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DISCOVERY OF THE POWER-SAVING PRINCIPLE OF ELECTROSTATIC DUST PRECIPITATION USING DC SUPPLY

ZHAO FU[1], YU WENHAI[1], WANG MEIJU[2] AND HE JIAN[1]

1. Automation Research Institute of Shijiazhuang City
No 452 Zhongshan East Road, Shijiazhuang City, 050031, China
2. Electric Power Plant Design and Research Institute of Hebei Province
No 6 Jianhua North Road, Shijiazhuang City, 050031, China

ABSTRACT
This article proves that electrostatic precipitators using DC power supply can save much more electrical energy than those using rectified AC power supply. The discovery of the mechanism of this energy-saving phenomenon lays a theoretical foundation for the use of DC power supply in electrostatic precipitation and greatly promotes a large-scale energy-saving movement in this field.

1 INTRODUCTION

Because of the birth of dust precipitation using optimum electrical spark rate[1], direct current power supply which has self-persisting electric discharge characteristic in the early stage. Then it's replaced by rectified alternating current power supply which has good self-extinguishing flash discharge characteristic. Until now alternating current power supply has been playing the dominant role in electrostatic dust precipitation system.

However, long time ago people found that dust precipitators using DC supply could save much more electrical energy. But few people knew why and how much power energy could be economized by using DC supply. As a result people ignored this phenomenon.

In our research on electrostatic dust precipitation and engineering practice we frequently met the above-described power-saving phenomenon. So we carried out a detailed research. We found that power-saving phenomenon is a universal objective physical process rather than an accidental and special condition. We point out that the theoretical value of power saving rate K_1 simply in electric field could be as high as 90%. This conclusion accords with the $K_1=86\text{-}93\%$ found in the engineering practice of large steel company in BeiJing capital of China using $80M^2$ electrostatic dust precipitators.

This article also points out the element that adopting the direct current supply can rise the rate of saving electricity. DC power energy saving mainly happens in dust precipitation electric field and power supply this two aspect. Moreover, their power saving mechanisms are totally different from each other. Therefore this article gives separate analyses on electric field power saving and power supply energy saving.

Note: Quantity values used this article are average values.

2 ANALYSIS ON THE MECHANISM OF POWER ECONOMIZATION IN ELECTRIC FIELD

2.1 DC power supply acting on electric field load

As we all know, the load characteristic of electrostatic dust precipitator is a complex function among the numerous electric field parameters. To simplify the analysis and focus the essence, we begin our approach by giving a detailed example and following the logical-inference of Particularity - Universality - Particularity[2] .

Therefore we based our analysis on the actual electric field characteristic of the site data collected from a horizontal dust precipitator used for a mechanical vertical kiln in Shandong Province. See Table 1.

Table 1 Operational Parameters of a Horizontal Dust Precipitator for a Vertical Kiln in a Cement Factory (1992)

U_0(KV)	0	10	20	30	40	45	48	50
I_0(mA)	0	0	0	0.1	0.4	0.8	2.0	3.9

Generally speaking, those alternative power current through rectifier filter, high frequency inversion rectified or three-phase full wave rectified can be regarded as direct current power supply. Obviously, when direct current acts on electric field load the load current I_0=const. For instance, when

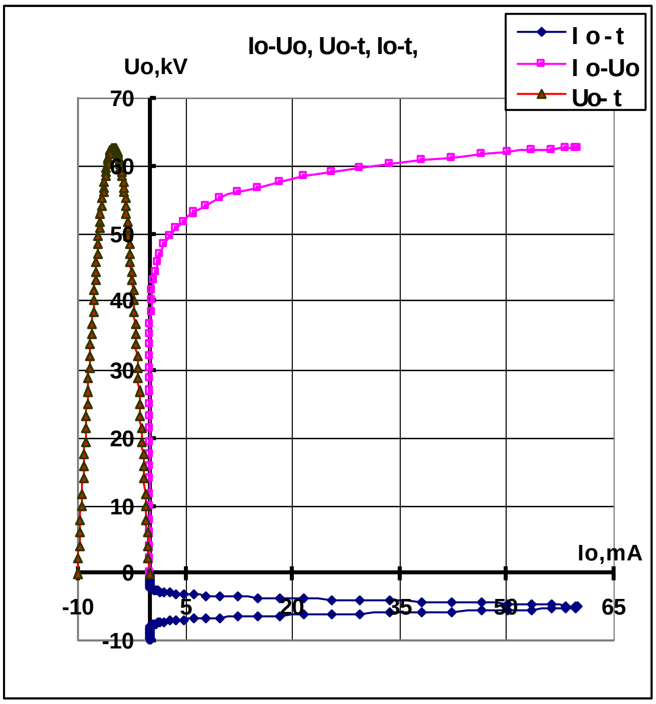


Figure 1 Dust Precipitator Load Driven by alternative Power Current

Note: Quadrant? refers to dust precipitator load.

Quadrant ? refers to alternative power current supply

Quadrant ? refers to load current.

$U_0(t)$=40kV(I_0 comes directly from Table 1)

I_{01}=0.4mA
U_{01}=40kV

2.2 Power current supply acting on electric field load

Dust precipitator load is the same as above. However, when power current drives the situation is totally different from direct current. See Figure 1.

We can see that when semiwave alternative power supply $U_0(t)=U_{0p}sin?t$ acts on electric field load , the generated load current $I_0(t)$ is a strong nonlinear bell curve:

$$I_0(t) = 2.9937E-05e^{2.3088E-01U_{0P}\bullet Sinwt} \quad (1)$$

Compared with DC supply the load current not only has a clear shape difference but also a much higher quantity value. Take this case for an example, when $U_0(t)$=40kV,

I_{02}=12.5mA
U_{02}=40kV
I0p=60mA
U0p=62.84kV

2.3 The quantity value of power economizing rate K_1

Section 1.1 describes that when $U_0(t)$=40kV the load current of dust precipitator using DC supply in mechanical vertical kiln is a stable direct current value.

I_{01}=0.4 mA
U_{01}=40kV

In Section 1.2 we conclude that the average load current of the dust precipitator using alternative power supply of average $U_0(t)$=40kV is as follows:

I_{02}=12.5mA
U_{02}=40kV

We observe the following fact: when dust precipitator electric field and dust condition are fixed, to get a similar dust emission target the required power supply voltage of alternative power supply is close to that of DC power supply. To make a comparison we suppose $U_{01}=U_{02}$=40kV. Then the ratio between the two condition load currents generally equals to the ratio between two power consumptions P_{01} and P_{02}. Now the power economizing rate K_1 from adoption of DC power supply instead of AC power supply can be worked out with the following formula:

$$K_1 = 1 - \frac{I_{01}}{I_{02}} = 1 - \frac{0.4mA}{12.5mA} = 96.8\% \qquad (2)$$

K_1 clearly reflects the amount of saved power energy in electrostatic dust precipitation using DC power supply instead of AC power supply.

2.4 Analysis on the Mechanism of Power Economization

1.4.1 Using DC power supply

Figure 2 is a schematic diagram for electrostatic dust precipitation using negative high voltage power supply. This diagram shows a dust granule passing vertically upward the electric field. m stands its mass and v stands for its speed.

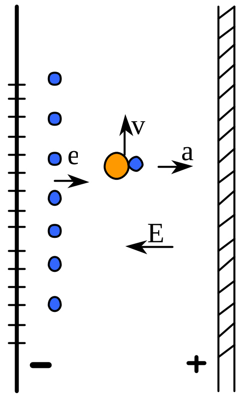


Figure 2 Schematic Diagram for Electrostatic Dust Precipitation

Suppose DC high voltage U_0 functions between corona wire and anode. With enough electric field intensity E_0 corona pole will generate large amount of electrons e that will fly to anode. During this process some electrons and neutral dust granules m adsorb each other. Certain quantity Q of electric charge is brought to these granules. Now the power supply has accomplished charging on dust granules. This stage is finished nearly in a blink and no considerable kinetic energy is provided to the granules.

The second stage is called electrostatic capture. Affected by the electric field force f the dust granule of mass m produces an accelerated velocity a towards anode and finally is captured by the anode. We observe that power supply does not apply work on dust granule m through horizontal component E of electric field intensity until dust granule is charged. Suppose a =const, then the average capture consumed power P_f is as follows:

$$P_f = \frac{1}{2} \bullet \frac{Q^2 E^2}{m} \bullet t_0 \qquad (3)$$

where, t_0 stands for the total time for the dust granule to fly horizontally to anode.

We observe that P_f is only related to the horizontal movement of dust granule. Therefore P_f normally has limited quantity value.

Of course, dust charged is a necessary process during charged dust precipitation. Accordingly electron outcoming and some "charging power" P_h paid out during speed acceleration are inevitable. Upon that, from the perspective of "dust removing" the sum of above described charging power P_h and capture power P_f can be regarded as the useful power P_y for electrostatic dust precipitation. On the other hand, to guarantee a valid charging on dust granules charged by Q, the space density for free electrons in the electric field should be in a surplus status in comparison with dust density?. In other words, power supply has to contribute some "idle work" P_w on surplus electrons outcoming and passing electric field as they are not charged on dust granules. As a result, the main power consumption $P_?$ during electrostatic dust precipitation (ignoring factors such as air friction) can be worked out from the following formula:

$$P_\Sigma = P_f + P_h + P_w \qquad (4)$$

When electric field and power supply match properly, satisfactory dust removing and minimum idle work Pw can be realized by adjusting power supply voltage U_0, thus achieving power energy conservation target. We can easily meet this target on dust precipitation system using DC power supply.

1.4.2 Using alternative power supply

Compared with direct current use, it's really different. Now the idle work Pw covers a greater percentage. See Figure 3.

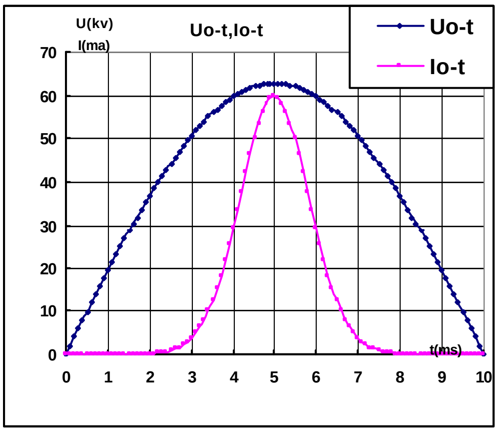


Figure 3 Current Waveform of Using Power Current Supply

We observe that power supply voltage is low and the corona current is small within 2/3 period of 0-3ms and 7-10ms half-wave voltages. In other words, no charging ability and capturing ability is generated. From equation 3 we know power supply applies little work on dust granule or gives little contribution to dust removal. Dust removal target lost in this 2/3 period of time must be compensated during the 1/3 period left. The only way to compensate this loss is to raise supply voltage, i.e. using peak voltage of half-sinusoid. But this also brings a secondary action: The very high voltage U_{0p} during this period will inevitably produce space electronic current of extremely high density. The overplus of space electrons cannot be used for dust charging and will fly directly to anode plate. Now there will be an enormous power consumption in the electric field: *Pop=Uop*Iop*. The formula 3, 4 tell us that the electron overplus produce nothing for "dust removal target", only forming an enormous idle work P_w.

Please bear in mind that Ph for dust charging in dust precipitation electric field using alternative power supply only covers around 1%[6] of the total power consumption. As for power Pf for dust capturing, the formula (3) only gives a limited quantity value. This means that using AC power will bring an enormous power loss around its peak value.

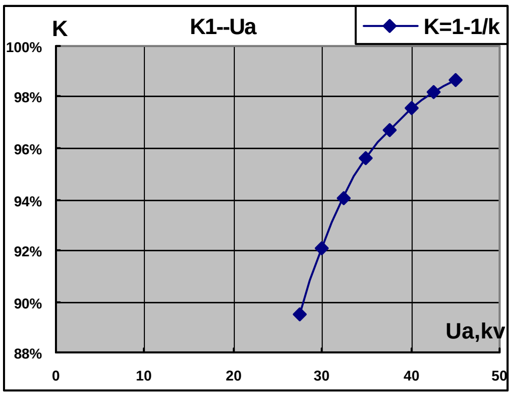


Figure 4 Relation between Power Conserving Rate K_1 and Voltage

Dust precipitation electric field using AC power supply cannot avoid this result. Compared with direct current supply it is very important for us to point out this inevitability.

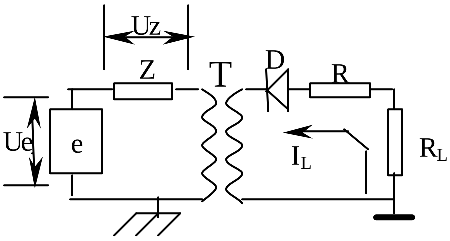
Dust precipitator load character- istic is determined by many complex factors. Therefore, the quantity value of K_1 is not only a function for power supply voltage but also a parameter for electric field atmosphere and components of dust-contained gas etc. Figure 4 gives an example. Usually K_1 value in wide pole span is higher than in narrow pole span, higher in high voltage than in low voltage, higher in high dust density than in low dust density. Practically speaking from the project dust precipitator of multilevel wide pole span using direct current supply has a considerable power-saving rate. Its general electric field power saving rate K_1>50%. The value is only a conservative figure.

2 ANALYSIS ON THE MECHANISM OF POWER CONSERVATION IN POWER SUPPLY

The "Optimum Electric Spark Rate Dedusting Method" requires that the electric field to be under a constant electric spark condition. Though AC power supply has a good self-extinguish capability, the ordinary AC power supply still cannot directly drive dust precipitator load R_L.

Figure 5 shows a dust precipitation system using AC power supply. In the figure e refers to ideal AC power supply, T refers to the ideal transformer and R_L refers to electrostatic dust precipitator electric field. We can observe that the leakage impedance Z is shown in front of the transformer T.

Figure 5 Schematic Diagram for Electrostatic Dust Precipitation System Using AC Power Supply



Usually the required ordinary AC power supply V_Z<5%. This means that when short circuit on secondary high voltage happens the primary received current impulse could be 20 times as much as the rated value. Therefore the frequent spark discharge in electric field could threaten the equipment safety and bring electromagnetic hazards to power line. So technical standards require that impedance voltage of AC power supply for electrostatic dust precipitation should be higher than that of ordinary AC power transformer. Usually V_Z>33%, sometimes it could be as high as 42%. Aside from this, a ballast resistor is frequently required at the high voltage output terminal, which also consumes considerable power.

When the power supplying system reaches the rated load current I_L, we can easily find out the average power consumption P_Z on leakage impedance Z through the following formula:

$$P_z = V_z \bullet P_{net}$$

where, *V_Z refers to the per unit value of impedance voltage, dimensionless.*
Pnet refers to the average power provided by power network, W.

This means that when dust precipitator uses AC power supply when load current is fully loaded, about 30-40% of the average power cannot be delivered to the electric field. This part of power is wasted within the AC power supply.

Dust precipitators using direct current supply will not require a spark discharging condition. Therefore the support of leakage impedance shown in Figure 5 is not required. Compared with AC power supply, DC power supply itself will produce a power conserving rate K_2.

$$K_2 = V_z \qquad (5)$$

We observe that a well-designed Best Electric Spark Rate Dedusting System is actually working near the fully loaded load current. Therefore we can get a conclusion from formula (5) that about 30% average power is lost by using power supply. This is universally true.

Though some people prefer a dust removing system operating under the best spark rate condition, still we might as well adopt DC power supply to get a higher power energy-saving rate. For instance, the F-series high frequency high voltage power[5] , the HFSMPS high frequency high voltage power[6] are both capable of resisting spark discharge attack. They do not need leakage impedance Z shown in Fig. 5, not even the ballast resistor R. They can help to meet the target of 30% power conservation for power network. In fact electrical power conservation is far from difficult if we have a correct understanding.

3 TEST AND VERIFY

Impedance voltage V_Z is the key factor for power conservation. When DC power supply is used there is no need to give an illustration for K_2 from formula (5). So we just give illustrations on K_1.

3.1 General illustration

As we mention at the beginning of this article, the above-described power-saving phenomenon was discovered by many people long time ago. For instance, statistics given by Hebei University of Science and Technology show that in dust removing electric field the power saving rate could be K_1˜ *1-1/5.6=82.1%*. Some document points out that under certain circumstances dust-removing target[3] can be met even when current flow in electric field falls two magnitude levels. Here is another example, site data provided by Tangshan ManxuanEnvironmental Protection Industry Co., Ltd. shows K_1˜ *1-1/6.65=85%*[7]. This site data was measured in the same electric field under the same dedusting condition. There are still many more examples. By now we have found any counterexample that can prove the use of DC power supply is more wasting than using AC power supply. These are general illustrations for the objectivity of power economization mechanism.

3.2 Typical illustration

The following example is a true case of $80M^2$ electrostatic dust precipitator used in the sintering plant of Shougang Group(large steel company in BeiJing capital in China). DC power supply and wide pole span structure are used. Detailed operation data are shown in Table 2.

Table 2 also provides the operational data of electric field using AC power supply in the same factory as the same time. Dust removing conditions for these two systems are similar.

We can see that in comparison with power supply, the use of direct current in dedusting electric field can save power energy with K_1 ˜ *90%*.The power energy saved is quite considerable.

Table 2 Comparison of Power Consumption between Two Dedusting Electric Fields

power supply	dust precipitator #	same pole span mm	valid sectional area M^2	date of record	power consumption KW	power consumption/ sectional area J, KW/M^2	power consumption multiple $k=J_2/J_1$	saving rate K=1-1/k
DC power supply	1	660	80	2001.12.30	4.85	J_1=0.0606	8.886	88.7
				2001.12.31	2.84	0.0355	15.169	93.4
				2002.1.31	6.07	0.0759	7.123	86.0
				average value	4.59	0.0573	10.393	89.37
AC power supply	2	400	130	2002.1.31	71.0	J_2=0.5385	1.000	00.0

Note: (1) Time of record: October, 2002

(2) Electric field structure: four-stage cascade

(3) Power source type: F200 high frequency high voltage

4 CONCLUSION

4.1 On Quantity of Power Economization and Steel Material

Above analysis shows that a well-matched electrostatic dust precipitator can save more 60% power energy in the areas of power supply and electric field when using DC power supply rather than using AC power supply. This is just a conservative conclusion. In fact this is of practical significance for dust precipitation engineering running 24 hours constantly.

Experience from Shougang Group also proves that a well-designed DC-driven de- dusting system can easily adopt wide pole structure, which can save over 10% of steel materials.

Therefore, de-dusting systems using DC power supply can save both power energy and steel materials.

4.2 On Sustainable Development

The discovery of Power-saving Principle of Electrostatic Dust Precipitation Using DC Supply and illustration is of great practical significance for the progress of de-dusting technology. Presently power current is the basic power supply for electrostatic precipitators following "best electric spark rate dedusting method", which not only excludes direct current from the field of electrostatic precipitation but also requires a “maximum power consumption” as the sacrificial condition[4]. It’s wast power energy. The discovery of Power-saving Principle and illustrations on it provide a theoretical basis for the return of DC power supply to electrostatic dust precipitation. It’s also save large scale power energy and steel material, offering the evidence and reference for large project. The adoption of DC power supply and wide pole span structure is beneficial for the sustainable development of de-dusting technology.

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