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Conference Paper

Investigations on the Outdoor Performance Characteristics of Multicrystalline Silicon Solar Cell and Module

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This Conference Paper is based on a presentation given by Sivakumar Parthasarathy at "International Conference on Solar Energy Photovoltaics" held from 19 December 2012 to 21 December 2012 in Bhubaneswar, India.

Multicrystalline silicon solar cell and its module with 18 cells connected in series were mounted on an inclined rack tilted 12° South positioned at latitude of 12.0107° and longitude of 79.856°. Corresponding solar irradiance was measured using an optical Pyranometer. Measured irradiance, open circuit voltage (V_{oc}), and short circuit current (I_{sc}) values were analyzed. V_{oc} values of both the cell and module were found saturated at above the critical value of illuminations which were different from each other. The integrated daily efficiency for the cell and module were ~10.25% and ~9.39%, respectively, that were less than their respective standard test condition's value. The reasons for this drop in efficiencies were investigated and reported.

1. Introduction

Uncertainty in the prediction of the performance of solar photovoltaic power systems (SPVPSs) is a major hindering fact that suppresses its utility. This uncertain output performance of SPVPS is due to the exposure of unpredictable solar irradiances that is found varying with the location [1]. Numerous approaches were made to overcome the hindering fact, but so far, all of them are unsuccessful [1–5]. In general, photovoltaic (PV) modules are rated at indoor standard test conditions (STCs) using the irradiance of 1000 W/m^2 and the temperature of 25°C [5]. However, the outdoor conditions do not follow the STC values and are found variable in nature due to the change in the position of sun and environmentally interference factors to the solar radiation such as the geographical location, cloud pattern, and blow of air mass [6]. It is reported that the seasonal variations shifts the spectral profile [7] and emboss variations in the spectrum & light intensity, reflection of unpolarized light, polarization and the temperature [4, 8–10]. Since, the solar illumination serves as the input to the SPVPS operation, any variation in the solar illumination results in a profound output changes. Hence, it is required to use output optimization devices such as DC/DC converter and the maximum power point tracker (MPPT) with due considerations on the characteristics of add on devices such as charge controller, battery, and inverter [11, 12]. It was demonstrated that the sizing of PV inverter is greatly influenced by site-dependent peculiarities like ambient temperature and solar irradiation distribution characteristics [12]. In addition, performance of PV module based on tilt angle and various mounting conditions are analyzed by [13, 14], and it was found that the outdoor weather conditions along with the tilt angle and its orientation play an important role in the performance characteristics of PV systems. Hence, understanding the performance of PV devices deployed under various environmental conditions of the geographical location is expected to assist in obtaining useful information for the development of SPVPS design parameters.

In considerations to the points discussed, outdoor performance characteristics of an individual solar cell and its assembled module mounted with a tilt angle of 12° facing

South were studied at a coastal site where there is a dynamic blow of air mass observed. The illumination-dependent daily outdoor efficiency and the power output of both the cell and its module were analyzed and reported.

2. Materials and Methods

Outdoor performance measurement was conducted at the Pondicherry University Campus, Puducherry, India (Latitude: 12.0107° and Longitude: 79.856°) March. Multicrystalline silicon solar cell of 25 cm^2 and its module of 5 W containing 18 cells in series (450 cm^2) laminated using the standard industrial module making process by Maharishi Solar Technologies Pvt. Ltd., India, and mounted on a rack held at a tilt angle of 12° elevation towards South were employed for this study. Current-voltage characteristics of solar cell and its module were measured at indoor standard test condition. The measurement revealed that the individual solar cell with an area of 25 cm^2 resulted in V_{oc} of 0.582 V and I_{sc} of 0.7404 A. Similarly, the module assembled using 18 cells in series resulted in V_{oc} of 10.5 V and I_{sc} of 0.73 A. The maximum power output (P_{max}) of the individual solar cell was found as 0.3153 W with fill factor (FF) and efficiency (η) of 73.14% and 12.21%, respectively. Similarly, the P_{max} of the module was found as 5.003 W with FF and η of 65.2% and 11.11%, respectively.

Solar irradiance was measured by an optical Pyranometer with computer-assisted data acquisition system. Outdoor illumination-dependent cell and module outputs were measured using Agilent table-top multimeters. Output power of the solar cell and module was deduced from their V_{oc}, I_{sc}, and FF values for the further analysis as per the procedure reported elsewhere [15]. Daily efficiency of both the cell and module was calculated using Pyranometer measurements and the solar cell/module output values.

3. Results and Discussion

Figure 1 shows the plot of global solar spectral irradiance data measured by Pyranometer for the entire duration of the day. The plot shows that the solar irradiance is scattered rather than the expected bell-shaped distribution profile. Maximum illumination of 1014 W/m^2 is recorded at 11.50 a.m. It is found that the solar irradiance was reduced to ~181 W/m^2 by the movement of air mass which started at 9.30 a.m. and released at 11.20 AM. Except this durable scattering, the remaining entire duration of the day is found following the average bell-shaped profile of irradiance.

Figure 2 shows the plot of measured V_{oc} of both the module and cell. It is seen that the module voltage is found saturated at 9.53 V at the illumination level between ~463 W/m^2 and 471 W/m^2, whereas, the cell voltage was found saturated at 0.533 V at the illumination level between ~173 W/m^2 and 253 W/m^2.

Moreover, even though the cell and module were laminated using similar industrial lamination process, the voltage saturation of both the cell and module required different critical illumination values. The values are ~173 W/m^2 for the cell and ~463 W/m^2 for the module, respectively, in the morning. And these values are found increased to 253/m^2 for the cell and 471 W/m^2 for the module in the afternoon stabilization. Furthermore, it is also noticed from Figure 2 that this occurrence of voltage saturation upon illumination is disturbed whenever the illumination level falls below the critical illumination. In the present case, the fall in illumination to ~181 W/m^2 from the requirement of saturation (~463 W/m^2), that is, the fall of 60% in critical illumination, leads to the fall of ~6.09% in V_{oc} in the case of module. Therefore, a fall in the illumination below the critical illumination value for voltage saturation leads to the drop in V_{oc} as well as the maximum output voltage (V_m) of the modules exposed outside.

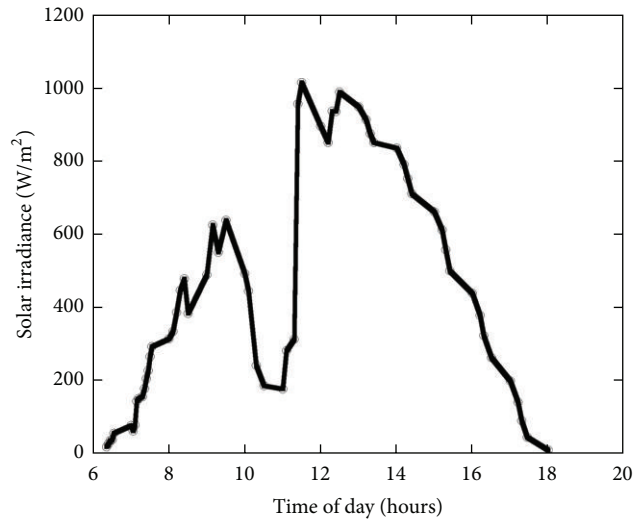

Figure 1: Plot of solar irradiance versus time duration of the day.

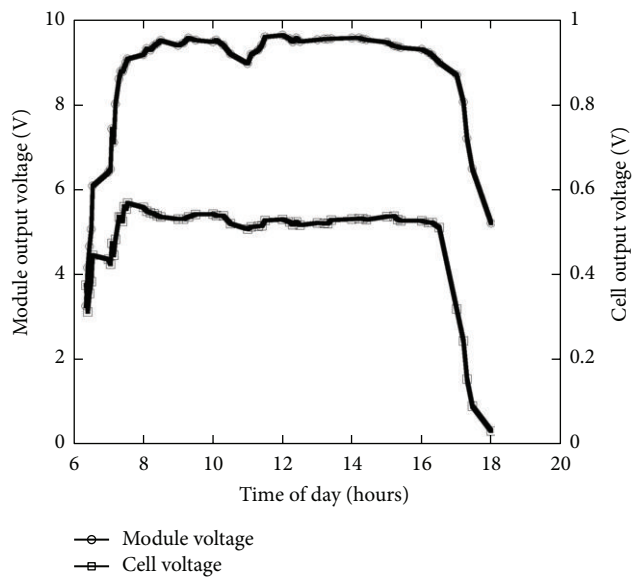

Figure 2: Plot of module and cell output voltage versus time duration of the day.

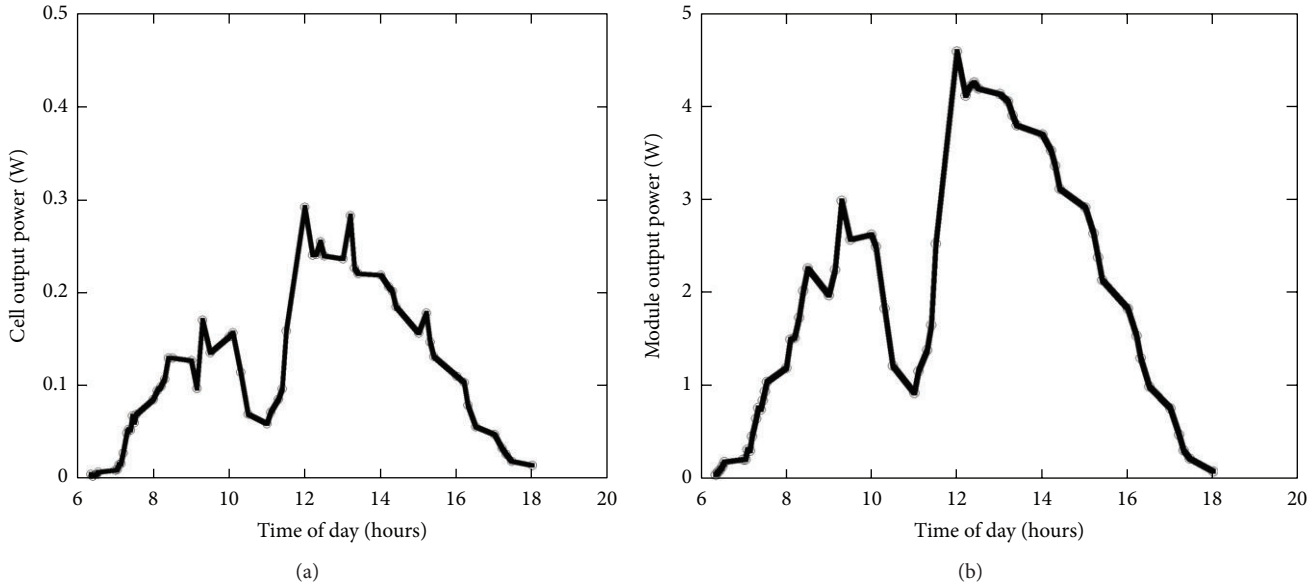

Figure 3: (a) Plot of cell output power versus time duration of the day. (b) Plot of module output power versus time duration of the day.

Figure 3 shows the plot of cell and module output power obtained from the multiplications of measured V_{oc}, I_{sc}, and the FF of the module. Even though, the measured V_{oc} is saturated at above critical illumination for both the cell and module, the efficiency is highly sensitive to the measured output current, which in turn is proportionally dependent on the illumination. Further, both the measured solar irradiance and the power output were used to calculate the efficiency as reported [15]. Figure 4 shows the calculated efficiency for both the cell and module. It is found that the conversion efficiency is scattered with the time duration of the day. The average value is also found varying with the time duration. The value at 12 noon was found as ~10.6% for the cell and 9.53% for the module, respectively. These loss in performance for the reduced illumination of 11% resulted in an efficiency reduction of 13.19% for cell and 14.33% for the module from their respective STC-measured efficiencies.

In addition, the daily integrated efficiency was calculated using the output power of both the cell and module with respect to the illumination of the day measured by Pyranometer. The values are found to be 9.39% for the module and 10.25% for the cell, respectively. Comparison of these values to the STC values of efficiencies revealed that there is a drop in efficiency of ~1.96% for the cell and ~1.72% for the module.

Hence, it is identified that the photovoltaic conversion efficiencies of cell and module exhibit always a reduced performance upon their exposure to the outdoor illumination. This reduced performance may be accounted mainly to the optical losses, since the optical field of each and every location is highly dynamic due to the change in the environmental parameters such as the input irradiance, temperature, and air mass concentration and blow, which in turn leads to the optical losses based on reflection caused from the changes in incidence angle, azimuth angle, module tilt angle, and reflection loss caused monotonically due to the blow of air mass [4, 16].

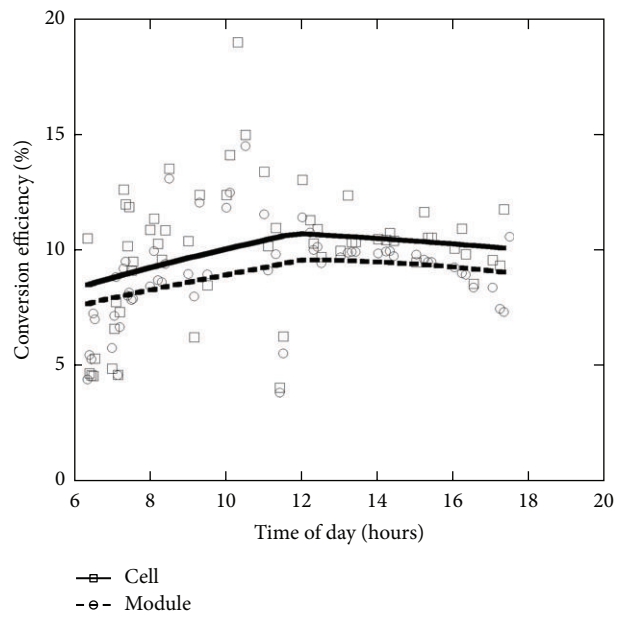

Figure 4: Plot of efficiency of cell and module versus time duration of the day.

4. Conclusion

Outdoor performance measurement of multicrystalline silicon solar cell and its module mounted on a rack held at a tilt angle of 12° towards south was carried out. It is found that the cell and module output voltage got saturated at a critical value of illumination, which is ~46.3% of the STC value for the module and 17.3% of the STC value for the cell. Moreover, this critical illumination was found increased to 47.1% for module and 25.3% for the cells, respectively, in the evening hours. This increase in the critical illumination may be related to the

effective temperature losses incurred upon exposure to the outside. The daily integrated efficiency of the cell and module was found 10.25% and 9.39%, respectively, which is lower than the STC values measured. The average efficiencies are found lower in the forenoon and afternoon hours than the noon hours. The demonstrated stability in output voltage indicates the solar cell and modules can be operated for ~9.10 hours and 7.18 hours in the voltage-stabilized mode, respectively.

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