Performance Enhancement of Electrostatic Precipitator using Feed Forward Adaptive Control

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Abstract *-In a thermal power plant, due to variation in coal property, the density of the dust particle from the flue gas also varies. Effective removal of the dust particle is very badly needed to improve the efficiency of the Electrostatic Precipitator (ESP). Due to nonlinear property, the existing control system is not suitable for optimizing the dust collection and minimizing the energy consumption. Hence it is proposed to have an efficient system using adaptive feed forward control. The proposed system will continuously monitor the solid particle matter in the flue gas at the outlet of ESP. Actual value is compared with the threshold value and will alter the current setting of the concern rectifier for maximum utility. Further the real time data from opacity sensor fitted near chimney will be used as feed forward input to alter the gain of the controller in an adaptive manner. This system is validated with the data collected from the thermal power plant and the superiority of the system is highlighted.*

I. INTRODUCTION

The utility boilers are large capacity steam generators used purely for the electrical power generation. In a Thermal power station, steam is produced in a boiler, is expanded in the prime mover (Turbine) and condensed in a condenser before feeding it into the boiler again. The turbine shaft is coupled with generator, which is used to produce electricity.

The electrostatic precipitator (ESP) is used in the thermal power plant for removal of fly ash from the flue gas because of the environmental laws. The presence of large quantities of the carbon in the gas can adversely affect the efficiency of the electrostatic precipitator.

Electrostatic precipitation is a process in which the particulate suspended in a flue gas stream electrically charged in a corona field and under the influence of the electric field, is driven to a collecting surface and separated from the flue gas.

The precipitation process involves 1) charging the particles by means of ions produced in a corona discharge 2) separating the charged particles from the gas stream in an imposed electric field 3) collecting the particles on a grounded surface and 4) removing the collected particles by knocking them off.

An electrostatic precipitator consists of electrically grounded plates with negatively-charged electrode suspended between them. The electric charge on the electrode creates a corona field which imparts a negative charge to the particulate. The charged plates are repeatedly struck by rappers to remove the particulate which falls into a hopper beneath the plates. Periodically, the particulate is removed from the hoppers.

Slobodan Vukosavic[1] has developed a method to enhance the collection efficiency and energy efficiency of the electrostatic precipitator by applying high frequency high voltage power supply (HF HV). He demonstrated that high frequency power supply is proven to reduce emission two times in controlled conditions while increasing energy efficiency of the precipitator, compared to the conventional thermistor controlled 50 Hz supply. Two high frequency high voltage units with parameters 70 kV and 1000 mA were installed at and tested. It was found that the HF HV power supply of the ESP increases collection efficiency also possible to make a rapid increase or decrease in voltage and to effectuate a very fast response to load changes.

Arrondel et al.[2] have proposed a method to maintain the maximum current (or infrequently the maximum voltage) with a limited number of sparks and no spark-over. This mode of control, by the number of sparks per minute (adjustable per field) is not suitable in the case of back-corona. If the ash resistivity is high, then intermittent energization has to be used. The simulation of performances of a dust collector operating under DC voltage was described and he presented a simulation of the performances of an electrostatic precipitator powered by intermittent energization using physical models. Intermittent energization performances are then compared to those of a normal control mode. Finally, continuously measured data on the dust collector of a coal-burning 250 MW unit using intermittent energization were analyzed.

A jaworek et al.[3] have investigated about the fractional collection efficiency of two-stage electrostatic precipitator comprising of alternating electric field charger and DC supplied parallel plate collection stage. The total number of collection efficiency of PM2.5 was higher than 95% and mass collection efficiency >99%. Fractional collection efficiency for particles between 300nm and 1μm was >95%.

Rameshprabu.Set al.[4] have briefly explained generalized formulation for the computer-aided analysis of induction motor driving a submersible pump. He demonstrated the dynamic model of the induction motor consists of an electrical sub-model to implement the three-phase to two-axis (3/2) d-q transformation of stator voltage and current calculation, a torque sub-model to calculate the developed electromagnetic torque, and a mechanical sub-model to yield the rotor speed. The submersible pump is modeled with the inputs as shaft speed, torque and head. The output variable is chosen to be discharge. With all these system modules, the electrical and mechanical condition of the pump under different operating condition is simulated with Matlab/Simulink model.

C R Mohanty et al.[5] presented basic factors that influence the fly ash resistivity and ultimately ESP performance. Factors that influence the electrical resistivity are coal, sulphur, flue gas moisture, flue gas temperature, and ash chemistry etc.

B. S. Rajanikanth et al.[6]have briefly described about the V-I Characteristic of Thermal Power Plant Precipitator. In this method he proposed the simulation of electrical conditions in a dc energized wire-duct electrostatic precipitator with and without dust loading. Simulated voltage-current characteristics with and without dust loading were compared with the measured characteristics for analyzing the performance of a precipitator. The simple finite difference method gives sufficiently accurate results with reduced mesh size. The results for dust free simulation were validated with published experimental data. Further measurements were conducted at a thermal power plant in India and the results compares well with the measured ones.

Kingshuk Mukherjee et al.[7]have briefly explained about Information Communication Technology (ICT). An Information Communication Technology (ICT) enabled electronic tool was presented for centralized monitoring of installed ESPs in different locations from a remotely placed monitoring center. It is a cost effective and an efficient tool for E-Governance and will fulfill the dream of a pollution controlled environment.

Malika Bengrit et al.[8] has propose a filtration efficiency evaluation technique based on the measurement of the electric charge. The latter is measured by means of a Faraday cages placed downstream of the ESP. The first Faraday pail is connected to a sensitive electrometer and controlled by a virtual instrument for data acquisition and processing, for measuring the electric charge unfiltered particles when passing through the Faraday cage. The second proposed method for assessing the ESP performance is based on an indirect charge measurement, corresponding to the corona discharge current following through the Faraday cage. Obtained results show significant concordance between the measured charge and the filtration efficiency.

Durga Prasad et al.[9] has briefly explained about a distributed control technique of ESP which uses the actual dust emission and boiler load as feedback inputs and also he described the electrostatic precipitator management system (EPMS), which is a system designed by M/S BHEL to meet the above control strategies using the distributed architecture to achieve efficient ESP operation.

ZhiyuanNing et al.10] has described he electro hydrodynamic flow inside the ESP and the particle collection efficiency by using Particle Image Velocimetry and Electrical Low Pressure Impactor respectively when several different electrode geometries were applied, in order to increase wide ESP efficiency.

Poor performance of ESP is due to large gas volume, unbalanced gas distribution, ash resistivity, ash particle size and improper control of voltage applied to the electrodes.

In order to increase the efficiency of Electrostatic precipitator an adaptive voltage controller scheme is proposed to optimize the electrical power delivered to the electrode. Increased electrical power into the electrostatic precipitator directly correlates with better precipitator performance, without applying too high voltages to avoid spark.

II. EXISTING SYSTEM FOR ESP CONTROL

ESP is used for removal of dust particles from flue gas. Electrostatic precipitation is a process by which suspended particles are electrically charged and passed through an electric field which forces the charged particles towards collecting plates. The charged particles stick to the plates, and periodically a rapping mechanism remove the collected particles from the plates. The removed particles drop into the collection hopper for removal. The hardware circuit is shown in figure1.

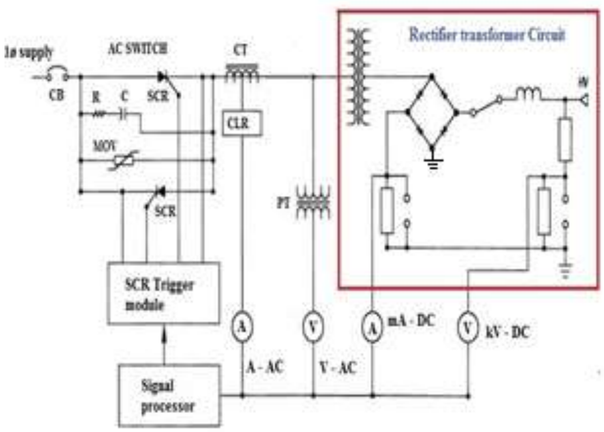

Fig.1. Control system component of ESP

The input is single phase power supply, 230 V, 50 Hz. By changing the firing angle through anti-parallel thyristors, the voltage is being changed in the range from 0 to 230 V and applied to the primary of the step-up transformer in order to change the secondary voltage from 45 kV to 90kV. The current limiting reactor is placed in-between. The secondary voltage is rectified and fed into the electrode in the ESP.

The automatic voltage control is achieved using Microprocessor or Microcontroller which gets Current and voltage feedback.

The secondary voltage automatically adjusted by altering the firing angle of the thyristor according to the current proportional to spark value. Sparks are detected from the voltage samples, they are continuously analyzed for spark over.

A voltage controller will monitor the voltage and current of the primary and secondary circuit, and detect a spark over condition. Once detected, the power applied to the field will be immediately altered, which will stop the spark.

III.ADAPTIVE PROPOSED FEED FORWARD CONTROL

Adaptive feed forward control provides an automatic adjustment of controllers in real time, in order to maintain a desired control system performance when the parameters of the plant changes dynamically with respect to time. The operating voltages for transformer-rectifier depend on the Collecting plate spacing, Gas and dust conditions, Corona current density etc. Corona power levels can be optimized by optimizing the voltage.

The on line emission monitoring turbo electro sensor is installed in the flue gas path where the emission particles are to be measured as shown in the fig.2. As the particles moves in the flue gas path, they strike and rotates the turbo electro Sensor, a current 4 to 20 mA is generated which is directly proportional to the dust particle flowing in the flue gas path to stack. These signals are conditioned and interfaced with data logging console, Programmable logic and Distributed Control System. This actual value is compared with the threshold value. The error signal is fed into a controller to control the electrode current and voltage.

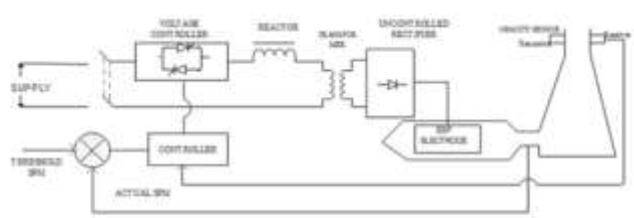

Fig: 2Adaptive Feed Forward Control System

Further the on line data obtained from Opacity sensor which is fitted in the stack will be given as feed forward information to the control system to alter the gain of the controller in an adaptive manner.

Smoke Density Monitor, a light beam is sent across the flue duct, from a light emitter to a light receiver. An electronic unit monitors the opacity. It indicates 0% if there is no black smoke present and 100% if the light beam is totally absorbed by the smoke.

The light intensity entering = I_0
The intensity leaving = I
Opacity is mathematically expressed as:
Opacity = $(1- I/I_0)\times 100\%$
If the intensities I and I_0 will be the same, then opacity is 0%.
If the particles block all light, then I = 0 and the opacity is 100%.

The gain of the Controller will be altered as per the level of opacity value, which in feed forward information.

The system can be viewed as having two loops.

- The inner loop composed of the control of current to the electrodes using SPM value
- Outer loop contains components that adjust the controller parameters on the basis of the opacity value.

IV. RESULT ANALYSIS

The data collected from the plant is utilized for analysing controller performance.

The details of equipment of Electro Static Precipitator considered are shown in table 1.

Table 1: Electrostatic Precipitator Details

No of Rectification transformer	5
No of field	5
Collecting plate electrode	975
Discharge electrode	370
Collecting electrode area	25650 m^2
Primary side	230 V
Secondary side	90 kV
Effective length of each field	4500 mm
Width of field	15200 mm
Effective height	15000 mm

Experiment were conducted with current control method first and then with adaptive control method. In current control method, the charge ratio is playing a major role to trigger SCR to alter primary voltage.Pulse charge is the firing angle applied to the thyristor to control the secondary voltage of the transformer. For example if the rate is 1:3 means the interval between the two pulses is three.

Table 2: Measured values of DC power and SPM for various pulse rate

Pulse Rate	**Secondary Side DC**			**Conventional SPM**	**Adaptive SPM**
	current ma	**voltage kv**	**Power kw**	**mg/m^3**	**mg/m^3**
1:1	50	30.7	1.54	49.3	29.1
	100	34.9	3.49	45.7	24.3
	150	38.3	5.75	45.1	22.1
	200	40.2	8.04	46.8	25.1
	250	42.7	10.68	45.6	20.5
	300	44.4	13.32	45.1	23.0
1:3	50	37.6	1.88	50.2	29.8
	100	39.5	3.95	45.8	25.1
	150	30.4	4.56	45.3	22.5
	200	31.7	6.34	44.7	25.8
	250	32.6	8.15	44.3	21.3

For different pulse rate, the secondary current, voltage and SPM values are noted and tabulated as presented in table 2. The experiments were repeated using adaptive feed forward method for the same secondary current voltages and noted SPM values. The average variation of SPM with respect secondary current for existing and the proposed method is shown in fig.3. When compared to existing method, the proposed adaptive method shows good improvement.

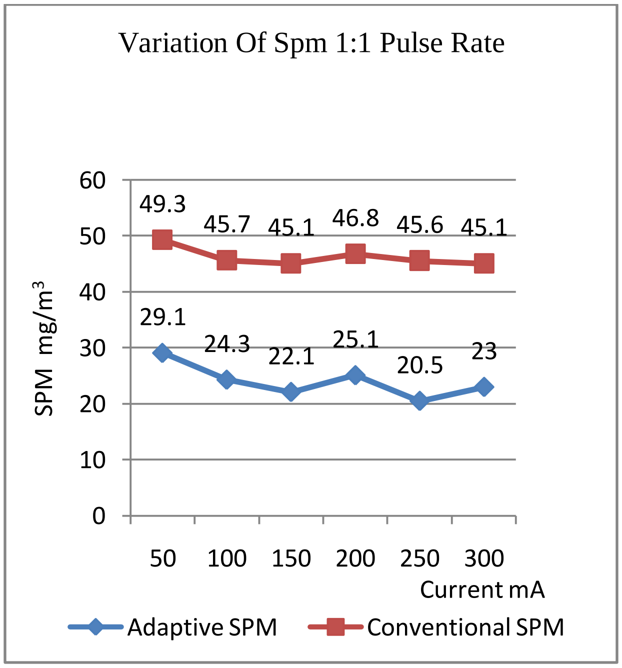

Fig. 3. Average variation of SPM with respect to Secondary Current

V. CONCLUSIONS

Efficiency of the electrostatic precipitator of the proposed method has been analyzed qualitatively and quantitatively. Adoptive control is established through additional feed forward information from opacity sensor. Thisgives anticipatory control signal to the electrodes current to enhance the collection efficiency. Through adaptive control, the average SPM was reduced to 24 mg/m3, indicating that the dust particle collection efficiency has been improved at almost 50%.

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