ICESP X – Australia 2006
Paper 3B2

THE NEWEST RESEARCH RESULTS FOR COLLECTION OF HIGH SPECIFIC RESISTANCE DUSTS WITH ELECTROSTATIC PRECIPITATORS

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ABSTRACT

In this paper the newest results in industrial ESPs for collecting high resistivity dusts are summed up as follows:
(1) The negative resistance zone in the V-A characteristics when back corona occurs is not a inevitable result due to back corona, but due to the characteristics of the energization to the ESP. With modern techniques is able to stop the appearance of the negative resistance zone by accurate recognition of back corona signals, tracking and controlling them.

(2) Three joint hazards due to electrostatic attractions, electrostatic repulsions and back corona discharges may exist when ESPs are used to collect high resistivity dusts, leading to a far lower precipitation efficiency than that for common dusts.

(3) For collection of high resistivity dusts with ESPs. If accurate recognition of back coronas, tracking and controlling them to increase effective voltage and corona current as a means to increase dust particle charging can be realized then the structure design of the ESPs and the mode of the energisation would not obey the formula jpd=E_S. On the contrary if ESPs with narrow gaps, strong corona cathode wires and the electric field strength same as that in wide gaps ESPs are adopted collection of high resistivity dust can be remarkably increased.

1. TWO COMPLETELY DIFFERENT RESEARCH RESULTS

It is well-known that the range of high specific resistance of dusts is defined by $p_d=A\cdot 10^{11}$ O·cm.

Up to now the problem for collecting high specific resistance dusts with ESPs is not well resolved. In this connection the researches both domestic and overseas in this respect are very active all along and a good many papers related have been published and the discussions have come to a common theoretical sense. For the years past the authors published the results in their papers. We compared them with our results obtained by modern technical means and discovered that the newest results we obtained are completely different from many key conclusions in the past researches.

1.1 The traditional theoretical research results

The theoretical research results obtained by both domestic and overseas scholars can be summed up as follows:

(1) Discovery of the phenomenon of "back corona discharge" in the high specific resistance dusts

With an ESP collecting a high specific resistance dust negative ions attached to the dust particles is accumulated in the dust layers on the plate electrodes, generating (negative) electric field in the layers. With increase of thickness of the layers the field strength continuously increases until the insulation of the dust layers is breakdown and electric discharge to the anodes are generated. This discharge is called "back corona discharge".

(2) A theoretical explanation on the hazard of "back corona" was raised

When the back corona during ESP collecting high specific resistance dusts comes to some serious extent there appears "positive charge cloud" nearby the anode plates, diffusing into the bulk of the ESP and leading to thorough destruction of dielectric insulation, abrupt decrease of the operational voltage and increase of current and decrease of precipitation efficiency by a large margin.

(3) V-A characteristics for the back corona are plotted.

When back corona comes out in the electric fields there appears a "negative resistance zone" in the V-A characteristics as shown in Fig.1.

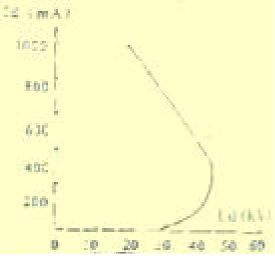


Fig.1

(4) An inequality for controlling the hazard of "back corona" was raised

which is $jp_d=Es$

where j is electric current density A/m^2; p_d - dust specific resistance kO·m and E_S - breakdown strength of the dust layer kV/m

(5)Two key measures for controlling the hazard of "back corona" were raised, which are:

- reduction of the operational electric current density;
- reduction of the specific resistance of the dust layers through chemical agent conditioning.

1.2 The newest research results

(1) More thorough studies on the "three kinds of hazards" affecting high resistance dust precipitation efficiency

The first hazard (a hazard of electrostatic attraction) - There exists a hazard of

electrostatic attraction when a ESP collects high specific resistance dusts

When a ESP collects a high specific resistance dust. The dust carrying negative charge would be adhered to the anode plates, which leads to difficulties to clean it up. Continuous increase of thickness of the dust layer on the anode plates leads to reduction of breakdown voltage of the ESP and finally simultaneous reduction of both operational parameters and precipitation efficiency in a large margin.

The simple method to check the existence of the electrostatic attraction hazard is "power off rapping". After the high voltage on the ESP is turned off the electrostatic force vanishes and a large amount of the dust falls off from the anode plates. Further cleaning the plates by rapping makes them dust-free so that both operational parameters and precipitation efficiency temporally go up by a large margin. That is shown in Fig.2

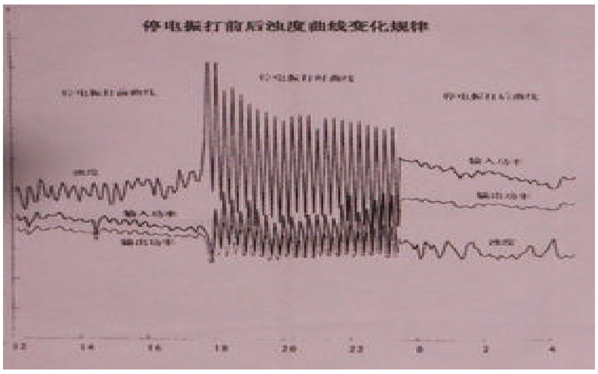


Fig.2

The second hazard (the hazard of back corona discharge) - The back corona discharges happen when the electrostatic hazard develops to its extremity.

Along with more and more accumulation of negative charges in the dust layers the negative electric field on the surfaces of the layers becomes stronger and stronger until the insulation of the layers is broken down, i. e. "back corona discharges " occur.

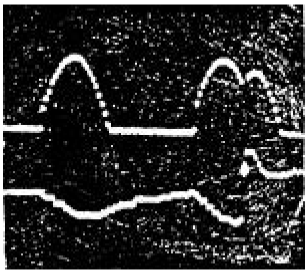
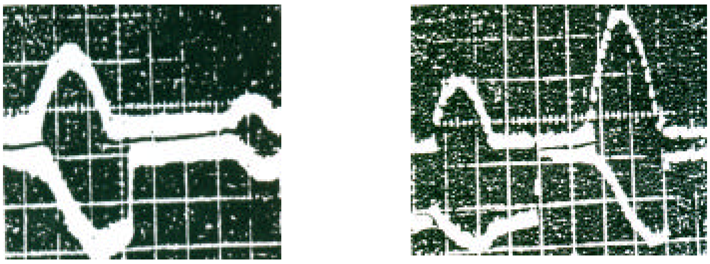


Fig.3 The characteristics of a flash discharge waveform

Back corona discharges" are sharply different discharges from the normal "flash discharges"

Fig. 3 shows a typical waveform of a flash discharge, whose flash voltage corresponds to the highest voltage (peak voltage) able to exert between the cathodes and the anodes.

However the back coronas are stochastic as shown in Fig.4. The back corona discharge can occur even when the operational voltage of the electric field decreases to zero (valley point). It is just these stochastic discharges unable to be controlled by the energyzation system that leads to sharp decrease of the operational voltage



(a) (b)

Fig 4 the characteristics of back corona discharges

The negative resistance zone in the V-A characteristic curve is not an inevitable outcome due to back corona discharges.

Under the conditions of back corona discharges adoption of two different phase shift amplitude modulation energisation systems generates sharply different V-A characteristic curves as shown in Fig. 5 and Fig.6.

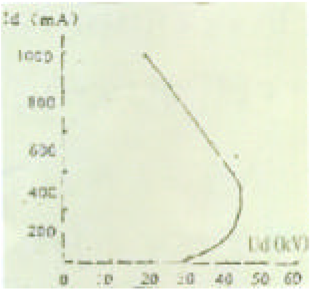


Fig.5 a V-A characteristic curve with a negative resistance zone

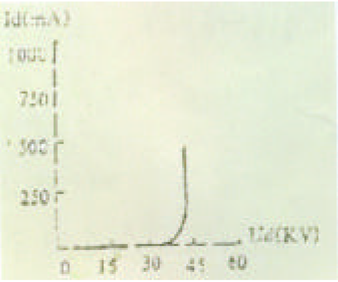


Fig.6 a V-A characteristic curve without any negative resistance zone

Existence of the "negative resistance zone" in the V-A curve is due to the improper controlling characteristics of the energisation system

Following traditional theory it may be considered that when "back corona discharges" exist controlled silicon phase shit amplitude modulation intermittent energisation or some others may be recommended in general. However when "back corona discharges" frequently emerge the V-A waveforms become seriously distorted waveforms as shown in Fig.8.

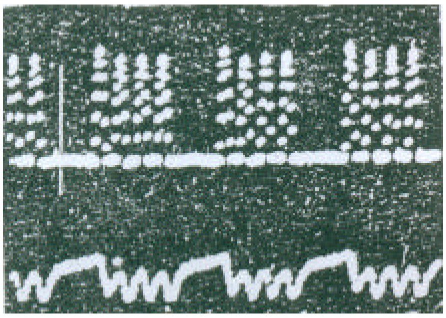


Fig.7 Waveform of intermittent energization mode

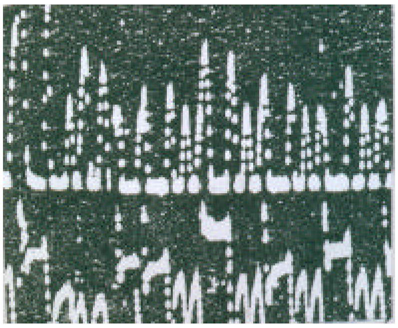


Fig.8 distorted waveforms due to frequent flashovers

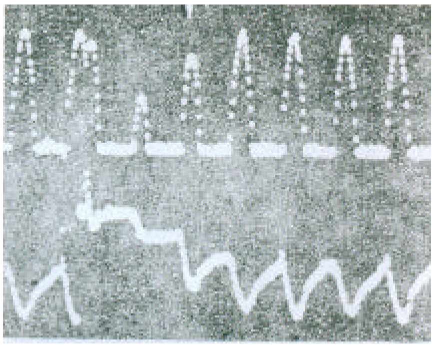


Fig.9 The waveform of flashover in a continuous energization

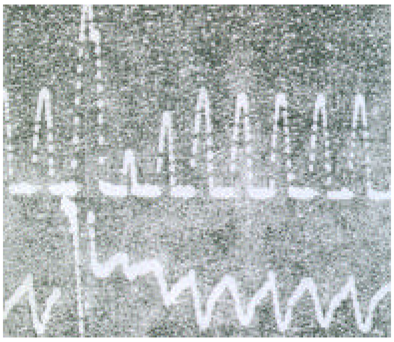


Fig.10 A "back corona discharge" waveform in a continuous energization

Under the same conditions controlled silicon phase shift amplitude modulation modes with different controlling characteristics that is the "continuous energisation" mode as shown in Fig.9 have no different V-A waveforms of back corona discharges from those the normal energisation modes have.(Fig.10)

The 3rd hazard (the hazard due to electrostatic repulsion)

The existence of the electrostatic repulsion makes the movement of the charged particles toward anodes slower and slower.

The negative field generated by the negative charges in the dust layers shields the anodes repulses the negatively charged particles moving toward the anodes and makes their movement slower and slower.

(2) The comprehensive effect on the precipitation efficiency due to the three hazards

(i) The mutual effect due to the "electrostatic attraction hazard" and the "back corona hazard" makes the operational voltage of the fields decrease greatly. That is the initial reason of the decrease of the precipitation efficiency.

(ii) Owing to reduction of the operational voltage of the fields the interrelated effect initiated is deterioration of the field corona effects (respective reduction of the charge carried by the dust) so that the electrostatic force exerted to the dust particles is weakened. Simultaneous reduction of both operational voltage and current results in decrease of the charged particle speed moving to the anodes.

(iii) When the charged particles move slowly to and approach the anodes nearer and nearer the repulsion exerted to them by the "negative electrostatic field" generated by the charged dust layers on the anode plates becomes stronger and stronger so that the speed of the charged particles moving to the anodes becomes lower and lower

(iv)The comprehensive function of these three factors basically results in great decrease of the precipitation efficiency of the high resistance dust.

(3) Using narrow gap ESPs may increase the precipitation efficiency of high resistance dusts.

Up to now scholars, both domestic and overseas, consider that wide gap structure of ESP is one of the main measures for collecting high resistance dusts. On the contrary the authors' test results reveal that narrow gap structure of ESP improves precipitation efficiency of high resistance dusts. It is shown in Fig.11 that:

(i) Under the conditions of the same outer size of two ESPs with two different gaps the particles with the same charge quantity in the same field strength (The particles have the same drift speed) reach the anodes earlier in the narrow gap ESP.

(ii) Narrower electrode gap essentially makes the distance the particles travel shorter, leading to larger W.

(iii) Narrower gap essentially leads to larger A.

(iv) Finally both larger W and A allow higher precipitation efficienc C.

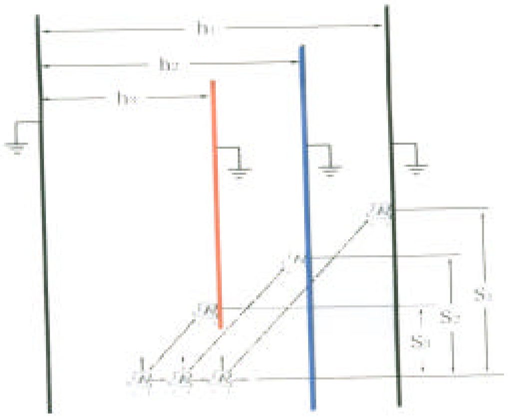


Fig.11

(4) The preconditions for using narrow gas ESPs to collect high resistance dusts to raise precipitation efficiency

To discuss the precipitation efficiency Deutsche formula should be paid attention to. The simplified form of Deutsche formula is expressed as:

$$C=>W\cdot A \qquad (1)$$

where C - precipitation efficiency (%)
A - (total)dust collecting area of the anode plates (m^2)
W - drift speed of the charged particles moving to the anode plates (m/s)

Obviously with the same size a narrow gap ESP has larger area of anode plates than that of a wide gap ESP. However it is difficult to make a positive conclusion that the precipitation efficiency may become higher when the area of plates is larger. That is because W in (1) can be expressed as

$$W= K_{?}\cdot E_d^2 \qquad (2)$$

Where $K_{?}$ - a comprehensive coefficient for flue gas conditions
E_d - field strength for dust collection and corona generation (kV/m)

Obviously to guarantee higher precipitation efficiency in a narrow gap ESP than that in a wide gap ESP for collecting high resistance dusts the reconditions should be: under the same operational conditions it is needed the field strength for charging and collecting particles and the charge quantity on every particle in the narrow gap ESP be the same as or higher than those in wide gap ESP.

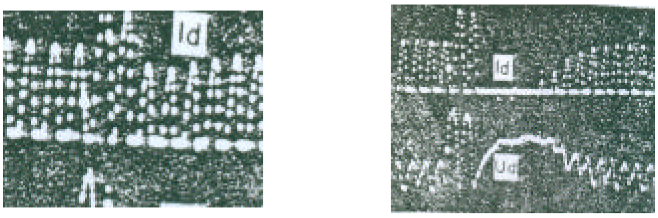
To obtain these preconditions depends upon:
(i) high voltage energisation mode and its controlling characteristics
(ii) structure and quality of the ESP

2 THE ENERGIZATION MODE AND ITS CONTROLLING CHARACTERISTICS FOR HIGH RESISTANCE DUST COLLECTING ESPS

As for energisation mode for ESPs there are rapid developments in recent years. The following discussion is about the “AC industrial frequency (50Hz) single phase controlled silicon phase shift voltage regulating booster rectifiers” the authors developed through a very long-term research and the most extensively used domestically. But the newest developed energisation system is excluded.

2.1 The controlling characteristics the ESP energisation systems should posses

The first controlling property - Ability to identify “back corona discharge signals” and timely track them and protect the “V-A characteristics” from the “ negative resistance zone”



(a) A flash signal without identification and treatment

(b) A flash signal after identification and treatment

Fig.12

This controlling property of an energisation system required is that of first importance in all of its controlling properties because if this property is not possessed all other controlling properties become meaningless. If it only possesses this property, but no others mentioned in the following the precipitation efficiency will be affected more or less.

The second controlling property

The ability to accurately identify the flash signals and treat them in an optimum way

This controlling property allows the losses of both operational voltage and current to be controlled to their lowest degrees. It is shown as Fig.(12)the secondary (V and A) waveforms must be stopped after the flash is identified and treated. The waveform shown in Fig.13 is the required result of optimum identification and treatment of the flash.

From the waveform of the identified and treated flash in Fig. 13 it is not difficult to find accurate identification for flash signals, very fast resuming and low loss of voltage /current values (almost equal before and after the flash).

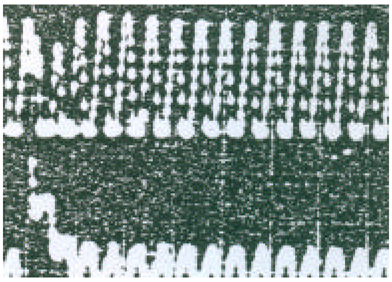


Fig.13 The optimum identification and treatment of a flash

To realize this the controlling system must have very high sampling operational accuracy. In addition it should be able to (actively) control the strength of the flash signals so as to limit destruction of insulation of the electric fields to a minimum degree. In this way the secondary current after the flash can be quickly resumed to the level before the flash.

The third controlling property - The ability to maintain the operational voltage to close in on the breakdown voltage from beginning to end.

Only the power supply, which possesses this kind of properties, can provide field strength for dust precipitation higher than that provided by other power supplies of the same kinds as shown in table 1.

Table 1

Primary voltage £ V£ ©	Primary current £ A£ ©	Secondary voltage £ KV£ ©	Secondary current £ mA£ ©	Flash rate (1/min)
214	30	46	168	7
192	26	45	144	6
218	32	46	175	8
198	27	45	175	8
mode D				
330	54	47	270	149
304	49	46	247	152
310	51	46	253	149
316	53	46	263	157

It is not difficult to find from Table 1, that whether the ESP operates at low flash rate (flash rate =10 (1/min)) or at high flash rate (≈ 150(1/min)). The voltages are approximately equal.

The fourth property - The ability to adjust, control and increase the "effective corona current"

As shown in table2, with increase of flash rate the secondary operational current remarkably increases.

The flash rate of this kind of energisation systems should be controllable, i. e. its flash rate does not change with different technological conditions, but is actively set through active tracking. In this example it is 50, 100 or 150(1/min). In fact it can be arbitrarily set within 10~150 (1/min) with a deviation of ± 10%

table2

Primary Voltage £¨V£©	Primary current £¨A£©	Secondary voltage £¨KV£©	Secondary current £¨mA£©	Flash rate (1/min) £¨´Î·Ö£©
252	31	48	146	48
244	27	47	131	50
252	31	48	145	50
276	35	47	213	93
324	49	49	277	96
294	40	48	236	100
312	49	47	276	149
308	47	48	264	153
318	53	47	294	157

It should be emphasized that the power supply with such a adjusting and controlling property must primarily have those controlling properties mentioned above.

Only when the power supplies with the controlling properties mentioned above are used the operational voltage and charging efficiency can be high enough to remarkably increase the precipitation efficiency in collecting high resistance dusts.

2.2 Results in industrial practices

To prove the effectiveness of ESP's high resistance dust collection by improving the controlling properties of the power supplies the authors did a good many industrial contrast tests on industrial ESPs. By use of DJ series of microcomputer-controlled high voltage ESP energisation systems the authors developed and through adjusting flash rate to adjust and control the effective corona current in the fields the precipitation efficiency of high resistance dust ESP is remarkably increased.

Results of the first industrial contrast test at Fujian Shaowu Power station

Specific resistance: $p_d=(1.6 - 5.5)\times10^{12}$O.cm

Results are shown in Table3

Results of the second industrial contrast test at Ningxia Dawukou Power Station

The operational conditions of the ESPs in this station are very adverse. The boilers burn gangue of very low caloric value with a dust emission of a concentration 30g/Nm^3, high dust specific resistance $p_d=2.5\times10^{11} - 3.7\times10^{12}$O·cm. The wind speed in the ESPs is high - 1.5m/s.

The dust concentration at the outlet of the ESPs was as high as 1.2g/Nm^3 when the old power supply was used.

By use of different energisation modes the results of the industrial contrast tests is shown in Table 4.

Table3

test equipment	Operational mode	inlet concentration g/Nm^3	outlet concentration g/Nm^3	wind speed m/s
domestic made simulation rig	general spark tracking	24.410	1.2543	1.13
DJ-1type microcomputer control rig	Intermittent energisation	24.333	0.9272	1.13
	simplified pulser	21.210	0.6745	1.15
	few sparks< 10 (1/min)	34.814	0.7397	1.11
	spark rate50(1/min)	35.492	0.8364	1.12
	spark rate100(1/min)	29.336	0.6932	1.14
	spark rate150(1/min)	35.107	0.56.9	1.13

Table 4

test rig	operational modes	inlet concentration g/Nm^3	outlet concentration g/Nm^3	wind speed m/s
domestic made simulation rig	general spark tracking	29.095	2.704	1.5m/s
DJ-1 MC Controller	intermittent energisation	33.291	2.076	1.5m/s
	simplified pulser	30.593	1.225	
	few sparks < 10/min	30.722	1.394	
	spark rate 150/min	30.683	1.103	

2.3 Amplitude modulation phase shift controlled silicon voltage regulating technique makes the operational parameters and precipitation efficiency of ESPs increase simultaneously.

(i) Superiority of Amplitude modulation phase shift controlled silicon voltage regulating technique

The first point of superiority - The “fatal weakness” of the “single phase shift voltage regulating” technique is eliminated.

The “single phase shift voltage regulating” technique is most widely used for ESPs both domestically and abroad at the moment. Its fatal weakness is: when the operational conditions deteriorate with continuous decrease of the breakdown voltage the flow angle becomes smaller and smaller, but the peak voltage goes higher and higher and the average voltage becomes lower and lower so that a vicious circle forms. This energisation system is unable to be free from this fatal weakness. However in combination of amplitude modulation with phase shift this weakness can be overcome and both operational parameters and precipitation efficiency can be improved simultaneously.

The second point of superiority - a progress from the “single phase shift voltage regulating” technique. The controlling properties, voltage regulating and rectification mode of the “single phase shift voltage regulating” technique are retained in this technique. The only difference is that in between the output terminals of the original “single phase shift voltage regulating” technique and the input terminals of high voltage rectifier an “amplitude modulation/phase shift” voltage regulator (a key link) is added. Through software control the function of voltage regulating by combination of amplitude modulation with phase shift can be realized.

The third point of superiority - Popularization is simple and easy. The simplicity and easiness for popularization (especially directed to reconstruction of a “single phase shift voltage regulating” energisation system) are embodied in the following:

(i) The former high voltage control cabinet and rectifier transformer are all retained, just inserting an “amplitude modulation/phase shift” voltage regulator between them.

(ii)`Install a multi-use voltage regulating controlling cabinet with the same size as the former ones to every ESP chamber (for three /four fields)

(iii)Connect the “input/output” cables from the former cabinet to high voltage rectifier transformer (main circuit/controlling circuit) correspondingly to the comprehensive “amplitude modulation/phase shift” voltage regulating cabinet and hook up three sets (6 wires) trigger signal wires from the comprehensive voltage regulating cabinet to every “amplitude modulation/phase shift” voltage regulator

That is total work burden for reconstruction.

2.4 The implemented examples of using “amplitude modulation/phase shift” energisation systems to improve the operational parameters and increase the precipitation efficiency

The example of Shanghai Shidongkou power station can be evidence.

(i) A DJ-TY type “amplitude modulation/phase shift” energisation system is used.

(ii) The structure is narrow gap of 300mm. The cathode wires are RS tubular spine wires.

(iii) The sulfur content of the coal $< 0.4\%$ (a typical high resistance dust)

The results of the contrast tests are shown in table 5.

Table 5

Parameters equipment	U_1 (V)	I_1 (A)	U_2 (KV)	I_2 (mA)	precipitation efficiency (%)	emission concentration (mg/Nm^3)
DJ type	244	83	42	340	99.3	120
DJ-TY type	293	135	48	644	99.8	34

3. PRINCIPLES FOR DESIGN OF THE STRUCTURES OF HIGH RESISTANCE DUST COLLECTING ESPS

3.1 Prerequisites for the structure design of high resistance dust collecting ESPs

In the present scope of controlled silicon phase shift voltage regulating technique the structure of the main body of a high resistance dust collecting ESP must be fitted with the energisation systems with the controlling properties and voltage regulating mode author developed otherwise things go worse.

3.2 The structure of the main body of high resistance collecting ESPs

(i) Using narrow plate gap (=300mm). It is more reasonable to use narrower gap in more rear fields, but it is not to use wider gap in more rear fields as used at the moment.

(ii) Using double strengthened type cathodes: The cathode wires should be of strengthened type to protect from deformation and break. The corona effect of the cathode should be strengthened.

(iii) To guarantee the rapping system to have excellent dust cleaning effect.

(iv) The integral hanger structure of the cathode system in every field region of the existing ESP is retrofitted and divided into a few smaller regions in which smaller cathode systems are hanged independently in parallel.

(v) Wind speed in the fields 1m/s (especially when dust emission of =50mg/Nm^3 is demanded.)

(vi) It is the best to use negative pressure dust cleaning.

4. CONCLUSIONS

(1) With an ESP to collect high resistance dusts existence of "back corona discharges" and their hazards are inevitable phenomena.

(2) The "three hazards" and their interaction are the essential reasons leading to great reduction of the operational parameters and precipitation efficiency.

(3)The emergence of the "negative resistance zone" in the "V-A characteristic curve" is not an inevitable result due to "back corona discharges". With technical progress so long as the energization systems have ability to identify the back corona signals and track and control them by use of modern control techniques the "negative resistance zone" can be avoided. Under these conditions the operational voltage and current (increasing charge quantity the dust carries), the precipitation efficiency of high resistance dust collection ESPs can be remarkably increased.

(4) According to conclusion (3) when an ESP collects high resistance dusts both its main body design and its type selection of energization mode and the control characteristic do not obey the formula $j_d=E_s$. Using the energization technique and the main body structure design this paper recommends may allow remarkably increase of precipitation efficiency in collecting high resistance dusts.