{V_{hm}}\right), \left(V_{Tf} \cdot V_{Tm}\right), B, D \tag{16}$$

The formula (15) indicated that dust removal efficiency η was proportional not only to A and $\frac{1}{Q}$,but also to the effective drift velocity ω_T, ω_h, the peak voltage ratio and the minimum voltage ratio between two working modes, the peak voltage, the minimum voltage and coefficients of K, B, D under the working mode of efficiency enhancing and energy saving. This formula is suitable for the working modes of pulse power supply, spark and intermittent power supply.

This formula indicated that the peak and the minimum voltage should be enhanced to improve the dust removal efficiency under the working mode of efficiency enhancing, energy saving and intelligent optimization control. Although

there was not corona current I_2 in this formula, the meaning of I_2 was contained. If V_f is higher, the instantaneous field intensity is bigger, the corona discharge is more intense, the instantaneous secondary current of pulse (peak value) voltage is also bigger, the dust charge amount is bigger, the drift velocity and the dust removal efficiency is higher. The efficiency enhancing was combined with the energy saving as a result of the difference between duty ratio and amplitude ratio. Moreover, this formula mainly represented the comparison between efficiency enhancing and energy saving working mode and spark setting working mode. η and D, ($V_{Tf} \cdot V_{Tm}$) were proportional, which did not show the board spacing is the bigger, the better.

4.3 Significance of the Dust Removal Efficiency Formula of Efficiency Enhancing and Energy Saving

The drift velocity and the dust removal efficiency of efficiency enhancing and energy saving are proportional to the peak voltage and the minimum voltage supplied by the high voltage power supply equipment, which indicated the importance of high voltage power supply performance,

This formula used the effective drift velocity and the ratio between the peak voltage and the minimum voltage under the efficiency enhancing and energy saving working mode and spark setting working mode, which indicated the effect of efficiency enhancing and energy saving under the former working mode,

The dust removal efficiency formula of efficiency enhancing and energy saving indicated that in order to get good running effect, we should pursue the peak value and the minimum value of the secondary voltage,

In the dust removal efficiency formula of efficiency enhancing and energy saving, except the drift velocity, A and Q were the parameters of main body, V_{Tf}, V_{Tm}, V_{hf}, V_{hm}, K, B and D were the electrical parameters of high voltage power supply. This had manifested the electrical equipments played an important role,

The function of efficiency enhancing and energy saving is the enormous technical support for the main body of EP. This can relieve the pressure which is produced by strict dust emission standard and change the conventional concept that the efficiency is reduced by increasing the main body collection dust area and the EP main body volume.

5 CONCLUSIONS

[1] The dust removal efficiency formula of efficiency enhancing and energy saving and the dust removal efficiency formula of White corona power had indicated that there were two ways to raise the dust removal efficiency. First, raising the corona power, second, optimizing the secondary voltage waveform and the pulse frequency. The latter was more scientific and more suitable to the operation status of EP in China.

[2] The dust removal efficiency formula of efficiency enhancing and energy saving indicated that the peak value and the minimum value of the secondary voltage were in the direct ratio to the dust removal efficiency. This formula had reflected the characteristic of efficiency enhancing, energy saving and intelligent optimization control of the high voltage power supply.

[3] The dust removal efficiency formula of efficiency enhancing and energy saving was suitable for the working modes of the pulse power supply, the intermittent power supply, the spark setting, as well as the working mode without the reverse corona.

[4] The dust removal efficiency formula of efficiency enhancing and energy saving indicated that in order to get good running effect, we should pursue the peak value and the minimum value of the secondary voltage instead of pursuing the working mode of high power and high energy consumption.

[5] The efficiency enhancing and energy saving is the direction for electrostatic precipitation technology. Because of the efficiency enhancing, energy saving and intelligent optimization control of high voltage power supply, the good effect of energy saving and emission reduction can be reached. This formula supply the theoretical basis for efficiency enhancing and energy saving and for the shift from the spark setting working mode to the efficiency enhancing and energy saving working mode.

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