OUTPUT CHARACTERISTICS INVESTIGATIONS OF SILICON PHOTOVOLTAIC MODULE

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Abstract: Outdoor performance measurement of Photovoltaic (PV) module was conducted at Pondicherry University campus, Puducherry, India (Latitude: 12.0107º and Longitude: 79.856º). Mono-crystalline silicon PV module of 75 W with active area of 0.5625 m^2, containing 36 cells of 12.5 x 12.5 cm^2 in series mounted on a rack held at 12^0 elevation towards facing south was employed for this study. Output current and voltages of outdoor exposed silicon PV module with respect to the solar irradiance was measured continuously for the entire duration of a day. Optical pyranometer was used to record the corresponding solar irradiance. The temporal output characteristics with respect to the time and irradiance were analyzed to understand the impact of irradiance on the output performance. It was found that the current output is highly sensitive to the climatic condition rather than the output voltage. The average efficiency and the daily integrated efficiency of the PV module was found to be ~ 13.10% and 13.04% respectively that were less than its standard test condition value. The reasons for this drop in efficiency were investigated and reported.

***Index Terms* - PV module, outdoor performance, irradiance, efficiency, air mass.**

I. INTRODUCTION

Solar energy is one type of environment friendly energy that is more flexible, cost effective and commercially widespread [1]. Hence, it is widely used today in many applications such as water heating system, satellite power system, electricity power generation and others [1,2,3]. One of the promising applications of renewable energy technology is the installation of photovoltaic (PV) systems using sunlight to generate electrical power without emitting pollutants and requiring no fuel [4]. People pay more and more attention to the high-quality and renewable solar energy, therefore, testing, predicting and proper utilization of PV systems in order to put solar energy into full use become a focus. The heart of PV systems is the PV module that consists of a collection of solar cells connected in series and/or parallel [5]. Each of these cells is basically a p–n diode that can convert the light energy into electrical energy. The parameters of PV module provided by manufacturers are given in the standard testing conditions-STC (Irradiance of 1000 W/m^2, Temperature of 25ºC and Air Mass 1.5 Spectrum) [6]. These parameters at STC do not actually reflect the characteristics of PV arrays in actual application conditions [7] because of various reasons such as: Modules operate at cell temperatures ranging from the ambient temperature to temperatures which are about 40°C above the ambient temperature (non-concentrating), the incident irradiance varies between 0 and 1200 W/m ^{2}, there are changes in the relative spectral distribution which lead to higher or lower efficiencies compared to the efficiency under the AM1.5 reference spectrum, at high angles of incidence the incoming light is more reflected than at direct normal incidence indoors under the light of the solar simulator, the name-plate rating itself is guaranteed by the manufacturers only within a certain range (module-to-module variability), etc., Therefore relying solely on the standard parameters of PV module, PV system design will always be difficult to achieve the desired effect as the STC data can lead to an improper estimation of the production. Reliable knowledge on the performance of photovoltaic module under actual operating conditions is essential for correct product selection and accurate prediction of their electricity production.

Up to the present, most of the studies have been interested in only specific factors affecting efficiency of PV modules and/or PV systems [3,8,9,10]. Some studies can be found in literatures on field and technical performance evaluation [11.12.13,19], degradation of PV performance [14], energy rating methods [15], design and optimization [16], outdoor monitoring [17], PV system sizing [18] and energy forecasting [19] of standalone PV system. But, there is no much study that presents power performance characteristics in actual operating condition which is important for rating of PV modules, is available in the literature.

Considering this, outdoor performance analysis was performed to PV module mounted with a tilt angle of 12^0 facing south at a coastal site where there is dynamic blow of air mass. Irradiance induced power performance characteristics and its iimpact on their efficiency were analyzed and reported.

II. MATERIALS AND METHODS

Outdoor performance measurement of PV module was conducted at the Pondicherry University campus, Puducherry, India (Latitude: 12.0107º and Longitude: 79.856º). Mono-crystalline silicon PV module of 75 W with active area of 0.5625 m^2, containing 36 cells of 12.5 x 12.5 cm^2 in series laminated using the standard industrial module making process by BEL, India, mounted on a rack held at 12^0 elevation towards facing south was employed for this study. The output characteristics of the PV module tested at AM 1.5 STC resulted in the open circuit voltage (V_{oc}) of 21 V, Short circuit current (I_{sc}) of 5.85 A, Maximum output power (P_{max}) of 75 W, Efficiency of 13.33% and Fill factor (FF) of 61%. Solar irradiance was collected by an optical Pyranometer installed with computer controlled data acquisition system. Irradiance dependent output measurements were carried out using high precision Agilent table-top multi-meters for the entire duration of the day from Sun-rise to Sun-set. The measured module output current, module output voltage and solar irradiance were used further to obtain the output power and efficiency by following the standard procedures.

The output power (P_{od}) of a solar module can be obtained from their measured V_{oc} and I_{sc} values by multiplying with its fill-factor (FF) as reported [20]

$$P_{od} = V_{oc} \times I_{sc} \times FF \qquad (1)$$

On the other hand, in general the power produced by a solar module (P_{od}) is dependent of the active area of the module (A_{act}), module efficiency (η_{mod}) and the solar irradiance (P_{irr}) as defined [21],

$$P_{od} = A_{act} \times \eta_{mod} \times P_{irr} \qquad (2)$$

The outdoor efficiency was further calculated using the following relation

$$\eta_{mod} = P_{od} / (P_{irr} \times A_{act}) \qquad (3)$$

III. Results and Discussion

The daily output of a PV module depends on solar irradiance. Fig. 1 shows the plot of global solar irradiance data obtained for entire duration of the day from Pyranometer. The measurements were set with global measurement condition (direct + diffuse radiation). Pyranometer data revealed that the solar irradiance is affected by the blow of air mass. The disturbances were found both in the morning as well as in the afternoon hours. This may be related to the blow of air mass from land-to-sea and sea-to-land driven by the temperature differences. The maximum irradiance of the day was observed to be 841 W/m^2 at 11.45 a.m. Correspondingly, the recorded output voltage (V_{oc}) and output current (I_{sc}) for the PV module were plotted and presented in Fig. 2 and Fig. 3. It can be seen that the variation in plane of irradiance is directly proportional to short circuit current obtained from PV module. The open circuit voltage, however, depends logarithmically on light intensity and was found saturated at around 18.9 V above the irradiance level of 215 W/m^2. The small variation in V_{oc} during the day is due to temperature changes and cloud cover. By continuous monitoring of short circuit current (I_{sc}) and open circuit voltage (V_{oc}), it is possible to immediately detect the performance of the PV module. It can be sighted from Fig. 2 and Fig. 3 that the output voltage builds up primarily before the current output at low illumination condition. Fig. 4 shows the plot of output power (P_{od}) of the PV module with respect to the time duration obtained using the Eq. 1. Though the output voltage attains constant after some time of day, the current stays in profile with irradiance leading to this bell shape. The outdoor efficiency calculated using Eq. 3 is plotted with respect to time of the day and is presented in Fig. 5. The plot clearly indicates that the efficiency varies with the growing hours of the days. The average efficiency of module is ~ 13.10% with minimum and maximum values of ~3% (early hours) to ~ 17% (late hours) respectively. The variation in efficiency of module from STC is because that the maximum efficiency is calculated from one data at STC, whereas under field condition varying environmental parameters affect the efficiency.

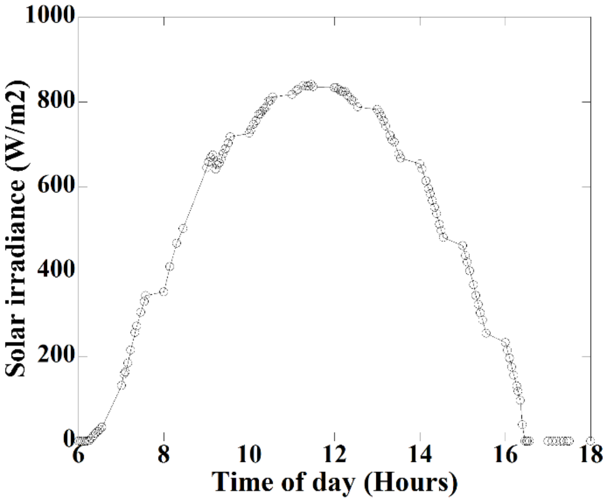

Fig. 1. Plot of solar irradiance versus time duration of the day

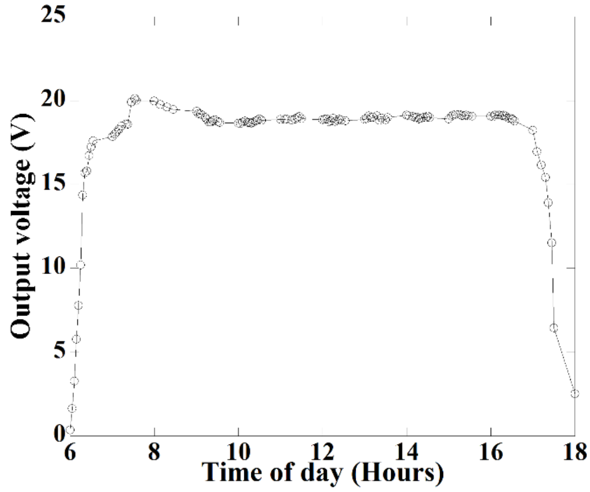

Fig. 2. Plot of module output voltage versus time duration of the day

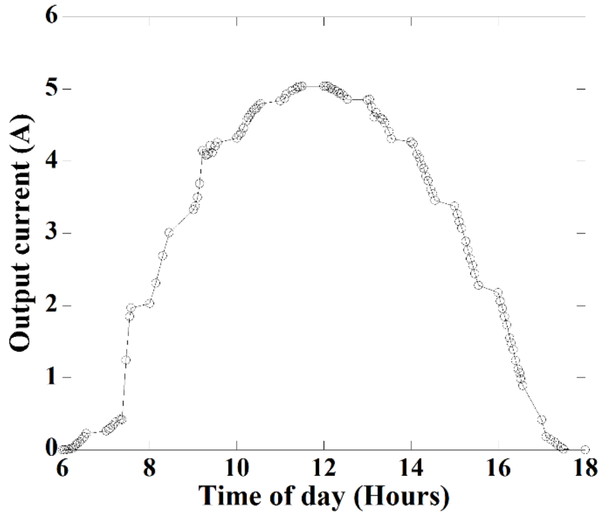

Fig. 3. Plot of module output current versus time duration of the day

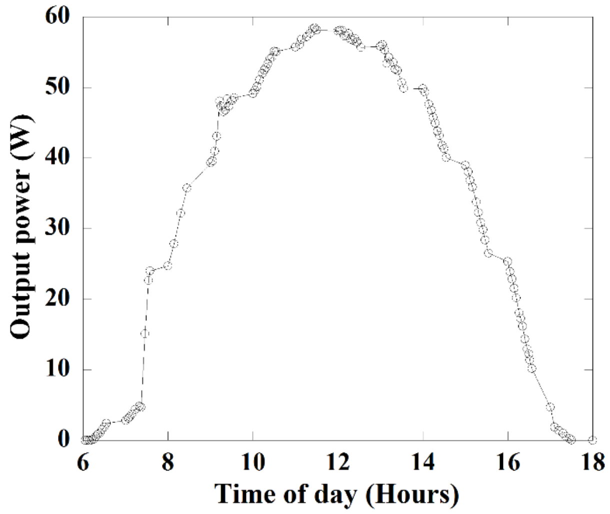

Fig. 4. Plot of module output power versus time duration of the day

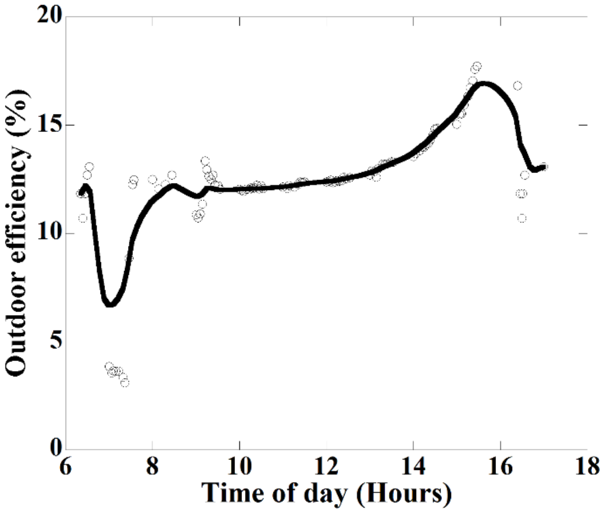

Fig. 5. Plot of efficiency of module versus time duration of the day

In addition, the daily integrated efficiency calculated using the output power of the PV module with respect to the irradiance of the day measured by pyranometer was found to be 13.04%. Comparison of this value to the STC value of efficiency revealed that there is a drop in efficiency of 0.3% for PV module. Hence it is identified that the photovoltaic conversion efficiency of the PV module exhibits a reduced performance upon their exposure to the outdoor irradiance condition.

Due to the apparent motion of sun, the position of sun varies each and every day of a year leading to changes in the incident angle of the light to that of the PV module. In case of coastal site, it was reported that there will be heavy variation in air mass [22]. A value greater than AM1.5 would indicate a blue shifted spectrum (more high energy photons) and a lower value indicate a red shifted spectrum (low energy photons) [23]. It was reported that the blow of air mass induces Raleigh scattering [24] making the spectrum of light to have longer wavelength which leads to low angle of incidence of light to that of the PV module [25]. The low angle of incidence of sunlight light to that of the PV module is an indicator of difficulty faced by the sun light to pass through the atmosphere to reach the earth surface [26] and hence the amount of irradiance reaching the PV module for power generation is reduced. Also due to blow of air mass, spectral variation occurs that results in mismatched current produced by individual cells in a module [23] forcing the PV module to operate with the current produced by weak cell leading to loss of power.

IV. CONCLUSION

Outdoor performance measurement of Photovoltaic (PV) module was conducted at the Pondicherry University campus, Puducherry, India (Latitude: 12.0107^o and Longitude: 79.856^o). Mono-crystalline silicon PV module of 75 W with active area of 0.5625 m^2, containing 36 cells of 12.5 x 12.5 cm^2 in series mounted on a rack held at 12^0 elevation towards facing south was employed for this study. It was found that the current output is highly sensitive to the climatic condition rather than the output voltage. The average efficiency and the daily integrated efficiency of the PV module was found to be ~ 13.10% and 13.04% respectively that were less than its standard test condition value. The reason for such energetic loss relative to STC was identified to be the variation in the position of sun and blow of air mass at coastal site, that leads to the low angle of incidence of sunlight light to that of the PV module which reduces the amount of irradiance reaching the PV module for power generation. Also due to blow of air mass, spectral variation occurs that results in mismatched current produced by individual cells in a module forcing the PV module to operate with the current produced by weak cell leading to loss of power.

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