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Analysis of PV Panels under Various Weather Conditions

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Abstract-

Research and development in photovoltaic (PV) systems has usually been concentrated in studies on radiation availability, efficient operating strategies, design and sizing of these systems. On the other hand, the influence of dust on the performance of PV systems has not been given much attention. The work described here contributes considerably to overcome this deficit. To validate that concept, we have developed an experimental set up of Solar panel located at the rooftop of Gyan Ganga Institute of Science and Technology, Jabalpur (23.1667° N, 79.9333° E).The test-bed consisted of two identical open-rack mounted polycrystalline silicon photovoltaic panels installed side-by-side and tilted at 10° to the ground facing southwards. Both panels experienced the same instantaneous insolation levels, ambient temperatures and wind incidence the experimental set-up for finding the mass of dust settling and its effect on electrical output of the solar panels was performed in the following way. Experimentation occurred between March 2015 and May 2015.

Key words- Solar cells, Dust deposition density, PV Panels, Experimental analysis, Solar Energy

I. INTRODUCTION

According to Max Planck, energy is defined as the ability of a system to cause external action. In this respect the following forms of energy are distinguished: mechanical energy (i.e. potential or kinetic energy), thermal, electric and chemical energy, nuclear energy and solar energy. In practical energy appliances, the ability to perform work becomes visible by force, heat and light. The ability to perform work from chemical energy, as well as nuclear and solar energy is only given if these forms of energy are transformed into mechanical and/or thermal energy.

The term energy carrier – thus a carrier of the above defined energy – is a substance that could be used to produce useful energy, either directly or by one or several conversion processes. According to the degree of conversion, energy carriers are classified as primary or secondary energy carriers and as final energy carriers. The respective energy content of these energy carriers consists of primary energy, secondary energy and final energy. Definitions of the individual terms are as follows.

- Primary energy carriers are substances which have not yet undergone any technical conversion, whereby the term primary energy refers to the energy content of the primary energy carriers and the "primary" energy flows. From primary energy (e.g. wind power, solar insulation) or primary energy carriers (e.g. hard coal, lignite, crude oil, and biomass) secondary energy or secondary energy carrier can either be produced directly or by one or several conversion steps. Secondary energy carriers are energy carriers that are produced from primary or other secondary energy carriers, either directly or by one or several technical conversion processes (e.g. gasoline, heating oil, rape oil, electrical energy), whereby the term secondary energy refers to the energy content of the secondary energy carrier and the corresponding energy flow. This processing of primary energy is subject to conversion and distribution losses. Secondary energy carriers and secondary energies are available to be converted into other secondary or final energy carriers or energies by the consumers.
- Final energy carrier and final energy respectively are energy streams directly consumed by the final user (e.g. light fuel oil inside the oil tank of the house owner, wood chips in front of the combustion oven, district heating at the building substation). They result from secondary and possibly from primary energy carriers, or energies, minus conversion and distribution losses, self-consumption of the conversion system and non-energetic consumption. They are available for the conversion into useful energy.
- Useful energy refers to the energy available to the consumer after the last conversion step to satisfy the respective requirements or energy demands (e.g. space heating, food preparation, information, transportation). It is produced from final energy carrier or final energy, reduced by losses of this last conversion (e.g. losses due to heat dissipation by a light bulb to generate light, losses of wood chip fired stove to provide heat).

The entire energy quantity available to humans is referred to as energy basis. It is composed by the energy of the (predominantly exhaustible) energy resources and the (largely renewable) energy sources.

II. LITERATURE BASED ON EFFECT OF DUST ON SOLAR COLLECTORS

Studies related to dust accumulation is critical as a further decrease in the (practical) system efficiency will tend to make PV systems an unattractive alternative energy source particularly for the larger domestic markets. Current research into characterizing deposition of dust and their impact on PV system performance is limited given the fact that dust deposition is a complex phenomenon and is influenced by diverse site-specific environmental and weather conditions.

The paper presented by B. Ghosh provides current status in studying such impact on PV system performance and identifies challenges to overcome the problem. Dust not only reduces the radiation on the solar cell, but also changes the dependence on the angle of incidence of such radiation. J. Zorrilla-Casanova et. al. presents the results of a study carried out at the University of Malaga to quantify losses caused by the accumulation of dust on the surface of photovoltaic modules. The results obtained after study shows that mean of the daily energy loss along a year caused by dust deposited on the surface of the PV module is around 4.4%. In long periods without rain, daily energy losses can be higher than 20% . Figure shows the framework to understand the various factors that govern the settling/assimilation of dust is.

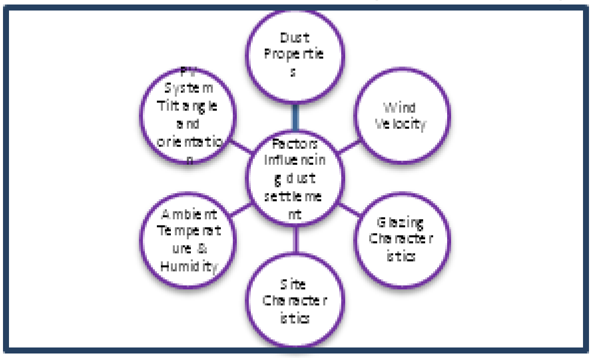

Figure 1 Factors That Influences the Dust Settlements

Sudan, for example, has worse dust accumulation 9 times that of UK fallen in one month without cleaning. "A dust layer of one-seventh of an ounce per square yard decreases solar power conversion by 40%," Mazumder explains "In Arizona, dust is deposited each month at about 4 times that amount. Deposition rates are even higher in the Middle East, Australia, and India.

Hussein A Kazem et. al. experiments concerning the effects of air pollutants including red soil, ash, sand, calcium carbonate, and silica on the power generated are conducted and analyzed. The reduction in PV voltage and power is strongly depends on pollutant type and deposition level.

2.1 Literature based on different tilt angles and orientation

The tilt angle and orientation of the PV modules are important factors that affect the performance of PV modules. H.M.S. Hussein and G.E. Ahmad presented a study, in which the performance of mono-crystalline silicon type PV modules has been investigated theoretically at different tilt angles and orientations.

Determination of the optimum collector tilt angles for low latitudes is the main subject of study made by C.O.C. Oko and S.N. Nnamchi. The monthly, seasonal and yearly average daily values of insolation were calculated for tilt angles ranging from 0-40o. The calculus method of optimization was employed to establish the optimum tilt angle for low latitudes, 4.86-13.02 oN, spanning the territory of Nigeria. Expressions for the optimum tilt angles with respect to the low latitudes were also obtained. The results obtained compare favorably with those in literature and are useful for designing solar equipment in the range of the low latitudes considered in this study.

In another research study Jayanta Deb Mondol, Yigzaw G. Yohanis and Brian Norton investigated the performance of a grid-connected PV system for various PV surface orientations and inclinations under maritime climates. For a south facing surface with an inclination of 30°, the maximum annual insolation and PV output were found. The monthly optimum collection angle for a south-facing surface maximizing incident insolation varied from 10° in June to 70° in December and seasonally from 20° in summer to 60° in winter.

Ian H. Rowlands, Briana Paige Kemery and Ian Beausoleil-Morrison did a case study on optimal solar-PV tilt angle and azimuth. The purpose of this article is to determine the tilt angle and azimuth for a photovoltaic panel in Ontario (Canada) at which revenue is maximized.

2.2 Effect of humidity on PV cell performance

For understanding the effect of humidity, S. Mekhilef,R. Saidurb, M. Kamalisarvestani considered the two scenarios. The first scenario is the effect of water vapour particles on the irradiance level of sunlight and the second scenario is humidity ingression to the solar cell enclosure.

When PV cells are exposed to humidity for long term there will be some degradation in performance. It has been observed that the high content of water vapour in the air causes encapsulant delamination .

2.3 Effect of Temperature and wind speed

According to the results obtained in the study done by John K. Kaldellis, Marina Kapsali, Kosmas A. Kavadias, the higher (absolute) values for the efficiency (or power) temperature coefficient corresponded to the unventilated roof integrated case. In this context, our findings have clearly shown that the difference between cell and ambient temperature decreases with increasing wind speed, thus experimentally highlighting the important role of adopting cooling measures (e.g. extracting heat and use it for other purposes) in cases of high temperatures and unventilated modules.

Finally, regarding the determination of the wind's effect on the thermal loss mechanisms of PV panels, the results were found rather close but not identical (especially for the open area PV farm) to those existing in the literature and used by the existing PV simulation/sizing software.

III. RESEARCH METHODOLOGY

As discussed by H.M.S. Hussein et. al. to analyze the performance of PV modules as a power source, their main parameters, such as short circuit current, open circuit voltage, maximum output power and instantaneous efficiency, should be determined. For simplicity, the analysis is based on the following assumptions [1]:

The shunt resistance of the PV modules is infinite. So, the current in the shunt resistance can be neglected. (A shunt resistance is the reason for power losses it is due to manufacturing defects, rather than poor solar cell design.)

The short circuit current of the PV modules is assumed to be equal to their light generated current.(The generation of current in a solar cell, is known as the "light-generated current")

The resistance of the PV module is assumed to be not dependent on the incident solar radiation and the module surface temperature.

As a result of the above assumptions, the output current of a group of PV modules (I) connected in series-parallel combinations can be calculated as follows

$$I = I_1 - I_0[\exp\left(\frac{V_t + IR_s}{V_t}\right) - 1\,]\,A \ldots\ldots..\ (1)$$

The light generated current of the PV modules can be calculated according to the following equation

$$I_1 = N_P\left(\frac{G}{G_t}\right)\{I_{lr} + \mu_{sc}(T_{pv} - T_{pvr})\}A \quad ..\ (2)$$

The saturation current of the PV modules (I0) can be calculated as

$$I_0 = CN_p T_{pv}^3\{\exp(-N_c N_s V_g/V_t)\}A\ldots..\ (3)$$

3.1 Experimental Methodology

The methodology of this study is based on data collected from Solar panel located at the rooftop of Gyan Ganga Institute of Science and Technology, Jabalpur (23.1667° N, 79.9333° E).The test-bed consisted of two identical open-rack mounted polycrystalline silicon photovoltaic panels installed side-by-side and tilted at 10° to the ground facing southwards. Both panels experienced the same instantaneous insolation levels, ambient temperatures and wind incidence the experimental set-up for finding the mass of dust settling and its effect on electrical output of the solar panels was performed in the following way. Experimentation occurred between March 2015 and May 2015.

2. Measure the effect of dust on photovoltaic performance the data is collected

To measure irradiation on the solar panel, a Lux meter was used (figure 3.3). For the measurements of voltage and current, ammeter and voltmeter were used in the arrangement as illustrated in Figure 3.4 and 3.5.

Field Measurements

To begin testing, the battery was turned off as a safety parameter, allowing for safe cleaning. Then the panels were cleaned with water, according to the frequency of cleaning originally proposed. Water was used to give a more thorough reading since it removes the smallest particles from the panel. Another data are also recorded like temperature wind velocity and humidity. The following steps are followed.

With the beginning with short-circuit the output terminals of the PV panel are shorted with a wire. Then the short circuit current and panel output voltage are measured.

A heavy-duty variable resistors is then connected to the panel, starting from lower resistance to higher one so that the panel voltage increases from zero toward open circuit in steps of approximately 2~3V. Voltage and current for each resistor are measured and recorded in the table. The data recorded is used to draw the I-V curve. This procedure is repeated for different tilt angles.

3.2 Data Calculation

The difference between the control and baseline data was used to describe the amount of panel degradation. Theoretically, the measurement of Panel 1 (Clean) on April 4th should be the same as Panel 1 on April 11th. This would show that there is no degradation in the actual panel; therefore, any discrepancies between these two are accounted for by dust accumulation.

April 4th was a day where both the panels were cleaned and measured at the same efficiency, so the data of April 4th is used to standardize all of the other data. The data is collected at each and after 10 minutes during the day. The cell temperature is recorded with the help of thermocouple.

3.3 To find out the effect of Ambient Temperature and Air Velocity

The experiment has been done with same experimental set up as stated earlier as shown in Figure 3.1.

The instantaneous effciency of the PV modules at the maximum power point (gmp) is calculated as follows (H.M.S. Hussein et. al.)

$$\eta_{mp} = \frac{P_{mp}}{GA_{pv}} \qquad \ldots\ldots\ldots\ldots\ 4)$$

And the daily efficiency (η) of the PV module can be determined from the following relationship (Tanima Bhattacharya et. al.)

$$\eta = \frac{\sum_{i=1}^{i=n} Pi}{A\sum_{i=1}^{i=n} Ei} \qquad \ldots\ldots\ldots\ldots\ (5)$$

Where P= PV module power in watt and

A= PV module area in square meter.

The values of efficiency were calculated for each day at intervals for one hour interval and from that the daily monthly average values were calculated. The daily monthly average values of ambient temperature were calculated by the digital thermometer. The purpose of the part of this study is to find out the variation of efficiency of solar photovoltaic module with ambient temperature and wind speed.

IV. RESULTS & ANALYSIS

4.1 Parametric Results

The various parametric results have been found out are:

4.1.1 The impact of ambient temperature on the power output of solar cell

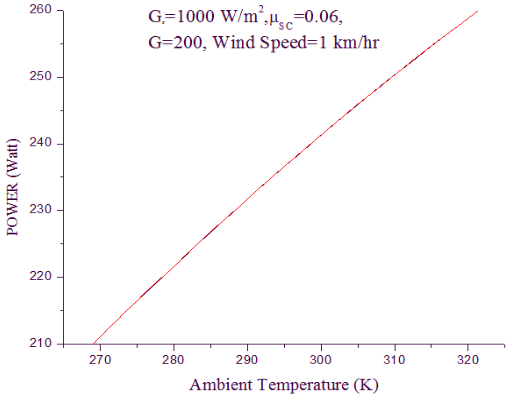

Figure 2 Impact of ambient temperature on the power output.

4.1.2 The impact of Wind Speed and solar radiation on the power output of solar cell

As stated previously, the PV cell performance is sharply sensitive to cell temperature. PV cell temperature is a function of different parameters such as weather variables (ambient temperature, wind velocity, etc.), solar irradiance, cell material and system dependent properties (glazing cover transmittance, plate absorption, etc.).

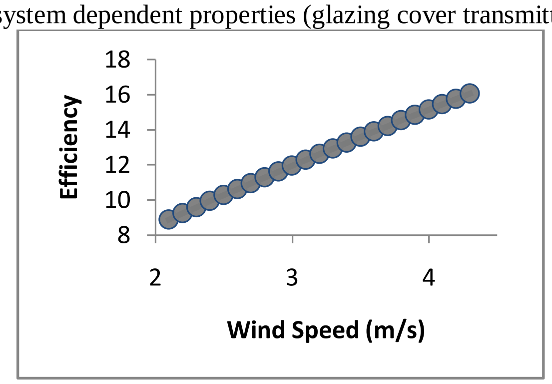

Figure 3 Impact of wind speed on the power output.

As the air velocity increases the cell temperature will drop and better PV cell efficiency will be resulted. The temperature dependency of PV cell performance is greatly related to cell type. As it is expected for the hot and humid temperature of Jabalpur region.

It is seen from the pattern of the graph that the ambient temperature and efficiency are correlated with each other. It is seen from the result that the correlation between the efficiency and ambient temperature is very good as compared to the correlation between efficiency and wind speed. The ambient temperature has a positive correlation with the efficiency of the PV system which indicates that ambient temperature plays an important role in performance analysis.

Also, there is a direct proportionality between the efficiency of the PV system and the ambient temperature of the locality. It can be concluded that the ambient temperature can be preferred for predicting the performance of photovoltaic module compared to wind speed for the present area of study.

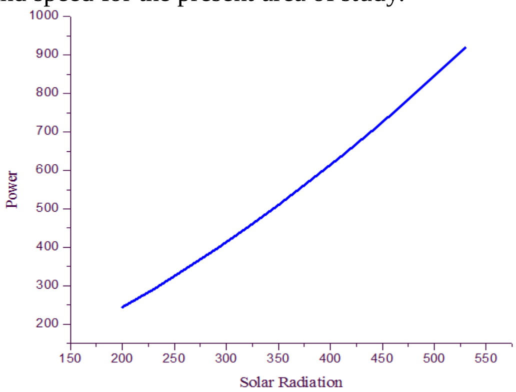

Figure 4 Impact of Solar Radiation on the power output.

It is obvious from the figure that on increasing the solar radiation will increase the power output. That's why the power output is more in the no cloudy region.

4.2 Experimental Results

4.2.1 The Effect of Dust Deposition

As the result output the I-V Curve is drawn. The I- V curve is the close relationship in between Current, voltage and Power. It is simple to find out the optimum power in correspondence with Current and Voltage. The IV curve drawn at the initial stage (or first day) of the experiment is shown in figure 4.

The panels installed on the outdoor experimental test-bed were checked to compare their performance under identical dust deposition regimes and their I-V characteristics were found to be nearly identical.

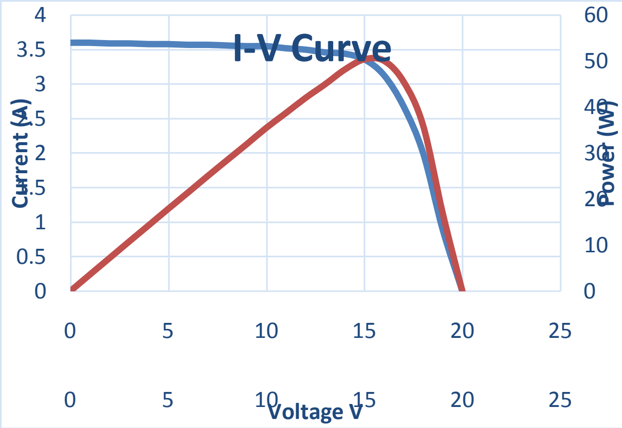

Figure 5 IV curve at the first day at the starting of Experiment

The figure 5 shows the current and voltage variation for the clean surface. The maximum value of current is 3.5 amp while the voltage is about 20 volt

2) The IV curve for dirty panel after 1 week (687 W/m^2)

We can safely assume that the dust deposition on both the panels was identical. After this check, one of the panels was cleaned of dust while the dust on the second panel remained undisturbed. The irradiance is about 687 W/m2 Figure 4.3 shows the I-V curve after 1 week deposition for the panel which has dust deposition.

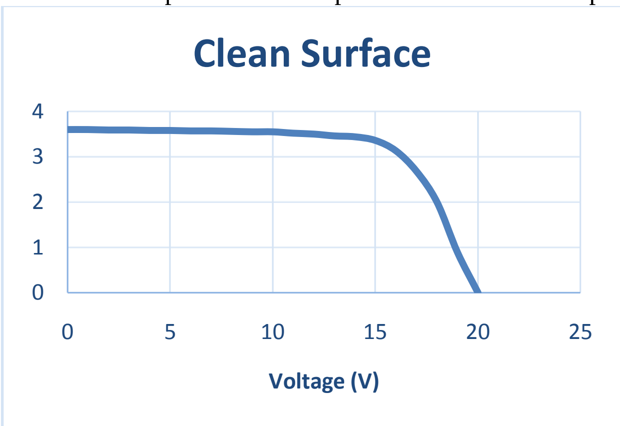

Figure 6 Current and Voltage variation at the starting day of Experiment

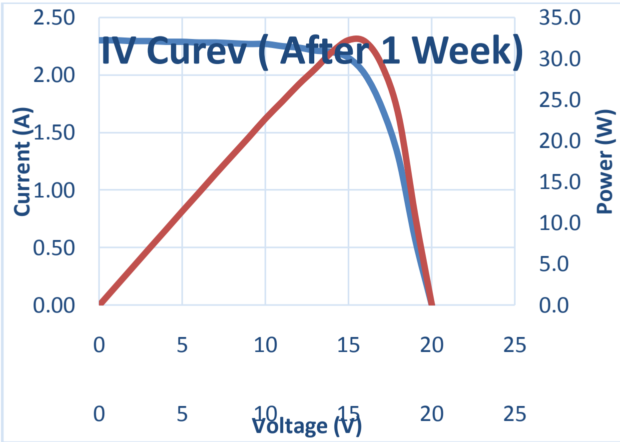

Figure 7 shows the I-V curve after 1 week dust deposition

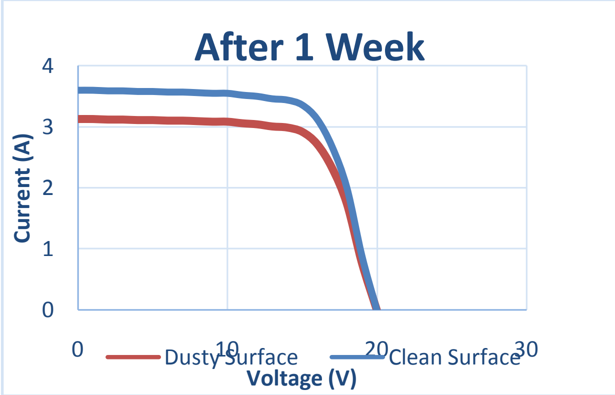

Figure 8 Current and voltage variation for clean and dusty surface after 1 week.

It is obvious from the figure7 and 8 that the value of current and power is reduced considerably. The maximum value of current is 3.6 A for clean surface while it is decreased up to 3.13 A for the dusty surface. The decrement is about 13.01% and the Maximum Power in case of clean surface is 50.4 W while for dusty surface it is about 43.8. The reduction in power outcome is 13.88%.

3) The IV curve for dirty panel after 2 week (450 W/m²)

The irradiance is about 687 W/m^2 Figure 4.5 shows the I-V curve after 2 week deposition for the panel which has dust deposition.

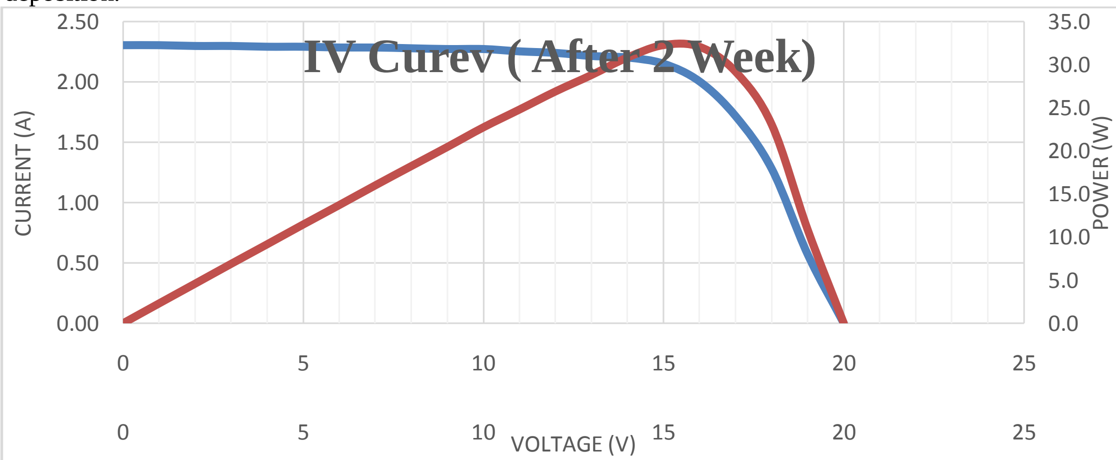

Figure 9 shows the I-V curve after 2 week dust deposition

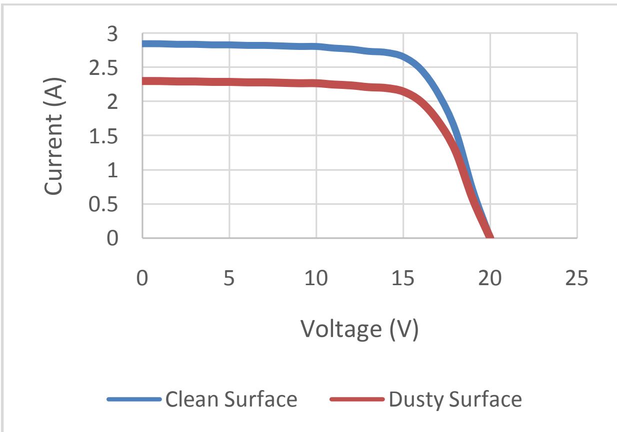

Figure 10 Current and Voltage Variation after two week dust deposition

It is obvious from the figure 9 and 10 that the value of current and power is reduced considerably more than 1 week dust deposition. The maximum value of current is 2.844 A for clean surface while it is decreased upto 2.3 A for the dusty surface. The decrement is about 17.5% and the Maximum Power in case of clean surface is 39.5 W while for dusty surface it is about 32. The reduction in power outcome is 18.98%.

3) The IV curve for dirty panel after 3 week (690 W/m²)

The irradiance is about 690 W/m^2 at the time of readings. Figure 11 shows the I-V curve after 2 week of dust deposition for the panel

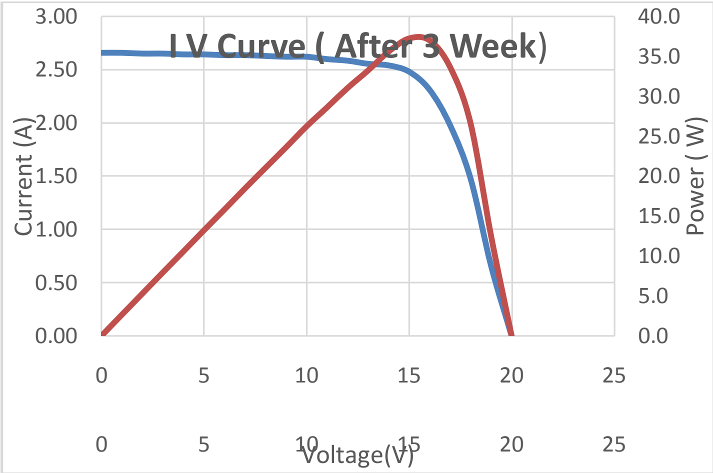

Figure 11 I-V curve after 3 week of dust deposition for the panel

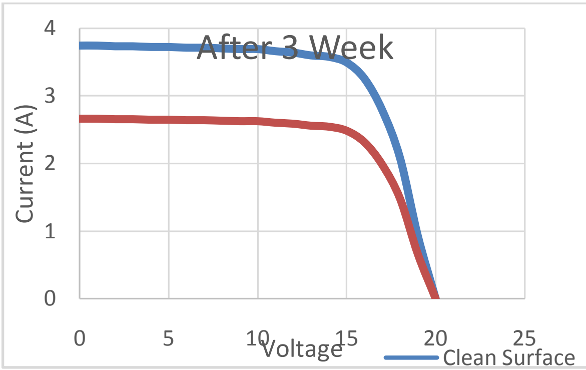

Figure 12 Current and Voltage variation after 3 week dust deposition

It is obvious from the figure 11 and 12 that the value of current and power is reduced considerably more than 2 week dust deposition. The maximum value of current is 3.74 A for clean surface while it is decreased upto 2.66 A for the dusty surface. The decrement is about 28.8% and the Maximum Power in case of clean surface is 52.416 W while for dusty surface it is about 37.2. The reduction in power outcome is 28.99%.

The table shows the reading of experimental results are as

Table 4.1 Experimental Results

Time	Intensity (W/m²)	Average Power output(W)		Short Circuit Current(A)		Open Circuit Voltage(V)	
		Clean	Dusty	Clean	Dusty	Clean	Dusty
1 Week	687	27.09	23.6	3.11	2.71	9.19	9.03
2 Week	450	21.4	17.3	2.457	1.99	8.92	8.89
3 Week	690	28.17	20	3.23	2.3	8.1	7.91

4.2.2 The Effect of Ambient Temperature and Wind Speed

Experimentally, the effect of ambient temperature and wind speed on the performance of PV cell has been examined.

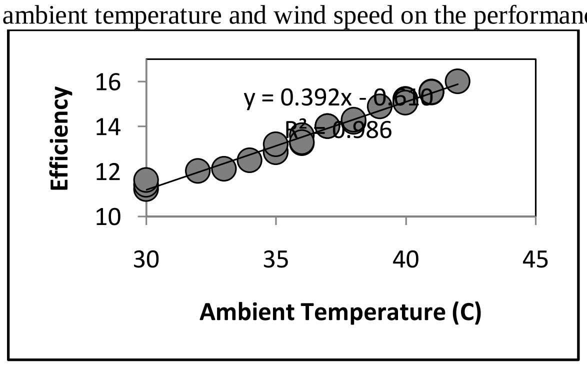

Figure 13 Impact of atmospheric temperature on PV cell efficiency

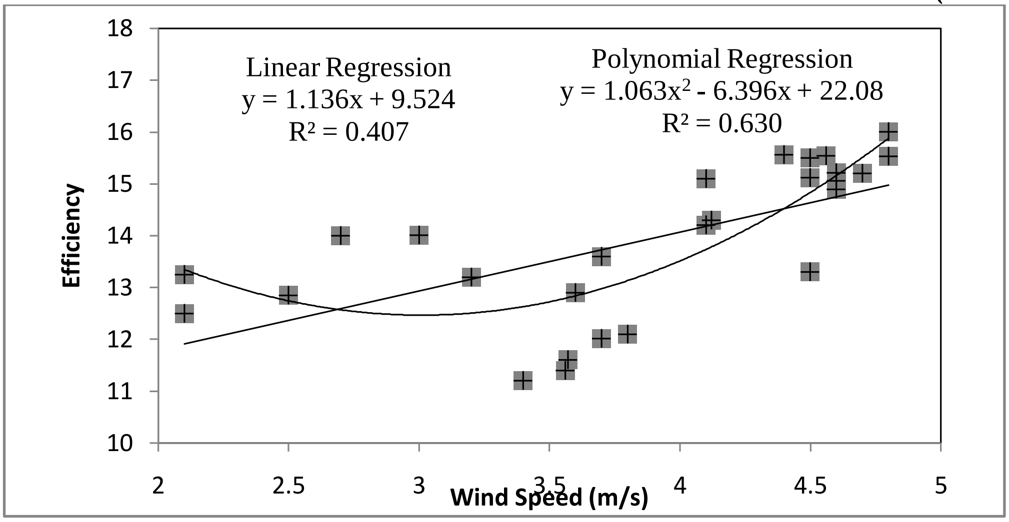

Figure 14 Impact of atmospheric temperature on PV cell efficiency

The experimental results for Ambient Temperature and Wind Speed is shown in figure 13 and 14 respectively.
Figure 13 shows the variation of daily average values of efficiency of the PV module against the ambient temperature for the period of study (i.e. month of April). It is seen from the pattern of the graph that the ambient temperature and efficiency are correlated with each other.
It is obvious from the statistical analysis that the value of correlation coefficient (R) is 0.9929, which confirms that a strong positive correlation exists between ambient temperature and efficiency.

The regression equation obtained from the analysis is
$y = 0.392x - 0.61$ ………. (4.1)
In this equation the X is for independent variable ambient temperature and Y is for the solar photovoltaic efficiency which is dependent variable in the case.

Again the value of coefficient of determination (R2) becomes 0.986, which indicates that 98.6% of the total variation in can be well explained with the help of the linear relationship between both the variables. Or it can be states that as the regression line passes through almost all the points, there is a direct proportionality between the two variables.
Figure 14 shows the variation of daily average efficiency of the PV module against the wind speed for the period of study (i.e. month of April). The value of correlation coefficient is about 0.407 when linearly regressed and 0.793 when it is polynomial regressed, which means that there is a moderate positive correlation between wind speed and efficiency in terms of nth polynomial and the value of n is about 2. The regression equations obtained from the analysis are
Linear regression
$y = 1.136x + 9.524$ ……. (4.2)
Polynomial regression
$y = 1.063x^2 - 6.396x + 22.08$ …. (4.3)

Where X is the wind speed (independent variable) and Y is the solar photovoltaic module efficiency (dependent variable). In this case coefficient of determination (R2) becomes 40.7% (Linear regression) and 63% (polynomial) which explains a moderate positive linear relationship between the module efficiency and wind speed but the 37% of the total variation in wind speed is remains unexplained.

V. CONCLUSION

Solar irradiance has the greatest impact on the power output of a PV system. Beyond irradiance, weather conditions such as ambient temperature along with several other factors (e.g. angle of incidence (AOI), dust, etc. may also affect a module's or an array's power output and energy production. To this end, module temperature is influenced by the ambient temperature, cloud patterns and wind speed, while the rate of temperature change depends also on the PV material and position of the frame.

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