Communications on Applied Electronics (CAE) – ISSN : 2394-4714
Foundation of Computer Science FCS, New York, USA
Volume 5 – No.4, June 2016 – www.caeaccess.org

Performance of a Multicrystalline Photovoltaic Module in Critical Climatic Conditions of Western Rajasthan, India

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ABSTRACT
The energy yield of a Photovoltaic (PV) power plant depends upon the dc power output of the PV module. The irradiance and temperature are the two most important parameters affecting the dc power output. This paper analyses the dc power output of a multicrystalline PV module in the realistic environmental condition with respect to solar irradiance, ambient temperature and cell temperature. The real time data is collected from a 5 MW grid connected solar PV plant located in Jaisalmer, a district in Western Rajasthan. The paper brings forward a crucial and valuable fact that the modules work more efficiently at high temperature and high solar irradiance. For a multicrystalline PV module with maximum dc power output (P_{max}) at STC condition equal to 118.687KW, analyzed over a period of one year it is found that maximum dc power output (P_{dc}) at 22^{o}C ambient temperature and 40 cell temperature is only 72 KW while maximum P_{dc} at cell temperature around 50-55^{o}C and ambient temperature around 35-38^{o}C is 90-92KW. Slight negative temperature coefficient for P_{dc} with respect to temperature is observed if ambient temperature and cell temperature is greater than 35^{o}C and 50^{o}C respectively. However power output increases in direct proportion to irradiance outweighing the change in temperature. Higher the irradiance, higher is the dc power output, higher is the efficiency and correspondingly higher is the energy yield of the PV module. The multicrystalline PV module works efficiently and gives high yield in the extremely high temperature of Western Rajasthan. Rajasthan which receives world second largest radiation has the capability to meet the energy demands of India and the world as well if solar energy is harnessed in appropriate way.

General Terms
Solar photovoltaic, Power output, Performance of PV module

Keywords
Performance of PV module, Ambient temperature, Cell temperature, DC power output, Multicrystalline Photovoltaic module, Western Rajasthan, Critical climatic condition.

1. INTRODUCTION
Sun the driving power to photovoltaic is an inexhaustible source of energy. It provides about 10,000 times more energy than we consume. The solar photonic cells convert the light spectrum directly to electricity. A single cell produces about 0.5V. Cells are wired in series to form either 12V or 24V module. In turn modules are connected in series and parallel to increase voltage and current respectively to obtain desired power output. With reference to cell temperature 25^{o}C, the short circuit current (I_{sc}) increases in direct proportion to irradiance while open circuit voltage (V_{oc}) undergoes modest positive change. At the same time, with increase in cell temperature above 25^{o}C, V_{oc} decreases substantially while the short circuit current increases only slightly [1].The result is that power output decreases with increase in cell temperature above 25^{o}C. However in one of the paper entitled "High Temperature Effect on Multicrystalline Photovoltaic Module in Western Rajasthan, India", it has been shown that dc output voltage does not decrease with increase in cell temperature above 25^{o}C instead stable and high dc output is obtained only when cell temperature is greater than 50^{o}C [2]. The results of the above paper are further verified by the work done in this paper. This paper correlates dc power output of a multicrystalline PV module with Global Horizontal Irradiance (GHI), ambient temperature and cell temperature for real time data. The real time data is collected from a 5MW solar PV power plant located in Ramgarh, district Jaisalmer, one of the hottest cities of Western Rajasthan. The results of analyses clearly show that dc power obtained at cell temperature 50^{o}C is far greater than obtained at cell temperature 25^{o}C. P_{dc} as high as 86.71 KW is obtained at 62^{o}C cell temperature while P_{dc} obtained at 25^{o}C cell temperature is insignificant. The result is in accordance to paper [2] where it was concluded that dc output voltage shows negative temperature coefficient for cell temperature greater than 52^{o}C and not 25^{o}C. The existing literature and even manufacturers do specify negative temperature coefficient for maximum power output (P_{max}) with reference to 25^{o}C cell temperature. The value of temperature coefficient for P_{max} for the module that has been used in the plant is -0.447 %/^{o}K as shown in table number 2. However the result show slight negative temperature coefficient if ambient temperature and cell temperature are greater than 35^{o}C and 50^{o}C respectively. Ambient temperature, cell temperature and irradiance vary due to various environmental factor like wind speed, wind direction, humidity, cloud, dust storm and dust clouds a peculiar feature of Western Rajasthan but overall dc power output increases with increase in irradiance showing that irradiance is the dominating factor in determining the dc power. High irradiance at high temperature for long duration and for almost eleven months can lead to highly efficient solar PV plant in Western Rajasthan. Thus Rajasthan receiving second largest amount of radiation in the world as per studies conducted by U.S Department of Energy [3] has enormous potential in the field of photovoltaic. It receives about 6-7 KWh/m^2 of solar insolation with about 325 sunny days [4]. It has the capability to meet the energy demands of the world provided solar energy is harnessed in a way that maximum irradiance is captured.

2. METHODOLOGY

2.1 The data set used in analysis is from one of the 5 MW grid connected PV power plant located at Ramgarh, in district Jaisalmer, Rajasthan, India.

2.2 The characteristic of the PV module are specified at STC condition shown in Table 1. The data and result correspond to multicrystalline module with specifications as shown in Table 2.

2.3 The global horizontal irradiance is measured by Pyranometer at 15 minutes interval and stored by the SCADA (Supervisory Control and Data Acquisition) system.

2.4 The analysis is based on variation of dc power output of a multicrystalline PV module specifically PV array with maximum power output equal to 118.687 KW.

2.5 The panel temperature corresponds to cell temperature in the graph shown in the paper

2.6 The average DC power of five arrays over a period of one year May 2014 to April 2015 has been analyzed.

2.7 The effect of various other environmental parameter like wind speed, wind direction, humidity, cloud, dust particle, dust storms and dust clouds etc. have not been considered in the present analyses.

2.8 The graph leading to vital conclusions have been shown in the paper.

2.9 AMB, PANEL, PDC corresponds to ambient temperature, panel temperature and dc power output respectively in the graphs. The short forms are followed by the related date for example PDC 11-3-15 means dc power output for 11 march 2015.

Table 1. STC condition

S. No	Parameters	Value
1	Irradiance	1000W/m^2
2	Module Temperature	25^{o}C
3	Air Mass	1.5
4	NOCT (Nominal Operating Cell Temperature)	47^{o}C
5	Operating Temperature	-40^{o}C to + 85^{o}C

Table 2. MBSL Elite PV Module Characteristic

S. No.	Electrical Characteristics	Values
1.	Maximum power P_{mpp}/ P_{max}	247.39W
2.	Voltage at P_{max}, V_{mpp}	30.64V
3.	Current at P_{max}, I_{mpp}	8.07 A
4.	Open circuit voltage V_{oc}	37.67 V
5.	Short circuit current I_{sc}	8.26 A
6.	Temperature coefficient of P_{max}	-0.447 %/ ^{o}K
7.	Temperature coefficient of V_{oc}	-0.353 %/ ^{o}K
8.	Temperature coefficient of I_{sc}	0.104 %/ ^{o}K
9.	Power Tolerance	-0 / + 5 W
10.	Fuse rating	15 A
11.	Maximum System Voltage	1000 V
12.	Maximum array voltage	735.36 V (24*30.64)
13.	Maximum array current	161.4 A (8.07*20)
14.	Maximum array power	118.687 KW (735.36*161.4)

3. EXPERIMENTAL DATA ANALYSIS

The effect of GHI on dc power output of the multicrystalline PV array has been analyzed for very high temperature considering four specific dates 15th April 2015, 26th May 2014, 5th June 2014 and 6th July 2014 (Figure 1). The dc power output (P_{dc}) increases with increase in GHI. It can be seen that constantly increasing and high P_{dc} is obtained for GHI greater than 700W/m^2. The corresponding cell temperature is around 42-52^{o}C for GHI greater than 700W m^2.

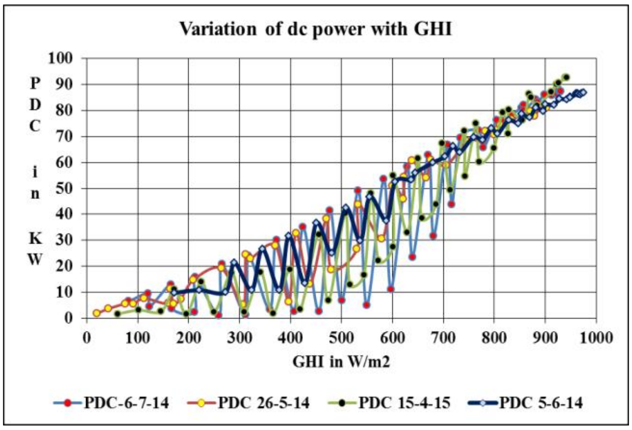

Fig 1: Variation of P_{dc} with GHI in summer (April-July).

The detailed analyses of P_{dc} with GHI are shown in figure 2 and figure 3.

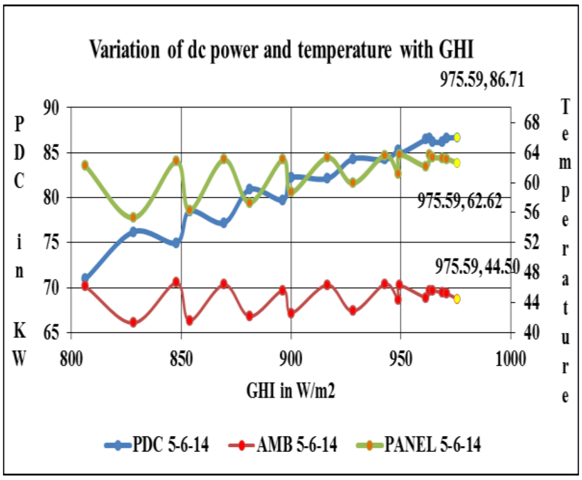

Fig 2: Variation of P_{dc} with GHI greater than 800W/m^2 for 5th June 2014.

Figure 2 shows variation of P_{dc} with GHI greater than 800W/m^2, ambient temperature varying in the range of 40-45^{o}C and cell temperature varying in the range of 56-64^{o}C. It can be seen that as ambient temperature and cell temperature increase P_{dc} reduces and vice versa but still P_{dc} increases from 70 KW to 86.71 KW as GHI increases from 800 to 975.59 W/m^2. P_{dc} equal to 86.71KW is obtained at cell temperature 62.62^{o}C and ambient temperature 44.50^{o}C.

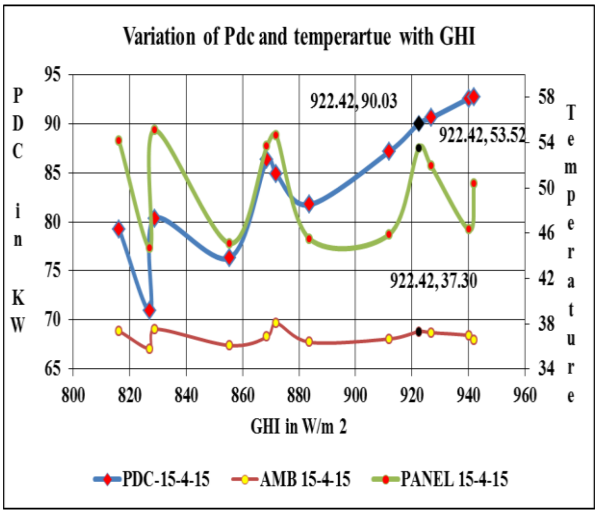

Fig 3: Variation of dc power output for GHI >800W/m^2 for 15th April 2015.

Figure 3 shows variation of P_{dc} with GHI greater than 800 W/m^2. The ambient temperature varies between 35-38^{o}C and panel temperature varies between 42-55^{o}C. Here Pdc increases with increase in ambient and cell temperature. The power output increases in direct proportion to irradiance. It increases from 70 to 92.58 KW as GHI increases from 800 to 940 W/m^2. P_{dc} equal to 90.03 KW is obtained at ambient temperature 37.30^{o}C and cell temperature 53.52^{o}C. This shows that P_{dc} has positive temperature coefficient for ambient temperature up to 35-38^{o}C and cell temperature up to 50-54^{o}C.

It is seen that in winters specifically 15th December (Figure 4) maximum temperature is around 25^{o}C, maximum GHI is around 700W/m^2 and the PV module does not give the desired power output.

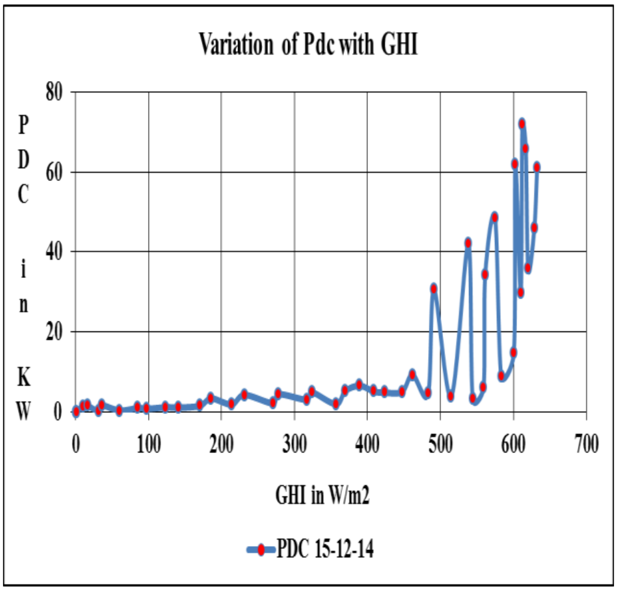

Fig 4: Variation of dc power output with GHI for 15th December 2014

The output goes high for very short duration indicated by very few points in figure 4 while in summer much higher output is obtained for enormous points (figure1) that is for longer span. High temperature and high irradiance for long duration will give higher dc output for longer duration and corresponding power yield will also be higher.

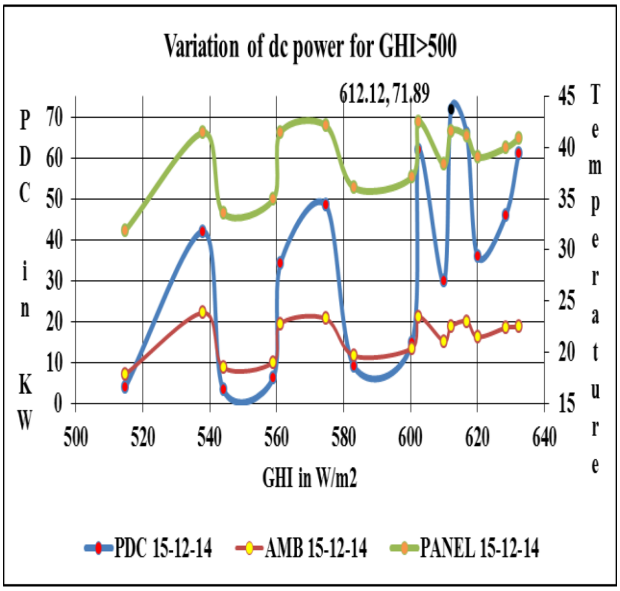

Fig 5: Variation of dc power output with GHI greater than 500W/m^2 for 15th December 2014.

The detailed view of figure 4 is shown in figure 5. It can be seen that P_{dc} increases as ambient and panel temperature increases as ambient temperature is less than 35^{o}C and panel temperature is less than 50^{o}C. Maximum P_{dc} is 71.89KW at ambient temperature 22.51C and cell temperature 41.55C.

4. RESULT AND DISCUSSIONS

(i) The multicrystalline PV module works more efficiently at cell temperature around 50-55°C. Positive temperature coefficient is observed as long as cell temperature is less than 53°C as shown in figure 3.

(ii) Negative temperature for P_{dc} is observed when cell temperature is greater than 50-55°C and ambient temperature is greater than 36-38°C. However P_{dc} increases in direct proportion to irradiance outweighing change in temperature.

(iii) Maximum P_{dc} for specific day at 40°C, 53°C and 62°C cell temperature is 71KW, 90KW and 87.6 KW respectively. Noteworthy output is not attained until cell temperature is greater than 35°C and GHI is greater than 600W/m^2.

(iv) Long duration of high irradiance in summer (figure 1) gives much higher output compared to shorter span in winter as in December (figure 4) .

(v) The module efficiency varies in direct proportion to dc output power. Therefore multicrystalline module works very efficiently in critically high temperature of Western Rajasthan.

(vi) Negative temperature coefficient for maximum dc power (Pmax), needs to be revaluated for the real time conditions.

(vii) Western Rajasthan is highly suitable for solar photovoltaic power generation.

(viii) Low cost concentration technique to capture maximum solar irradiance should be employed in order to increase dc power output especially in winters in Western Rajasthan and year round in the countries receiving low solar irradiance. If successful it can reduce the cost significantly and can give new impetus to solar industry.

5. CONCLUSION

The analysis of real time data in critical climatic conditions of Western Rajasthan show that multicrystalline PV module works very efficiently even at extremely high temperature. P_{dc} in the range of 70-93KW is attained as ambient temperature varies from 35-38°C and cell temperature varies from 42-55°C. Maximum output is attained for cell temperature in the range of 50-55°C. Negative temperature coefficient for P_{dc} is seen for cell temperature greater than 52°C. P_{dc} increases with increase in irradiance outweighing change in temperature. If somehow cell temperature is maintained near 50°C with increase in GHI above 800W/m^2, the module efficiency will improve. Efforts must be made to capture maximum irradiance. The findings are very important for Western Rajasthan and other countries experiencing record high temperature and high insolation. As a further work impact of employing concentration technique to increase solar insolation on the dc power output should be studied. Temperature coefficient for dc power needs to be re-evaluated for the real time weather conditions.

6. ACKNOWLEDGMENT

The authors would like to acknowledge the support of Shri J. K. Borgohain, Executive Director, Rajasthan Project. Oil India Lmt., Jodhpur, Shri D. C. Gogoi, Head, Technical Service, Oil India Lmt, Jodhpur; Shri Rajesh Kundoo, Incharge, PV Power Plant at Ramgarh, Jaisalmer in conducting this study.

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