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Electrical Characteristics of My Sugar Cogeneration Plant Electrostatic Precipitator

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Abstract: To control particulate matter in many industries, the Electrostatic precipitators have been used over half a century. Simulation of Voltage-current characteristics of ESPs used in MySugar Cogeneration plant which is located in Mandya of Karnataka state is obtained and analysed. The ESPs employed a two-stage configuration, where particles are charged by low voltage compared to single stage in one chamber and then collected by oppositely charged surfaces in a second chamber. Simulated Voltage-current characteristics of ESP for each stage configuration using MATLAB/SIMULINK and electrical characteristics of ESPs are analysed.

Keywords: Electrostatic Precipitator (ESP); two-stage ESP configuration; collection efficiency; MATLAB/SIMULINK; MySugar Cogeneration plant.

I. INTRODUCTION

An Electrostatic precipitator is a filtration device that filters various particulates such as dust, smoke, pollution particles etc which causes Air pollution [5]. As per the environmental standardization, particle size less than 10µm in diameter are identified as hazardous in nature and the chances are there to settle down in lungs which may lead to severe health issues [3]. Electrostatic precipitator finds their place in Coal power plant, Cement industry, Chemical industry, flour mills, Metal and Paper industries. We find more utilization of coal for the power production which releases huge amount of particulate matter to the atmosphere [2]. An ESP works on the principle of Electrostatic attraction (like charges repel; unlike charges attract) [7]. The MySugar Cogeneration plant located in Mandya of Karnataka state is a 30 MW Cogeneration plant which employs two working ESPs working in it where flue gases pass through it before emitted into the atmosphere. The Voltage-current (V-I) characteristics can determine the performance of an Electrostatic precipitator [1]. In India most of the ESPs are DC energized and are facing severe back corona problems. The optimal operation of ESP is closely related to its electrical energization [8].

In this paper, the secondary voltage reading and their corresponding secondary current reading of each stage of ESPs are tabulated. The V-I characteristics of same is obtained using MATLAB/SIMULINK and the electrical characteristics of ESPs are analysed.

II. THEORETICAL SIMULATION

The principle of an ESP is the charging of particulate matter which is then allowed to settle down on the collector plates. There are different process that are explained theoretically. They are as follows:

A. Electrical Operating Points

Voltage and Current are the electrical points for an ESP. The electrical operating points are depended on the corona value. The corona discharge relation for an ESP is

$$I = KV (V - V_c)$$

where K = constant, V_c = Initial corona voltage, I = current and V = applied voltage. Generally negative corona is used in industrial ESPs because it operates at higher voltages before spark-over than positive corona.

The corona is produced by the following electric field is

$$E_c = 3.126 \times 10^6 \, d_r \left[1 + 0.0301 \left(\frac{d_r}{r_\omega} \right)^{0.5} \right]$$

where E_c = corona field (V/m), r_ω = radius of wire (m) and d_r = relative gas density. The voltage that must be applied to wire to obtain this corona field is

$$V_c = E_c r_w \ln (d / r_w)$$

where V_c = corona voltage (V), d = wire plate separation (m).

No current will flow until voltage reaches this value [4]. The amount of current increases steeply as voltage reaches this value. The maximum current density on the plate under the wire is

$$J = \mu \in_0 (V^2 / 1^3)$$

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where J = maximum current density (A/m^2), μ = ion mobility (m^2/Vs), V = applied voltage and l = shortest distance from wire to collecting plate.

$$E_s = 6.3 \times 10^5 \left(\frac{273}{T} p\right)^{1.65}$$

where E_s = sparking field strength (V/m), P = gas pressure (atm) and T = absolute temperature (K).

B. Particle Charging

Due to the attachment of ions produced by the corona discharge, the suspended particles get charged. By the electric field and/or by thermal diffusion, the ions are transported. The particle charging by the ions transfer by electric field is called field charging. For larger particles ≥ 2 μm and for smaller particles ≥ 0.2 μm, field charging is more dominant. The charge of a spherical particle is given by

$$q(t) = q_\infty \{ t/\tau / [1 + (t/\tau)] \}$$
$$q(t) = \pi\epsilon_0 [3\epsilon_s/(\epsilon_s+2)] d^2_p E$$
$$\tau = 4(\epsilon_0 E / J)$$

q_∞ = saturation charge (C), t = charging time (s), τ = time constant of the field charging (s), ε_0 = permittivity of vacuum 8.85×10^{-12} F/m, ε_s = specific permittivity, d_p = particle diameter (m), E = field strength (V/m) and J = current density (A/m^2).

The electric field strength is proportional to the saturation charge q_∞ [6]. The ionic current density (J) is inversely proportional to the time constant (τ). So to impart a high particle charging, E and J should be high.

The particle charge by diffusion charging q'_∞ is expressed as

$$q'_\infty = q' \ln (1 + t/\tau')$$
$$q' = 2\pi\epsilon_0 d_p kT / e$$
$$\tau' = 8\epsilon_0 kT / d_p C_i n_i e^2$$
$$= 8\epsilon_0 (m_i kT/3)^{1/2} (\mu_i E / d_p J_e)$$

q' = charge constant (C), τ' = time constant of the diffusion charging (s), K = Boltzmann constant $\approx 1.38 \times 10^{-23}$ j/K, T = temperature (K), e = electronic charge $\approx 1.6 \times 10^{-19}$ (C), C_i = thermal velocity of ion (m/s), n_i = number density of ions in space (m^{-3}), m_i = ion mass (kg), μ_i = ion mobility (Vm/s^2), E = field strength (V/m) and J = current density (A/m^2).

C. Migration Velocity Of Charged Particles

The migration velocity is the velocity of the charged particles by which these particles travel toward the collecting plate [6]. The Coulomb force of a suspended charged particle in an electric field is

$$F = q E$$

F is the Coulomb force (N), E is the electric force (V/m) and q is the positive charge (C).

The force on the moving charge particle is given by

$$F_s = 3\pi\mu d_p \omega_e / C_m$$

where ω_e = velocity of charged particles

$$\omega_e = qEC_m / 3\pi\mu d_p$$
$$C_m = 1 + 2.54 (\lambda / d_p) + 0.8 (\lambda / d_p) \exp (-0.55 d_p / \lambda)$$
$$\lambda = 6.61 \times 10^{-8} (T / 293) (101.3 \times 10^3 / P)$$

ω_e = migration velocity (m/s), μ = viscosity (Pa s), d_p = diameter of particle (m), C_m = Cunningham correction factor, λ = mean free path of gas molecules (m), T = temperature (K), P = pressure (Pa) and λ = 0.07 micro meter for air at atmospheric pressure and room temperature (300 K).

The migration velocity for field charging is written as

$$\omega_e = qE / 3\pi\mu d_p = [\epsilon_0\epsilon_s / \mu(\epsilon_s + 2) d]_p E^2$$

The migration velocity is proportional to the particle diameter (d_p) and square of the field strength (E). The migration in diffusion charging is

$$\omega_e = 6.2 (2\pi\epsilon_0 d_p kT / 3\pi\mu d_p e) E C_m$$

$$= (4\epsilon_0 k / \mu e) T E C_m$$

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D. Collection Efficiency

The collection efficiency of an ESP [6], η is given by

$$\eta = 1 - \exp(-\omega_e f)$$
$$= 1 - \exp(-\omega_e A / Q)$$

ω_e = migration velocity (m/s), f = A/Q is the specific collection area (s/m), A = area of the collecting electrode (m^2) and Q = gas flow rate (m^3/s).

Collection efficiency is affected by following factors. Those are Geometry of the electrode and Characteristics of the dust particles. Collection efficiency can also found by this relation

$$\eta = 1 - \exp(-\omega_e L K / v_0 d)$$

L = length of the collecting electrode along the gas stream (m), v_o = gas velocity (m/s), d = separation between the discharge electrode and the collecting electrode (m) and K = correction factor determined from actual measurements.

$$t_0 = L / v_0$$

t_0 = detention time, v_o = gas velocity. These are important factors for determining the performance of an ESP. W.e get this relation, by substituting detention time relation in above efficiency relation

$$\eta = 1 - \exp(-\omega_e K t_0 / d)$$

By considering the effect of voltage and the current on the collection efficiency, the following relationship can be obtained which is useful in Industrial ESP.

$$\eta = V^n I$$

By operating in maximum available voltage, the higher collection performance of an ESP is achieved. In industrial application the value of n is used is 2.

III. EXPERIMENTAL STUDIES

The ESP used at MySugar Cogeneration plant is of wire-plate, two-stage type, this consist of a charging state, which utilize thin wires or spikes equally spaced from the parallel or cylindrical grounded plates or tubes and a collection stage has separate parallel metal plates that collect positively charged particles at negatively charged plates. The polarity of the voltage applied to the ionizer is positive. A corona discharge between each wire and a corresponding tube charges the particles suspended in the air flow as they pass through the ionizer. In the ionizer stage the particles receive a positive charge and are collected at the negative plates.
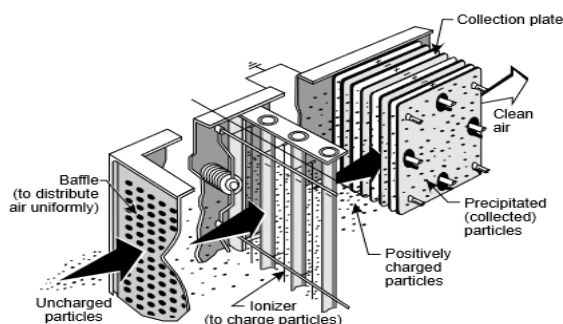

Fig. 1. Representation of gas flow in a two-stage Electrostatic precipitator

The details of ESP are as follows:

Input voltage	415 AC, single phase
Voltage variation	+/- 10%
Frequency	50 Hz
Output voltage	120 KV DC peak
Output current	1st stage 200 mA DC 2nd stage 400 mA DC
Type of Electronic Controller	Microcontroller based

Electrical resistivity and Particle size distribution are the factors on which Electrostatic precipitator's performance is depended on, that effects collection efficiency.

Particles having low resistivity easily become charged and readily release their charge to the grounded collection plate.

Particles with high resistivity are difficult to charge. But once it get charged, they are not ready to give up their acquired charge on arrival at the collection electrode. Another problem that occurs is called back corona. Disruptions of the normal corona process reduce the ESP's collection efficiency, may fall below 50%. When back corona is present, the dust particles build up on the electrodes forming a layer of insulation and the most common problem is increased electrical sparking. When this sparking rate exceeds the "set spark rate limit," the automatic controllers limit the operating voltage of the field.

Both extremes in resistivity prevent the efficient functioning of ESPs. ESPs work best under normal resistivity conditions.

In an ESP, V-I characteristics are used to diagnose any electrical problems occurring in it.

There are three zones of ESP for V-I characteristics. They are as follows:

1) Operating Zone: With the increase of field voltage KV (DC), field current (mA) increases linearly and no spark is emitted.
2) Back Corona Zone: Spark starts emitting causing decrease in field voltage KV (DC) with high increase in field current (mA).
3) Field short Zone: Spark persist continuously causing field voltage KV (DC) to become zero with maximum flow of field current (mA).

IV. RESULTS AND DISCUSSION

"MATLAB R2018a" tool was used for executing the program developed for the simulation of dust loaded V-I characteristics of ESP. The secondary voltage (KV) and secondary current (mA) of first stage and second stage of ESP is obtained and shown in the below table. As increase in field voltage (KV), field current (mA) increases linearly and hence no spark is emitted. As the obtained data from MySugar plant is linearly increasing, Electrostatic precipitator(ESP) is in good condition i.e, in operating Zone.

TABLE I. TWO-STAGE ESP (1st STAGE)

Secondary Voltage(KV)	Secondary Current(mA)
21	20
25	40
27	60
29	80
31	100
33	120
34	140
35	160
36	180
37	200

TABLE II. TWO-STAGE ESP (2nd STAGE)

Secondary Voltage(KV)	Secondary Current(mA)
24	40
29	80
34	120
37	160
41	200
44	240
46	280
49	320
51	360
54	400

For the above readings, V-I characteristics curve has been simulated using MATLAB/SIMULINK and it is shown below:
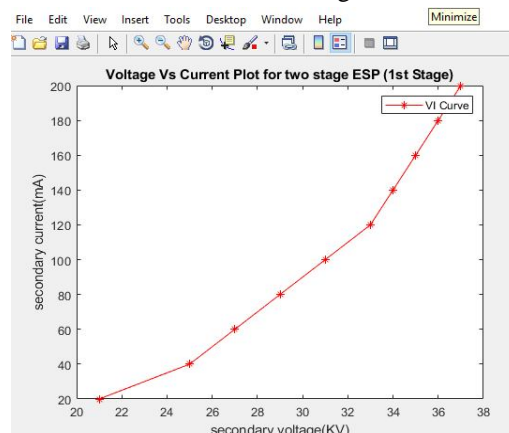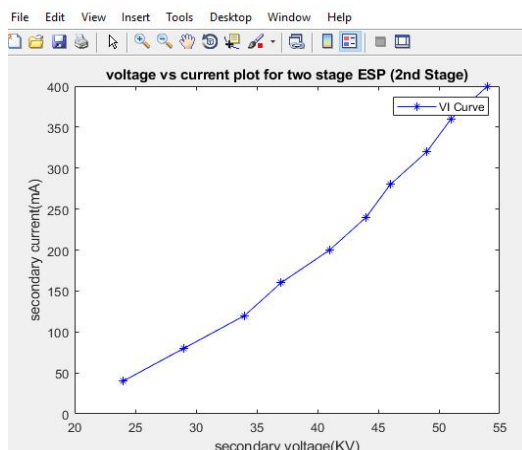

Fig. 2. V-I characteristics of two-stage ESP(1st stage)

Fig. 3. V-I characteristics of two-stage ESP(2nd stage)

V. CONCLUSION

Simulation of V-I characteristics of ESP were developed for loaded conditions of ESPs of MySugar Plant which is located in Mandya of Karnataka state. As secondary voltage and second current reflecting running performance of ESP, V-I characteristic curve is used to analyse ESP's operating condition and electrical characteristics in order to find out the major influences on ESP collection efficiency.

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