Simulation and Experimental Studies on an Existing Industrial Electrostatic Precipitator

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ABSTRACT

The Electrostatic precipitator (ESP) is one of the important applications of static electric field used for abatement of pollution. Research is taken up at different dimensions (both simulation and experimental) involving study of V-I characteristics, effect of electrode configurations, load and ambient conditions on the working of ESP. In this paper, studies are made on an existing ESP at one of the industries. A simulation model is formulated to study the V-I characteristics of clean air and actual exhaust. Further, the characteristics are compared with the experimental results. It is observed that the simulated and experimental results match to a reasonable degree. Finally suggestions have been made to improve the performance of the existing ESP.

Keywords: ESP, Pollution abatement, Simulation Model, V-I characteristics.

1. INTRODUCTION

The processes used in the removal of particulate matter from flue gases employ electrical, aerodynamic, or mechanical forces for separating the particles from the gas stream. So-called mechanical devices such as cyclones have been used for many years for gas cleaning. Wet scrubbers, in which the gas is passed through a water spray or over a film of water, are widely used for the removal of particulate matter, especially when a gas such as sulfur dioxide is to be removed simultaneously. Fabric filters are also widely used for industrial gas cleaning, particularly when the gas volume is small.

Electrostatic precipitators are unique among gas cleaning equipment in that forces separating the particulate from the gas stream are applied directly to the particles themselves and hence the energy required to effect the separation is considerably less than for other types of gas cleaning systems. Several researchers across the globe have been carrying out studies on ESP (both simulation and experimental) at various dimensions [1-8]. In this paper, studies are made on an existing ESP at one of the industries. A simulation model is formulated to study the V-I characteristics of clean air and actual exhaust. Further, the characteristics are compared with the experimental results. It is observed that the simulated and experimental results match to a reasonable degree. Finally suggestions have been made to improve the performance of the existing ESP.

2. EXPERIMENTAL SETUP

Schematic diagram of the thermal plant and the ESP configuration are shown in fig 1 and fig 2 respectively. The precipitator set which we have used for our study is the one existing in the co-generation plant, at M/S. Falcon Tyres Ltd Mysore, India. The ESP is manufactured and installed by Cethar Vessels Pvt Ltd [9]. The electronic controller (Thyristor controller) used for the operation of the precipitators was manufactured and installed by Hind Rectifiers Ltd . There are three precipitators used in the Co-Generation plant. Currently, only one precipitator is operated and other precipitators are kept idle. In case of overload or any fault in the precipitator, it is shut down and the other precipitator is operated. Sometimes the precipitators are operated alternately to improve the performance.

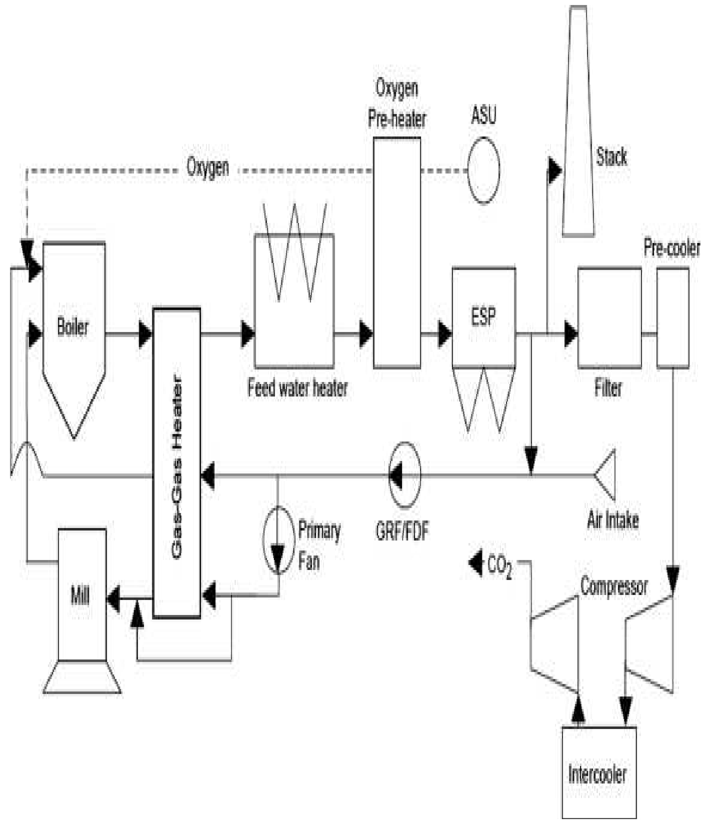

Fig 1. Schematic block diagram of Coal based Thermal Plant

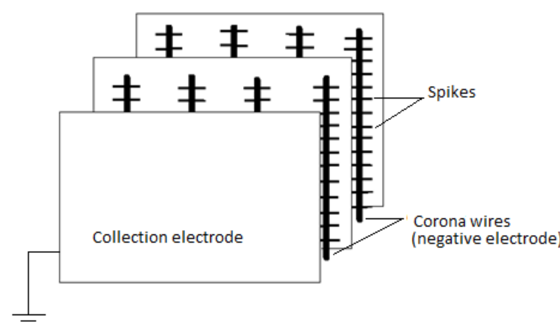

Fig 2. ESP Electrode Arrangement

The electrical circuit for ESP consists of a Transformer and Silicon Control Rectifier set which can apply a voltage up-to 74 kV negative DC mean, a current of 350mA DC mean with a current regulation of $\pm$5%. Single phase back to back connected rectifiers have been used as controller. The table 1 gives technical details of the ESP.

1	Input Voltage	415v AC
	Phase	Single
	Voltage variation	+ or – 10%
	Frequency	50hz
2	Output Voltage	120kv DC peak corresponding to 74kv DC mean
	Current	370mA DC mean
	Current Regulation	+ or – 5% for load variation full load
	Configuration	Single phase back to back connected silicon controlled rectifiers(SCRs)
3	Method Control	By means of SCRs
4	Ambient Temperature	Ambient: 50 c maximum
5	Installation	Electronic controller suitable for indoor installation only (preferably in air conditioned room)
6	Atmosphere	Dusty
7	Cooling	Transformer rectifier oil cooled
		Electronic controller air cooled
8	Scope of supply	Transformer rectifier unit
		Electronic controller panel

Table1. Details of ESP at M/S. Falcon Tyres Ltd

3. RESULTS and DISCUSSIONS

The V-I characteristics of ESP are obtained from both experimental and simulation studies. The characteristics in each case are obtained for free air as well as actual exhaust. In this paper results are presented initially for experimental studies and later for simulation studies.

3.1. Experimental Results

3.1.1. V-I characteristics with free air

Free air was passed through ESP continuously and for various operating voltages the corresponding currents were noted and were tabulated as in table 2.

Voltage (kV)	Current Density (mA/m^2)
17	8.5282e-07
23	7.6754e-06
23	9.3811e-06
26	1.5350e-05
29	1.8762 e-05
30	2.2173 e-05
32	2.7290 e-05
32	3.0701 e-05
34	3.6671 e-05
35	4.0082 e-05
36	4.3494 e-05
37	4.8611 e-05
38	5.2022 e-05
40	5.7992 e-05
40	6.1403 e-05
41	6.6520 e-05
42	7.1637 e-05
43	7.5048 e-05
44	7.9313 e-05
44	8.5282 e-05

Table 2. Voltage-Current density values for free air

3.1.2. V-I characteristics with Actual Exhaust

Actual exhaust was passed through ESP and for various operating voltages, corresponding currents were noted down for different load conditions and were tabulated as shown in table3.

Voltage (kV)	Current Density (mA/m^2) for different loads			
	2MW	3MW	4MW	6MW
24	8.5283e-07	0	0	0
29	5.9697e-06	5.9697e-06	6.8226e-06	5.9697e-05
32	1.0234e-05	1.0233e-05	1.0233e-05	9.3811e-05
33	1.3645e-05	1.3645e-05	1.3645e-05	1.9645e-05
36	1.8762 e-05	1.8762e-05	1.8762e-05	1.7909e-05
38	2.2173 e-05	2.3879e-05	2.3879e-05	2.2173e-05
39	2.8143 e-05	2.7290e-05	2.8143e-05	2.8143e-05
40	3.1554 e-05	3.1554e-05	3.1554e-05	3.1554e-05
41	3.6671 e-05	3.7524e-05	3.7524e-05	3.5818e-05
42	4.1788 e-05	4.0082e-05	4.1788e-05	4.0080e-05
43	4.6052 e-05	4.6052e-05	4.5199e-05	4.5199e-05
43	4.9463 e-05	4.9464e-05	4.7758e-05	4.9463e-05
44	5.4580 e-05	5.4581e-05	5.4581e-05	5.3728e-05
44	5.9697 e-05	5.9697e-05	5.9697e-05	5.9697e-05
45	6.3109 e-05	6.1403e-05	6.1403e-05	6.3109e-05
45	6.6520 e-05	6.7373e-05	6.7373e-05	6.7373e-05
46	7.1637 e-05	7.1637e-05	7.1637e-05	6.9931e-05
46	7.5048 e-05	7.5901e-05	7.5901e-05	7.3343e-05
47	7.9312 e-05	7.9313e-05	7.9313e-05	7.9312e-05
47	8.4429 e-05	8.4429e-05	8.3577e-05	8.4429e-05

Table 3. Voltage- Current density values for actual exhaust

3.2. Simulation Results

MATLAB R2008a (7.60) has been used for executing the program for simulation of V-I characteristics of ESP. The simulated V-I characteristics for free air is shown fig 3.

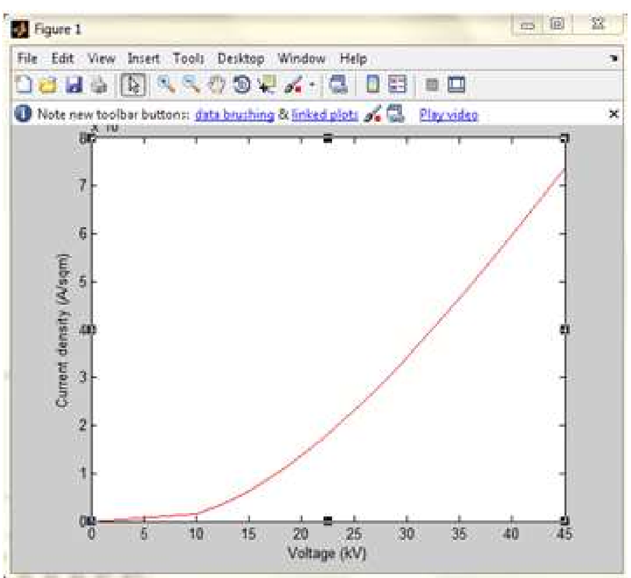

Fig 3 V-I characteristic (simulated) for free air

The flowchart for the simulation program is shown in fig 4.

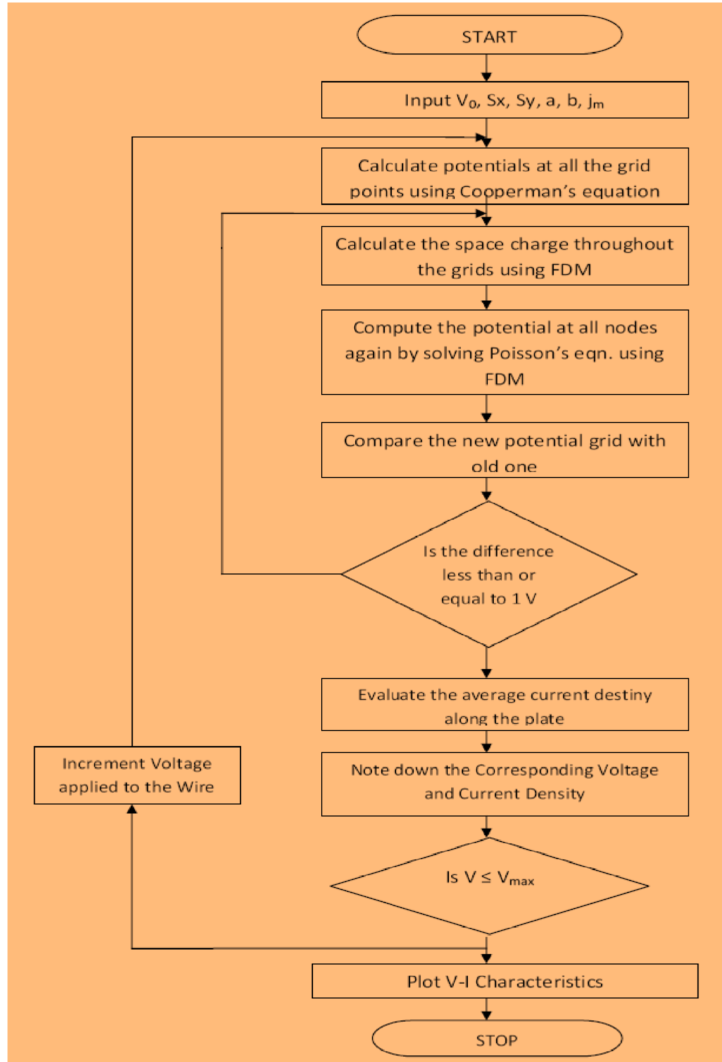

Fig 4. Flowchart for V-I Characteristic (simulation)

3.3. Comparison of the results

3.3.1. Comparison of V-I characteristics of free air- Simulation and Experimental

The fig 5 shows the comparison of experimental and simulated V-I characteristics for free air. It is observed that the simulation results are in close agreement with experimental results but for slight deviation at some operating voltages caused due to experimental errors and alterations in the alignment of plates, electrodes, spikes of electrodes etc.

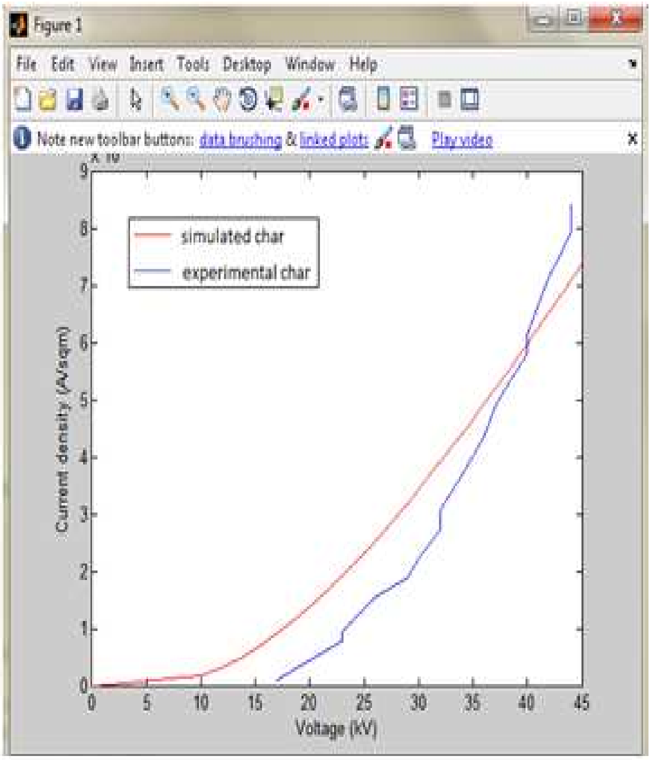

Fig 5. Comparison of experimental and simulated characteristics for free air

3.3.2. Comparison of V-I characteristics of free air and actual exhaust – Experimental

It is observed that for a given current density there is an increase in the corona inception voltage for actual exhaust. This can be due to a heavy load (dust concentration) on ESP due to which the emitter electrode gets deposited with the dust resulting in effective increase in the wire diameter which in-turn increases the corona inception voltage.

The fig6. shows the comparison of V-I characteristics of free air and actual exhaust obtained from experimental studies.

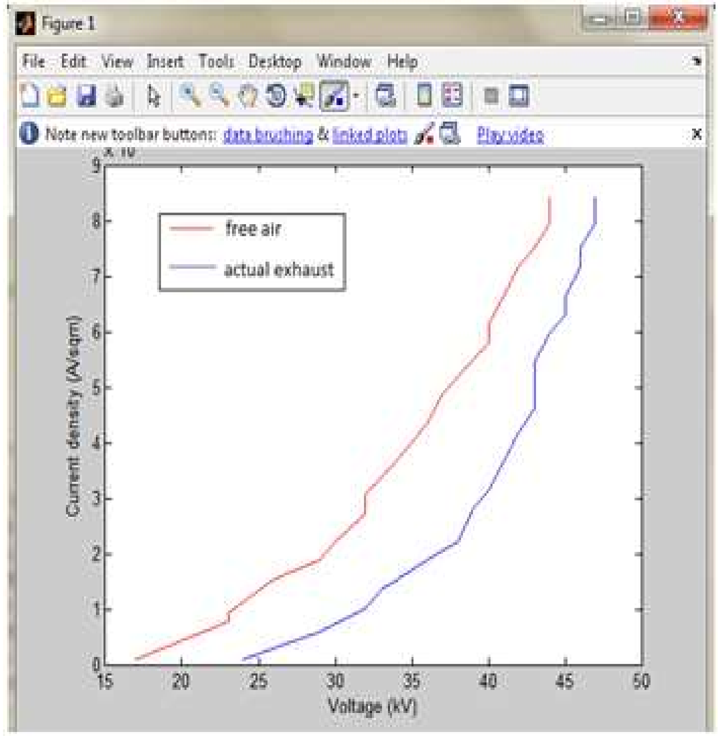

Fig 6. Comparison of V-I characteristics of free air and actual exhaust (Experimental)

3.3.3. Comparison of V-I characteristics for different loads - Experimental

The fig 7. shows the comparison of V-I characteristics for different loads.

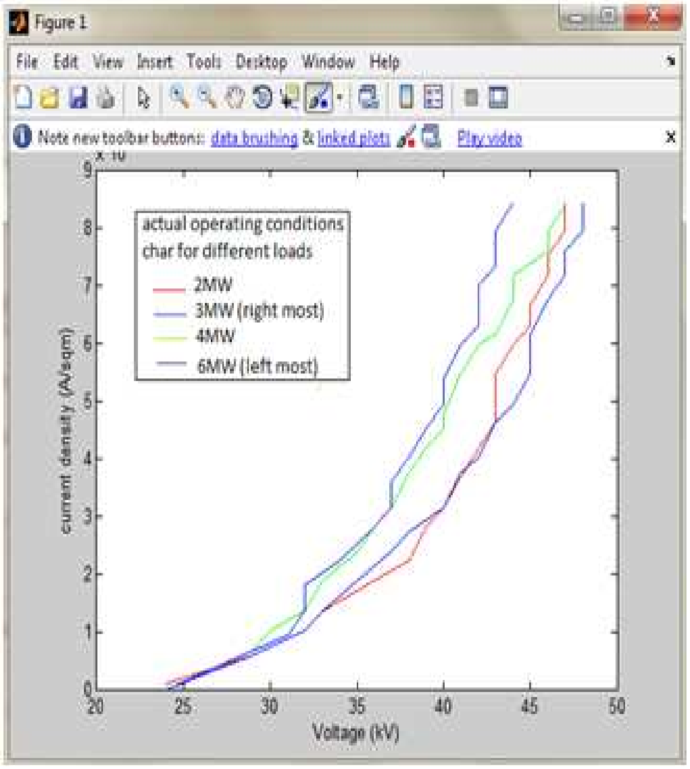

Fig 7 Comparison of V-I characteristic for different loads

Theoretically the V-I characteristics should not be affected by the plant load. This is confirmed in the above fig 7 where for various loads there is a negligible change in V-I characteristics

3.4 Effect of Operating voltage on Particulate removal efficiency

Particulate removal efficiency is defined as

$$\eta = \left(1 - \frac{Final\ concentration}{Initial\ concentration}\right) X\ 100\ \%$$

The initial concentration was measured when the ESP was OFF while the final concentration was measured when the ESP was ON for different voltages.

Sl. No.	Operating Voltage	Initial Concentration (mg/Nm^3)	Final Concentration (mg/Nm^3)	Collection efficiency (%)	Electric power Consumed (kW)
01	35	106.4	68.3	35.81	1.032
02	42	106.4	67.2	36.84	3.108
03	48	106.4	66.4	37.59	5.528

Table 4. Effect of operating voltage on particulate removal efficiency

The table 4 shows effect of operating voltage on particulate removal efficiency of ESP. From the table it is observed that the precipitator is operating at low efficiency (36.84%). This is due to a low operating voltage of the ESP (42 kV) against the rated voltage of 74 kV. This low voltage has been chosen by the industry as the permissible limit for particulate is 100mg/Nm^3 which is satisfied with a removal efficiency of 36.84% operating at a voltage of 42 kV. The table 4 also shows energy calculation corresponding to the operating voltage and efficiency. It is seen that though a better efficiency can be achieved with 48 kV, a voltage of 42 kV is chosen as the optimum operating voltage due to lower electrical consumption. However operating at much lower voltage is not advisable as efficiency small.

4. CONCLUSIONS

Based on the experimental and simulation studies done on the existing ESP, the important conclusions drawn are-

- The precipitator is working under heavy load (high dust concentration) condition.
- The simulated V-I characteristic is in close agreement with experimental V-I characteristic for free air.
- There is negligible change in corona inception voltage with different loads.
- The particulate removal efficiency increases with increase in voltage. However an optimum operating voltage of 42 kV has been selected to satisfy the Pollution Control Norms and to minimize energy consumption.

Acknowledgement

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