700 MW HOT-SIDE EP PERFORMANCE IMPROVEMENT BY OPTIMIZING ENERGIZING CONDITIONS

Masaaki Orimoto
Electric Power Development Co., Ltd.
Takehara Power Station
Nishi-Nagahama, Tadanoumi-cho, Takehara-city
Hiroshima Pref., Japan

Kazuo Koyata
Central Research Institute of Electric Power Industry
Yokosuka Research Laboratory
2-6-1 Nagasaka, Yokosuka-city
Kanagawa Pref., Japan

Osamu Tanaka
Sumitomo Heavy Industries, Ltd.
2-1-1 Yato-cho, Tanashi-city, Tokyo, Japan

Abstract

The hot-side electrostatic precipitator (EP) for 700 MW coal fired boiler at Takehara Power Station Unit 3 has been operating satisfactorily since start-up in 1983 as far as outlet particulate mass loading is concerned, however under the present stringent circumstances it is desirable for plant operation to improve the cleanliness of the stack outlet gas by further improving EP performance.

The electrostatic precipitator is equipped with a unique high voltage controller which can optimize the intermittent ratio for alleviating back corona by checking the behavior of the secondary voltage wave form.

This paper discusses the optimization of intermittent energizing conditions by observation of V-I characteristics and secondary voltage wave forms which, as a result, realized EP performance improvement with reduced power consumption as well as much cleaner stack outlet gas. The improvement of the fractional collection efficiency of sub micron particles with optimized energizing conditions is also reported.

Plant Description and EP Specification

Takehara Power Station Unit 3 has a generating capacity of 700 MW using an imported coal fired boiler. It commenced commercial operation in March 1983. Annual consumption of imported coal is approximately 1.6 million tons, and its major sources are Australia, China, U.S.A., and South Africa. Since the unit is located in the Setouchi Inland Sea National Park, wet FGD and SCR-DeNOX together with hot-side EP were provided in constructing the unit, as shown in Fig. 1 to meet with strict environmental regulations.

The outlet particulate mass loading from the stack has been kept below the emission limits agreed with municipal government, however present stringent requirements are urging plant operation with less smoke visibility. Hence, the work presented in this paper was initiated for the purpose of contributing to an improvement in stack outlet conditions.

The hot-side EP is located ahead of the SCR-DeNOX in a double deck arrangement as shown on Fig. 2. The major specifications of the EP are as follows ;

Gas Flow Rate	:	2,740,000 Nm^3/H
Gas Temperature	:	380 Deg. C.
Dust Collection Efficiency	:	99.2 %
No. of Units	:	4 Units (2 Units/Deck X 2 Decks)
No. of fields along gas flow path	:	5
No. of T/R sets	:	20
T/R set Rating	:	45 KV - 2,800 mA
Collecting Plate Size	:	Length 2,730 mm X Height 11,000 mm
Collecting Plate Spacing	:	250 mm
No. of Gas Passages	:	416 (104/Unit X 4 Units)
Type of Disch. Electrode	:	Weighted Wire
Disch. Electrode Rapping	:	Flail Hammering at top of Support Frame
Collecting Plate Rapping	:	Flail Hammering at bottom of Plate

Fig. 3 shows the configuration of the EP in the direction of gas flow. Each field in the direction of gas flow is energized by an independent T/R set. There are 3 rows of hoppers, the first row for the first and second fields, the second row for the third field, and the third row for the fourth and fifth fields.

Optimizing Procedure for EP Energization

Even if a transformer and rectifier set is of conventional type, back corona can be detected and alleviated by optimizing intermittent energization (1). Fig. 4 shows the power supply circuit for an EP, where the section consisting of R_{EP} and C_{EP} represents an equivalent circuit for the EP. R_{EP} has the same resistance as that of corona discharge,

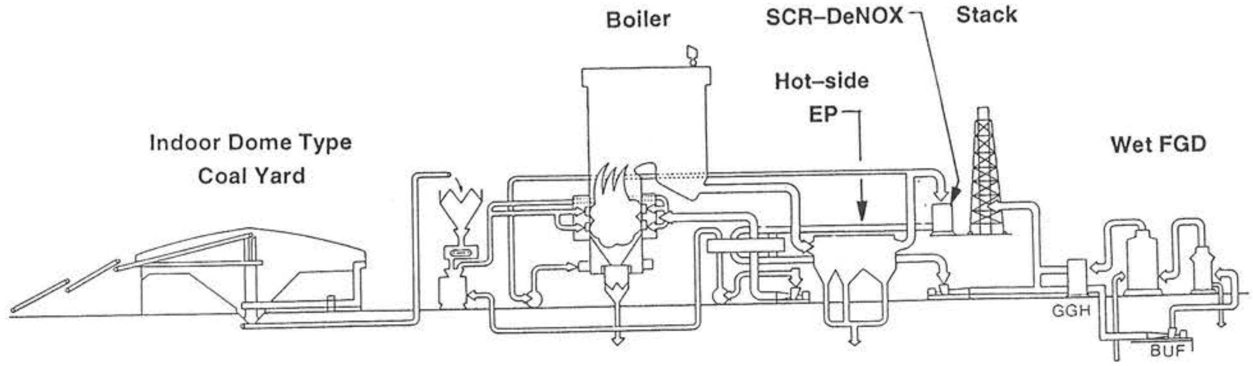


Fig. 1 Takahara Power Station, Unit 3, 700 MW Coal Fired Unit
Schematic Diagram

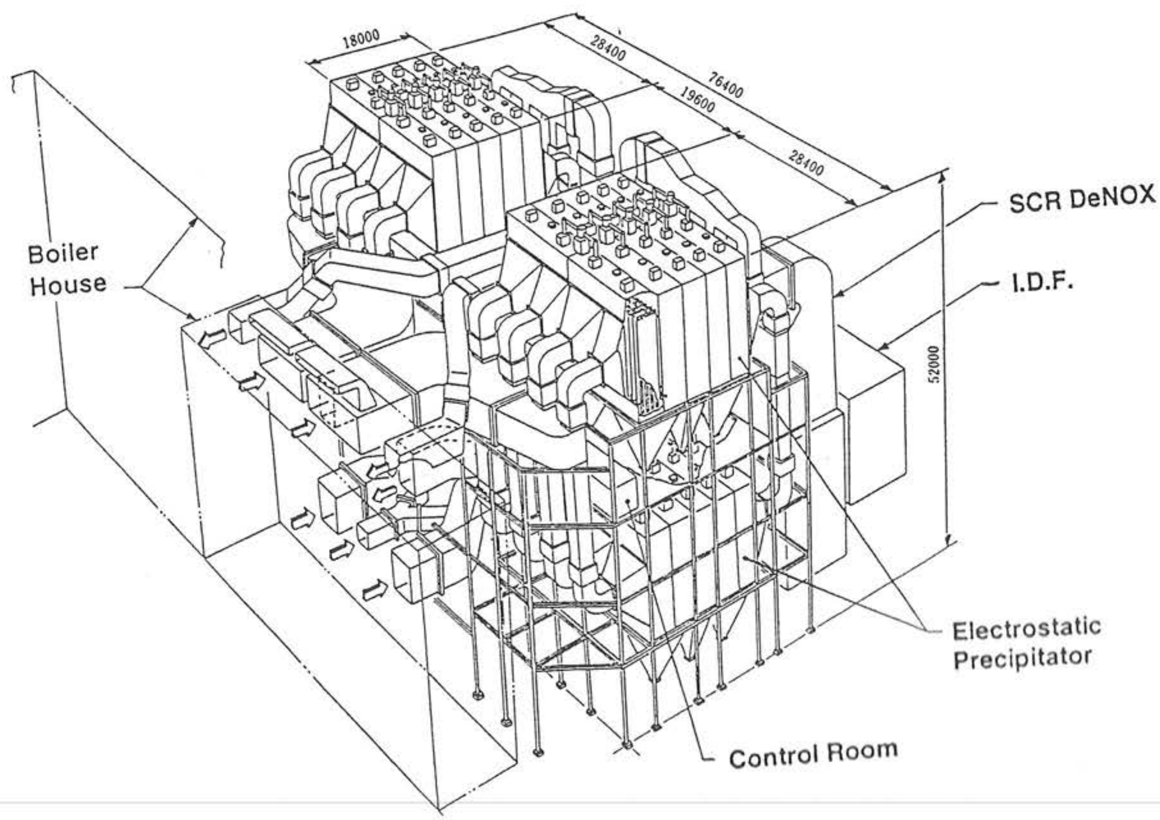


Fig. 2 Electrostatic Precipitator, Pictorial View

and C_{EP} has the same capacitance as that between the discharge and collecting electrodes of the EP.

Referring to Fig. 4, if the absolute value of the secondary EMF of the transformer is smaller than the voltage across the C_{EP}, the rectifier bridge is reverse biased, so that current I in the secondary circuit no longer flows. Therefore, current I becomes pulsive as shown on Fig. 5. In the period of I = 0, EP voltage V decreases according to the following equation,

$$-dV/dt = i/C_{EP}$$

where i is corona current flowing in R_{EP}. When I starts to conduct, C_{EP} is charged and the EP voltage V increases. As illustrated in Fig. 5, the maximum value at the peak of the wave form is called peak voltage (V_P), whereas the minimum value at the trough is called bottom voltage (V_B). In back corona phenomena, the current flowing through R_{EP} increases, and V_B drops substantially as the i of the above equation becomes larger. Therefore, back corona can be detected and alleviated by observing the behavior of V_B. Practically, this is realized by checking the variation of the bottom level of the secondary voltage wave form when changing the duty ratio of intermittent energization. (Duty Ratio : DR = ON time / ON + OFF time).

The original high voltage controllers for Takehara Unit 3 EP did not have the above function, so they were modified in 1989 to supplement such function to the controllers.

Fuel coal for Unit 3 is stored in an indoor dome type coalyard (27 days capacity) which has difficulty in supplying the preferred kind of coal for EP performance evaluation at the desired occasion. Therefore, the program to optimize EP energizing conditions, which started in 1990 took 21 months to complete. The program undertook two steps during this period, the activities at each step being as follows ;

First Step (Late 1990 to Mid 1991)

Coals Subject to Investigation. 9 kinds of coal were selected for preliminary investigation. These coals were as follows ;

- BA (Australian coal)
- MB (Australian coal)
- LG (Australian coal)
- LM (Australian coal)
- WW (Australian coal)
- SH (Colombian coal)
- DD (Chinese coal)
- SK (Indonesian coal)
- ER (South African coal)

Investigation of Energizing Conditions. In order to understand the dependency of back corona intensity on coal type and location of energizing field, V-I characteristics of all T/R sets were measured when firing each of the above 9 coal types at full load

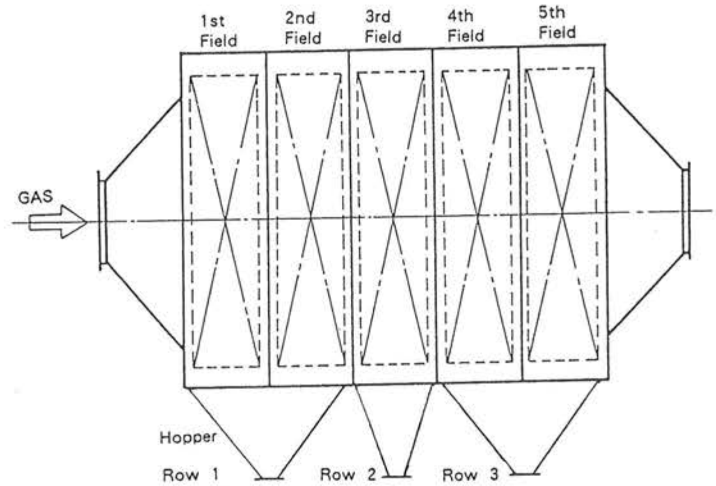


Fig. 3 EP Side Elevation

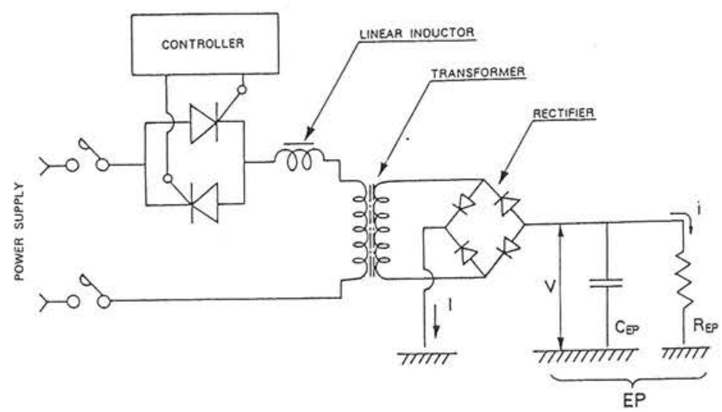


Fig. 4 Typical Energizing Circuit of an EP

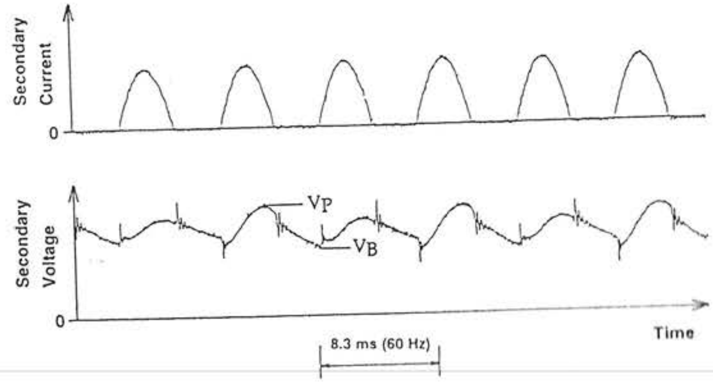


Fig. 5 Wave Form of Secondary Current and Voltage

(700 MW). At the same time, the relationship between the bottom level of secondary voltage (V_B) and secondary current (I) were recorded at all T/R sets to enable examination of the optimum duty ratio when intermittent energization would be applied. V_B was measured with an oscilloscope.

Analysis of Ash Characteristics. Fly ash from representative coal types was sampled from the EP hoppers to see the difference of ash characteristics between lower deck and upper, and gas flow direction. The samples were analyzed for the following characteristics ;

- Electrical Resistivity
- Particle Size Distribution
- Chemical composition

Observation of Energizing Conditions. When one kind of coal was fired for a sufficient period, the EP energizing conditions, particularly applicable maximum secondary current, were observed to check if there was any time-dependent degradation of conditions which could be caused by insufficient rapping.

Second Step (Late 1991 to Mid 1992)

Coal Types Subject to Investigation. Based on the results from the First Step investigation, 3 types of coal, as listed below were selected for confirming the effect of optimized energizing conditions. These coal types also had the most representative nature for future operation of the unit as regards availability.

- BA (Australian coal)
- LG (Australian coal)
- WB (South African coal)

Improving Rapping Sequence. Prior to energizing optimization, the effect of increased rapping frequency on secondary current was examined, and the rapping sequence was adjusted so as to maximize secondary current at continuous energization.

Optimization of Intermittent Energization. At this step, the bottom level of secondary voltage(V_B) during ON time was measured at different duty ratios to allow selection of the optimum duty ratio (DR_{opt}). ON time was fixed at 2 cycles (33.3 milliseconds at 60 Hz), and OFF time was varied between 1 and 6 cycles.

Fig. 6 illustrates typical V_B vs. DR characteristics at which back corona takes place, and explains how DR_{opt} is selected. The V_B vs. DR curve shown on the figure consists of a straight line zone in Regions 1 (V_B ; high) and 3 (V_B ; low), and a curved line zone in Region 2 connecting the above. Each region can be interpreted as follows ;

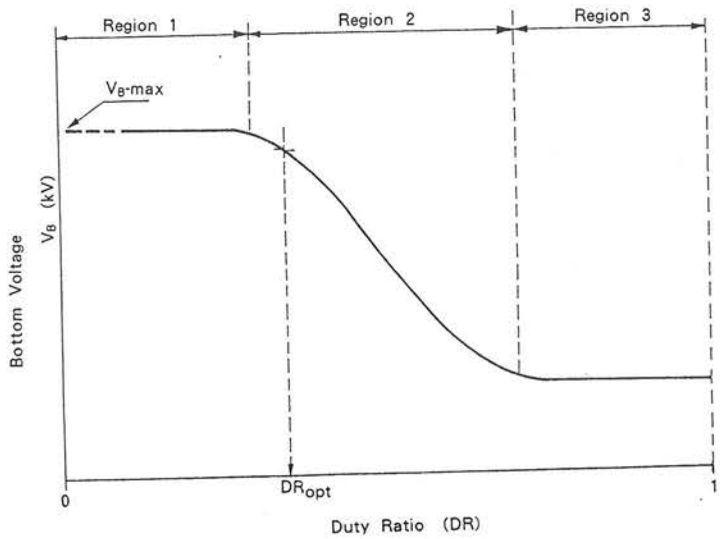


Fig. 6 Bottom Voltage vs. Energizing Duty Ratio

- Region 1 : Back corona is almost suppressed
- Region 3 : Back corona is present
- Region 2 : Intermediate area

Consequently, a value of DR immediately following entry into Region 2 from Region 1 represents DR_{opt}.

At Takehara Unit 3 EP, V_B vs. DR characteristics of all T/R sets were investigated to determine DR_{opt}.

Confirmation of EP Performance Improvement. During the optimization, EP outlet dust loading was monitored with an opacity meter. Visibility of the smoke from the stack was checked by trained observers.

Since the wet FGD system located downstream of the EP has a poor performance for collection of fine particles, visibility of the smoke discharged from the stack is directly affected by those fine particles not collected at the EP. Therefore, in addition to the above monitoring, 0.003 to 1.0 micron particles at the EP outlet were measured by an EAA (Electrical Aerosol Size Analyzer) , and 0.3 to 5.0 micron particles were measured by an ASS (Andersen Stack Sampler) in order to verify the effect of EP performance improvement on smoke visibility at the stack outlet.

Analysis of Ash Characteristics. Ash samples from the EP hoppers when firing South African coal (WB) were analyzed for the same items that were listed in Step 1.

Results

Ash Characteristics

Chemical Analysis. Table 1 compares the chemical analysis of the fly ash sampled at different hopper rows when firing Australian coal (BA). Also, ash analysis at the first row of hoppers is shown on the same table for Australian coal (LG) and South African coal (WB).

When firing with coal (BA), there is not so much difference in chemical analysis between hopper rows, however an increase of Na_2O content, lowering resistivity, is found with gas flow direction from Row 1 to Row 3. Ash analysis from other coal types indicated a similar trend to the above.

These 3 coal types, (BA), (LG), and (WB), have relatively low Na_2O content. It should be noted that Coal (WB) has the typical ash characteristics of South African coal (low Sodium / high Calcium) which would be detrimental to hot side EP performance.

Table 1

Fly ash Chemical Analysis from Coal types (BA), (LG), and (WB). (% by wt.)

Chemical Composition	Coal-BA 1st Row Hopper	Coal-BA 2nd Row Hopper	Coal-BA 3rd Row Hopper	Coal-LG 1st Row Hopper	Coal-WB 1st Row Hopper
Na_2O	0.15	0.21	0.29	0.08	0.15
CaO	0.27	0.35	0.58	0.31	8.44
SiO_2	61.7	56.9	56.4	66.8	44.0
Al_2O_3	29.1	31.7	34.7	24.6	33.0
Fe_2O_3	1.87	1.42	1.95	1.16	3.67
MgO	0.23	0.32	0.49	0.23	1.24
K_2O	0.40	0.53	0.67	1.95	0.51
SO_3	0.06	0.12	0.35	0.12	0.23
TiO_2	1.26	1.46	1.59	0.93	1.55
P_2O_5	0.18	0.36	0.75	0.14	2.02

Particle Size Distribution. Mass median diameter of the ash (in microns) against hopper location when firing Coal (BA) was as follows ;

Lower Deck EP			Upper Deck EP		
Row 1	Row 2	Row 3	Row 1	Row 2	Row 3
26.5	10.5	2.3	14.5	8.2	2.0

The above figures indicate that the upper deck collects finer ash than the lower deck, and ash particle size at Row 3 is approximately one tenth of Row 1. The same tendency was observed for ash size distribution from other coal types.

Electrical Resistivity. Fig. 7 shows a temperature-dependent electrical resistivity curve for ash from coal types (BA), (LG), and (WB). Coal types (LG) and (WB) at high temperatures, had almost the same ash resistivity. It should be noted that ash from these 2 coal types exhibited a higher level of resistivity at hot side temperatures than ash from other coal types examined.

Fig. 7 also indicates the ash resistivity difference between hopper rows for Coal (BA). From the figure, it can be seen that resistivity reduces along with gas flow, and that this phenomena is consistent with the increase of Na_2O content described in the foregoing section.

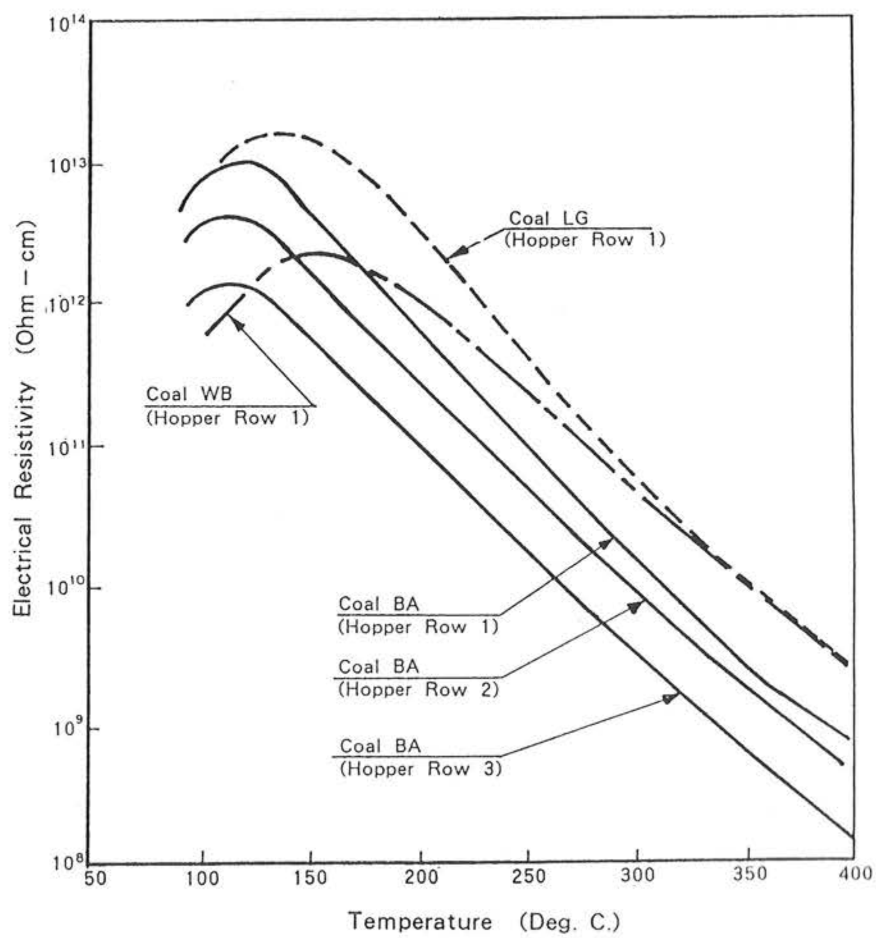


Fig. 7 Temperature dependent Electrical Resistivity of Ash

Effect of Rapping Frequency

When firing Australian coal (BA), the relationship between rapping frequency and maximum applicable secondary current at continuous energization was investigated. The results are shown in Fig. 8 for representative fields of the EP (second field and fifth field). An increase of current with increase of rapping frequency was observed.

Based on this result and further investigation carried out for coals (LG) and (WB) which suggested the necessity of more frequent rapping, the rapping schedule was improved so that more frequent rapping could be applied to the outlet side fields as shown on Table 2. As can be seen from the table, the number of hammer strokes in 24 hours on the outlet side collecting plates was approximately tripled, and the number of strokes on the outlet side discharge electrodes was approximately doubled.

Table 2

No. of Hammer Strokes in 24 hours
Before and After Rapping Schedule Improvement

		No. of hammer strokes in 24 hours	
Electrode	Fields	Before Improvement	After Improvement
Collecting Plate	1st.	76	76
	2nd.	38	51
	3rd.	13	34
	4th.	13	34
	5th.	13	34
Discharge Electrode	1st.	76	65
	2nd.	38	40
	3rd.	13	23
	4th.	13	23
	5th.	13	23

Intensity of Back Corona

Fig. 9 shows typical V-I and V_B-I characteristics with continuous energization at each energizing field in the direction of gas flow which were recorded for Australian coal (BA) during the first step investigation. From these VB-I characteristics, it can be said that the back corona becomes more intensive with progress towards the EP outlet as the degree of V_B reduction at increased secondary current becomes larger. Also, the figure suggests that there is no back corona at the first field, and optimum duty ratio (DR_{opt}) of intermittent energization would be around 0.5 for the second field and around 0.3 for the third to fifth fields.

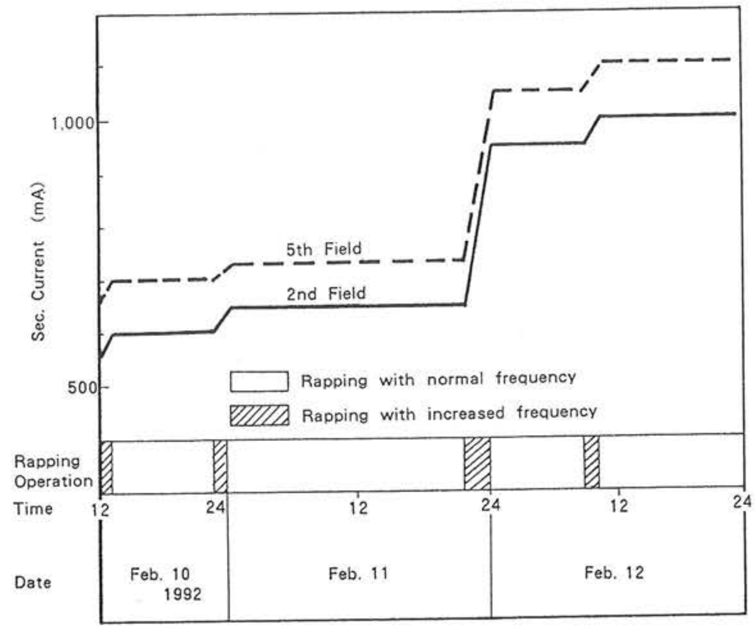


Fig. 8 Effect of Rapping with Increased Frequency

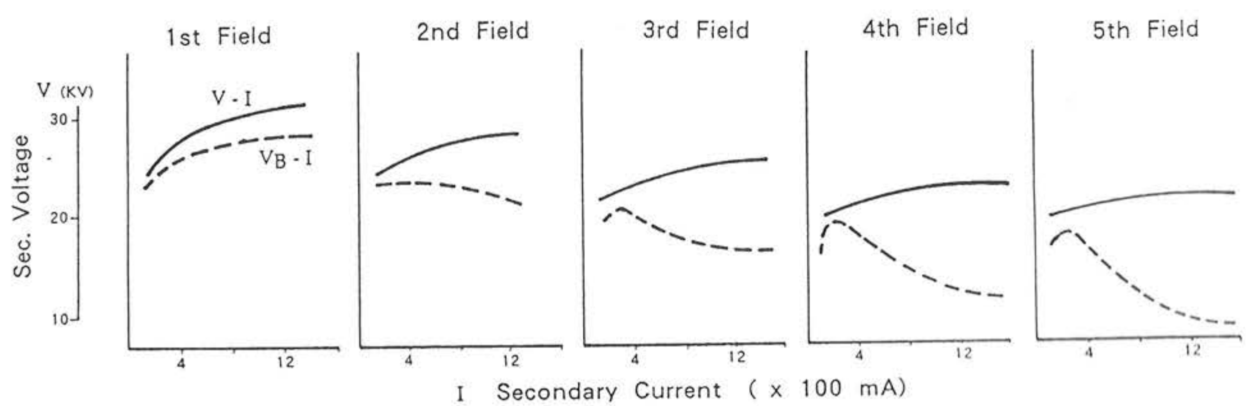


Fig. 9 V - I and V_B - I Characteristics (Continuous Energization, Coal - BA)

While Fig. 9 shows the characteristics for Coal (BA), similar V_B-I curves were exhibited by Coals (LG) and (WB). Accordingly, at the second step, V_B vs. DR (Duty Ratio) characteristics were investigated from the second to fifth field only. The first field was operated with continuous energization.

Optimum Duty Ratio (DR_{opt})

V_B vs. DR characteristics obtained in the step 2 investigation are shown in Fig. 10 for 3 types of coal, (BA), (LG), and (WB). DR_{opt}, evaluated from the curves, is summarized as follows ;

	Optimum Duty Ratio (DR_{opt})			
Coals	2nd field	3rd field	4th field	5th field
Australian BA	0.50(2/2)	0.33(2/4)	0.33(2/4)	0.33(2/4)
Australian LG	0.50(2/2)	0.40(2/3)	0.33(2/4)	0.40(2/3)
S. African WB	0.50(2/2)	0.33(2/4)	0.33(2/4)	0.33(2/4)

The first number in parenthesis is the number of ON cycles, and the second number is the number of OFF cycles.

Opacity at EP Outlet

Opacity monitoring at the EP outlet confirmed that optimized energizing conditions using the DR_{opt} described above accomplished reduction of opacity with all 3 types of coal. Fig. 11 was recorded when firing Coal (BA), and is a typical example of the effect of the optimization. The figure includes the secondary current meter readings for all T/R sets for both energizing conditions, i.e. before and after optimization.

Sub micron Particle and Visibility

Fig. 12 compares the results of sub micron particle measurement carried out at the EP outlet for the following 4 cases ;

- S. African coal (WB) before optimization (Continuous energization)
- S. African coal (WB) with optimized energizing conditions
- Australian coal (BA) with optimized energizing conditions
- Australian coal (LG) with optimized energizing conditions

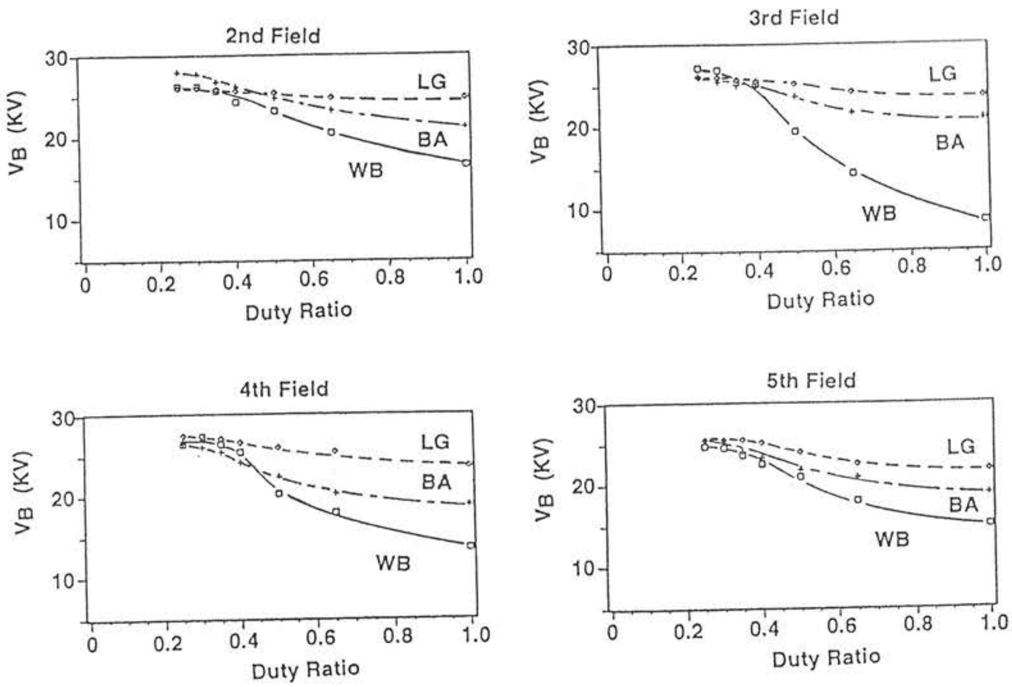
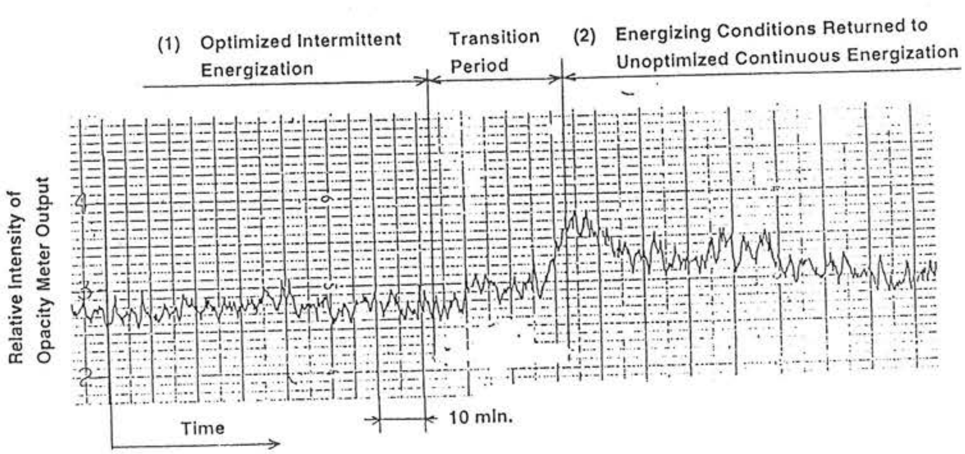


Fig. 10 V_B vs. DR Characteristics for 3 Coals (BA, LG, WB)



Sec. Current Meter Readings (mA) at (1)

		Fields				
		1st	2nd	3rd	4th	5th
Lower Deck	Side A	1100	500	320	400	400
	Side B	1100	300	320	280	200
Upper Deck	Side A	1100	400	320	240	280
	Side B	1100	280	320	200	233

Sec. Current Meter Readings (mA) at (2)

		Fields				
		1st	2nd	3rd	4th	5th
Lower Deck	Side A	1100	1000	800	1000	1000
	Side B	1100	700	800	700	600
Upper Deck	Side A	1100	800	800	600	700
	Side B	1100	700	500	600	700

Fig. 11 Comparison of Opacity Meter Output

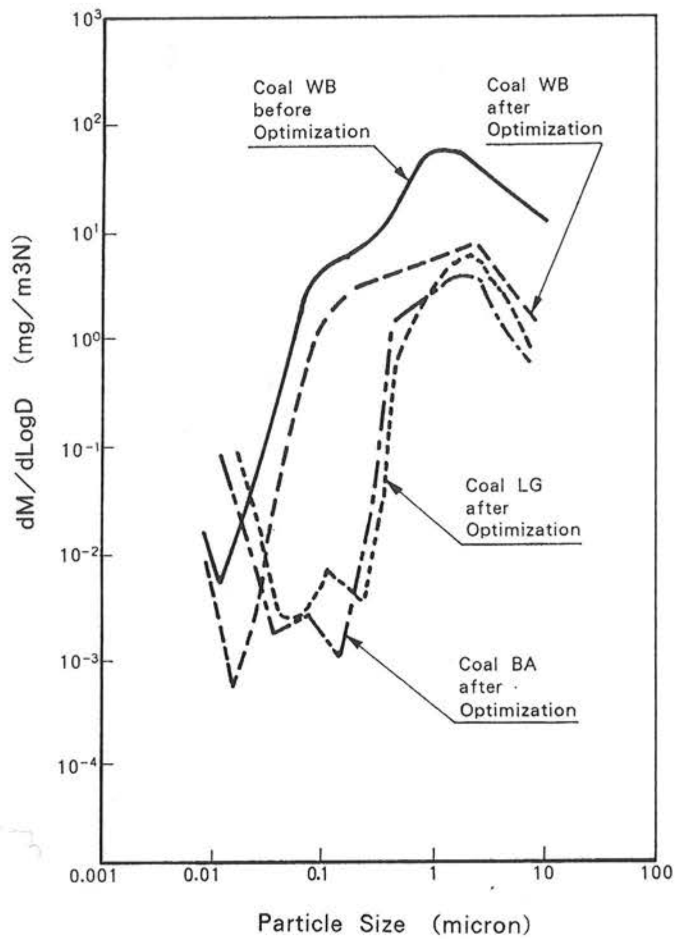


Fig. 12 Comparison of Sub micron Particle Size Distribution at EP Outlet

From this figure, the reduction of sub micron particles due to optimized energizing conditions can be seen for South African coal (WB). No measurement was made before optimization for coals (BA) and (LG), however the curves at optimized conditions for these coal types indicates a lower distribution of 0.1 to 5 micron particles than for Coal (WB).

Optimized energization, together with opacity improvement, made the smoke from the stack much less visible, as confirmed by trained observers.

Power Consumption

A rough comparison of power consumption before and after optimization can be made by totaling secondary current meter readings of all T/R sets. This calculation gives the following results from the table given in Fig. 11.

Before optimization	:	16.4 Amps
Optimized energization	:	9.3 Amps

Thus an approximate 43 % reduction of power consumption is gained by optimization in this case. On average, optimization of energizing conditions realized approximately 50 % reduction of power consumption at the EP.

Conclusion

An investigation of optimization of energizing conditions has been carried out at a 700 MW Hot-side EP while firing 10 types of imported coal, and the following was accomplished ;

1. Considerable reduction of smoke visibility at the stack outlet, as evidenced by improvement of sub micron particle distribution at the EP outlet

2. Approximately 50 % reduction of power consumption for EP operation

3. An increase in types of coal usable at the unit for future operation

References

1. T. Noda, H. Terai, and T. Kameshima. "A Method of Back Corona Detection and Its Application." Proceedings of Second International Conference on Electrostatic Precipitation, Kyoto, Japan (November 1984), pp.812-821