Variation in the Performance of Solar Photovoltaic Power Plant Due to Climatic Parameters in Composite Climatic Zone

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Abstract – Solar photovoltaic (SPV) power plant's performance is directly dependent on the sun's incoming solar radiation availability and its intensity. The energy yield of SPV Power Plant is limited by many climatic parameters like temperature, wind velocity, humidity, dust, rain etc. In this paper, the Performance of a 5kVA photovoltaic power plant installed at the Centre of Excellence in Renewable Energy Education and Research, University of Lucknow (New Campus) is calculated on the basis of the collected data of two reference modules. The data analysis shows that some climatic parameters degrade the performance of solar photovoltaic power plants like dust, temperature and humidity and some put positive effect on the output power of modules like rain. Due to deposition of dust, modules loss their output power upto 11.4 % in one Month. A correlation established between the different climatic parameters and the module efficiency, which is important to evaluate the daily and monthly yields of Solar Photovoltaic Power Plant. Performance Ratio of 5kVA photovoltaic power plant calculated on the basis of the regressed model and measured data. Regressed model is very useful for predicting the performance of the solar photovoltaic power plants in composite climatic conditions.

Index Terms – Energy yield, Climatic Parameters, Performance, Performance Ratio, Regressed model, Composite climate.

1. INTRODUCTION

Due to the rapid growth of world population and industrialization, demand for electricity increases, which increase the burden on the electric utilities to upgrade their generation. The scarcity of conventional energy resources and environmental problems associated with them has emphasized to use the renewable energy sources. In the present time, Solar Photovoltaic (SPV) power generation technology is superior to all other renewable sources to generate electricity from solar radiation. The advantages of SPV technology with respect to its environment-friendly nature cause increasing installation of the same for small power generation systems as well as for electrical grid. India is a developing country, even though he is rapidly developing renewable energy sources. The Government of India has recently revised its Jawaharlal Nehru National Solar Mission (JNNSM) to set an aggressive target of 100GW of installed PV by the year 2022, out of which 40GW is roof-top solar PV and 60GW is ground mounted large grid-connected PV system (T. Kapoor, 2015).

Large-scale solar photovoltaic power plants are generally located in arid and semi-arid areas of the world where sunlight is abundant. These SPV plants suffer from many climatic parameters such as temperature, humidity, and wind velocity and dust accumulation (soiling). Accumulation of the dust is one of the main parameters which affects the performance of power plants to a great extent. The output power of module reduces with the deposition of dust and it increases with the increasing concentration of dust (El-Shobokshy and Hussein, 1993). R Siddiqui et.al (2012) collected the data for one year to know the effect of dust on the module's efficiency and found that there is a significant loss in module's efficiency due to the accumulation of dust in composite climate. Further, they developed a relation between differences in efficiencies of the module with respect to the thickness of dust collected on the module. Elsherif and Kandil, (2011) have found that the efficiency of the cells has decreased by 25 % in the first two months of operation, and by 40 % after one year. Pande (1999) found that the current of module reduced up to 30% in one year due to dust.

In the present research paper, the effect of soiling on the performance of power plant have been measured for the month of April 2016. April month is chosen for the experiment because it is the driest month of the year with more sunlight compare to another month. The wind speed is highest during April than other months with average wind speed is 10 kmph. In fact, it is the windiest season for Lucknow as both the average winds and the strength of squall is highest. High wind speed promotes Aeolian dust which precipitates on the module and affects its output power and efficiency.

2. DUST

Dust is a general name for solid particles ranging in size from below 500 µm (M. Mani, 2010). Dust particles arise from natural sources such as soil dust lifted up by the wind and volcanic eruptions. These particles can be a mixture of various constituents such as pollen, fibers, metals, metal oxides, hydrocarbons, and organic matter (R.A Bowling, 1985). Atmospheric dust particles are generated through various mechanisms such as mechanical abrasions, chemical reactions, and combustion processes. The particle size, constituents, and shape can vary throughout different geographical locations of the world. Moreover, the deposition mechanism and the deposition rates can vary dramatically with geographical locations (J.J John, 2015).

3. EXPERIMENTAL METHODOLOGY

The experimental analysis is conducted in the Centre of Excellence in Renewable Energy Technology and Education Laboratory located at the new campus of the University of Lucknow. Lucknow, the capital of Uttar Pradesh is situated 123 m above sea level, which is a land locked city. It is situated on 26.30 & 27.10-degree North latitude and 80.30 & 81.13-degree East longitude.

The experiment is conducted by using the two 250 Wp solar panel. The modules are of similar specifications and tested in standard conditions at 1000 W/m^2 solar radiation, 1.5 AM and 25°C temperature, have the following specifications:

Table 01: Panel Specification

Maximum Power Output (Pmax)	250 W_p
Rated Voltage (Vmax)	35.00 V
Rated Current (Imax)	7.14 A
Open Circuit Voltage (Voc)	43.20 V
Short Circuit Current (Isc)	7.5 A
Panel Efficiency	13%
Tolerance	+3%

During the experiment, one module was cleaned daily with the help of wiper and collected dust carefully in the early morning when the wind speed is lowest compared to other time of the day, whereas the other module was left unclean throughout the study. Collected dust was measured in electrical balance with 0.0001 gm sensitivity. First weight of collected dust with fiber pot was measured and again the weight of fiber pot was measured after the dust was completely cleaned. The difference of two values gave the weight of dust. Initially, both modules were kept clean and measured output power (Pmax) of both modules simultaneously. All data were recorded for each day from 10 am to 4 pm. daily the average values of climatic parameters and modules electrical parameters were calculated.

Weather data logger installed on the roof of the university about 5 m far from the experimental setup, which measures the data for Temperature, Humidity, Wind Velocity, Rainfall, and Irradiance. The data logger records the values of every five-minute interval.

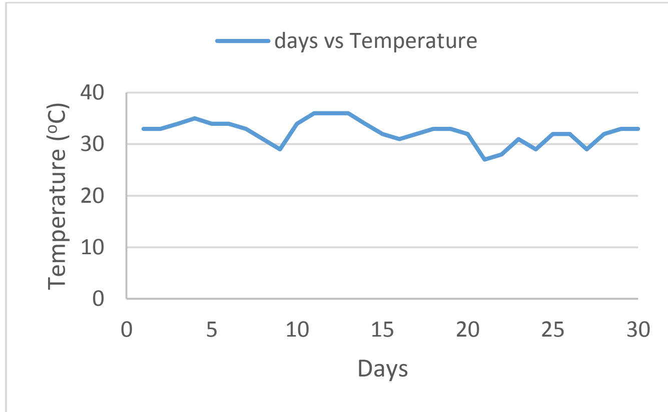

Fig.-1 Temperature variation during the month

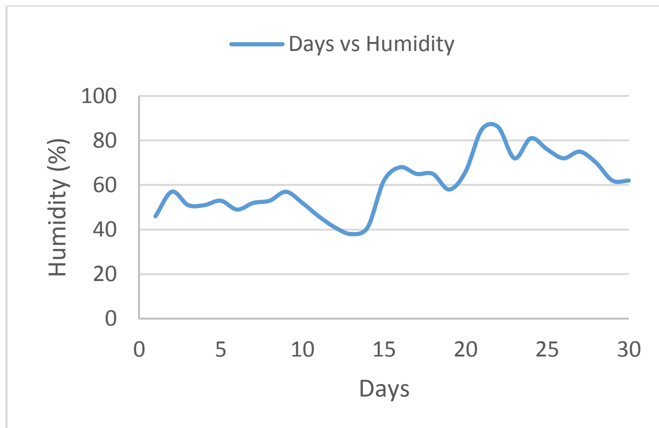

Fig.-2 Humidity variation during the month

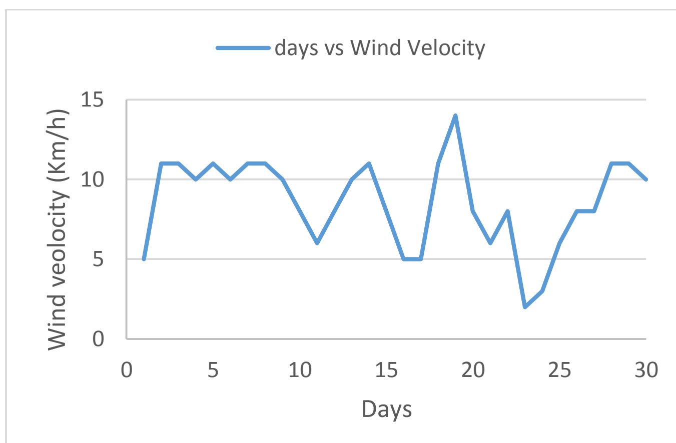

Fig.-3 Wind velocity during the month

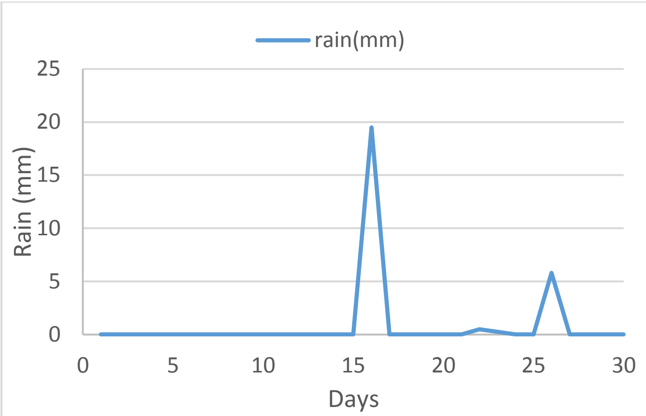

Fig.-4 Rain during the month

Average value of every day of all parameters takes into the calculation. In the April month, the average minimum temperature was 27 ºC and while the average maximum temperature was 36 ºC (fig 1). The output power of modules decreases with the increase of temperature. SPV modules have negative power coefficient of temperature (M.S. Vasisht, 2016). Average minimum humidity was 38% while Average maximum humidity was 86% (fig 2). Humidity makes the surface of modules sticky which attracts the dust particles and they make together a cement layer which prohibited to enter the sunlight into the glass cover. High humidity helps the formation of dew on the solar cell surface leading to more facile dust coagulation (Server et al., 2013). Average wind velocity varied from 0 km/h to 14 km/h during the experiment (fig 3). Higher Wind velocity promote to raised and dust action where it can promote the higher rate of dust accumulation due to surface collusion (Goossens et al., 1999). Heavy rain put the positive effect on the generation of power through the solar module, because it removes the accumulated dust upon the modules (Qasem et al., 2011). Average rain recorded during the month is 0.8mm. minimum rain during the experiment was 0 mm while maximum recorded rain was 19.50 mm (fig 4). A correlation established between the effects of different climatic parameters and the reduction in module efficiency by performing multiple regression analysis. On the basis of the regression model and measured data, the performance ratio of solar photovoltaic (SPV) power plant is calculated. SPV plant has 20 panels in which four modules connected in series make a string and this type of five strings are connected in parallel.

All panels of the plant have the same specification as the testing modules. Array output data collected by a computer with the help of the power conditioning unit (PCU) output parameters Monitoring software provided by Statcon Power Controls Ltd.

4. IN PLANE IRRADIANCE

The output power of PV module is directly dependent on the sun's incoming solar radiation availability and its intensity. Dust settles directly on the solar photovoltaic panels, blocking the cells from the sun's Intensity (Al-Hasan, 2005). Solar irradiance sensor has also been tilted to the same inclination of module to measures global solar irradiance.

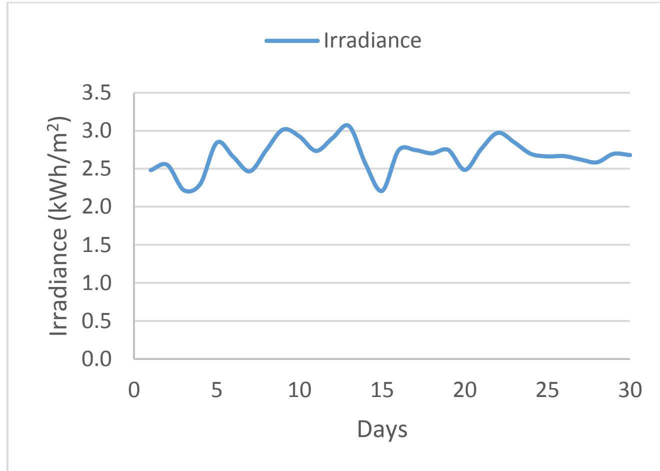

Fig.-5: In plane Irradiance during the month

5. RESULTS AND DISCUSSION

The present study is carried out in April month for a period of 30 days. Solar flux density is observed by using Weather Data logger for the duration of the experiment. To measure the quantity and rate of dust settling onto the panel's surface, the everyday dust has collected from 1 April to 30 April in the morning when the wind velocity comparatively low. Then the efficiency and power of clean and dusty panels were calculated. After that percentage efficiency and power loss calculated with the help of measured data.

$$\% \text{ reduction in efficiency} = \frac{\text{Efficiency without dust} - \text{Efficiency with dust}}{\text{Efficiency without dust}} \times 100$$

$$\% \text{ reduction in power} = \frac{\text{Power without dust} - \text{Power with dust}}{\text{Power without dust}} \times 100$$

6. LOSS IN OUTPUT POWER OF MODULE

Output electrical parameters of both modules measured in every 5-minute interval. Sedimentation caused by the dust concentration does affect the open-circuit voltage (Voc) (Elsherif and Kandil, 2011), resultant loss in the output power of dusty module.

Accumulation of dust on the surface of a photovoltaic module decreases the radiation reaching the solar cell causes transmission loss due to the absorption and scattering of the incident light (Zorrilla et.al.2013). Poor output power due to scattering of incoming radiation by dust particles of silicon solar cell also claimed by (Bajpai and Gupta 1988). The graph (fig. 6) shows that the output power of clean panels is more than the dusty panel and it decreases with increasing the thickness of dust layer.

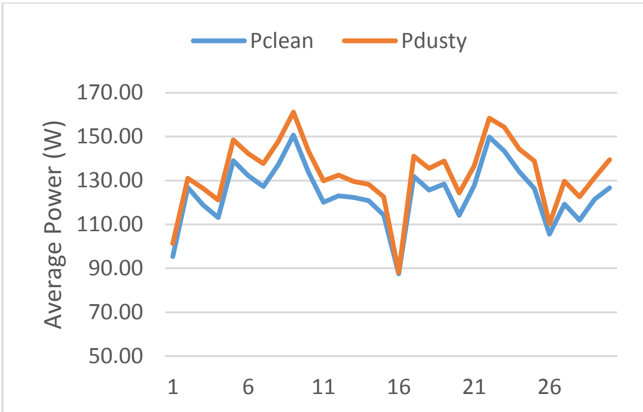

Fig.-6: Variation between the out Power of Dusty and Clean Module

7. LOSS IN MODULE EFFICIENCY

Efficiency is calculated from the formula-

$$\eta = \frac{I_m \; V_m}{I_T \, A_c} = \frac{FF I_{sc} V_{oc}}{I_T \, A_c}$$

Where

I_T = incident solar flux and

A_c = area of the panel

Panel efficiency has calculated per day with the help of daily average output power, daily average hourly solar radiation data on the module, and the area of panels. The efficiency of the panels has calculated before and after deposition of dust and then compare with the clean panel.

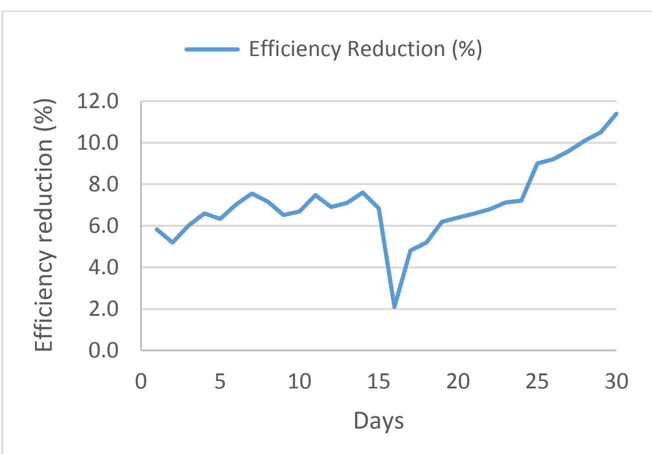

Fig -7: Percentage Efficiency Reduction of Panel

The result shows a considerable loss in Efficiency. The efficiency of panel decreases with increasing of dust accumulation. Percentage efficiency loss of panel varies up to 11.4%. (fig-7). The graph plotted between the calculated per day efficiency of panel and date, which clearly shows that efficiency of plant reduces with the deposition of dust. Efficiency is directly affected with the concentration of deposited dust, efficiency decreasing with increasing of dust concentration. After raining the panels plant recovers its normal efficiency. Lowest peak in the graph shows the rainy day during the experiment. 19.5mm rain recorded on 17 April which shows the minimum reduction in the efficiency of the module.

8. EFFECT OF CLIMATIC PARAMETERS ON THE EFFICIENCY OF PANEL

All climatic parameters affect the output power and efficiency of Panel in a different way. But It is difficult to calculate combine effect of the climatic parameters on the module's performance in open environment. To know the effects of these parameters a multiple regression is done with the help of Microsoft Excel. The regressed model shows a correlation between all parameters.

Regression Statistics	
Multiple R	0.825
R^2	
0.771	
Adjusted R^2	
0.745	

ANOVA	
	Significance F
Regression	0.015

	Coefficients	P-value
Intercept	8.732	0.082
X_1	-0.479	0.025
X_2	0.391	0.035
X_3	-0.002	0.122
X_4	-0.069	0.025
X_5	0.094	0.140
X_6	-0.004	0.315
X_7	2.023	0.247

The regressed model takes the form of the following equation-

$$Y=A+A_1X_1+A_2X_2+A_3X_3+A_4X_4+A_5X_5+A_6X_6+A_7X_7 \qquad (6)$$

Where-

Y = Efficiency of dusty module

A = Intercept

X_1 = Ambient Temperature (°C)

X_2= Cell Temperature (°C)

X_3= Relative Humidity (%)

X_4= Wind speed (Km/h)

X_5 = Rain (mm).

X_6= Inclined Irradiance (W/m^2)

X_7 = Dust deposition Rate (g/day).

Final equation takes the form-

$$Y= 8.732-0.479X_1+0.391X_2-0.002X_3-0.069X_4+0.094X_5-0.004X_6+2.023X_7 \quad (7)$$

9. ESTIMATION OF PERFORMANCE RATIO OF PLANT

Performance Ratio (PR) is an important parameter for evaluating the performance of a SPV plant, which is the ratio of the actual energy yield and theoretically calculated energy yield.

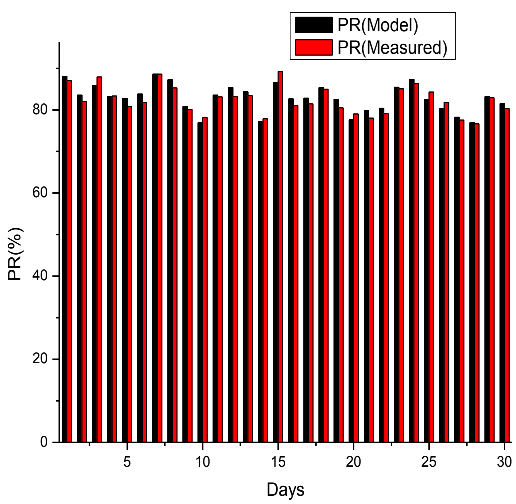

Fig-8: Performance Ratio of SPV Plant on the Basis of Measured and Estimated Data

Performance ratio of 5kVA photovoltaic power plant calculated on the basis of the regressed model and measured data. Total energy (kWh) generated by the plant is recorded with the help of the data acquisition system incorporated in the (PCU). The regressed model gives minimum value of SPV power plant performance ratio 77.57% and maximum value 89.26%, whether calculated minimum performance ratio of the plant is 76.59% and maximum 88.56% (fig. 8). Which recommends that the model predicts significantly close value to the measured value.

9.1 The validity of the model

To evaluate the accuracy of the correlations described above, the root mean square error (RMSE), mean bias error (MBE), percent root mean square error (%RMSE), percent mean bias error (%MBE) were used.

Table 02: Different Errors for The Model

RMSE	0.45
MBE	0.68
%RMSE	0.83
%MBE	0.55

The regression model gives 0.83 %RMSE value which is in acceptable range.

10. CONCLUSION

The output power of module at STC (Standard Test Conditions) can't be found in the real environment due to the variable conditions. Climatic parameters restrict the performance of SPV modules as well as degrade the material of the solar cell. The deposition or accumulation of dust particles on the PV panels significantly affects the performance of SPV panel. The collection of dust on a solar photovoltaic module's surface reduces the solar irradiance reaching to the solar cell and produces the reduction in the and output power efficiency. Percentage efficiency of PV panel reduced upto 11.4% for April month. Panel performance decreases with increasing deposition of dust. A correlation established between the effects of different climatic parameters and the reduction in module efficiency, which is important to evaluate the Performance of Solar Photovoltaic Power Plant in the different climatic zone.

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