Analysis of rooftop solar system's performance under real conditions

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Abstract

Performance of rooftop solar power system under real climatic conditions was studied for a particular day of consideration. The present study covered all three types of Si modules like amorphous (a-Si), mono crystalline (Mono-Si) and poly crystalline (Poly-Si) was compared for their behaviour against change in temperature and irradiance. Different crucial solar module characteristics like efficiency, short circuit current, open circuit voltage and fill factor were scrutinised to find out the temperature coefficient of open circuit voltage of all three technologies. The derived values of temperature coefficients for a-Si, Mono-Si and Poly-Si modules are -0.068, -0.063 and -0.066 V/ºC, respectively. Moreover, nature of variation in fill factor (FF) with temperature was studied and maximum change in FF is about 0.18%, 0.25% and 0.5% for a-Si, Mono-Si and Poly-Si, respectively. This study will help end users to opt for an appropriate selection of Si modules based on real climatic conditions on a site of installation.

Keywords: Rooftop solar, open circuit voltage, fill factor, insolation, temperature coefficient

1. Introduction

Green pathway for energy generation and utilization is one of the most trending research fields in the past few decades. Various green energy solutions like solar photovoltaic, solar thermal, biogas, wind have shown their own potential in the field of future energy demand. At the same time, possible solutions of global warming are highly dependent on selection, efficient usage and best utilization of each of these green pathways. Among all, solar photovoltaic has shown tremendous potential due to different reasons like matured technology, easy installation, zero maintenance and longer lifespan. Nowadays, rooftop solar plants have become much acceptable due to available subsidiary and different policies under national solar mission/s. However, most of the end users are not aware of technological insights of the solar PV, resulting in wrong selection of type of solar modules for the household usage. Thus it is important to put forward performance studies of all three types (a-Si, Mono-Si and Poly-Si) of commercially available Si modules. Few reports have been found which can provide guidelines towards the selection of appropriate solar technology for rooftop installation.

In the present paper, we have reported performance analysis of all three Si technologies under real climatic conditions like varying temperature and irradiance. We have also presented the variation of crucial solar module parameters like efficiency (η), short circuit current (I_{sc}), open circuit voltage (V_{oc}), and fill factor (FF).

2. Theoretical background

Photovoltaic module, a series and parallel combination of PV cells, is a p-n junction diode which can directly convert incident solar energy into the electrical energy. Si is a widely used material in the fabrication of commercially available crystalline solar cells. Solar cells operate as a quantum device exchanging photon for electrons. Photons from the sun with higher energy than the band-gap of semiconductor material can be absorbed in the absorber layer of solar cell which will finally create pairs of photo generated electrons-holes. Valance electrons which get sufficient energy from photon will jump into the conduction band and at the same time leaves the corresponding hole in the valence band. Thus accumulation of positive and negative charges create potential difference and resulted into an electric field within depletion region which helps in drifting the photogenerated electrons and holes towards n and p regions, respectively. In this way the photon energy may be successfully converted into the electrical energy.

The efficiency of solar photovoltaic cell is defined as the ratio of the generated maximum electrical power to the incoming power of solar radiation for the given area of exposures. Under optimum operating conditions, maximum output power (P_{max}) may be defined as,

$$P_{max} = V_{oc}\, I_{sc}\, FF \tag{1}$$

The short circuit current (I_{sc}) is directly proportional to the effective radiation and can be expressed as:

$$I_{sc} = q \int_{Eg/h}^{\infty} Q_v \,.\, p_v \; dv \tag{2}$$

Where, q is the charge of electron, Q_v the minority charge carriers collection efficiency and P_v the function of incoming solar radiation spectral distribution.

The relation between V_{oc} and I_{sc} is,

$$V_{oc} = \frac{A*k*T}{q} \ln\left(\frac{I_{sc}}{I_o} + 1\right) \tag{3}$$

Efficiency ɳ varies logarithmically with irradiance as,

$$ɳ = \frac{n*I_L*\left(\frac{kT}{q}\right)*\ln\left(\frac{I_L}{I_0}\right)*FF}{P_{in}} \tag{4}$$

Variation in V_{oc} with temperature can be found by,

$$\frac{dV_{oc}}{dT} = \frac{1}{T}\left(V_{oc} - \frac{E_g}{q}\right) \tag{5}$$

According to eq. (5), influence of both irradiance and temperature on efficiency will be as,

$$ɳ = \frac{FF*V_{oc}*q*\int_{v=E_g/h}^{\infty} P_v\, Q_v\, dv}{\int_{v=0}^{\infty} P_v dv} \tag{6}$$

and

$$\frac{\triangle\eta}{\eta}(\%) \simeq \frac{kT}{q} * \frac{ln(n)}{V_{oc}} \tag{7}$$

Where n is radiation intensity factor.

As it can be understood, temperature has a direct proportionality on the overall performance of solar cell. Hence, values of temperature coefficient can be derived and further used to find out expected behaviour of installed solar power system under real conditions. Such coefficients can be determined for efficiency (η), short circuit current (I_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and maximum power point (P_m). However, in this we will restrict ourselves only to V_{oc} and FF studies.

3. Instrumentation and measurement

It was first and foremost required to measure an accurate solar irradiance received by the modules during the day of study. So, pyranometer, calibrated against secondary standard which can be traceable to international standard has been used for the study. Infrared based hand held non-contact thermometer was used for the measurement of front and back module temperatures. Mercury based thermometer was employed to continuously record the ambient/surrounding temperature of the site. The specifications of commercial photovoltaic modules under study are tabulated in Table-1. The solar insolation, ambient temperature and front & back temperatures of all three types of solar modules were carefully recorded on predefined interval of time. Standard 4 quadrant source measure unit was externally connected to record the real time current-voltage data. The measurements were carried out under recorded irradiance from 450-900 w/m^2. After measuring module temperatures and irradiance, set of recorded current-voltage data was interpolated in smallest possible interval. This was done for each module for above mentioned irradiances. From these data we have calculated different solar module parameters like maximum power point (MPP), series resistance, shunt resistance, fill Factor and power conversion efficiency.

4. Results and discussion

Measured V_{oc}, I_{sc} and efficiency numbers were further used to calculate expected theoretical values by incorporating standard temperature and pressure (STP) conditions. V_{oc} data which measured near the ambient temperature (300K) were used for temperature correction. Similarly for correction in irradiance, efficiency measured near to the AM-1.5 radiance was considered. At the end with the help of this dataset, we could back calculate respective V_{oc} and efficiency values for each temperature and irradiance. It is noteworthy that V_{oc} and J_{sc} are the most dominant parameters for overall module performance. However, based on theoretical aspects, J_{sc} increases linearly while V_{oc} increases logarithmically with increase in irradiance which resulted in logarithmic increase in power conversion efficiency (as expected from eq. (4)). On the other hand V_{oc} decreases linearly while J_{sc} increases logarithmically with increase in temperature which leads to linear decrease in efficiency as per eqs.(5) and (6). Expected efficiency values for observed temperature and irradiance were calculated using eq. (7). Based on this, a comparison of efficiency for three different types of Si-modules can be drawn out. Temperature dependency of V_{oc} is calculated and from which the coefficients of temperature are calculated. Values are as -0.067, -0.062, -0.067 V/^{o}C for a-Si, mono-Si and poly-Si, respectively. This calculated coefficients showed good agreement with prior study by

Ewa Radziemska. Observed V_{oc} values show deviation from the theoretical values on the higher side for a-Si while it is on the lower side for other two types of modules. It is mostly assumed that variation in V_{oc} is not dependent on the solar irradiance. Irradiance dependency of J_{sc} for all three Si technologies is found out. The temperature coefficients of J_{sc} must be normalized by standard 1000 W/m^2 which was used for calculating their coefficients.Variation in J_{sc} with irradiance follows the expected nature based on theoretical assumptions. Apprx. 11-15% deviation was found in experimentally and theoretically determined J_{sc} values which may be due to real time increase in module temperature that enhanced the rate of charge carrier generation. Observed variation in FF was about a factor of 0.18% for a-Si, 0.25% for mono-Si and 0.5% for poly-Si modules. This indicates the superiority of mono-Si over a-Si and poly-Si in the context of the overall performances. Importantly, a-Si was found to be most stable under temperature variation as expected after first few 100 hours of installation and operation. Variation in solar irradiance, temperature and back module temperature throughout the study is plotted in Fig-1.

5. Conclusion

Present study facilitates users to find out the expected performance of installed solar module parameters by incorporating real irradiance and temperature data. Obtained correction factors for all three Si technologies will be helpful to estimate the parametric role behind the poor performance of any module under real climatic conditions. Through the present study we have reconfirmed the superiority of a-si over crystalline one under elevated temperature conditions. This may be due to active reversible light induced phenomena in a-Si modules. After stabilization of a-Si module, light induced defects cease to decrease with rapid annealing and hence one can observe much stable performance. As an important outcome of the study, temperature coefficients of V_{oc} and FF have been provided to the society which will help not only towards the selection of technology but also catch-up the possible routes of improvement in the power plant design.

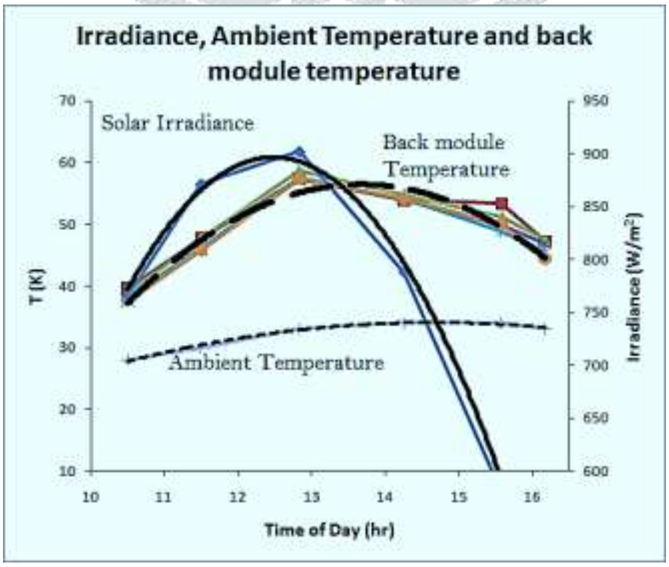

Fig-1 Measured trend of variation in solar irradiance, ambient temperature and module temperature

Table 1 PV Module specifications

Sr. No	Technology	Module active area (m^2)	Cell configuration
1	a-Si	1.8	NA
2	mono-Si	0.6	4 x 9 (series connected)
3	poly-Si	0.6	4 x 9 (series connected)

Table-2 Solar irradiance and module back temperature dataset

Ambient Temperature (K)	Irradiance (W/m^2)	Back module Temperature(K)		
		a-Si	Mono-Si	Poly-Si
306	450	322	321	321
307	500	313	313	312
307	750	326	326	325
301	800	322	320	320
306	900	329	330	330