International Journal of Natural and Engineering Sciences 10 (1): 14-18, 2016
ISSN: 1307-1149, E-ISSN: 2146-0086, www.nobel.gen.tr

Influence of Ambient Temperature and Solar Radiations on Photovoltaic Module's Temperature and Power Output

Abdul Rehman JATOI* Saleem Raza SAMO Abdul Qayoom JAKHRANI
Energy and Environment Engineering Department, Quaid-e-Awam University of Engineering, Science and Technology (QUEST), Nawabshah, Sindh, Pakistan

*Corresponding Author:
E-mail:arjatoi@quest.edu.pk

Received: January 18, 2016
Accepted: March 01, 2016

Abstract

The influence of ambient temperature and solar radiations on variation of photovoltaic module temperature and power output was measured using four different photovoltaic module technologies, namely polycrystalline, monocrystalline, amorphous and thin film. The experimental setup was made by installing the whole system over the roof of the departmental building. The data was rerecorded in the three winter months from January to March 2016. The hourly average daily ambient temperature was 29.1°C, global solar radiation 727W/m², wind speed 2.5m/sec and relative humidity 84.0% during analysis period. It is revealed that monocrystalline module exhibited 0.6, 1.2 and 1.7°C more temperature than polycrystalline, amorphous and thin film modules respectively. The polycrystalline and monocrystalline produced higher voltage outputs when the module temperature was less than standard test conditions, whereas, the amorphous and thin film performed well when their temperature was slightly above standard test conditions. The module temperature is found directionally proportional to the ambient temperature, and output voltage is inversely proportional to the ambient temperature. The polycrystalline produced 41.6%, monocrystalline 38.6%, amorphous 32.0% and thin film 40.5% of their rated power output. It is revealed that polycrystalline performed well and amorphous poor than their counterpart modules during winter conditions.

Keywords: Ambient temperature, global solar radiation, module temperature, power output of PV modules

INTRODUCTION

Energy is essential for the economic and social development, and improved quality of life in any country; whether, it is in the form of oil, gasoline or other renewable energy source [1]. Out of all renewable energy resources, solar energy is one of the most feasible alternative and sustainable energy resources in the world. It is green technology resource, environment and nature-friendly, does not produce emissions that contribute greenhouse effect or destroy the ecological balance. It is omnipresent, safe, abundant and freely available [2, 3]. Solar energy is the most appropriate energy resource of Pakistan due to availability of 3000-3300 annual sunshine hours [4]. Photovoltaic (PV) modules are best option to convert solar energy into electricity through photovoltaic effect by creating voltage or electric current in a material upon exposure to light [5-8]. Each photovoltaic module can generate a specific voltage and current under manufacturing and physical constraints. However, PV modules are usually influenced by a number of environmental factors, such as, solar radiation, ambient temperature, wind speed, humidity and atmospheric dust, longitude, latitude and the type of PV technology used [9-10].

In general, PV modules are rated at indoor standard test conditions (STC) using the solar irradiance of 1000W/m², temperature 25ºC and air mass 1.5. Since, outdoor conditions do not follow the STC values because of random nature of sun's position with respect to location, and variation of solar radiation, ambient temperature, cloud pattern, and wind speed and direction. Therefore, the actual outdoor conditions vary time to time even at small intervals [11, 12]. Moreover, the operating temperature of solar PV modules plays a key role in the PV conversion process, because these are sensitive to temperature like all other semiconductor devices. The increase of temperature reduces the band gap of PV modules and increases the energy of the electrons in the material. Therefore, lower energy is required to break the bond, which affects the performance of PV modules [13, 14]. The rise of operating PV module temperature beyond standard operating conditions is inversely proportional to the efficiency of PV modules. Therefore, the electrical efficiency as well as power output of PV modules depends linearly on the operating temperature [15, 16]. Open circuit voltage (Voc), short circuit current (Isc), curve factor (CF) and efficiency (η) of PV modules are temperature dependent parameters. The PV modules give their maximum performance in cold climate and sunny skies rather than cloudy and hot climates [17]. Typically, the efficiency of PV modules decreases by 0.2% to 0.5%/ºC rise in ambient temperature beyond nominal cell operating temperature (NOCT). The NOCT is defined as the temperature reached by open circuited cells in a module under the irradiance on module surface of 800W/m², air temperature 20°C, and wind velocity 1 m/s with open back side mounting. However, the temperature of PV modules can reach between 60°C and 80°C in hot environments.

Photovoltaic Module Power Output

Electrical power is the product of voltage and current of any generator. It can either be measured directly using instruments or calculated after determination of voltage and current output from the generator [18-20]. The maximum power output P_n and normalized power output P_{max} of PV modules can be calculated using following Eq. (1) and (2) respectively.

$$P_{\max} = V_{\max} \times I_{\max} \qquad (1)$$

where V_{max}, and I_{max} are the maximum voltage and current outputs respectively. If the rated power output of PV module is different from other module, then normalized power output can be used for comparison purpose and performance evaluation. The normalized power output of PV modules can be calculated using Eq. (2).

$$P_n = \left(\frac{P_{\max}}{P_{\max(STC)}} \right) \times 100 \qquad (2)$$

where $P_{max(STC)}$ is PV module power output at standard test conditions. The PV module temperature T_m can be calculated using average of PV module surface temperature T_s and backside temperature T_b of PV modules using Eq. (3) [21].

$$T_m = \left(\frac{T_s + T_b}{2}\right) \tag{3}$$

The growing demand of PV technologies led to research in the various aspects of its components from module technologies to the modeling, size optimization and system performance [18]. The reduction in PV performance is associated with various parameters like their types, configuration, installation, wind speed, solar radiations, and ambient temperature [19]. It is imperative to investigate the impact of such parameters on performance of PV modules under outdoor conditions. This study explores the influence of ambient temperature and solar radiations on variation of PV module temperature and power output.

MATERIALS and METHODS

The study was conducted on four PV module technologies namely polycrystalline, monocrystalline, amorphous and thin film. All selected PV modules were purchased from Karachi electronic market. Three of them were 40W rated power, and only thin film was of 50W, because of its unavailability in the market. The specifications of examined PV modules are shown in Table. 1. The experimental setup was made on the roof top of the departmental building at Energy and Environment Engineering Department, QUEST, Nawabshah. The modules were secured on a fixed iron structure, facing true south at the slope of 12° with respect to horizontal.

The climatic parameters, such as ambient temperature, Ta (ºC), global solar radiation, GSR (W/m²), wind speed, Vw (m/sec) and relative humidity, RH (%) were measured with a Professional Weather Station Model HP-2000. The surface and back surface temperature values of each PV module were logged using a Taiwan made Prova-830, Paperless Recorder. Two thermocouples were fixed on each PV module, one on its surface and other on its back. A total of eight K-type (Nickle-Chromium) thermocouples were used for recording of surface and back surface temperature. The electrical characteristics of each PV module like voltage (V), current (A) and power (W) were recorded through Taiwan made Prova-210, PV Analyzer. The installed experimental setup comprised of weather station, PV modules, thermocouples and data loggers as shown in Figure 1.

The data loggers were being connected with power output of PV modules, and interfaced with computer in order to store the recorded data for further analysis. The voltage, current and power of each PV module was recorded approximately with an average of 35 seconds. The readings were recorded on hourly basis from 07:00 to 18:00 hours Pakistan Standard Time. The data loggers were calibrated with standard of ISO-9002 Regulation before start of recording respective parameters. The power output (Pmax) of PV modules were directly measured with Prova-210, whereas, the normalized power output , and module temperature of PV modules were determined using Eq. (2), and (3) respectively.

RESULTS and DISCUSSION

The values of ambient temperature, solar radiation, wind speed and relative humidity as well as module temperature, and output voltage, current and power of PV modules for three winter months from January to March, 2016 were recorded on hourly basis.

Climatic Conditions

The hourly average ambient temperature (Ta), global solar radiation (GSR), wind speed (Vw) and relative humidity (RH) during study period are shown in Figure 2. In all three months, the maximum average ambient temperature was 29.1ºC at 16:00 hours and minimum 13.13ºC at 07:00 hours. The maximum GSR was found 726.9W/m² at 13:00 hours and minimum 20.4W/m² at 07:00 hours. The maximum Vw was recorded 2.5m/sec at 13:00 hours and minimum 0.8m/sec at 07:00 hours. When the level of GSR and Ta were low the RH was high with 84.0%, and when the intensity of GSR and Ta was high the RH was 24.7%. It is deduced from the analysis that relative humidity is inversely proportional to the intensity of global solar radiation and ambient temperature.

Photovoltaic Module Temperature

The hourly average values of GSR, Ta and PV modules temperatures (Tm) of winter months are shown in Figure 3. The average hourly maximum Ta was noted as 29.1°C at 16:00 hours. The hourly average maximum values of PV modules temperatures (Tm) from polycrystalline (Tm,p), monocrystalline(Tm,m), amorphous (Tm,a), and thin film technologies (Tm,t) were 49.4, 49.9, 48.8 and 48.2ºC respectively at 13:00 hours and minimum 21.0, 18.3, 19.9 and 19.3ºC respectively at 07:00 hours. It was observed that monocrystalline module attained more temperature between 09:00 to 15:00 hours. After the execution of highest temperature, its temperature was being quickly reduced among other examined PV modules. Moreover, it is found that thin film module accomplished and released temperature slowly and gradually.

Power Output of Photovoltaic Modules

The polycrystalline module produced maximum voltages 34.2V at 09:00 hours when module temperature was less than STC conditions, and minimum 27.2V at 18:00 hours when level of solar radiations and PV module temperature was less. The polycrystalline module produced 2.0V, 2.9V and 10.9V less than average maximum voltages, rated voltages and open circuit conditions respectively. Besides that, the maximum recorded current was 0.9A at 13:00 hours when the module temperature was high and minimum current was 0.02A at 07:00 hours when the module temperature was less. It is discovered from analysis, when module temperature was high the polycrystalline produced more current and less voltage as shown in Figure 4.

Figure 5 shows the results of monocrystalline module. The monocrystalline module produced maximum voltage of 17.5V at 08:00 hours when the module temperature was less than STC conditions and minimum 14.0V at 18:00 hours. The monocrystalline module produced 0.9V, 1.2V and 5.2V less voltages than the average maximum voltages, rated voltages and open circuit conditions respectively. Besides that, the maximum recorded current was 1.72A at 13:00 hours when module temperature was high and minimum 0.04A at 18:00 hours when module temperature was low. It is discovered from analysis, when module temperature was high, the monocrystalline produced more current and less voltages from the average values.

In contrary to the polycrystalline and monocrystalline PV modules, the amorphous module produced maximum voltages 21.7V at 08:00 hours when module temperature was slightly more than STC conditions, whereas minimum 17.3V at 18:00 hours as shown in Figure 6. The amorphous module produced 2.2V and 8.8V less than its rated voltages and open circuit conditions respectively. Besides that, the maximum recorded current was 1.17A at 13:00 hours when module temperature was 48.7°C and minimum 0.02A at 18:00 hours when module temperature was 28.2°C. It is discovered from analysis, when module temperature was high, the amorphous produced more current and less voltage than maximum.

The thin film PV module produced maximum voltage of 40.7V at 09:00 hours when module temperature was 30.6ºC, and minimum 30.0V at 18:00 hours as shown in Figure 7. The thin film module produced 5.4V and 25.4V less than its rated voltages and open circuit conditions respectively. Besides that, the maximum recorded current was 1.0A at 12:00 hours when module temperature was 46.6°C and minimum 0.02A at 18:00 hours when module temperature was 26.7°C. It is discovered from analysis, when module temperature was high with 48.2°C, the thin film produced slightly more current and less voltage than maximum value.

It is revealed that the module temperature is directionally proportional to the ambient temperature and voltages are inversely proportional to the module as well as ambient temperature. It is because the voltage output was found dropping when the module temperature was increasing than standard test conditions, however, the current output was slightly increasing.

Normalized Power output of PV Modules

The maximum power output of polycrystalline, monocrystalline and amorphous modules were recorded as 74.1%, 68.1% and 57.5% respectively at 13:00 hours and from thin film 74.8% at 12:00 hours as shown in Figure 8. The minimum power output of polycrystalline was 1.9%, monocrystalline 2.7%, amorphous 1.8% and thin film 2.2% at 07:00 hours. Generally, polycrystalline produced 41.6%, monocrystalline 38.6%, amorphous 32.0% and thin film 40.5% of their rated power output. It is observed that the polycrystalline module produced 6.0% more power than monocrystalline and 17% than amorphous at 13:00 hours when the ambient as well as module temperatures were high. It is revealed that polycrystalline performed well and amorphous worse than their counterpart modules during study period.

CONCLUSIONS

It is found from the study that the hourly average maximum ambient temperature during analysis period at the location was 29.1°C, global solar radiation 727.0W/m^2, wind speed 2.5m/sec and relative humidity 84.0%. It was discovered that monocrystalline module attained 0.6°C, 1.2°C and 1.7°C more temperature than polycrystalline, amorphous and thin film modules respectively. Therefore, monocrystalline is more sensitive to temperature than other examined modules.

The polycrystalline and monocrystalline produced maximum voltages when the module temperature was less than standard test conditions, and amorphous and thin film produced higher voltages when module temperature was slightly above standard test conditions. The maximum current output from all examined modules was recorded at 13:00 hours when module temperature was high except thin film, which gave maximum current at 12:00 hours. It was also found that the module temperature is directionally proportional to the ambient temperature, and output voltage is inversely proportional to the ambient temperature.

The polycrystalline produced 41.6%, monocrystalline 38.6%, amorphous 32.0% and thin film 40.5% of their rated power output. It is observed that the polycrystalline module produced 6.0% more power than monocrystalline and 17% than amorphous at 13:00 hours when the ambient as well as module temperatures were high. It is revealed that polycrystalline performed well and amorphous worse than their counterpart modules during study period.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support provided by the authorities of Quaid-e-Awam University of Engineering Science and Technology, (QUEST), Nawabshah, Pakistan for conducting this research.

REFERENCES

[1] Jakhrani AQ, Othman AK, Rigit ARH, Samo SR. 2011. Model for Estimation of Global Solar Radiation in Sarawak, Malaysia. World Applied Sciences Journal, Special Issue of Food & Environment. 14: 83-90.

[2] Jakhrani AQ, Othman AK, Rigit ARH, Samo SR. 2013. Assessment of solar and wind energy resources at five typical locations in Sarawak. Journal of Energy and Environment, 4(1):1-6.

[3] Jakhrani AQ, Samo SR, Rigit ARH, Kamboh SA. 2013. Selection of Models for Calculation of Incident Solar Radiation on Tilted Surfaces. World Applied Sciences Journal. 22 (9): 1334-1341.

[4] Ulfat I, Javed F, Abbasi FA, Kanwal F, Usman A, Jahangir M, Ahmed F. 2012. Estimation of Solar Energy Potential for Islamabad, Pakistan. Energy Procedia. 18: 1496-1500.

[5] Kalogirou SA. 2014. Solar Energy Engineering: Processes and Systems, 2nd edition. Academic Press: Elsevier, Amsterdam.

[6] Duffie JA, Beckman WA. 2013. Solar Engineering of Thermal Processes, 4th edition. John Wiley & Sons, Inc., Hoboken, N.J, USA.

[7] Jakhrani AQ, Othman AK, Rigit ARH, Samo SR, Kamboh SA. 2012. A Novel Analytical Model for Optimal Sizing of Standalone Photovoltaic Systems. Energy. 46 (1): 675-682.

[8] Adinoyi MJ, Said SA. 2013. Effect of dust accumulation on the power outputs of solar photovoltaic modules. Renewable energy. 60: 633-636.

[9] Jiang H, Lu L, Sun K. 2011. Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules. Atmospheric Environment. 45(25): 4299-4304.

[10] Cañete C, Carretero J, Sidrach-de-Cardona M. 2014. Energy performance of different photovoltaic module technologies under outdoor conditions. Energy. 65: 295-302.

[11] Minemoto T, Fukushige S, Takakura H. 2009. Difference in the outdoor performance of bulk and thin-film

silicon-based photovoltaic modules. Solar Energy Materials and Solar Cells. 93(6): 1062-1065.

[12] Bahaidarah H, Subhan A, Gandhidasan P, Rehman S. 2013. Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions. Energy. 59: 445-453.

[13] Alami AH. 2014. Effects of evaporative cooling on efficiency of photovoltaic modules. Energy Conversion and Management. 77: 668-679.

[14] Dubey S, Sarvaiya JN, Seshadri B. 2013. Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World–A Review. Energy Procedia. 33: 311-321.

[15] Arjyadhara P, Ali SM, Chitralekha J. 2013. Analysis of solar PV cell performance with changing irradiance and temperature. International Journal of Engineering and Computer Science. 2(1): 214-220.

[16] Bashir MA, Ali HM, Khalil S, Ali M, Siddiqui AM. 2014. Comparison of performance measurements of photovoltaic modules during winter months in Taxila, Pakistan. International Journal of Photoenergy, 1-8.

[17] Trinuruk P, Sorapipatana C, Chenvidhya D. 2009. Estimating operating cell temperature of BIPV modules in Thailand. Renewable energy. 34(11): 2515-2523.

[18] Jakhrani AQ, Othman AK, Rigit ARH, Baini R, Samo SR, Ling LP. 2012. Investigation of Solar Photovoltaic Module Power Output by various Models. NED University Journal of Research, Thematic Issue on Energy. 25-34.

[19] Kurnik J, Jankovec M, Brecl K, Topič M. 2008. Development of outdoor photovoltaic module monitoring system. Informacije MIDEM. 38(2): 75-80.

[20] Jakhrani AQ, Samo SR, Kamboh SA, Labadin J, Rigit ARH. 2014. An Improved Mathematical Model for Computing Power Output of Solar Photovoltaic Modules. International Journal of Photoenergy. 1-9. Article ID 346704. http://dx.doi.org/10.1155/2014/346704.

[21] Jakhrani AQ, Othman AK, Rigit ARH, Samo SR. 2011. Comparison of Solar Photovoltaic Module Temperature Models. World Applied Sciences Journal. 14: 1-8.

LIST of TABLES

LIST of FIGURES

Table. 1. Physical and electrical characteristics of selected photovoltaic modules

Module Parameters	Units	Module Technologies			
		Polycrystalline silicon (p-Si)	Monocrystalline silicon (c-Si)	Amorphous (a-si)	Thin film
Manufacturer		SANAK SK UNION	SANAK SK UNION	SHENZHEN TOPRAY SOLAR TPS-113	GS-SOLAR (FU-JIAN)
Model	--	SUN-40P	SUN-40M	TPS-40	GS-50
Open circuit voltage (Voc)	V	43	21.5	29	62
Short circuit current (Isc)	A	1.29	2.55	2.3	1.42
Rated Voltage (Vmax)	V	35	17.5	18	43
Rated Current (Imax)	A	1.14	2.29	2.2	1.17
Rated Power (Pmax)	W	40	40	40	50
Testing condition	STC	STC	STC	STC	STC
PV module expose area with sun	m^2	0.27470	0.242094	0.765072	0.744198

Figure 1. Experimental setup including modules, data loggers and weather station

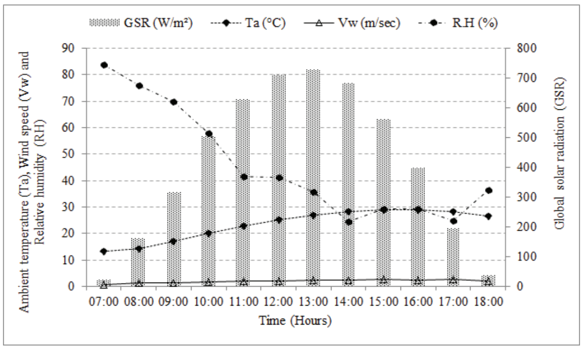

Figure 2. Daily average hourly climatic parameters versus time

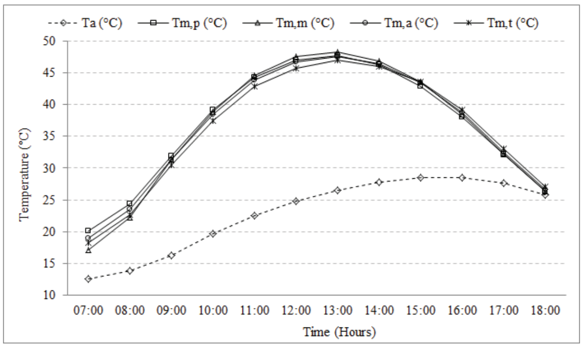

Figure 3. Hourly average global solar radiations versus ambient temperature and module temperature

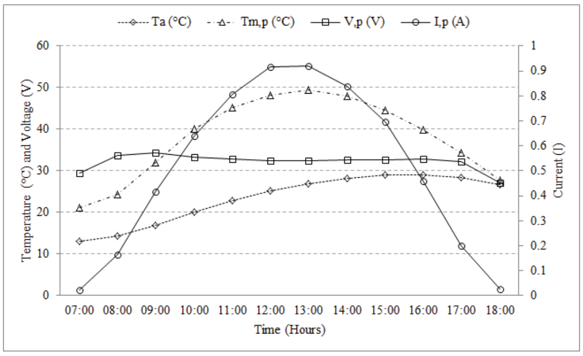

Figure 4. Hourly average ambient temperatures, module temperature, voltage and current of polycrystalline module

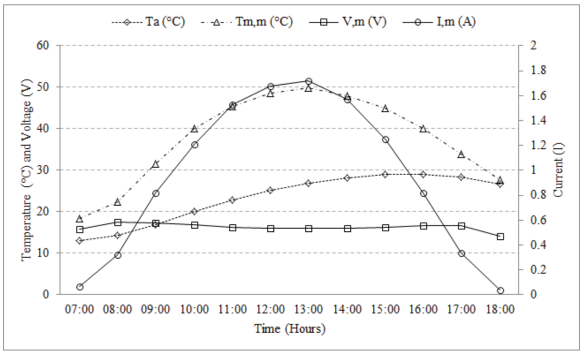

Figure 5. Hourly average ambient temperatures, module temperature, voltage and current of monocrystalline module

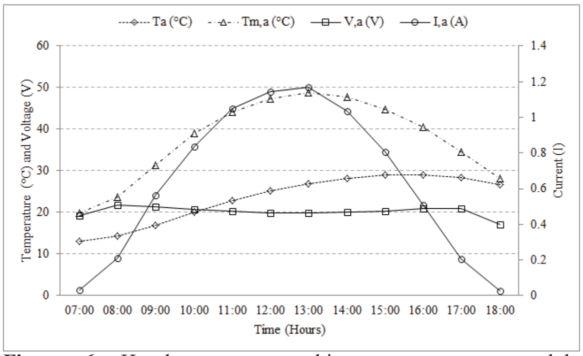

Figure 6. Hourly average ambient temperatures, module temperature, voltage and current of amorphous module

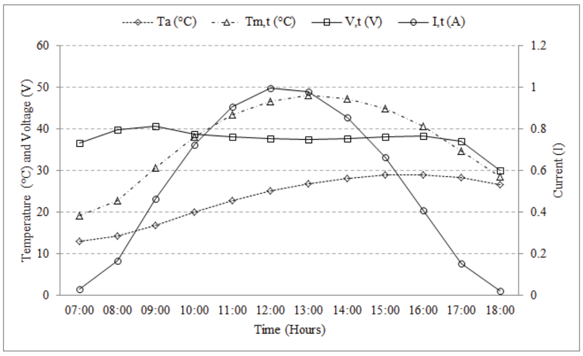

Figure 7. Hourly average ambient temperatures, module temperature, voltage and current of thin film module

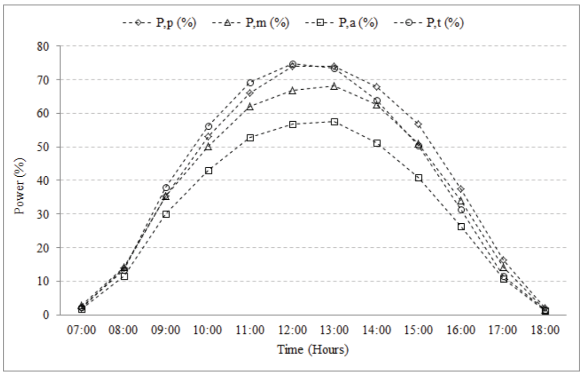

Figure 8. Hourly average normalized power output of selected modules