Laboratory Investigation on the Impact of Coal Dust Deposition on PVPannel Performance

Abhishek Kumar Tripathi¹, Sandeep Prasad² and Shashwati Ray³

¹Assistant Professor, Department of Mining Engineering, Aditya Engineering College, Surampalem, Andhra Pradesh, India, E-mail: abhishekkumar@aec.edu.in
²Assistant Professor, Department of Mining Engineering, A.K.S. University, Satna, India E-mail: sandeep0908024@gmail.com
³Professor, Department of Electrical Engineering, Bhilai Institute of Technology, Durg, Chhattisgarh, India Email: shashwatiray@yahoo.com

Abstract. The generation of electric power through solar photovoltaic panel is highly sensitive towards its operating environment. Dust is one of the important operating parameters which affect the performance of photovoltaic panel. The aim of this study is to understand the effect of dust mass deposition on the output power of the solar photovoltaic panel. In order to conduct this study a filed collected coal dust was used in different mass on the surface of photovoltaic panel and its output power was calculated. Further, based on obtaining output power for different mass of coal dust deposition, a mathematical model was developed between panel output power and the amount of coal dust deposit. The developed model has shown a good coefficient of correlation, i.e., 0.94974 and strong negative correlation with the Pearson’s correlation coefficient of -0.97712. The outcome of this study will help to understand the performance of solar photovoltaic panels under the dusty environment.

Keywords: Solar, Photovoltaic Panel, Output Power, Coal Dust, Coefficient of Correlation

1. Introduction
The creation of electrical energy depends on non- sustainable and sustainable power sources. In this, sustainable power sources are viewed as perfect and ecologically benevolent vitality source. There are numerous sustainable power sources, yet among all the solar energy source experienced quick development and ubiquity in the most recent decade due to its simplicity in the installation and ease of maintenance. Hence, solar energy is turning into an imperative wellspring of electric power generation in a current circumstance. The solar power also has greater impact on Indian economy and it has implements in various management principles. [1-8].

At present, the fundamental power generation source of mining industries are the fossil fuels (gas, oil, coal) and because of the use of fossil fuels, ozone depleting substances (CFC, CH₄, O₃, however predominantly CO₂) transmit into the climate which is answerable for an Earth-wide temperature boost just as the ecological contamination. Then again, there is a disturbing energy emergency worldwide as the storage of fossil fuel decline and the power plants which are depending on fossil fuels are going to
shut in the coming future. Thus, from the part of a global warming and deficiency of natural gases, researchers and specialists are searching for perfect, sustainable power sources and here solar energy could play an imperative role in this age of power generation.

Solar energy is promptly accessible anywhere and wherever on earth. The solar energy can be used as point power source because the sunlight falling at the certain point can be converted into electrical power. The solar-powered structure depends on this idea which may be installed in any industries and households. The solar energy can be directly utilized by converting the sunlight into electrical power and the conversion is called photovoltaic effect. The device which perform this task is called as solar photovoltaic (PV) panel.

The PV panel installation requires vast land which is easily assessable in the mining areas in the form of waste dump yard, abandoned mine area, pit bottom area, tailing ponds etc. In these areas PV panels can be effectively installed and utilized. The electricity thus generated by solar energy can be utilized for spot lighting, haul road lighting, lighting crusher and office premises, beneficiar plant, pumping area etc. But due to dusty and bad environment prevailing in the mines PV panel may not perform well as ensured by the manufactures. In fact, the performance of PV panel degrades with time due to such dusty and bad environment.

In solar energy system, sunlight is converted in to the electricity by the aid of solar photovoltaic (PV) cell [9]. Whenever, the sunlight falling on the photovoltaic cell surface, it excites the electrons of the valence band to move to from valence band to conduction band and this generates hole in valence band. As a result of this, photo current starts flowing to the external circuit. In solar photovoltaic system, a photovoltaic module consists a group of PV cells and a PV panel consists a group of PV module. In general, the PV panel are operated in an open atmosphere, where it experiences a significant variation in atmospheric parameters, such as wind speed, atmospheric temperature, solar irradiance, moisture content in the atmosphere and dust pollutants [10]. These atmospheric parameters disturb the effective operation of solar PV panel in an open atmosphere and among them dust plays a vital role in reducing its performance.

The accumulation of dust on PV panel surface makes a boundary between the PV panel surface and sunlight which is falling on its surface. As a result, panel not able to receives 100% of falling sunlight. This reduction of falling sunlight depends on the size, mass and type of dust. This reduction of sunlight significantly reduces the output of solar PV panel. [11-12].

In one investigation it was discovered that because of dust deposition on panel surface the generation capacity and conversion efficiency of PV panel diminishes to 92.11% and 89%, respectively [10]. A work did to examine the impact of dust on glass transmittance of panel demonstrated that there is a decrease in the transmittance which ranges from 12.38% to 52.4% for 4.48 to 15.84 g/m2 of dust settlement [13]. One more investigation announced that the decrease in the final efficacy of PV panel because of dust deposition was 10%, 16% and 20%, respectively, for 12.5 g/m2, 25 g/m2 and 37.5 g/m2 of dust amount [14].

The main purpose of this study is to understand the effect of coal dust deposition on the output response of solar PV panel. The outcomes of this study will help the coal mining sector to understand the feasibility of solar panel utilisation under the harsh environment of coal mining industries. Further, the outcome of the paper explains the nature of output power degradation the deposition of coal dust.

2. Materials and Methods
This research was purely conducted inside the laboratory under the controlled environment condition (which helps in understanding the solo effect of coal dust deposition on PV panel performance). A special type experimental set-up was arranged in order to conduct the present research which can be seen by Figure 1. Here, a panel stand of height 1 meter was used which can hold the PV panel and this
horizontal surface covers by the lighting shade which provides a desire amount of artificial sun light inside the laboratory. A20 watt multi-crystalline panel was used in this study. To measure the input and output of the solar PV panel the various devices such as, solar power meter, rheostat, voltmeter and voltmeter were used in the study. To conduct the present study the PV panel was exposed to 722 w/m² artificial solar radiation thereafter the output of the panel was measured for the clean surface of the panel under the varying load condition of with the help 320Ω wire rheostat. Further, the output response of the panel was measured under the deposition of field collated coal dust which were distributed at different mass. This coal dust was collected from one of the coal mines of south eastern coal field India and it was collected on the filter paper so that a required size of coal dust can be settled. For the measurement of electrical output of the sola PV panel under the effect of different mass of coal dust was performed with the help of an electrical circuit diagram which is shown in Figure 2.

Figure 1. Experimental set-up

Figure 2. Electrical circuit diagram

3. Results and Discussion

The output current and voltage of the multi-crystalline panel was measured under varying load condition for the clean and coal dust contaminated panel surface. At the initial of the output measurements when load was almost zero that time the current was measured as the short circuit current and voltage was zero, thereafter, the load increases linearly till it reaches the maximum value at this time the measured voltage is termed as the open circuit voltage and current at this point was almost zero. It means that during the increase of the load from zero to maximum the voltage was increases (reaches towards short circuit voltage) whereas current was decreases (proceeding towards the open circuit current) thus it was observed that the maximum value of output power of solar panel was achieved in between the zero and maximum value of load. This particular load point is called as the maximum power point where the
value of output power is maximum and, corresponding value of current and voltage are termed as the maximum current and maximum voltage. The measured output values of multi-crystalline PV panel under different panel surface condition is presented in Table 1.

| Mass of Coal Dust Deposition (g) | Output voltage at maximum point (volt) | Output current at maximum point (amp) | Output Power at maximum point (watt) |
|-------------------------------|----------------------------------------|--------------------------------------|--------------------------------------|
| 0                             | 16.7                                   | 0.36                                 | 6.012                                |
| 1                             | 16.7                                   | 0.32                                 | 5.344                                |
| 2                             | 16.7                                   | 0.28                                 | 4.676                                |
| 3                             | 16.7                                   | 0.26                                 | 4.342                                |
| 4                             | 16.7                                   | 0.21                                 | 3.507                                |
| 5                             | 16.7                                   | 0.16                                 | 2.672                                |
| 6                             | 16.7                                   | 0.11                                 | 1.837                                |
| 7                             | 16.7                                   | 0.1                                  | 1.670                                |
| 8                             | 16.7                                   | 0.09                                 | 1.503                                |
| 9                             | 16.7                                   | 0.07                                 | 1.169                                |
| 10                            | 16.7                                   | 0.07                                 | 1.169                                |

Based on the readings obtained in Table 1, it can be seen that the output power of the panel linearly decreases as the deposition of coal dust on its surface increases. Therefore, a mathematical attempt was done performed in order to establish relation between mass of coal dust deposition and power output of the panel. To perform this a linear regression technique was used so that mass of coal dust and output power of the panel can be correlated. Here, the mass of coal dust was considered as the independent variable and outpower as the dependent variable. The formulas used for the regression analysis are given by equation (1), equation (2) and equation (3).

\[ P_{\text{max}} = a_0 + a_1 M \]  
\[ \sum P_{\text{max}} = n a_0 + a_1 \sum M \]  
\[ \sum P_{\text{max}} \times M = a_0 \sum M + a_1 \sum M^2 \]

where,  
\( P_{\text{max}} \) = Output power of PV panel at maximum point (watt),  
\( M \) = Mass of coal dust deposition on the panel surface (g),  
\( n \) = Number of observations,  
\( a_0 \) = Intercept of the line (regression constant), and  
\( a_1 \) = Slope of the line (regression constant).

A mathematical relation was developed based on equations (1), (2) and (3), which is given by equation (4). The regression statics of the mathematical relation (i.e. equation (4)) is presented in Table 2. As indicated in Table 2, the regression statics has a very good R square value of 0.94974 and Pearson’s r value of -0.97712, which is shows a strong negative relation between mass of coal dust and output power of the panel. Thus, the equation (4) can be taken as an inappropriate equation, and using it, the value of maximum output power for a 20 watt multi-crystalline PV panel can be calculated under the influence of coal dust deposition. The graphical relation between maximum power output of the panel and mass of coal dust deposition is presented in Figure 3. In figure 3, the red line represents the
simulated readings of the output power which is tightly follow the black line which is nothing but the observed value of output power of the panel[15-18].

\[ P_{\text{max}} = 5.69741 - 0.5223M \] \hspace{1cm} (4)

where, \( P_{\text{max}} \) = Output power of PV panel at maximum point (watt),

\( M = \) Mass of coal dust deposition on the panel surface (g).

| Sl. No | Parameter            | Values   |
|-------|----------------------|----------|
| 1     | R Square             | 0.94974  |
| 2     | Standard error       | 0.0379   |
| 3     | Observations         | 11       |
| 4     | Degree of freedom    | 9        |
| 5     | Pearson’s r value    | -0.97712 |

Table 2. Regression statics of the developed equation

![Figure 3](image-url)  

**Figure 3.** Relation between output power of PV panel with mass of coal dust deposition

A residual analysis for the developed equation (4) was performed which helps in understanding goodness of the fitted curve in the developed equation. The residual plot is nothing but the combination of X and Y axis where residuals (difference between actual and predicted value) values is mention in the Y axis and the independent variables (i.e., mass of coal dust) is shown in X axis. If the points in a residual plot are randomly dispersed around the horizontal axis, a linear regression model is appropriate for the data; otherwise, a non-linear model is more appropriate[19-22]. The residual plot of the developed equation (4) is shown in Figure 4. As shown in Figure 4, the residual points are randomly distributed around the horizontal axis which supports the developed liner regression model.
4. Conclusions
In the age of green power, the mining industries also moves towards the efficient utilisation of green energy as their primary electrical power supply. Solar photovoltaic is one of the good choices of the green energy which is more frequently using in mining industry. But, due to the dusty and harsh environment of the mining industry the solar PV panel fails to operate efficiently. In this, regard, the study of coal dust deposition effect on the output response of the PV panel was conducted in this paper. The main concern of this research is to investigate the influence of the mass deposition of coal dust on solar PV panel performance. The obtained results showed a significant loss in the output power of PV panel due to the deposition of coal dust on its surface. In this paper, a mathematical correlation between mass of coal dust deposition and output power of the panel was developed. The developed model had showed a good coefficient of correlation, i.e., 0.94974 and strong negative correlation with the Pearson’s correlation coefficient of -0.97712. The outcome of this paper will help in the efficient utilisation of solar energy in mining industries.

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