Communications on Applied Electronics (CAE) – ISSN : 2394-4714
Foundation of Computer Science FCS, New York, USA
Volume 7 – No. 19, August 2018 – www.caeaccess.org

Unfolding Extraordinary Positive Effect of High Temperature and High Irradiance on DC Power Output of a Multicrystalline PV Module: A Case Study of Western Rajasthan

Shalini Garg
Government Polytechnic College, Jodhpur, India

Arun J. B.
Teacher's Training Center, Jodhpur, India

ABSTRACT
The solar cell generates voltage when exposed to sunlight, producing direct current electricity, the power being equal to product of current and voltage. Literature and research papers shows negative temperature coefficient for both dc voltage and dc power for cell temperature greater than 25^{o}C. However, no attempt has yet been made to visualise and evaluate as to how the dc voltage, dc current and dc power varies with irradiance and temperature acting concurrently on the PV module. This paper evaluates the relative contribution of temperature and irradiance particularly POA (Plane of Array Irradiance) acting concurrently on the dc power output of a multicrystalline PV module. The cell temperature varies linearly with irradiance but due to the dominating effect of high irradiance relative to slight increase in temperature, a multicrystalline PV module gives outstanding performance at high cell temperature and high irradiance, showing remarkably overall positive effect of high cell temperature and high irradiance. In contrast to literature this paper brings forward two most vital facts. Firstly, dc power increases with increase in temperature and maximum dc voltage about 80% of its rated value is obtained at cell temperature 58.14^{o}C. Secondly, despite the negative temperature coefficient of voltage for cell temperature greater than 49^{o}C instead of 25^{o}C, significant dc voltage and dc power is obtained only for cell temperature greater than 49^{o}C. This paper also explores the input condition required to obtain high energy yield.

General Terms
Solar Irradiance, Energy yield, Grid connected PV power plant, Western Rajasthan.

Keywords
Multicrystalline PV module; Plane of array irradiance (POA); Cell temperature; DC voltage; DC power; Efficiency.

1. INTRODUCTION
The performance of a PV system depends on its basic characteristic, system design, location and climatic conditions of the site. Among the various climatic parameters like temperature, irradiance, cloud coverage, humidity and wind speed, irradiance and temperature are the two most important parameters affecting the efficiency of PV power plant. [1,2]. Several studies have been conducted in various parts of the world but so far no such investigation has been done for Western Rajasthan. This paper evaluates joint effect of irradiance and temperature the two major environmental parameters on the dc voltage, current and power output of a multicrystalline PV module for the climatic conditions of Western Rajasthan. Western Rajasthan commonly known as 'Thar Desert' has around 208000 square Km of flat desert land with slope less than 1^{o} readily available for solar electricity generation. It is blessed with high solar irradiance with clear sunny days greater than 325, together with high temperature.

Literature and many researchers show that module efficiency decreases with increase in temperature due to negative effect of temperature on voltage although current has slight positive effect. This is because they have considered variation in voltage and current with temperature keeping irradiance constant. However, both voltage and current and in turn power depends upon the relative contribution of cell temperature and irradiance acting together.

Some of the authors have evaluated performance of PV plant with varying environmental conditions and show positive linear relationship of module efficiency with temperature. Bhattacharya et al. [3] have shown that a strong positive correlation exists between ambient temperature and module efficiency for a monocrystalline solar photovoltaic module located in Tripura. Vasisht et al. [4] have shown that ambient temperature between 20 to 38^{o}C has positive correlation with the efficiency of a monocrystalline PV system. The results of Garg et al. [5] also show that dc voltage decreases with increase in temperature only for ambient temperature greater than 38^{o}C and cell temperature greater than 50^{o}C. Garg et al. [6] have shown that dc power output varies in direct proportion to irradiance outweighing the change in temperature. Power output at cell temperature 50-55^{o}C was far greater than power output at 40^{o}C. Garg and JB [7] have also shown that dc voltage attains a point of saturation maintaining nearly constant value in the range of 80-85% of its rated value for cell temperature greater than 49^{o}C. Mustapha et al. [8] while evaluating the performance of a polycrystalline solar photovoltaic module under Maiduguri-Nigeria weather conditions have shown that current generated is directly proportional to solar irradiance and is almost independent of temperature. The maximum rated power was achieved during the sunniest month and module current increased by 0.1 A/^{o}C with increase in temperature, while module voltage decreased by 0.05 V/^{o}C leading to increase in power with increase in temperature.

Many authors [2,9,10] have reported more power yield in summer compared to winters. Babatunde and Abbasoglu [10] while evaluating a power plant in Northern Cyprus found that energy production in summer was 111% higher than in winters and concluded that long duration of high solar radiation outweighs the negative effect of temperature. Panagea et al. [11] have shown that relative contribution of temperature and irradiance varies from region to region. In some cases, the two parameters mutually compensate each other. In some region like Eastern Greece the effect of

temperature is negative, while in Western Greece the effect of temperature is outweighed by significant increase in radiation and lower cloud coverage, increasing power by 4-5%.

2. METHODOLOGY

The data and result correspond to of the 5 MW grid connected PV power plant located at Ramgarh, in district Jaisalmer of Western Rajasthan. The analysis is based on the average reading of five array with maximum rated dc voltage, maximum rated dc current and maximum rated dc power being equal to 735.36V, 161.4A and 118.687KW respectively at STC conditions.

i. The data corresponds to data over a period of one year from September 2015-August 2016.
ii. In real field cell temperature varies linearly with irradiance and concurrent effect of temperature and irradiance is evaluated by analysing various parameters on daily basis in the same time interval.
iii. The dc power, dc voltage, dc current, cell temperature, ambient temperature and plane of array irradiance are designated as P_{dc}, V_{dc}, I_{dc}, T_c, T_{amb} and POA respectively.
iv. P_{dc} is evaluated in the time interval when V_{dc} experiences negative effect of temperature.
v. The V_{dc} experiences negative effect of temperature for cell temperature greater than 48-49^oC. The cell temperature increases with increasing POA and decreases with decreasing POA. However, as the cell temperature cannot change instantaneously there is a short duration of about half an hour soon after POA starts reducing for which cell temperature increases with decreasing POA. In this interval P_{dc} reduces slightly due to increase in temperature and decrease in POA but is insignificant and is not considered in this paper.
vi. V_{dc}, I_{dc} and P_{dc} are evaluated in % with reference to their maximum rated value and are designated as V_r, I_r and P_r respectively.
In particular
$V_r = (V_{dc}/ V_{rated})*100$; $I_r = (I_{dc}/I_{rated})*100$; $P_r = (P_{dc}/P_{rated})*100$.
vii. Change in V_{dc}, I_{dc}, P_{dc}, POA, T_{amb} and T_c are designated as ΔV, ΔI, ΔP, ΔPOA, ΔT_{amb} and ΔT_c where
- $\Delta V = V_2 – V_1$; V1 = V_{dc} at time X_1; $V_2 = V_{dc}$ at time X_2;
- $\Delta I = I_2 – I_1$; $I_1 = I_{dc}$ at time X_1; $I_2 = I_{dc}$ at time X_2;
- $\Delta P = P_2 – P_1$; $P_1 = P_{dc}$ at time X_1; $P_2 = P_{dc}$ at time X_2;
- $\Delta POA = POA_2 – POA_1$; POA_1 = POA at time X_1; POA_2 = POA at time X_2 ;
- $\Delta T_{amb} = T_{amb2} – T_{amb1}$; T_{amb1} is cell temperature at time X_1; T_{amb2} is cell temperature at X_2
- $\Delta T_c = Tc_2 – T_{c1}$; T_{c1} is cell temperature at time X_1; T_{c2} is cell temperature at X_2
- X_2-X_1 represents the only time interval when V_{dc} experiences negative effect of temperature.

viii. Percentage change in V_{dc}, I_{dc} and P_{dc} with reference to their maximum rated value are designated as ΔV_r, ΔI_r and ΔP_r
Where
$\Delta V_r = (\Delta V/ V_{rated})*100$; $\Delta I_r = (\Delta I/ I_{rated})*100$; $\Delta P_r = (\Delta P/ P_{rated})*100$
ix. Weather monitoring station, pyranometer, and SCADA (Supervisory Control and Data Acquisition) are used to record and store various data.
x. The irradiance considered is the irradiance incident on the plane of the array- POA instead of GHI.
xi. The effect of other climatic parameters like wind speed and humidity have not been considered.

3. EXPERIMENTAL DATA ANALYSIS

The joint effect of temperature and irradiance on dc voltage, dc current and dc power output of a multicrystalline PV plant are visualised by plotting various parameters with respect to time on daily basis when Western Rajasthan experiences long duration of very high irradiance and correspondingly high temperature. Data is also analysed for the month having lowest temperature and lowest irradiance. The results for all dates in a month having similar weather conditions are almost similar although specific dates of the month have been chosen randomly.

3.1 Concurrent effect of temperature and irradiance on P_{dc}, V_{dc} and I_{dc} for 13th May 2016

Effect of temperature on V_{dc} in the time interval when V_{dc} experiences negative effect of temperature is analysed. The effect of irradiance on I_{dc} in the same time interval is analysed. Relative contribution of temperature and irradiance on P_{dc} is evaluated by visualising and analysing P_{dc} in the same time interval.

3.1.1 Effect of temperature on V_{dc} for 13th May 2016

Literature shows that with increase in cell temperature above 25^oC there is substantial drop in voltage while the while voltage variations are very small with increase in irradiance [12,13]. However, in contrast the real field analysis shows entirely different results as shown in figure 1.

The effect of high cell temperature on V_{dc} has been analysed by considering three different dates of the month having very high temperature for long duration. The time with corresponding POA over the interval when V_{dc} is reducing is marked in figure1.

The graphs of figure 1 and 2 demonstrate following attributes.

- Starting from the wake-up voltage V_{dc} drops rapidly as the sun begins to rise but very soon it starts increasing rapidly with increasing POA and increasing cell temperature. In the time duration 8:17:42 to 10:16:28, V_{dc} increases as POA increases from 373.58W/m^2 to 733.01W/m^2, cell temperature increases from 39.87^oC to 49.15^oC, reaching point of saturation, attaining 631.16V nearly 85% of its rated value at ambient temperature 37.90^oC and cell temperature 49.15^oC as shown in figure 1. The corresponding value of POA is equal to 733.01W/m^2 and is marked in figure 2.

- The negative effect of temperature on V_{dc} voltage is observed only in the time interval 10:16:28 to 12:44:55 after V_{dc} attains saturation and cell temperature is greater than 49^oC with corresponding increase in POA from 733.01W/m^2 to 916.81W/m^2. In this interval the following attributes are observed and are shown vide figure 1-

  (i) Cell temperature increases from 49.15 ^oC to 59.97 ^oC
  (ii) Ambient temperature increasing from 37.90^oC to 41.98^oC
  (iii) V_{dc} reduces from 631.16V to 601.07V i.e. from 85.8% to 81.73 % of its rated value but still V_{dc} is significant compared to its value for cell temperature less than 49^oC.

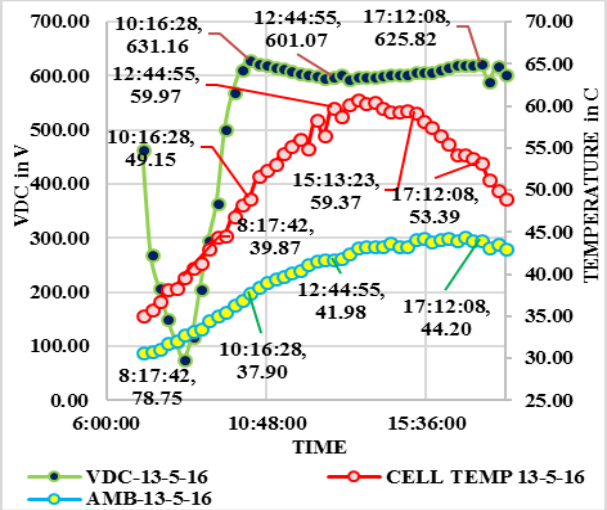

Figure 1- Variation of V_{dc}, T_c and T_{amb} with respect to time for 13th of May 2016

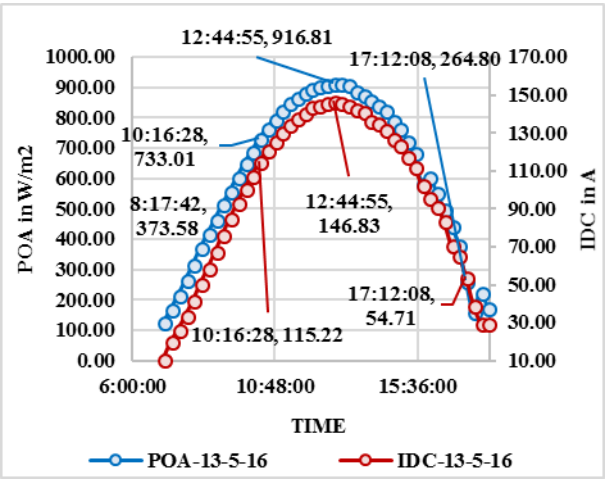

Fig-2 Variation of POA and I_{dc} with respect to time for 13th of May 2016

• With decreasing POA, cell temperature starts reducing consequently V_{dc} starts increasing although ambient temperature continues to increase. V_{dc} increases from 601.07 to 625.87V as cell temperature reduces gradually from 59.97 ^oC to 53.39^oC showing that V_{dc} is governed by cell temperature and not ambient temperature.

Thus, despite the negative effect of temperature on dc voltage, it remains within 85-80% of its rated value which is very high compared to V_{dc} at cell temperature less than 49^oC, making negative effect of temperature almost insignificant. In fact, in contrast to literature, this itself is the most remarkable positive effect of high temperature.

3.1.2 Effect of irradiance on I_{dc} for 13th May 2016

Literature shows that at constant cell temperature (25^oC), current increases in direct proportion to irradiance and increases slightly with increase in temperature [12,13]. In real field the increase in irradiance is so large compared to increase in temperature that I_{dc} varies linearly with POA irrespective of temperature showing strong dependence on irradiance.

In the time interval 10:16:28 to 12:44:55 when V_{dc} shows negative effect of cell temperature there is significant increase in POA from 733.01W/m^2 to 916.81W/m^2 although increase in cell temperature is only 10^oC, the result is perfectly linear increase of I_{dc} with POA from 115.22A to 146.83A shown vide figure 2.

3.1.3 Joint Effect of temperature and irradiance on P_{dc}

The joint effect of two parameters is observed in the time interval when V_{dc} experiences negative effect of temperature.

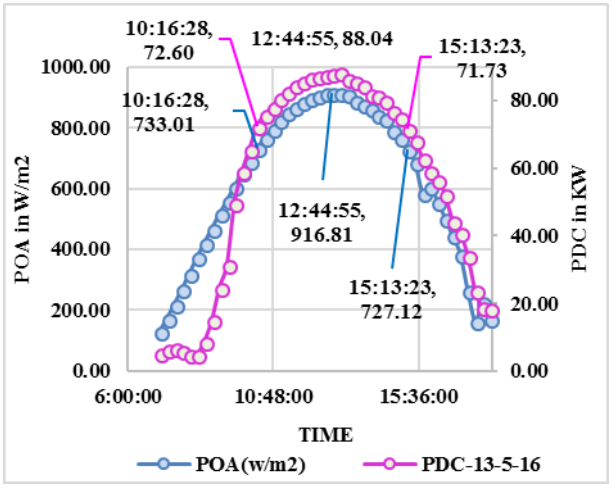

Figure 3- Variation of P_{dc} and POA with time for 13th of May 2016

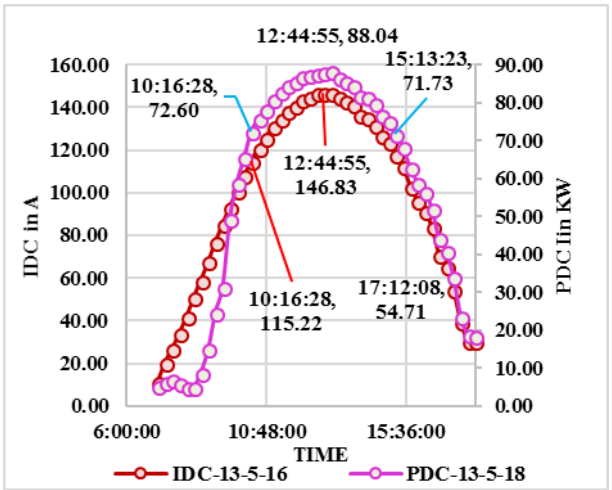

Figure 4- Variation of I_{dc} and P_{dc} with respect to time for 13th May 2016

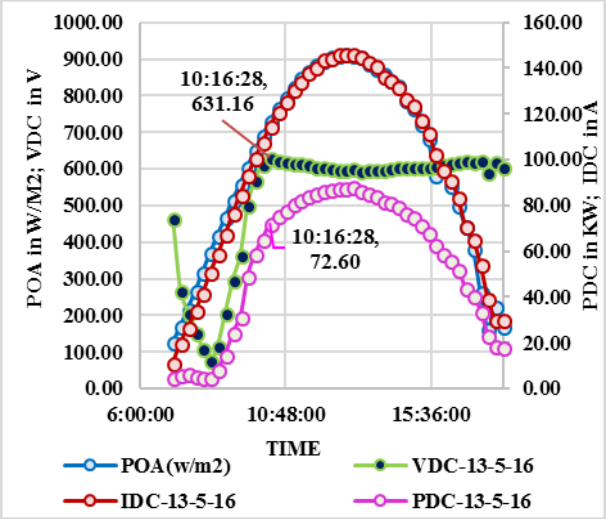

Figure 5- Variation of POA, V_{dc}, I_{dc} and P_{dc} with time for 13th May 2016

In time duration 10:16:28 to 12:44:55 when V_{dc} decreases due to increase in temperature I_{dc} increases due increase in POA. The increase in I_{dc} is much greater than decrease in V_{dc}, the result is that P_{dc} increases from 72.60KW to 88.04KW as shown in figure 3.

Once V_{dc} attains constant value variation in V_{dc} are negligible compared to large variation in current due to large variation in irradiance compared to small variations in cell temperature. As a result, P_{dc} varies in accordance to voltage until V_{dc} attains the point of saturation. Thereafter it varies in accordance to POA and I_{dc} as large variations in current now overtakes slight changes in voltage shown vide figure 4-5. The results are summarised in table 1.

Table 1- Evaluation of relative contribution of Irradiance and temperature for 13th of May 2016 on P_{dc} in the time interval when V_{dc} experiences negative effect of temperature.

Time interval	POA in W/m^2	Ambient temperature in ^{O}C	Cell temperature in ^{O}C	V_{dc} in V	V_r in %	I_{dc} in A	I_r in %	P_{dc} in KW	P_r in %
X_1 = 10:16:28 am	POA_1= 733.01	T_{amb1} = 37.90	T_{c1} = 49.15	V_1 = 631.16	85.83	I_1 = 115.22	71.38	P_1 = 72.60	61.2
X_2 = 12:44:55 pm	POA_2= 916.81	T_{amb2} = 41.98	T_{c2} = 59.97	V_2 = 601.07	81.73	I_2 = 146.83	90.1	P_2 = 88.04	74.2
$\Delta X = X_2 - X_1$ = 2:30 hrs	ΔPOA = +183.8	ΔT_{amb} = +4.08	ΔT_c = +10.82	ΔV = -30.09	ΔV_r = -4.09	ΔI = +31.61	ΔI_r = +19.1	ΔP = +15.44	ΔP_r = +13

The results of table clearly show that in the time interval 10:16:28 to 12:44:55, the only time when V_{dc} experiences negative effect of cell temperature.

- POA increases by 183.8W/m^2.
- Increase in cell temperature is only 10.82 ^{o}C.
- Decrease in V_{dc} is about 4% of its maximum rated value but still its value is within 86% to 82% of its rated value, which is very high compared to dc voltage at 25^{o}C.
- Increase in current is about 19% of its maximum rated value.
- P_{dc} increase by 13% of its maximum rated value, a remarkable increase in P_{dc} with increase in temperature.

Thus, high value of irradiance outweighs the negative effect of temperature making dc power output independent of temperature showing extraordinarily overall positive effect of high irradiance and high temperature.

Similar results are obtained for all clear sunny days having high irradiance and high cell temperature although results of 4th June and 11th July have been evaluated randomly.

3.2 Concurrent effect of temperature and irradiance on V_{dc}, I_{dc} and P_{dc}, for 4th of June 2016

The joint effect of irradiance and cell temperature for 4th June can be visualised in figure 6-7 and is evaluated in table 2.

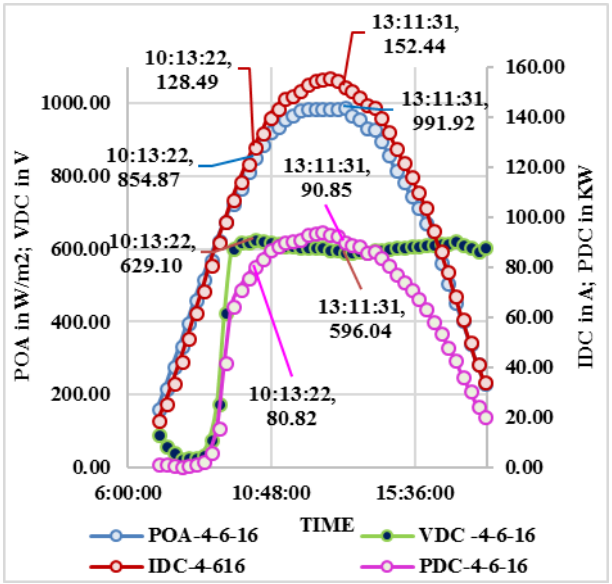

Figure 6- Variation in POA, V_{dc}, I_{dc} and P_{dc} with time for 4th June 2016

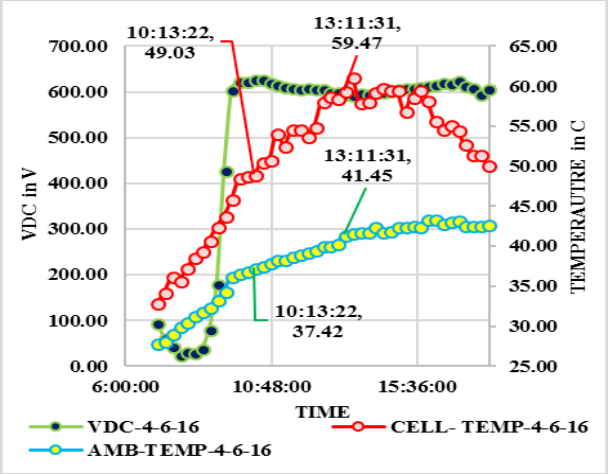

Figure 7- Variation of V_{dc}, T_c and T_{amb} with time for 4th June 2016

Table 2- Evaluation of relative contribution of Irradiance and temperature for 4th of June 2016 on P_{dc} in the time interval when V_{dc} experiences negative effect of temperature.

Time interval	POA in W/m²	Ambient temperature in °C	Cell temperature in °C	V_{dc} in V	V_r in %	I_{dc} in A	I_r in %	P_{dc} in KW	P_r in %
X_1 = 10:13:22	POA_1= 854.87	T_{amb1} = 37.42	T_{c1} = 49.03	V_1 = 629.10	85.56	I_1 = 128.49	79.7	P_1= 80.82	68.1
X_2 = 13:11:31	POA_2 = 991.92	T_{amb2} = 41.45	T_{c2} = 59.47	V_2 = 596.04	81.05	I_2 = 152.44	94.44	P_2= 90.85	76.54
$\Delta X = X_2 - X_1$ = 3hrs	ΔPOA= +137.05	ΔT_{amb} = + 4.03	ΔT_c = +10.44	ΔV = -33.06	ΔV_r = -4.51	ΔI = +23.95	ΔI_r = +14.83	ΔP = +10.03	ΔP_r = +8.45

The results again confirm remarkable increase in P_{dc} with increasing temperature for high value of irradiance and consequently resulting high temperature.

3.3 Concurrent effect of temperature and irradiance on V_{dc}, I_{dc} and P_{dc} for 11th July 2016

The joint effect of irradiance and cell temperature for 11th July can be visualised in figure 8-9 and is evaluated in table 3.

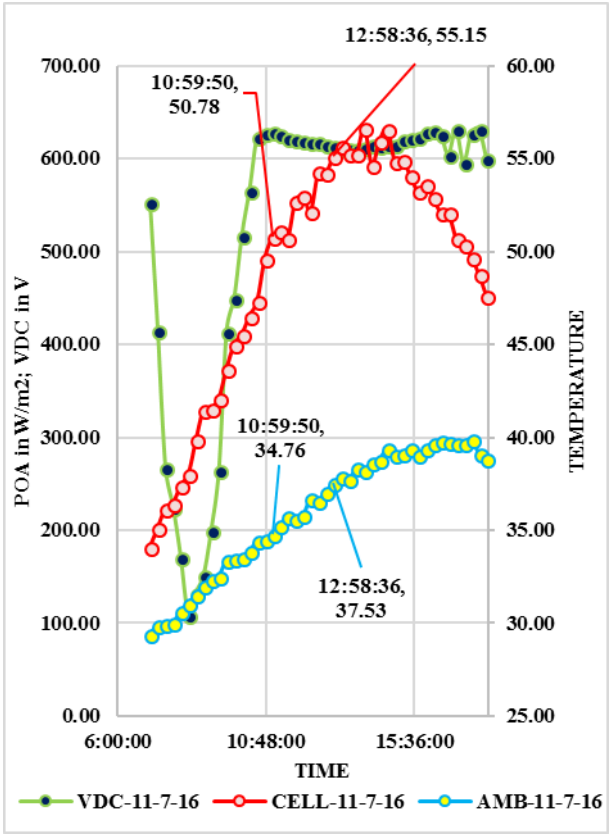

Figure 8- Variation of V_{dc}, T_c and T_{amb} with time for 11th July 2016

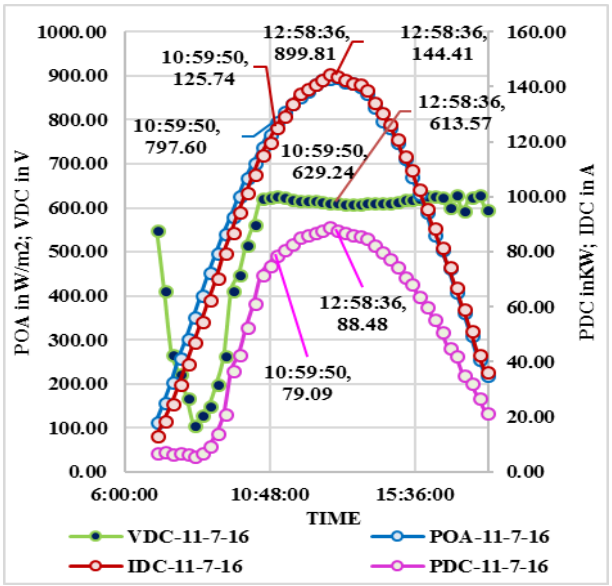

Figure 9- Variation in POA, V_{dc}, I_{dc} and P_{dc} with time for 11th of July 2016

Communications on Applied Electronics (CAE) – ISSN : 2394-4714
Foundation of Computer Science FCS, New York, USA
Volume 7 – No. 19, August 2018 – www.caeaccess.org

Table 3- Evaluation of relative contribution of Irradiance and temperature for 11th of July 2016 on P_{dc} in the time interval when V_{dc} experiences negative effect of temperature

Time interval	POA in W/m^2	Ambient temperature in ^oC	Cell temperature in ^oC	V_{dc} in V	V_r in %	I_{dc} in A	I_r in %	P_{dc} in KW	P_r in %
X_1 = 10:59:50	POA_1 = 797.60	T_{amb_1} = 34.76	T_{c1} = 50.78	V_1 = 629.24	85.35	I_1 = 125.74	77.9	P_1 = 79.09	66.63
X_2 = 12:58:36	POA_2 =899.81	T_{amb_2} = 37.53	T_{c2} = 55.15	V_2 = 613.57	83.36	I_2 =144.41	89.5	P_2 = 88.48	74.6
$\Delta X = X_2 - X_1$ ~ 2hrs	ΔPOA= +102.21	ΔT_{amb} = 2.77	ΔT_c= +4.37	ΔV = 15.7	ΔV_u = -1.9	ΔI = +18.67	ΔI_r = +11.56	ΔP = +9.47	ΔP_u = +7.987

The outcomes of table 1-3 undoubtedly illustrate that large variations in irradiance dominates over the sensitivity to temperature and so the dc power increases with increase in temperature.

Table 4- Estimation of average variation in irradiance and temperature and joint effect of two on V_{dc}, I_{dc} and P_{dc}

Date	ΔPOA in W/m^2	ΔT_c in ^oC	ΔV_r in %	ΔI_r in %	ΔP_r in %
13-05-16	ΔPOA_1 = +183.8	ΔT_{c1} = +10.82	ΔV_{r1} = -4.09	ΔI_{r1} = +19.1	ΔP_{r1} = +13
4-06-16	ΔPOA_2 = +137.05	ΔT_{c2} = +10.44	ΔV_{r2} = -4.51	ΔI_{r2} = +14.83	ΔP_{r2} = +8.45
11-07-16	ΔPOA_3 = +102.21	ΔT_{c3} = +4.37	ΔV_{r3} = -2.1	ΔI_{r3} = +11.56	ΔP_{r3} = +7.978
Average	ΔPOA_{avr} = +141.02	ΔT_{avr} = +8.54	ΔV_{avr} = -3.566	ΔI_{avr} = +15.16	ΔP_{avr} = +9.8

Where

$\Delta POA_{avr} = (\Delta POA1 + \Delta POA_2 + \Delta POA_3)/3$; $\Delta T_{avr} = (\Delta T_{c1} + \Delta T_{c2} + \Delta T_{c3})/3$;

$\Delta V_{avr} = (\Delta V_{r1} + \Delta V_{r2} + \Delta V_{r3})/3$; $\Delta I_{avr} = (\Delta I_{r1} + \Delta I_{r2} + \Delta I_{r3})/3$;

$\Delta P_{avr} = (\Delta P_{r1} + \Delta P_{r2} + \Delta P_{r3})/3$;

Variation in irradiance and temperature varies from day to day but for clear sunny days, roughly for every 100W/m^2 increase in irradiance temperature increases only by 5-6^{o}C. As a result, V_{dc} drops slightly around 2-3% while Idc increases significantly around 10-11% and correspondingly P_{dc} increases by 7-8%. Thus, the joint effect of two is positive confirming extraordinarily positive effect of high irradiance and high cell temperature.

3.4 Data analysis for the month of December, the coldest month of Western Rajasthan, particularly 22-12-15

The data for the month of December when Western Rajasthan has low irradiance and low temperature is also analysed to confirm the extraordinary positive effect of high irradiance and high temperature.

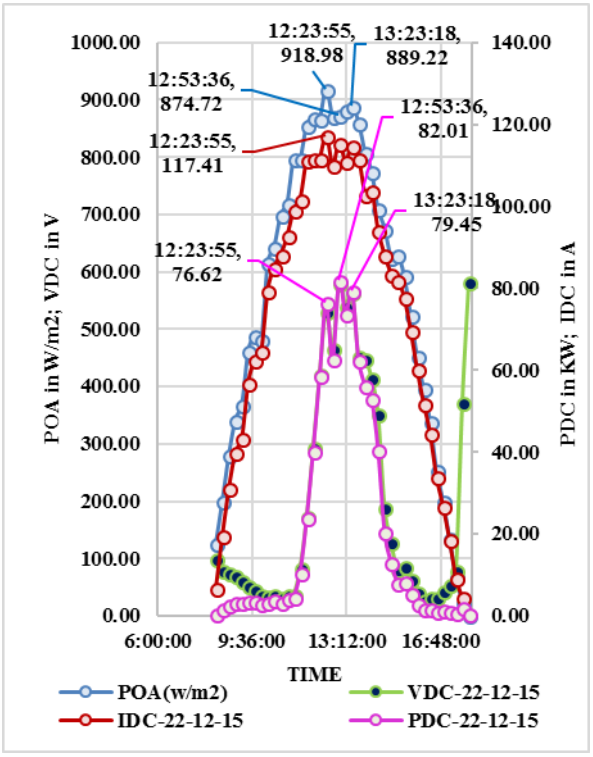

Figure 10- Variation in POA, V_{dc}, I_{dc} and P_{dc} with time for 22nd December 2015

In the month of December as the cell temperature is less than 47^{o}C, V_{dc} does not attain constant value. It drops rapidly with decreasing POA even though cell temperature starts reducing. P_{dc} varies in accordance to V_{dc} even though I_{dc} varies linearly with POA as variations in V_{dc} are large compared to variations in I_{dc}. High P_{dc} is obtained only for very short time. Time interval for which P_{dc} is greater than 60% of its rated value is evaluated in table 5.

Table 5- Evaluation of time duration for which P_{dc} is greater than 60% of its rated value

Date	Time X_1	POA at X_1 in W/m^2	Cell temperature at X_1 in ^{o}C.	P_{dc} at X_1 in KW	P_r at X_1 in %	Time X_2	POA at X_2 in W/m^2	Cell temperature at X_2 in ^{o}C	P_{dc} at X_2 in KW	P_r at X_2 in %	Time interval X_2-X_1 in hours

13.05.16	**10:16:28**	**733.01**	**49.15**	**72.60**	**61.2**	**15:13:23**	**727.12**	**59.37**	**71.73**	**60.4**	**~5:00**
4.06.16	**9:43:41**	**772.61**	**48.62**	**71.66**	**60.4**	**15:25:07**	**751.45**	**58.75**	**71.44**	**60.2**	**~5:48**
11.07.16	**10:30:09**	**740.13**	**47.36**	**72.15**	**60.8**	**15:12:13**	**716.44**	**54.94**	**71.51**	**60.3**	**~4:42**
22.12.15	**12:23:55**	**918.98**	**39.58**	**76.62**	**64.6**	**13:23:18**	**889.22**	**41.72**	**79.45**	**67**	**~1:00**

Table 5 clearly shows that for the clear sunny days having long duration of high irradiance and consequently high temperature, P_{dc} is greater than 60% of its rated value for 5-6 hours. On the other hand, in winters when high irradiance exists for very short duration, the subsequent cell temperature is also lower so P_{dc} greater than 60% of its rated value is obtained only for one hour. Further when P_{dc} is greater than 60% of its rated value, the corresponding cell temperature is in the range of 49-62^{o}C. In winters when cell temperature is low, higher Pdc is obtained for much higher value of POA, the reason being that although I_{dc} varies in direct proportion to POA, higher V_{dc} is obtained only for cell temperature greater than 48-49^{o}C. Maximum P_{dc} equal to 94.68KW that is 80% of its maximum rated value is obtained on 4th of June at cell temperature 58.14^{o}C. In fact, P_{dc} greater than 60% of its rated value is obtained for POA greater than 730W/m^2 and cell temperature greater than 48-49^{o}C. Thus, despite slight negative effect of high cell temperature, high irradiance and high cell temperature in the range of 48-62^{o}C has substantial positive effect on P_{dc}.

4. RESULT

The multicrystalline PV module gives excellent performance at high cell temperature and high irradiance.

- The cell temperature is directly proportional to irradiance.
- One of the most significant positive aspect of high cell temperature is that V_{dc} attains high nearly 86-80% of its rated value for cell temperature in the range of 48-62^{o}C.
- At high irradiance and subsequently resulting high temperature variations in POA are prominent compared to variations in cell temperature, the result is irradiance dominates over the negative effect of cell temperature.
- Long duration of high POA is bound to increase cell temperature to a very high value. The result is high V_{dc} due to high T_c, high I_{dc} due to high POA leading to high P_{dc} for 5-6 hours.
- Shorter duration of high POA results in lower cell temperature as change in panel temperature cannot be instantaneous. The result is lower V_{dc} at lower T_c, high I_{dc} for short duration leading to high P_{dc} for only one hour.
- P_{dc} greater than 60% of its maximum rated value is obtained for cell temperature in the range of 48-62^{o}C.
- At lower cell temperature high value of P_{dc} is obtained for correspondingly high value of POA.

In contrast to literature and research papers, all the above points signify extraordinarily positive effect of high cell temperature and high irradiance on dc power output which directly governs the efficiency of a PV power plant. The above results have been evaluated for the climatic conditions of Western Rajasthan and it can be predicted that above results will hold true for all sites having clear sunny sky with high insolation.

5. CONCLUSION

In contrast to negative effect of cell temperature greater than 25^{o}C cited in literature and research papers the results of this paper confirm to extraordinary positive effect of high cell temperature a consequence of high irradiance on the performance of a multicrystalline PV module. The negative effect of cell temperature on V_{dc} itself is insignificant which is further overruled by substantial increase in irradiance. In fact, cell temperature greater than 49^{o}C and POA greater than 750 W/m^2 are required to obtain high energy yield. The efficiency of plant being directly proportional to dc power increases significantly for cell temperature greater than 49^{o}C and POA greater than 750 W/m^2. Use of low cost reflector and concentrators in countries having lower irradiance and temperature or in winters in Western Rajasthan can increase the efficiency of plant considerably. As further work solar energy conversion efficiency, efficiency of PV solar power plant for multicrystalline and other types of photovoltaic cells in different seasons of Western Rajasthan needs to be evaluated. Also, seasonal and annual performance prediction of PV plants for the climatic conditions of Western Rajasthan and way to enhance the performance are to be done. In addition, viability and impact of use of reflectors and concentrators need to be analysed.

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.

7. REFERENCES

[1] Attari. K. Yaakoubi. A. E. Asselman. A. Comparative Performance Investigations between photovoltaic system for two different cities. 10th International conference inter disciplinary in Engineering, Inter-Eng 2016. Procedia Engineering 181 (2017) 810–817. Available online at www.sciencedirect.com.

[2] Huld. T. and Gracia, Amillo. A. M. Estimating PV Module Performance over Large Geographical Regions: The Role of Irradiance, Air Temperature, Wind Speed and Solar Spectrum. Energies 2015, 8, 5159-5181; www.mdpi.com/journal/energies.

[3] Bhattacharya. T. Chakraborty. A. K and Pal. K. Effects of Ambient Temperature and Wind Speed on Performance of Monocrystalline Solar Photovoltaic Module in Tripura, India. Hindawi Publishing Corporation, Journal of Solar Energy, Volume 2014, Article ID 817078, 5 pages.

[4] Vasisht. M. S. Srinivasan J. Ramasesha, S K. "Performance of solar photovoltaic installations: Effect of seasonal variations." Solar Energy 131 (2016) 39–46. www.sciencedirect.com

[5] Garg, S. and JB, Arun. 2016. High Temperature Effect on Multicrystalline Photovoltaic Module in Western

Rajasthan, India. Communications on Applied Electronics (CAE) – ISSN: 2394-4714 Foundation of Computer Science FCS, New York, USA, Volume 4 – No.2, January 2016 – www.caeaccess.org.

[6] Garg, S. JB, Arun and Surana, D. C. 2016. Performance of a Multicrystalline Photovoltaic Module in Critical Climatic Conditions of Western Rajasthan, India. 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

[7] Garg, S. and JB, Arun. 2017. Evaluating DC Voltage Temperature Coefficient of a Multicrystalline Module in Actual Environmental Conditions of Western Rajasthan, India Communications on Applied Electronics (CAE) – ISSN : 2394-4714 Foundation of Computer Science FCS, New York, USA Volume 7 – No. 6, September 2017 – www.caeaccess.org

[8] Mustapha. I. Dikwa M. K. Musa B. U and Abbagana M. Performance evaluation of polycrystalline solar photovoltaic module in weather conditions of Maiduguri, Nigeria. Arid Zone Journal of Engineering, Technology and Environment. August, 2013; Vol. 9, 69-81.

[9] N. Ciprian, M. Florin, A. Dragos. Annual Energy harvest of LACARP photovoltaic Systems. 6th International conference on modern Power systems MPS 2015, 18-21 May 2015, Cluj -Napoca, Romania

[10] Babatunde, A. A, Abbasoglu, S. Evaluation of field data and simulation results of a photovoltaic system in countries with high solar radiation. Turkish Journal of Electrical Engineering & Computer Sciences. August 2014.

[11] Panagea, S. I, Tsanis, K.I Koutroulis, G.A. and. Grillakis, G.M. Climate Change Impact on Photovoltaic Energy Output: The Case of Greece. Hindawi Publishing Corporation Advances in Meteorology Volume 2014, Article ID 264506, 11 pages http://dx.doi.org/10.1155/2014/264506

[12] Masters, G. M. Renewable and efficient electric power systems. Wiley Interscience. 2004.

[13] Mayfield, R. Photovoltaic design and installation for dummies. Wiley Publishing Inc. 2010.