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The Effect of Dynamic Weather Conditions on Three Types of PV Cell Technologies – A Comparative Analysis

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Abstract

The competition among numerous PV cell technologies in the market has necessitated the performance comparison and the viability of these technologies in actual weather conditions. This paper has presented an analysis of the impact of dynamic fluctuations in irradiance and temperature on the performance of different PV cell technologies. The study is aimed to give valuable information about the response of three different PV cell technologies such as monocrystalline, multicrystalline and thinfilm modules to different atmospheric conditions and the analysis is carried out according to Sandia standards. It is observed that all the three PV technologies reacted differently to different irradiance and temperature conditions, which in turn influenced their energy output.

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Keywords: Dynamic weather; PV module;Silicon solar cells,;Thinfilm solar cell

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1. Introduction

Since primary energy sources such as fossil fuels are rapidly depleting, owing to the increase in energy consumption, renewable energy sources have become promising in meeting the future energy demands. Of all the various renewable sources, use of solar energy has been increasing rapidly because it is bountiful and pollution free (Selami et al., 2014).

Generally, the PV industry is dominated by crystalline silicon technology (mono and multicrystalline), followed by thin-film technology. The energy generated by these different photovoltaic devices is an important aspect to be

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considered in choosing suitable technologies for efficient photovoltaic electricity. Previous studies show that each of the PV technologies currently available in the market has some merits and limitations while operating in different climatic conditions (Gottschalg et al., 2013, Carr et al., 2004, Cristina et al., 2014, Sharma et al., 2013).

PV module parameters provided by manufacturers are mostly tested and evaluated under standard test conditions (STC). However, the real time operating conditions are different from STC. This is mainly due to the fluctuations in environmental factors such as irradiation, temperature and clouds that may affect the performance of PV modules (Jia-Ying et al. 2013). Henceforth, better knowledge about the performance of PV systems in real weather conditions is essential for correct product selection and increased power generation. The aim of this paper is to analyse the effect of fluctuating irradiance and temperature on the performance of different PV cell technologies. Three types of module technologies are considered for the analysis.

2. PV Cell Characteristics

Fig.1 shows the single diode circuit model of PV cell (Bagnall et al. 2008, Aissa et al. 2012, Pallavee et al. 2013). It is represented as a nonlinear DC current source, since its power output varies with various environmental conditions.

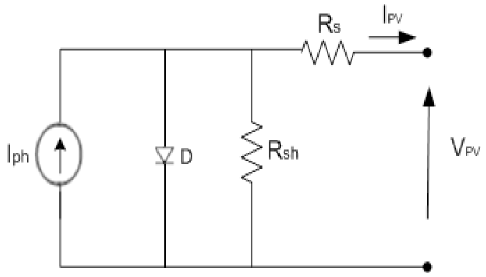


Figure 1 Equivalent circuit of a PV cell

The current-voltage characteristics of the PV cell are obtained using the following equation [Ashish et al. 2008]:

$$I_{PV} = I_{ph} - I_0 \left[e^{\left(\frac{V_{PV} + R_s I_{PV}}{V_T} \right)} - 1 \right] - \frac{V_{PV} + R_s}{R_{sh}} \quad (1)$$

Here I_{PV} is PV cell output current, V_{PV} is PV cell output voltage, I_{ph} is light generated current of the PV cell, I_o is cell reverse saturation current, V_T is thermal voltage, R_s is series parasitic resistance of PV cell and R_{sh} is the shunt parasitic resistance of PV cell respectively.

However, fluctuations in temperature and irradiation in actual weather conditions may affect the characteristics in different ways [Green 1998, Maria et al., 2013, Farivar et al., 2013, Elami et al., 2014] such as variations in open circuit voltage and short circuit current of the PV cells. This in turn leads to degradation of power output in PV modules. The effects of temperature and irradiance on the on current-voltage characteristics of the PV cell are shown in Fig.2.

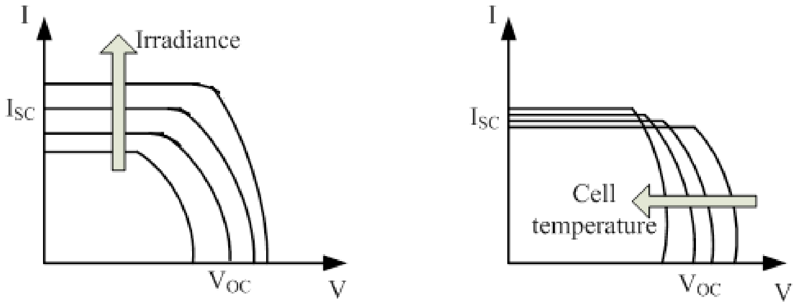


Fig. 2 Change in I-V characteristics due to change in irradiation and temperature [Kalogirou et al 2009].

3. Experiment Description

The impact of changes in module temperature and irradiance on the three types of PV cell technologies are measured indoors using a solar array simulator (SAS) to characterize their performance. The performance of the modules is determined by measuring the I–V characteristics following Sandia standard procedures.

Finding the maximum power points (MPPs) is crucial for evaluating the performance of PV modules under various environmental conditions (Joe et al. 2014). The test procedure provided by Sandia national laboratories is used to evaluate the performance of inverters for grid connected PV system applications (Ward 2004). The specifications of the three PV modules are given in Table 1.

Table 1 PV panel type descriptions

PV panel type	Fill factor (FF)	Temperature coefficient(β)
Monocrystalline	0.8	-0.5
Multi crystalline	0.68	-0.38
Thin-film	0.55	-0.25

For all the module types, reference conditions with irradiance of 1000 W/m2 and cell temperature of 50˚C are assumed. PV simulator Chroma 62150 is used to generate the I-V characteristics for all the PV technologies considered in this study.

The sandia test procedure for a clear (sunny) day and a cloudy day is given in Table 2.

Table 2 Ramp test procedure for a clear day and a cloudy day

Day	Repetitions	Slope ($W/m^2/s$)	Ramp up (s)	Dwell time (s)	Ramp down (s)	Dwell time (s)	Duration (s)
Sunny	1	0.5	1800	0	1800	0	3660
Cloudy	5	233	3	300	3	300	3090

The slow ramp of 0 to 100% insolation (1000 W/m2) represents the variation in insolation and temperature for a sunny day, with respect to time. After an initial settling time of 60 s for the stabilization of MPP tracker, the ramp starts from zero irradiance at a temperature of 5˚c and reaches the standard irradiance value of 1000 W/m2 at a temperature of 60˚c in 30 minutes. Immediately, it returns back to the starting irradiation and temperature in another 30 minutes. The total duration for the test is 1 hour, excluding the initial stabilization time.

Irradiation can change relatively quickly due to weather conditions, e.g. passing clouds. The purpose of considering a ramp of 10% to 80% variation in atmospheric conditions is to simulate the influence made by a cumulous cloud while it crosses the sun. The test is started with an irradiance change from 100 to 800 W/m^2 in 3 s , keeping the temperature steady at 50° c. After a stabilization time of 300 s, the ramp descends from 800 to 100 W/m^{2}in 3 sec. It remains at 100 W/m^2 for 300 s before starting the next cycle. This process is repeated to obtain 5 sets of results.

The laboratory setup for testing the whole system included PV simulator, PV inverter with rated power of 3 KW, 50Hz, 230 V single phase output**,** AC grid of 50Hz, 230V and computer. Perturb and observe MPPT algorithm is used in this work for tracking maximum power from the PV panels because of its simplicity and easy implementation. The specifications of the PV inverter considered for this study is given in Table 3.

Table 3 PV Inverter specifications

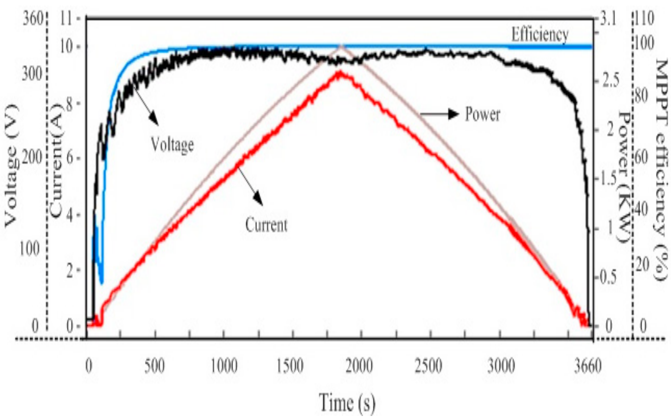
Specifications	**Values**
Maximum DC input power	3.3KW
Maximum DC input voltage	450 V
Maximum DC input current	14 A
MPPT voltage range	200-420 V
Rated AC output power	3 KW
Rated output voltage	230 V

4. Results and Discussion

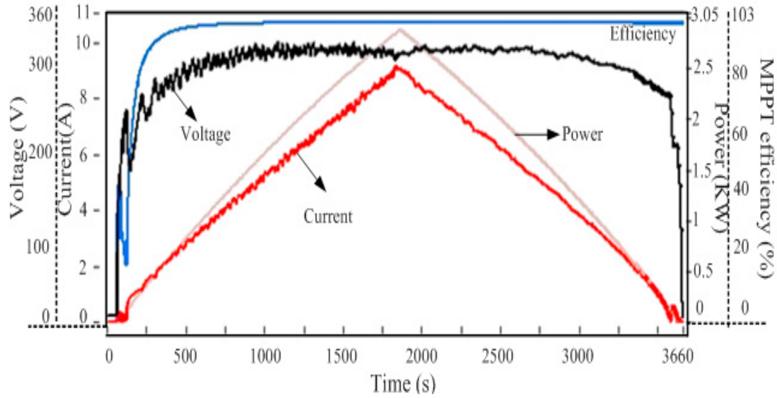
This section presents the end results of the test carried out, with regard to the performance of the three PV technologies for two types of weather conditions such as i. Sunny conditions and ii. Cloudy conditions.

4.1 Slow ramp test results for a sunny day

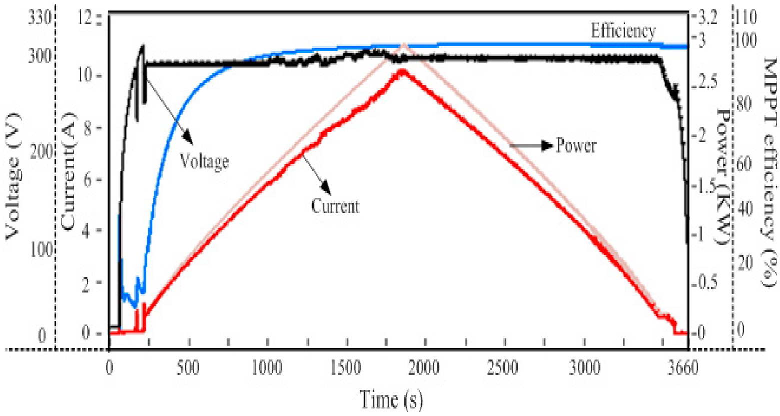
Fig.3 shows the output voltage, output current, output power and MPPT efficiency for the three PV technologies under sunny conditions.



a.Mono crystalline cell performance



b.Multi cyrstalline cell performance

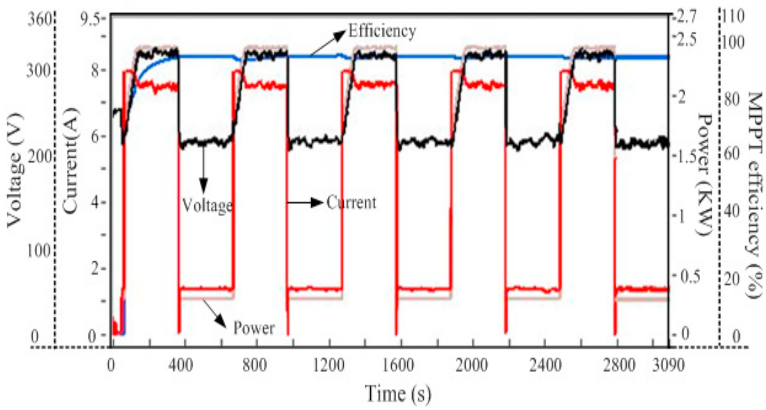


c.Thin-film cell performance

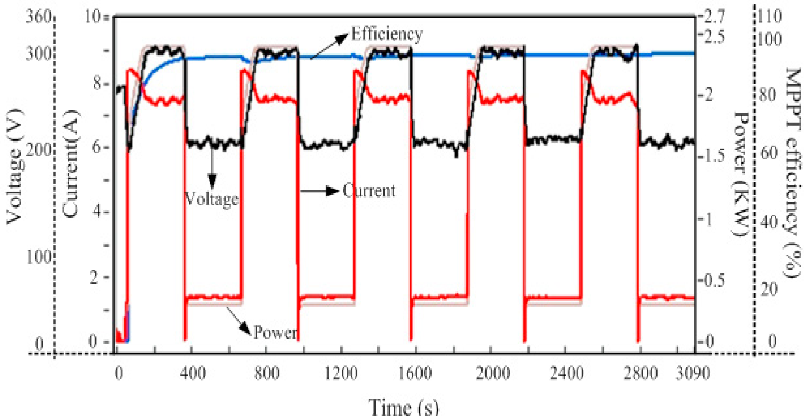
Figure 3. PV cell technologies performance in sunny conditions

4.2. Fast ramp test results for a cloudy day

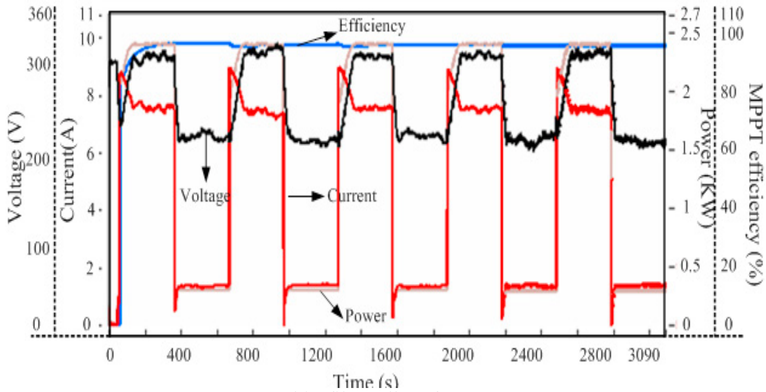
Fig.4 shows the output voltage, output current, output power and MPPT efficiency for the three PV technologies under fluctuating irradiance (cloudy) conditions.



a.Mono crystalline cell performance



b.Multi crystalline cell performance



c.Thin-film cell performance

Figure 4 PV cell technologies performance in cloudy conditions

From the results given in Table 5, it is observed that, mono-crystalline cell technology has produced more power in clear day conditions, compared to multi-crystalline and thin-film technologies. Also, the MPPT tracking is found to be better for crystalline modules than for thin film module in clear day conditions.

Compared to sunny day weather conditions, the energy yield during cloudy weather conditions is less as shown in Fig.5, because of the rapid dynamics in irradiance levels. From the measurements obtained from solar array simulator, it is observed that the maximum energy outputs of mono c-Si, multi c-Si and thin-film have decreased from 1560 Wh to 1104 Wh,1545 Wh to 1110 Wh and from 1512 Wh to 1118 Wh respectively when modules are subjected to fast fluctuations in irradiance.

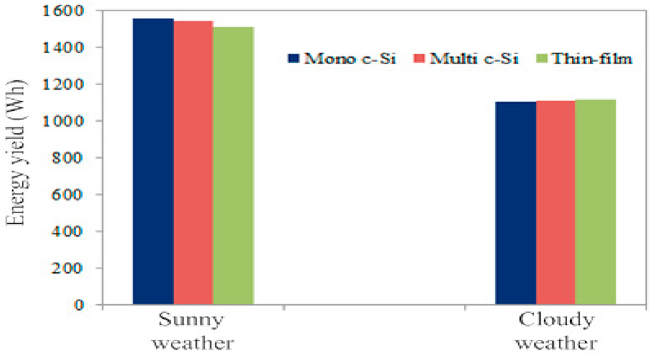


Figure 5 Energy output of the PV modules for different weather conditions

From the experimental results for cloudy conditions, it is observed that thin-film technology give higher power output at lower irradiances, while mono and multi c-Si technologies give higher output for higher irradiation levels. At the same time, there is a significant drop in output at low irradiances for crystalline technologies. It is observed from the results of tests under cloudy conditions, the energy delivered by thin-film technology is more than mono crystalline and multi crystalline cells as given in Table 5. Also, contrary to sunny conditions, the MPPT tracking for thinfilm module is found to better in cloudy day conditions.

This is because, with rise in temperature, fill factor decreases and hence there is decrease in PV cell efficiency. In the case of mono and multi crystalline modules, the fill factor remains nearly stable for higher irradiation levels, whereas started reducing for lower level irradiations, thereby producing comparatively better performance in sunny weather and degraded performance in cloudy weather. To the contrary, the fill factor is found to be stable for thin-film modules during both high and low irradiations, leading to more efficient operation in cloudy weather.

The given results obtained under laboratory conditions are expected to be closer to the real time weather conditions.

5. Conclusion

In this work, the energy generation of three different photovoltaic technologies such as mono crystalline, multi crystalline and thin film during dynamic weather conditions has been analyzed based on Sandia standard test procedure. From the experimental test results, it can be seen for all the three cell technologies, the highest energy generation is during the sunny conditions and the lowest during the cloudy conditions. It is revealed that each of the three PV technologies has different behavior and energy delivery capacity, regarding to changes in weather conditions. The comparative analysis can provide the researchers, a more accurate estimation of different PV modules performance in varying weather conditions and a better insight in the selection of appropriate technology for a particular environmental condition.

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