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Experimental Investigation of Factors Affecting Performance and Efficiency of Solar Photovoltaic (PV) Module

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Abstract—*Solar energy is one of the most popular, affordable, inexhaustible and clean renewable energy. There are many techniques to convert solar radiation into electric power, amongst which conversion through installation of photovoltaic (PV) panels is popular in India. PV panel's performance and efficiency is affected by various factors like PV cell technology, ambient conditions, selection of equipments and design parameters. To ensure full utilization of system capacity and deliver a consistent and reliable power it is essential to understand the significance of these factors on system performance. In this work we have reviewed the effect of Panel surface temperature, dust and irradiation. It includes the experimental results obtained during the test conducted on two identical panels (Multi Crystalline Silicon of 100W each) installed side by side at the rooftop. The dynamic study of current voltage (I-V) characteristics of two PV panels those were exposed to same ambient conditions but one has been varied among them showed that factors influence on panel performance. This comparative approach helped in better understanding of losses attributable to a particular factor. It also explained the phenomenon of power loss with the increasing quantities of dust deposition and panel temperatures. The graphs plotted with the data of the test clearly indicate that the open circuit voltage was not significantly affected by dust and irradiation however, short circuit current degraded to great extend. The results obtained were in good agreement with the trends available in previous literature. The drop in current and consequent drop in efficiency could result in immense loss of electrical power and economic loss considering the scale of the plant.*

Nomenclature

I_{sc} short circuit current

V_{oc} open circuit voltage

1. INTRODUCTION

Ever increasing world's demand for energy, huge emission of carbon dioxide and other toxic gases into the Earth's atmosphere and limited supply of natural resources are big Concerns over energy nowadays. In such scenario solar energy appears to be the most effective way to reduce carbon footprint to save environment and a promising source to lift an economy to new levels of prosperity. The government announcement of JNNSM has given pace to development of solar power plants under which it plans to expand its solar installation to 100GW by 2022. There are various factors which should be taken into consideration before installation so that one has realistic expectations of overall system performance and output [1]. The main limiting factors which slow down additional dispersion of PV uses include the high initial investment cost and the low conversion efficiency of PV cells. Consequently, in order to establish PVs as a commercially competitive technology high attention should be paid on the factors which affect their performance [7].

There are some factors which can be controlled and the losses occurring by them can be eliminated but few of them are inherent losses which can be reduced through proper designing but not completely avoided [3]. The main factor affecting the PV-modules' output, is the variation of the solar radiation intensity, increase of temperature and the accumulation of soil and dirt on the surfaces of PV-panels. Although dust effects are a priori site-specific i.e. depend on local conditions such as the presence of air pollution, frequency of rain, wind speed, humidity, as well as on the panels' orientation and inclination, certain attempts have been made to determine the influence of dust on the performance of PV-panels and draw some more generic conclusions [2-8].

Most of the available PV module in market can convert 6-20% of the incident solar radiation into electricity; this is entirely dependent upon the type of solar cells used in the module and the climatic conditions at the location of installation. The rest of the incident solar radiation is converted into heat, which significantly increases the temperature of the PV module and reduces the PV efficiency of the module [6].

In this context, considering the increasing share of PVs in all fields including the educational institutes, investigation of these effects on the performance of PV-modules becomes of special interest, especially in the case of our campus which got its solarification just few years ago.

Table 1: Major effects on the energy production of PV module[7].

Effect	Range
Temperature	1%-10%
Angle of incidence	1%-5%
Ageing	5% over lifetime
Soil and dirt	0%-15%
Snow	Location dependent
Partial shading	Location dependent
Diodes and wiring	3%

2. METHDOLOGY

Fig. 1: Outdoor experimental setup

The method employed for processing of this experiment in the outdoor conditions involved the study of I-V curves obtained from two identical panels of the same specified ratings installed side by side at an angle of 29^o to the ground (which is the latitude of the place) facing southwards on the rooftop of mechanical and industrial engineering department IIT Roorkee (latitude 29°N, longitude 77°E). The PV modules which are studied in this work are 100W Multicrystalline silicon, which is the most widely used type among all other types of PV module available today. Multicrystalline silicon cells are less expensive and simple to produce than monocrystalline once, with an efficiency range of about 12-14% [1].

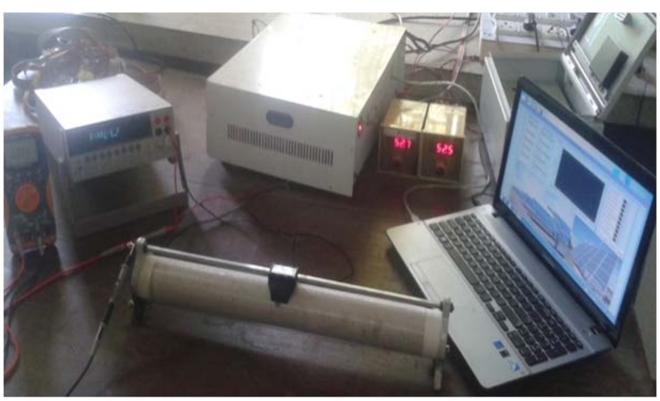

Fig. 2: Indoor Unit

Table 2: Panel Specification

Dimensions	
Module Dimensions (mm x mm x mm)	1150 x 675 x 35
Cell Dimensions (mm x mm)	45 x 61
Cells per module	36
Cell area per module(mm2)	0.776250x106
Electrical specification	
Maximum power (W)	100W
Open circuit voltage (V)	21.5V
Short circuit current (A)	6.30A
Voltage at maximum power(V)	17.5V
Current at maximum power(A)	5.80A

The arrangement for the outdoor experimentation is depicted in Fig. Both panels experienced the same instantaneous insolation levels, ambient temperatures and wind incidence. The solar radiations were measured using two pyranometers of kipp & Zonen. The voltage was recorded by keithley 2701 Ethernet Multimeter and Data Acquisition system and the current was recorded by DM-501 Digital Multimeter. A rheostat was used as a variable load to get the characteristics curves. The top and bottom panel surface temperatures were measured using calibrated T-type thermocouples and were recorded through a T-type thermocouple temperature indicator. The thermocouple sensors were kept in contact with the top and bottom surfaces of the panel. The data were recorded every 5 min interval in various batches. The first set of readings was taken when both panels were clean, in order to characterize the performance of the two panels under identical ambient conditions. For the second batch of measurements, the panel on right in Fig. above was spread with dust layer in order to approximate the reduction in the performance due to dust. For the last batch of readings the date of few months was collected, with different panel surface temperatures but almost same irradiation levels. Even at times the panel was maintained at required temperatures by the flow of air from duct below the panel. The experimental results have been described in the following section.

3. RESULTS AND DISCUSSIONS

In order to indentify that the two same specified panels installed are also similar in their behavior, it was first required to plot the IV characteristics curve of the two panels under similar conditions.

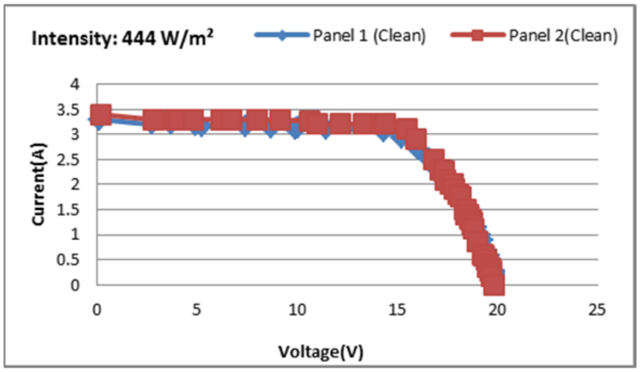

Fig. 3 I: V characteristics of both panels with clean surfaces.

Fig 3 demonstrates the comparision of the I-V curves of the two modules at the irradiance level of 444 W/m^2. It can be seen in fig that the two profiles are nearly overlapping each other. The open circuit voltage and the short circuit current are almost same for the two cases. After this performance check we have safely assumed that the panels are identical for our further work.

Effect of solar intensity

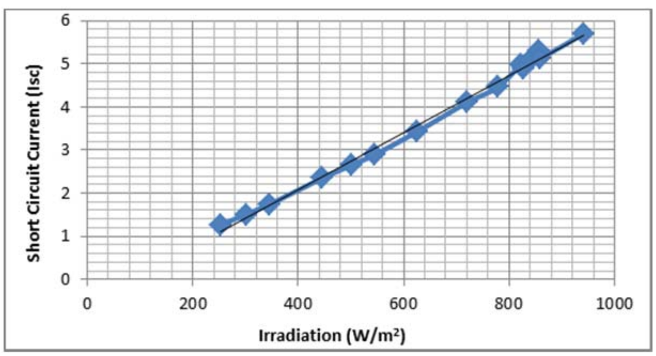

Fig. 4 :Varition of short circuit current(I_{sc}) under different solar irradiances.

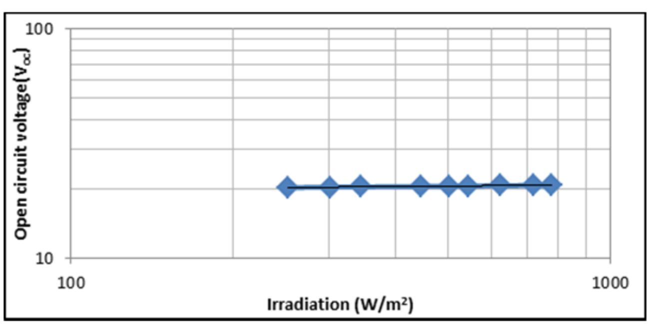

Fig. 5 Log Log graph of open circuit voltage ($V_{oc)}$ with rradiation.

As seen from Fig. (4,5), the short circuit current increases with the increasing solar radiations, whereas the open circuit voltage increases logarithmically, which in the above figure is a horizontal line when plotted on a log-log graph.

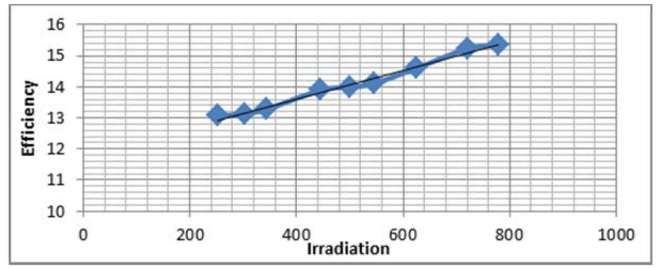

Fig. 5: Output efficiency Variation with solar irradiances.

The influences of irradiance on the cell characteristics are shown in Fig.

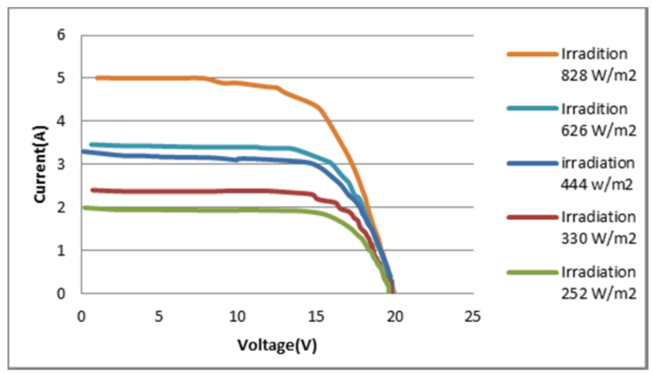

Fig. 6 I-V characteristics at different irradiation and similar surface temperatures.

To show the variation of panel performance under variable solar insolation levels the data obtained with different irradiation value but same temperature was chosen and I-V curves were plotted. The curves clearly indicate that with the increasing solar radiations the short circuit current increases significantly whereas the open circuit voltage increases slowly. Thus the output power increases. This again proves the linear relation of I_{sc} and a logarithmic relation of V_{oc} with solar radiations.

Effect of surface temperature

The influence of panel surface temperature on the cell characteristics is shown in Fig. 7.

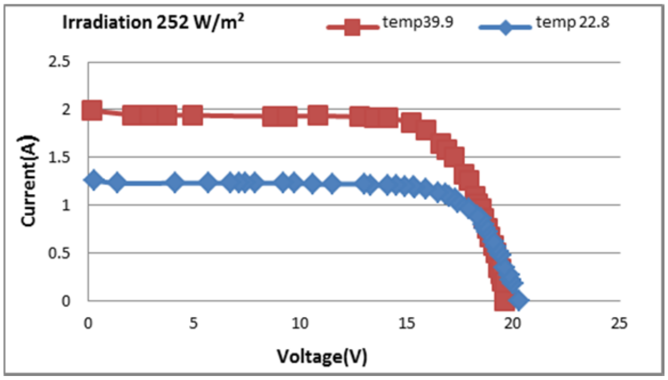

Fig. 7: I-V characteristics at 252 W/m^2 at two different surface temperatures.

The effect of the increase in panel temperature is on short circuit current, which increases with the cell temperature as well as on, the open circuit Voltage which decreases with the increase of the cell temperature.

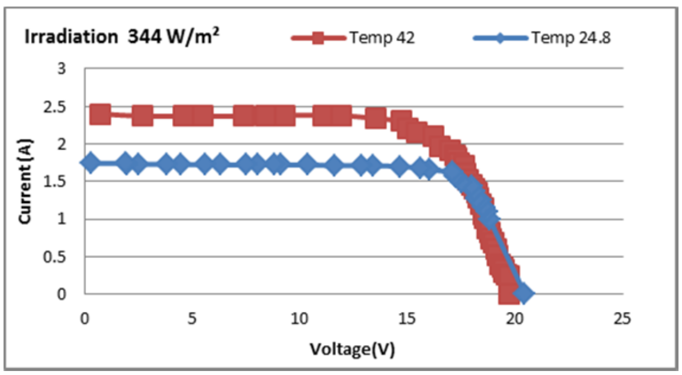

Fig. 8 I-V characteristics at 344 W/m^2 at two different surface temperatures.

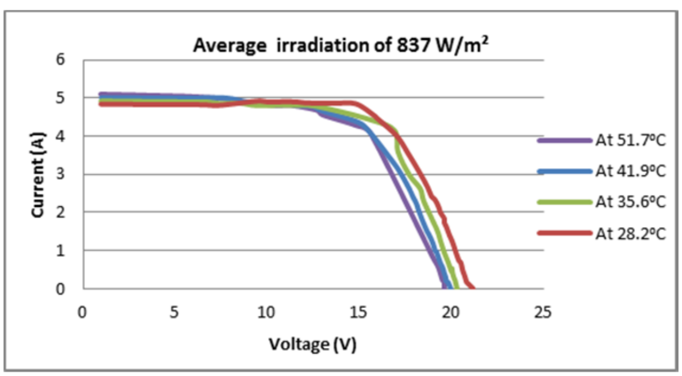

Fig. 9: Effect of increased cell temperature on PV cell characteristics at 837 W/m^2.

Effect of dust deposition density

The effect of dust on panel performance was investigated by obtaining I-V characteristics of identical panels subjected to the same conditions of insolation and ambient temperature, while one of the panels was totally clean whereas the other was spread with dust on its surface. A comparative analysis of the I-V curves led to an understanding of the phenomenon of power loss due to dust accumulation on photovoltaic surfaces.

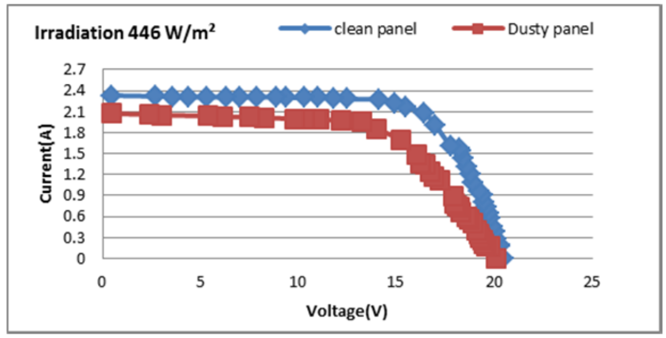

Fig.10 I-V characteristics at 252 W/m^2 of Clean and Dusty panel.

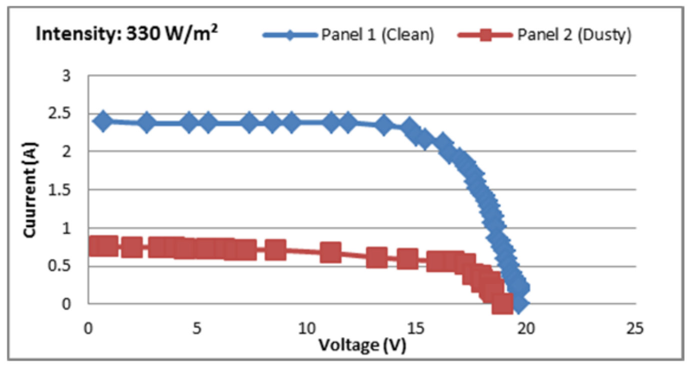

Fig.11: I-V characteristics at 252 W/m^2 of Clean and Dusty panel.

From the recordings and the graphs, the following observations can be drawn:-

- It is clearly visible from the graph that dust deposition does not largely affect the open circuit voltage of the panel. It is very slightly reduced from the clean panel voltage I-V characteristics at 446 W/m2 and cell surface temperatures of 30°C at various irradiation levels.
- Dust has a huge impact on short circuit current of the panel which kept on reducing from that of the clean panel short circuit current values with the increasing quantities of dust at all solar radiation intensities.
- Power output was reduced due to dust deposition. This effect of reducing power output became more severe with the increasing quantity of dust layer thickness.
- Power loss due to dust at higher values of irradiation is higher than at lower solar radiations.
- Dust deposition on panels does not show any particular influence on the cell operating temperatures. Sometimes dusty panel was operating at few degrees higher and

sometimes at same temperature and sometimes at lower temperature.

4. CONCLUSION

This study was done to get understanding of the scale of influence of factors like solar radiation, panel temperature and dust deposition on photovoltaic system efficiency and performance. Two similar PV modules were installed and tested for various days. The data collected was compared in order to plot different characteristics curves. Curves to show the relationship for reduction in performance and efficiency with these factors were also obtained. From the study conducted and the experimental results obtained, following conclusion can be summarized

With the increase in the solar radiation from 0 to 1015W/m^2, the open circuit voltage increases logarithmically (19.5V to 21.2V) whereas the short circuit current increases linearly (1A to 5.9A) and thus the output power increases.

The effect of increased panel surface temperature is on both the short circuit current which increases and the open circuit voltage which decreases. For a temperature increase of about 20^{0}C of the panel, power varied upto 12W and efficiency upto 5%.

It was observed that dust deposition does not significantly alter the open circuit voltage of photovoltaic systems. However, the short circuit current was seriously affected by dust deposition. For an increase in the dust deposition density growing from 0 to 25gm/m^2 the drop in the power output increased from 0 to 25W and the consequent drop in efficiency also grew to 9.6%.

These small losses will prove to be an enormous wastage of available energy when scaled up from a 100W experimental test setup to a few MW sized photovoltaic power plant.

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