Matlab/Simulink Modeling to study the effect of partially shaded condition on Photovoltaic array's Maximum Power Point

Khaled Matter[1], Hala J. El-Khozondar [2], Rifa J. El-Khozondar[3], Teuvo Suntio[4]

[1]*Electrical Engineering Department, Islamic University of Gaza, Palestine.*
[2]*Electrical Engineering Department, Islamic University of Gaza, Palestine, Email: hkhozondar@iugaza.edu.ps*
[3]*Physics Department, Al-Aqsa University, Gaza, Palestine.*
[4]*Dept of Electrical Engineering, Tampere University of Technology, Finland.*

Abstract - ***Solar energy is an important source of renewable energy due to the easy access to the source. One drawback in this system is achieving the maximum efficiency of the system. The photovoltaic (PV) cell is the fundamental unit in the power conversion of the solar system. The extracted maximum output power of PV cell reduces when it exposes to partial shading causing remarkable reduction in the efficiency of the system. In this work, PV modules under various shading condition is simulated using Matlab/Simulink. Results show that the power-voltage (P-V) characteristic of PV modules exhibit several local maximum power points (MPP) in comparison with unique MPP in case of full insolation causing more complication to the system and a noticeable reduction in the efficiency of the system.***

Key Words: *PV, MPP, Partial shading, Matlab simulation.*

1. INTRODUCTION

The rapid development of renewable, clean and green energy technology plays an important role in clean application especially in electric power generation. Energy obtained from renewable resources including sun, wind, biofuels and others is called renewable energy [1]. Solar energy, the most popular form of renewable energy, provides electric energy directly by using PV modules then using MPP tracker (MPPT) to maximize the efficiency of the PV system. The PV system has a single MPP at the peak values of voltage and current [2]. The power yield of PV modules is a function of different weather conditions including solar irradiance [3], temperature [4] and partial shading [2]. However, Chin [2] did not consider a detailed description of shading effects on the PV parameters. This paper aims to present a detailed study of various shading conditions on PV modules.

Section 2 is dedicated to present the equivalent circuit to a PV cell. The effect of Partial Shading on a PV cell is explained in section 3. Matlab/Simulink numerical simulation of PV module exposed to different shading effects is presented in section 4. Finally, the conclusion is given in Section 5.

2. PHOTOVOLTAIC EQUIVALENT MODEL

PV array consists of solar cell stacks. Solar cell turns light into electricity. A solar cell equivalent circuit is displayed in Fig-1. It is simply consist of a diode, a photo current (I_{PH}), an internal resistor (R_S), and a shunt resistor (R_{SH}). The current at the terminal of the solar cell is formulated as follows [2]:

$$I = I_{PH} - I_S\left[exp\left(q\frac{(V + IR_S)}{KT_C A}\right) - 1\right] - \frac{V + IR_S}{R_{SH}} \quad (1)$$

where I_S is the saturation current, q stands for electron charge, k is Boltzmann's constant, T_C is the temperature in Kelvin, and A is an ideal factor.

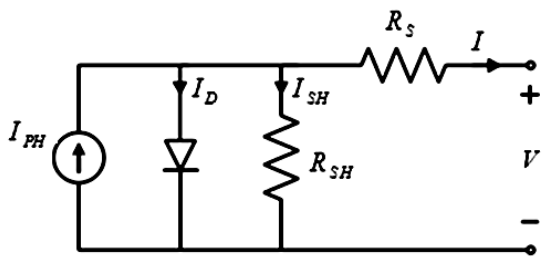

Fig -1: Equivalent circuit of a PV cell

In a simple representation to a PV cell, $R_{SH} = \infty$ *and* $R_S = 0$ [5]. This ideal case is not possible; however, scientists work to reduce the effect of both the series and the shunt resistance**.** Usual PV cell yields below 2W at 0.5V, which is considerably low. For larger output power values, a PV array is used, which consists of several modules connected in series and parallel arrangements. Each module is composed of PV cells connected in series and parallel.

PV modules are simulated using either mathematically using math function block or physically using SimPowerSystems toolbox. In general, the mathematical approach is easier to use than the physical model. In the

© 2015, IRJET.NET- All Rights Reserved

mathematical model; on the contrary to physical model, to attain a series-parallel combination for a PV cells no need for block diagram repetition [6]. Thus, in our work, we built the system depending on mathematical modeling.

3. EFFECTS OF PARTIAL SHADING ON PV

There is several factors that affect the PV output power including partial shading [7], configuration of the PV arrays, temperature, and solar insolation. Here, we will discuss the effect of several shading condition on the PV arrays that may occur due to presence of clouds, trees, and buildings [8]. The power-voltage (P-V) characteristic curves of the PV system with full insolation exhibits nonlinearity with one MPP. These complexity increases with changing insolation conditions [2] as in Figure 3 case 2. Under partial shading conditions, some of the PV cells, which collect even irradiance, will work with maximum efficiency. In the series structure, a uniform current is passing in each cell. Therefore, the cells experience shading should run in reverse biasing to yield equal current causing decrease in the value of MPP. A bypass diode is connected to selected cells in the series configuration to overcome this problem [8].

The addition of bypass diodes change the characteristics of an array. In the presence of the bypass diodes and under partial shading conditions many local MPP emerge. The bypass diodes creates a short circuit around the shaded cells allowing the current from unshaded cells to flow; therefore, the heating and array current losses are reduced[8-10].

We used a MATLAB simulation to investigate the characteristic curves of a PV array subject to diverse shading circumstances. Our model can be extended to study different MPPT techniques. Further, it can also be utilized to comprehend the dependence of output power of different PV arrangement on various shading forms. For a certain PV modules, the arrangement of PV array dramatically contributes in changing the values of the maximum power subjected to partial shading conditions [9].

4. SIMULATION OF PV ARRAY EXPOSED TO DIFFERENT PARTIAL SHADING CONDITIONS

In our simulation, we used an array consists of two PV module connected in series as in Fig-2. Each module receives numeral irradiance level. Data is taken form KC200GT panel datasheet (Appendix A) [11]. The output voltage of the system is connected to controlled voltage source to simulate the output voltage of the PV array.

The output parameters for the solar array with and without bypass diodes under different shading conditions are summarized in Table-1. The dependence of the current-voltage characteristic of PV module on shading is given in Fig-3. From Table-1 and Fig-3, we notice that we obtain almost the same values of MPP with and without using bypass diodes except in cases (7-10) in which one of the modules is under full shading. In the presence of bypass diode (e.g. Fig-3-case 3), we notice that the structure of the curves become more complex with the shading effects where several local MPP appear and one of them is the global maximum. The addition of the bypass diode becomes very important in the cases where one of the modules is under full shading (e. g. Fig-3 cases 7 and 9). We notice in cases 7 and 9 where we used bypass diode in the full shading condition in one of the module, we still obtain an output power. However, when we remove the bypass diode in cases 8 and 10, we get almost zero output power.

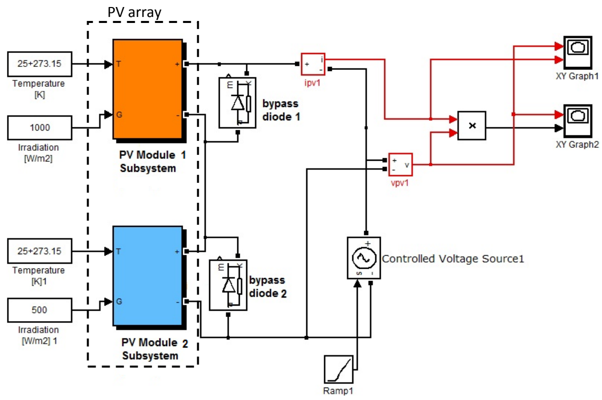

Fig-2: The Simulation block diagram of the PV array experiencing different shading conditions.

Shading causes a large reduction on total outcome power that does not commensurate with the small amount of shading. That is the relation between shading and output power is not linear. For further understanding, consider case 1 and case 3. In case 1 where both models are exposed to full irradiance condition the output power equals to 400.2 W. However, one module is under partial shading condition as in case 3, the output power decreases to 217.5 W. If the relation is linear, we might expect to get 300 W [200 W from the module under full irradiance effect and 100 W from the module under partial shading condition]. We also noticed that in cases 7 and 9, the output power is less than the expected value although we have bypass diodes. This may be interpreted that part of the power is dissipated into the deactivated parts of the circuit by the bypass diode.

We noticed that in the cases where both modules are under same irradiance condition as in case 1 and 5, we obtain little loss in the amount of output power. However, when the two modules are under different irradiance conditions as in case 3. In case 3, where module 1 is under full irradiance effect and module 2 is under partial shading effect, we expect 300 W; however, the output power is 217.5 W. We may refer this to the fact that the output power is not linearly related to the shading effect.

3. CONCLUSIONS

In this work, we examined in details the effect of different shading condition on PV modules output power. We used Matlab/Simulink to perform our simulations. For the

© 2015, IRJET.NET- All Rights Reserved

simulation, we extract our data from KC200GT panel datasheet. We realized that partial shading conditions on PV array makes the power curve more complex with the existence of multiple MPPs instead of unique MPP in the case of full insolation. In addition, we studied the effect of adding bypass diode to the modules. We conclude that the existence of the bypass diodes improve the output power value in particular in the cases where one of the modules is under full shading conditions.

REFERENCES

[1] Report issued by IEA,"Renewable Energy into Mainstream", SITTARD: The Netherlands, Oct. (2002).
[2] C. S. Chin, P. Neelakantan, S. S. Yang, B. L. Chua, K. K. Teo,"Effect of Partially Shaded Conditions on Photovoltaic Array's Maximum Power Point Tracking", *International Journal of Simulation Systems, Science & Technology* (IJSSST), vol. 12, no. 3, pp. 52-59, (2011).
[3] E. K. Syafanuddin and T. Hiyama, "Polar coordinate fuzzy controller based real-time maximum-power point control of photovoltaic system", *Renewable Energy*, vol. 34, no. 12, pp. 2597-2606, (2009).
[4] C. S. Chin, P. Neelakantan, H. P. Yoong, K. K. Teo,"Fuzzy logic based MPPT for phorovoltic modules influenced by solar irradiance and cell temperature", Proceedings of 13th international conference on computer modeling and simulation, Cambridge, United Kingdom, pp. 376-381,(2011).
[5] H. Tsai, C. Tu, Y. Su," Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK", Proceedings of the World Congress on Engineering and Computer Science (WCECS), San Francisco, USA, (2008).
[6] S. Said, A. Massoud, M. Benammar, S. Ahmed, "A Matlab/Simulink-Based Photovoltaic Array Model Employing SimPowerSystems Toolbox", *Journal of Energy and Power Engineering*, vol. 6, pp. 1965-19756, (2012).
[7] Y. J. Wang and P. C. Hsu," Analytical modelling of partial shading and different orientation of photovoltaic modules," *IET Renewable Power Generation*, vol. 4, no. 3, pp. 272–282, (2009) .
[8] M. Seyedmahmoudian, S. Mekhilef, R. Rahmani, R. Yusof , E. T. Renani ," Analytical Modeling of Partially Shaded Photovoltaic Systems", *Energies*, vol. 6, pp. 128-144, (2013), doi:10.3390/en6010128.
[9] H. Patel and V. Agarwal," MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics", *IEEE Transactions on Energy Conversion*, vol. 23, no. 1, pp. 302- 310, (2008).
[10] Y. H. Ji, D. Y. Jung, C. Y. Won, B. K. Lee, J. W. Kim," Maximum Power Point Tracking Method for PV Array under Partially Shaded Condition", Proceeding of Energy Conversion Congress and Exposition (ECCE 2009), IEEE, pp. 307-312, Sept. (2009).
[11] Datasheet of KC200GT solar panel, http://www.kyocerasolar.com/assets/001/5183.pdf

BIOGRAPHIES

Khaled Matter received the Master Degree of the control Engineering from Islamic University of Gaza in 2014. His research interest includes renewable energy and control systems. He contributed in local and international conferences.

Hala J. El-Khozondar is a professor at the EE department in the Islamic University of Gaza, Palestine. She is a recipient of Fulbright, AvH, DAAD awards, TWAS lecture medal prize, ISESCO prize, and the Islamic University Deanery Prize.

Rifa J. El-Khozondar is an associate professor at Physics department in Al-Aqsa University. She is AvH fellow and DAAD awardee. She is ICTP regular associate. She has contributed in local and international conferences.

Teuvo Suntio is Professor in Electrical Engineering (Power Electronics) in Tampere University of Technology, Finland. His research focus is on the dynamic issues in the renewable energy systems and their grid integration including photovoltaic, wind and fuel-cell systems.

© 2015, IRJET.NET- All Rights Reserved

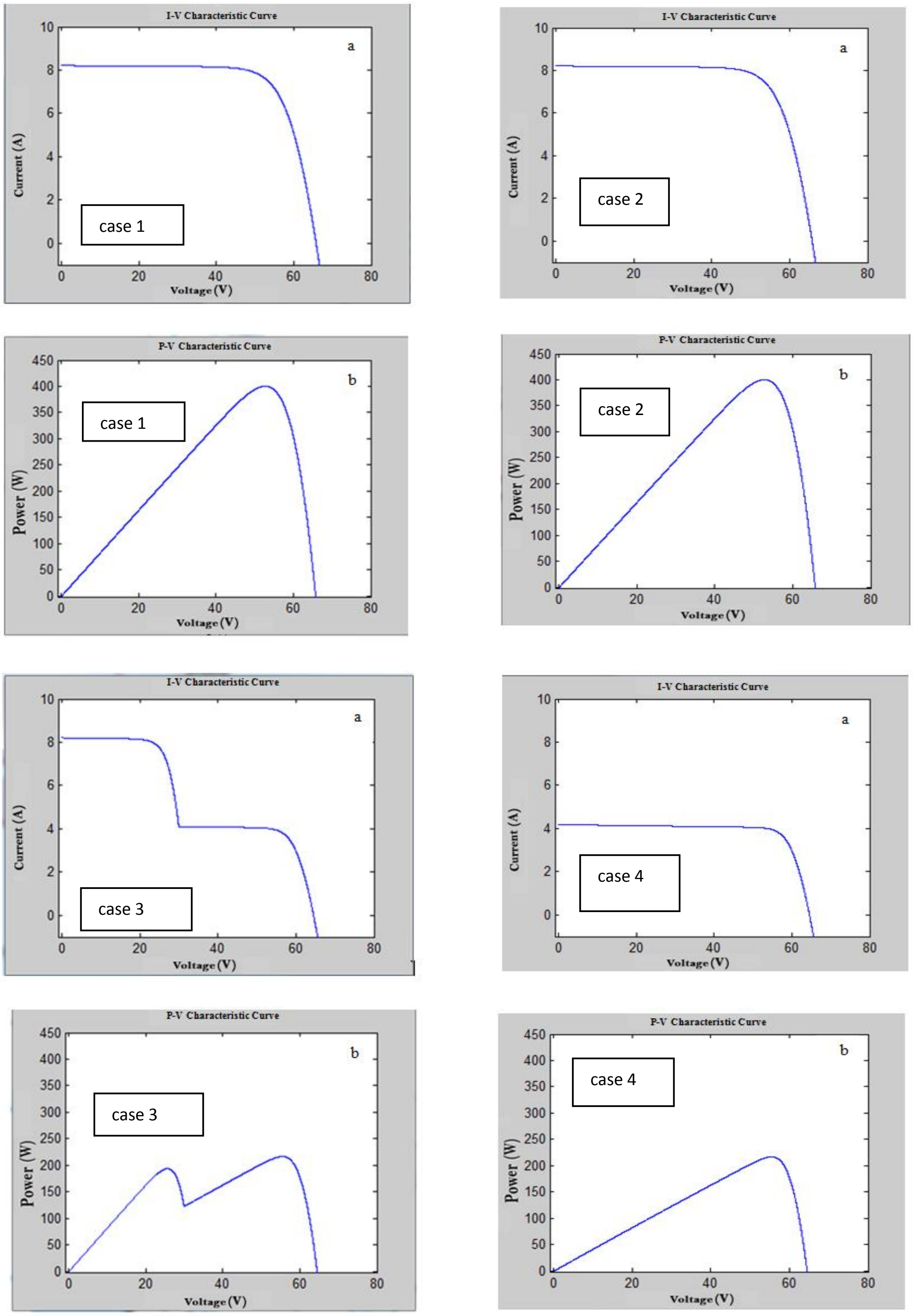

Fig-3: a) I-V curve of a PV modules subjected to various shading environments.
b) P-V curve of a PV modules subjected to various shading environments.
Cases 1-3-5-7-9 are with bypass diodes while cases 2-4-6-8-10 are without bypass diode

© 2015, IRJET.NET- All Rights Reserved

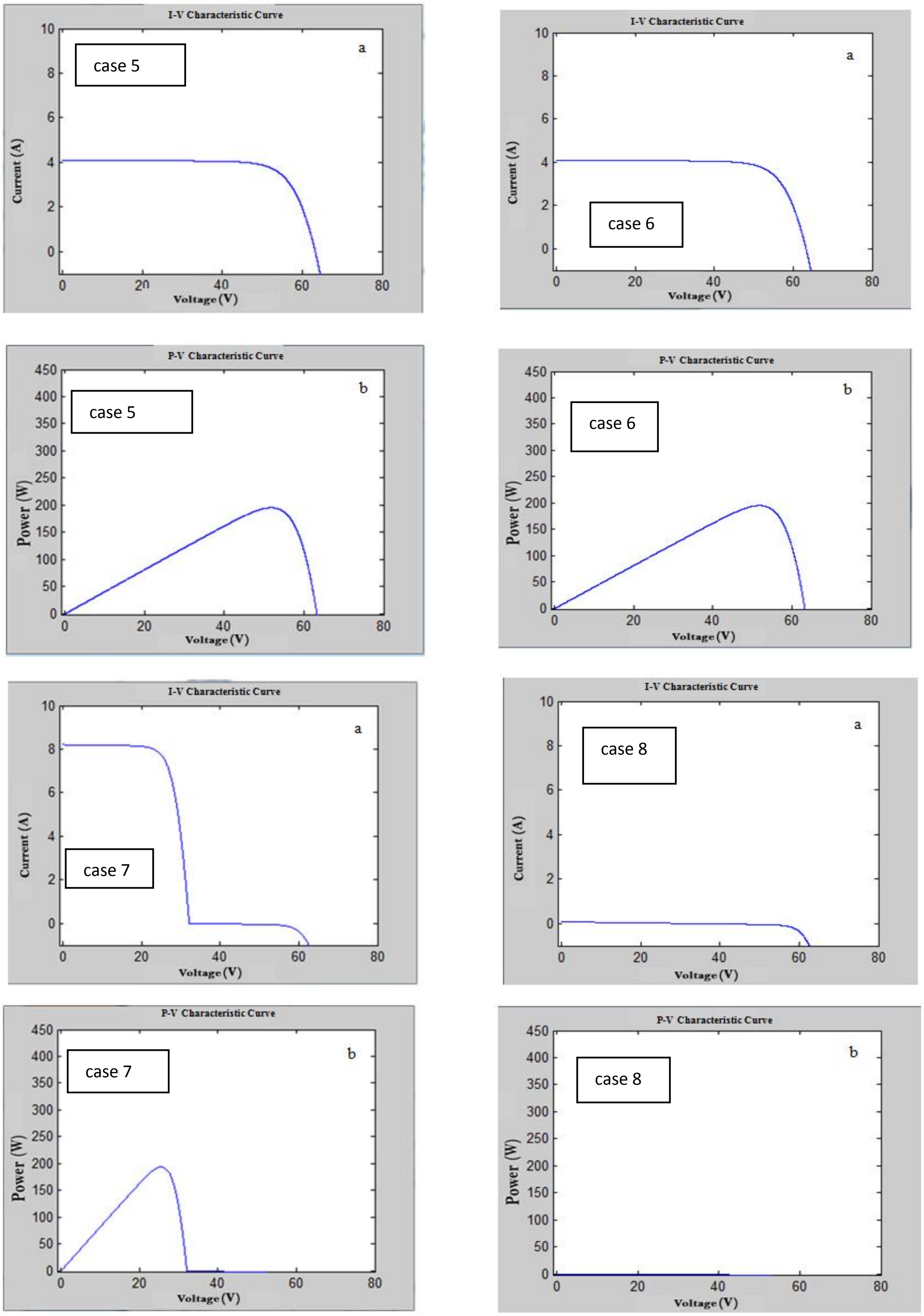

Fig-3: Continued

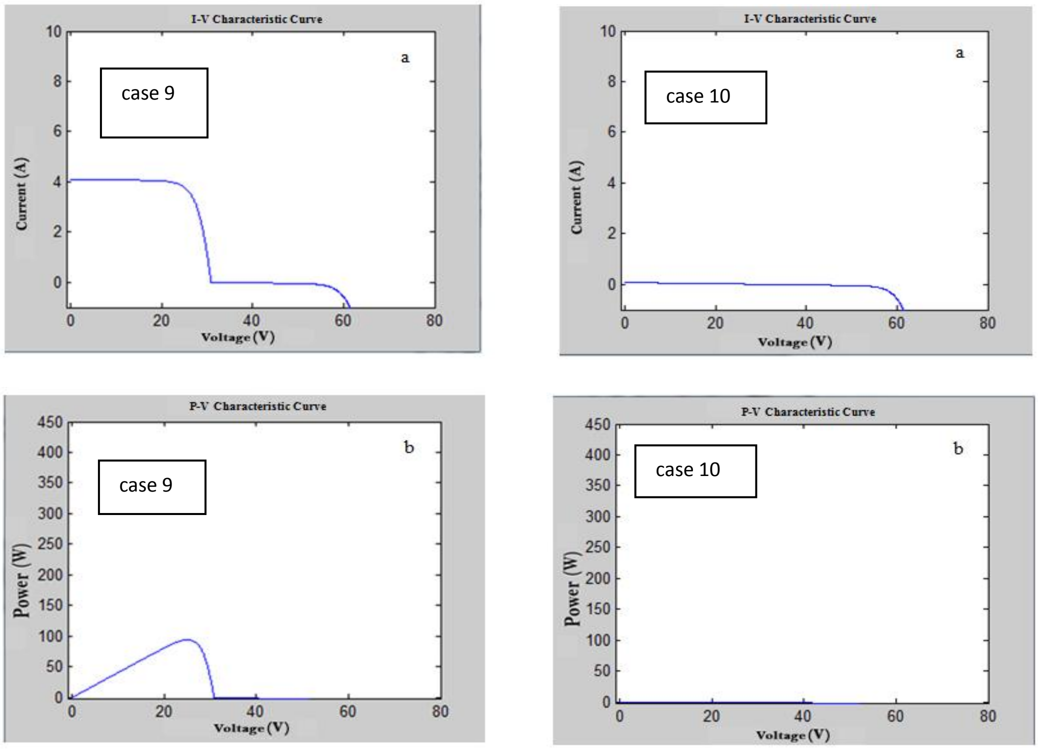

Fig-3: Continued

Table-1: Summary of diverse shading situations effects on PV modules with and without presence of bypass diodes

Case	Module 1 irradiance [W/m^2]	Module 2 irradiance [W/m^2]	MPP [W]	Voltage at MPP[V]	Current at MPP[A]
1. Both modules exposed to full irradiance in the presence of the bypass diodes.	1000	1000	400.2	52.43	7.633
2. Both modules are under full irradiance without the bypass diodes.	1000	1000	400.3	52.65	7.603
3. One module is under partial shading effect and the other is exposed to full irradiance in the presence of bypass diodes.	1000	500	217.5	55.4	3.927
4. One module is under partial shading effect and the other is exposed to full irradiance without the bypass diodes.	1000	500	217.6	55.6	3.914
5. The two modules are under partial shading effect in the presence of bypass diodes.	500	500	196.2	51.61	3.801
6. The two modules are under partial shading effect without the bypass diodes.	500	500	196.2	51.7	3.796

© 2015, IRJET.NET- All Rights Reserved

7. One module is exposed to full irradiance and the other is under full shading effect in the presence of the bypass diodes.	1000	0	193.9	25.47	7.614
8. One module is exposed to full irradiance and the other is under full shading effect without the bypass diodes.	1000	0	0.4491	16.63	0.02
9. One module is under partial shading effect and the second is under full shading effect in the presence of the bypass diodes.	500	0	94.88	24.77	3.83
10. One module is under partial shading effect and the second is under full shading effect without the bypass diodes.	500	0	0.4152	15.6	.02

Appendix A: Kyocera data sheet.

Kyocera KC Series Module Specification

Electrical Characteristics:@ STC							
Model Number	KC125GT	KC130GT	KC167GT	KC170GT	KC175GT	KC190GT	KC200GT
Rated Power, Watts (Pmax)	125	130	167	170	175	190	200
Open Circuit Voltage (Voc)	21.7	21.9	28.9	29.0	29.2	32.5	32.9
Short Circuit Current (Isc)	8.00	8.02	8.00	8.03	8.09	8.08	8.21
Voltage at Load (Vpm)	17.4	17.6	23.2	23.4	23.6	26.1	26.3
Current at Load (Ipm)	7.20	7.39	7.20	7.27	7.42	7.28	7.61
Maximum System Voc	600	600	600	600	600	600	600
Factory Installed Bypass Diode (Qty)	Yes (2)	Yes (2)	Yes (3)	Yes (3)	Yes (3)	Yes (3)	Yes (3)
Series Fuse Rating (Amps)	15	15	15	15	15	15	15
Thermal Characteristics:							
Temp. coefficient of Voc (V/•)	-8.21×10^{-2}	-8.21×10^{-2}	-1.09×10^{-1}	-1.09×10^{-1}	-1.09×10^{-1}	-1.23×10^{-1}	-1.23×10^{-1}
Temp. coefficient of Isc (A/•)	3.18×10^{-3}	3.18×10^{-3}	3.18×10^{-3}	3.18×10^{-3}	3.18×10^{-3}	3.18×10^{-3}	3.18×10^{-3}
Temp. coefficient of Vpm (V/•)	-9.31×10^{-2}	-9.31×10^{-2}	-1.24×10^{-1}	-1.24×10^{-1}	-1.24×10^{-1}	-1.40×10^{-1}	-1.40×10^{-1}
Physical Characteristics:							
Model Number	KC125GT	KC130GT	KC167GT	KC170GT	KC175GT	KC190GT	KC200GT
Length, Inches (mm)	56.1(1425)	56.1(1425)	50.8 (1290)	50.8 (1290)	50.8 (1290)	56.1(1425)	56.1(1425)
Width, Inches (mm)	25.7(652)	25.7(652)	39.0 (990)	39.0 (990)	39.0 (990)	39.0(990)	39.0 (990)
Depth, Inches (mm)	1.42(36)	1.42(36)	1.42 (36)	1.42 (36)	1.42 (36)	1.42 (36)	1.42 (36)
Weight, Pounds (kg)	26.9(12.2)	26.9(12.2)	35.3 (16)	35.3 (16)	35.3 (16)	40.8 (18.5)	40.8 (18.5)
Mounting Hole Diameter inches (mm)	0.28"(7) Qty – 8	0.28"(7) Qty – 8	0.28" (7) Qty – 4	0.28" (7) Qty – 4	0.28" (7) Qty – 4	0.28"(7) Qty – 4	0.28"(7) Qty – 4
Grounding Hole Diameter inches (mm)	0.28"(7) Qty – 2	0.28"(7) Qty – 2	0.28" (7) Qty – 2	0.28" (7) Qty – 2	0.28" (7) Qty – 2	0.28"(7) Qty – 2	0.28"(7) Qty – 2

© 2015, IRJET.NET- All Rights Reserved