STUDY OF PARTIAL SHADING EFFECT ON SOLAR PV ARRAY

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Abstract : The I-V and P-V characteristics of Photovoltaic system are non-linear and affected by the change in atmospheric conditions like temperature, Irradiance. For any given atmospheric condition, there is only one operating point where the available power is maximum and known as maximum power Point (MPP). In this paper, mathematical model and parameter extraction method is proposed. This mathematical model is used to do analysis of Solar PV system. The impact of partial shading on solar PV output power is also presented in this paper.

***IndexTerms* - Photovoltaic System, Maximum Power Point Tracking, Fuzzy Logic Control, Adaptive Perturbation and Observation, Solar Energy Conversion, Renewable Energy.**

I. INTRODUCTION

The major electricity demand is fulfilled by fossil fuels, but due to some major issues like environment pollution, global warming, depletion of natural resources and shoot up oil cost, renewable energy is allowed to replace the part of conventional electricity production sources. The renewable energy is an abundant source of energy, but unreliability and low efficiency are the major issue associated with it. In general, the reliability of the system is increased by operating the renewable energy and conventional energy plant side by side [1]. The solar energy is a major renewable energy source and has significant percentage of total install capacity. The photovoltaic panel converts solar radiation energy directly into DC electrical energy. Despite number of research and advance stage development in solar industries, the efficiency of solar PV panel is in between 20-25% [2]. The efficiency is further reduced due to environment conditions like temperature, irradiation, partial shading, dust etc. The partial shading is an important phenomenon which causes reduction in output power of roof type solar PV panel.

In section 2, the mathematical model of PV model is proposed. The modeling of PV panel consists of parameters value finding and use it for the mathematical model. In the research papers, various model of PV panel is presented. The single diode model and double diode method are the two important methods which is considered by most of the researcher. For implementing of model, five unknown parameters are calculated. This section provides a detail method to model PV module.

In section 3, the study of partial shading condition and it impact on solar PV panel / array is discussed. The impact of partial shading on Perturbation & Observation (PO) MPPT is presented in section 4. The simulation results are discussed in section 5. This paper provides a brief idea to identify the impact of partial shading on PV array output. Brief summary and future scope of work is concluded in section 5.

II. PHOTOVOLTAIC SYSTEM MODELING

A Photovoltaic cell is a p-n semiconductor which converts portion of sun radiation energy into electricity. The phenomenon to convert light energy into electrical energy is known as photo effect. Generally, the current and voltage of PV cell is very less. So, commercially it is available in module form with number of PV cells connected in series and parallel fashion. The single diode PV model is shown in Fig. 1. The PV cell is a radiation control current source with series and shunt resistance as a loss component [3-4]. Current across the PV cell (I_{cell}) is a sum of photo current($I_{PV,cell}$), diode current (I_d) and shunt component current ($I_{sh,cell}$) and given by (1)

$$I_{cell} = I_{PV,cell} - I_{o,cell}\left(\exp\left(\frac{q(V_{cell}+R_sI_{cell})}{akT}\right) - 1\right) - \frac{V_{cell}+R_sI_{cell}}{R_p} \tag{1}$$

where q is the electron charge, I_(o,cell) is dark saturation current of diode, T is an absolute temperature of PV cell, k is the Boltzmann constant ($1.38 * 10^{-23}\ J/K$) and a is the ideality factor of diode. The Equation (1) does not represent the actual model of PV module (or array). By considering the fact that inside the PV module, cells are arranged in series and parallel fashion and mathematical representation of PV module is given as

$$I = I_{PV} - I_o\left(\exp\left(\frac{q(V+R_sI)}{aN_skT}\right) - 1\right) - \frac{V+R_sI}{R_p} \tag{2}$$

where I_{PV} is the photovoltaic current and I_o is the saturation current of the diode. In (2), aN_skT/q is the thermal voltage (V_t) of the module with N_s represents connected cells in series. For the module with N_p strings in parallel, I_{PV} and I_o is expressed as $I_{PV} = N_pI_{PV,cell}$, $I_o = N_pI_{o,cell}$. The equivalent series and shunt resistance is represented by R_s and R_p.

In this paper, the single diode mathematical model is used as it is sufficient for system performance analysis. The important characteristics of PV module is shown in I-V and P-V vurve. The three important point of PV characteristics are open circuit point $(0, V_{oc})$, short circuit point $(I_{sc}, 0)$ and maximum power point (I_{mp}, V_{mp}).

Specification mentions in PV module datasheet is not enough to use it directly for PV modelling. Generally PV module datasheet provides the information of maximum power (P_m), short circuit current (I_{scn}), open circuit voltage (V_{ocn}), maximum current & voltage (I_{mpn}, V_{mpn}), temperature coefficient of short circuit current (K_I) and temperature coefficient of open voltage (K_V) under standard test condition (AM1.5, 1000 W/m^2, 25°C). For single diode modelling, the five unknown parameters are R_p, R_s, a, I_{PV} and I_o. Under STC condition, photo current I_{PVn} is approximately equal to I_{scn}. The photo current is given by

$$I_{PV} = (I_{PVn} + K_I \Delta T)\frac{G}{G_n} \tag{3}$$

$$I_{PV} = (\left(I_{scn}\frac{R_P+R_s}{R_p}\right) + K_I \Delta T)\frac{G}{G_n} \tag{4}$$

Diode saturation current is derived from (2) by equating $I_{PV} = 0$ for dark current condition and assuming shunt current is approximate zero, as shown in (5)

$$I_o = \frac{I_{sc}}{\exp(V_{oc}/V_t)-1} \tag{5}$$

$$I_o = \frac{I_{scn}+K_I\Delta T}{\exp\left(\frac{V_{ocn}+K_V\Delta T}{V_t}\right)-1} \tag{6}$$

In general, the ideality factor value is in between 1 to 1.5 and the value selection is totally depends upon other parameters of the module. In this paper, a=1.5 is considered. Still, two parameters remain unknown (R_s and R_P) [5-6]. It is found that R_s value usually remains very low and the value of R_P is high. Based upon the finding, some author considers R_P value as infinity. With this approach, the mathematical model becomes simple and can be design analytically. Some author uses iterative method to adjust R_s and R_P continuously and check the solution until it hypothetical curve match with experimental I-V curve. In this paper, maximum experimental power ($P_{m,e}$) is compare with maximum theoretical power($P_{m,t}$) for different $R_s$and R_P value and most resemble result is selected. At MPP, R_P is calculated using (3) and given by

$$R_p = \frac{V_{mp}(V_{mp}+I_{mp}R_s)}{\left(V_{mp}I_{mp}-V_{mp}I_o\exp\left(\frac{V_{mp}+I_{mp}R_s}{V_t}\right)+V_{mp}I_o-P_{m,e}\right)} \tag{7}$$

The $R_s$value is increased in step and for each step, equation (7) is used to calculate R_p. For $P_{m,t}$ calculation, equation (2) is solved for the range of voltage values $\epsilon[0, V_{oc}]$. The equation (2) is a transcendental equation and it is solved by using Newton-Rapshon technique ($I = f(I, V)$). The Fig. 2 shows the algorithm to solve $R_s$and R_P. The Datasheet of ELDORA 40P is used to calculate PV module parameters. The R_s and R_P value after execution of program is come out to be 0.307Ω *and* 341.1Ω respectively.

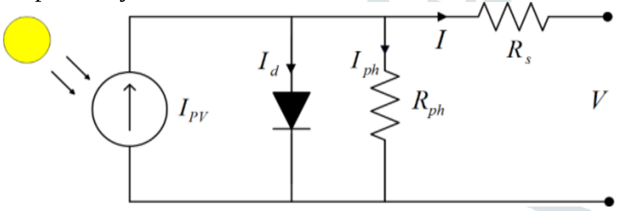
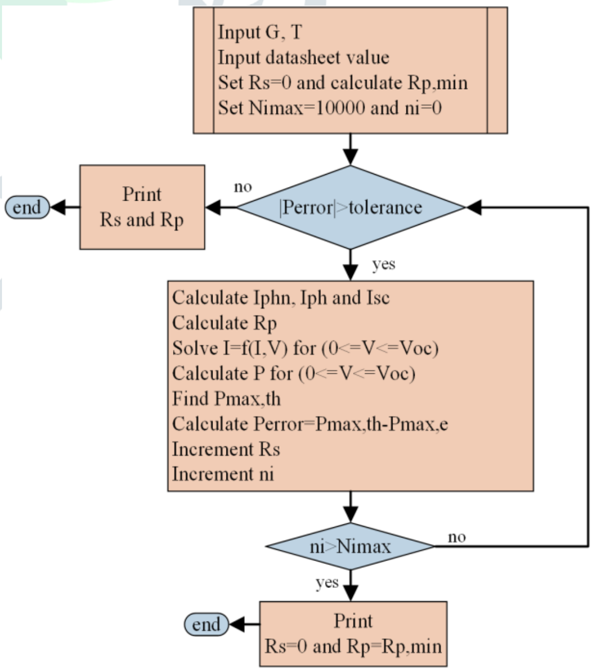


Fig. 1 Single diode model PV module. With series and shunt resistance



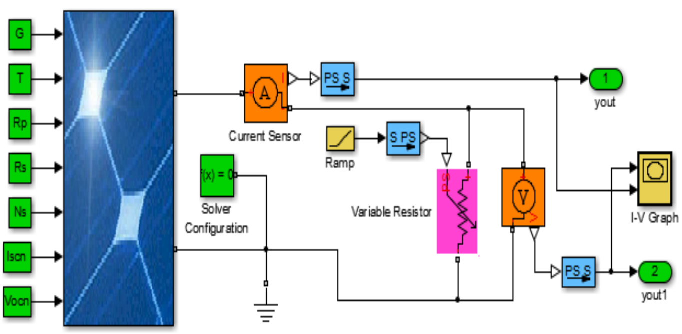


Fig. 2 The PV system model for the study of I-V and P-V characteristics

Fig. 3 Algorithm for PV module $R_p$and R_s calculation

The equations (3), (4) and (6) are used in subsystem to make a PV model in Matlab Simulink environment, as shown in Fig. 3. The comparison of characteristic response of the models is shown in Fig. 4. It is clear that above PV model works exactly like a Matlab library model and it confirmed that the proposed model is accurate enough to do an analysis [8]. The inputs for subsystem are solar irradiance and absolute Temperature and internal parameters. Before simulating the model, parameters of PV module are initialized by running script file (M-file) of parameter calculations. The Fig. 5 and Fig. 6 show the I-V and P-V characteristics of 40 W PV module under different irradiation and temperature condition. The curves demonstrate that with increase in solar radiation, the short circuit current is increased and similarly with increase in temperature, open circuit voltage is increase slightly.

III. STUDY OF PARTIAL SHADING AND MPP

The study of I-V and P-V curves conclude that for extracting maximum power from the PV module, it is essential to extract power at specific voltage point. This point of operation is known as Maximum Power Point (MPP) and a procedure to track this point using a combination of power electronic circuit and control circuit is known as Maximum Power Point Tracking (MPPT) method. In practical case, there are number of PV modules connected in series and parallel fashion.

For analysis purpose, it is considered that each and every PV module in an array receives an equal amount of solar radiation. Also in practical condition, each PV module receives nearly equal irradiation. But in real time situation, parts of PV array receive unequal solar radiation and this situation is considered as partial shading condition [7-8]. The partial shading condition causes reduction in overall current of the particular string. It is observed that if one cell of the string is shaded then it causes reduction of approx. 40-50% output power. Similarly, if two cells are connected in series with different irradiance then the maximum current is totally depends upon shaded cell. Also, the extra power loss due to shading causes junction hotspot at shaded cell and it may damage the cell permanently. The bypass diode is used across the cells to avoid the issue of hotspot and it bypasses the extra power in case of partial shading. There are various connection configurations such as Total-Crossed-Tied, Bridge-Link, Series-Parallel for reducing the effect of partial shading on PV array.

The most of the commercial PV module has 2-3 bypass diode and it helps to reduce the effect of partial shading by bypass the excess current from diode. It allows flow of maximum current from the string by bypassing the shaded portion. Due to bypass diode, the I-V and P-V characteristics are modified considerably under partial shading condition. The Fig. 7 shows the I-V and P-V curve for two series connected PV panel with one panel receives 1000W/m^2 and another panel receives 100W/m^2. The curve shows that there are two peak points.

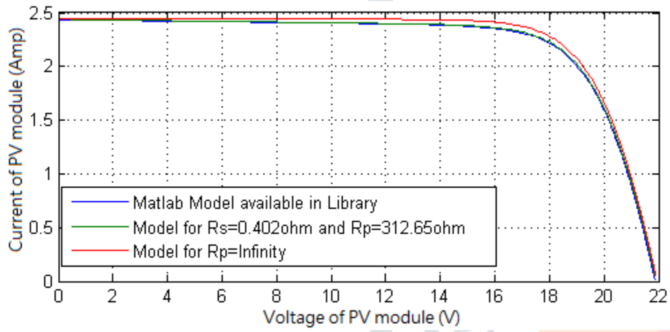


Fig. 4 The PV mathematical model comparison

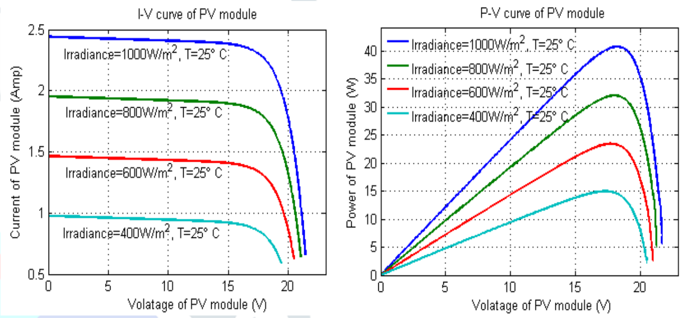


Fig. 5 The I-V and P-V characteristics of PV module for constant temperature and variable Irradiance.

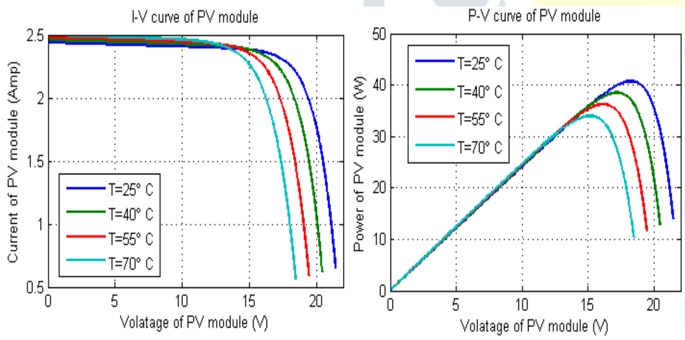


Fig. 6 The I-V and P-V characteristics of PV module for variable temperature and constant Irradiance.

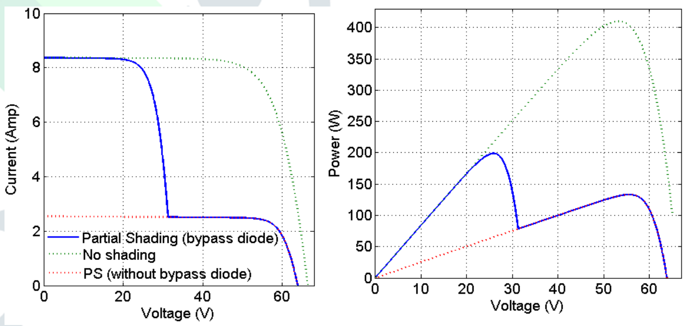


Fig. 7 The I-V and P-V characterisitcs of two series connected PV modules under partial shading

The pattern of I-V and P-V curve become more complex when large numbers of modules are connected in series and parallel. The P-V curves for series connected module (3Nos) are shown in Fig. 8. It has maximum 3 Local Power Point (LPP). Similarly, the more complex P-V curve with two string (with 3 module in series) in parallel is shown in Fig. 10.

IV. MPPT PERFORMANCE UNDER PARTIAL SHADING CONDITION

The MPPT algorithm is used to track the maximum power point. The most commonly use MPPT technique is Perturbation and Observation (PO) [9]. As the name suggest, it first perturb the variable (voltage or current) and then observe the output power. The algorithm either increases or decreases the voltage (current) in order to shift the point of operation toward Local Maximum Power Point. The algorithm to demonstrate the working of P&O is shown in Fig. 10.

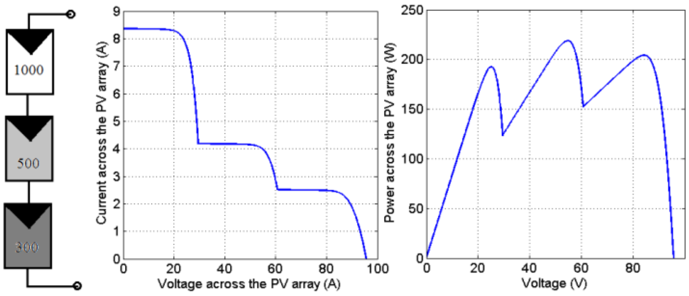


Fig. 8 The I-V and P-V characterisitcs for three series connected PV modules under partial shading

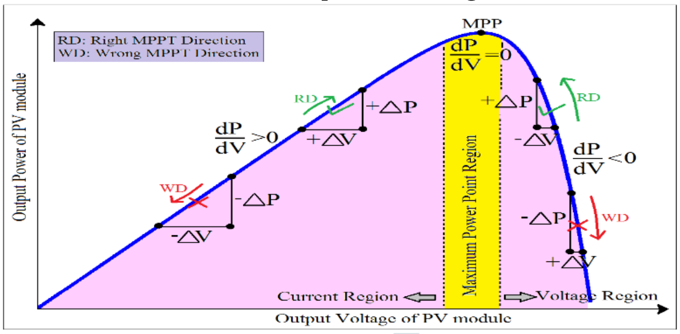


Fig. 9 Working demonstration of Perturbation and Observation MPPT

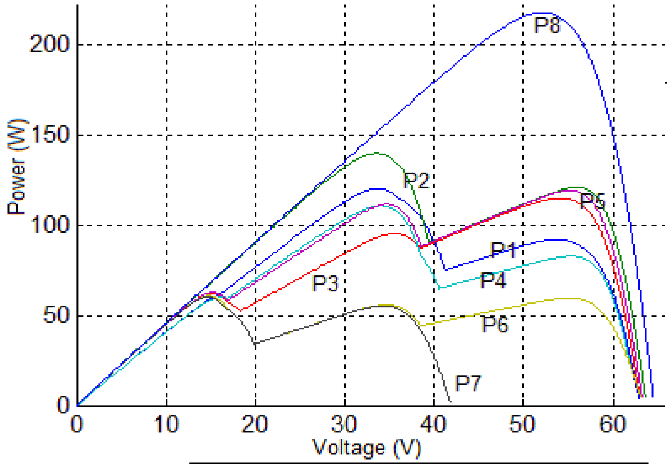


Table:Module No & its irraidiance level (W/m2)

M1	M2	M3	M4	M5	M6	Plot
800	700	600	1000	1000	200	P1
1000	1000	500	1000	1000	500	P2
1000	750	500	1000	500	500	P3
1000	750	500	800	500	200	P4
1000	750	500	1000	750	500	P5
1000	750	500	1000	0	0	P6
1000	750	0	1000	0	0	P7
1000	1000	1000	1000	1000	1000	P8

Fig. 10 The P-V curve for complex partial shading condition

The P&O MPPT is simple and easily implementable technique for tracking MPP. In case of partial shading, there is multiple power pick and P&O is unable to identify the correct MPP point. The analysis of essential to find the impact of partial shading on normal MPPT controller. In Fig. 11, the system configuration of two series connected PV module for observing the performance of P&O under partial shading condition is shown. The test condition is shown in Fig. 12. The result of P&O can be observed in Fig. 13.

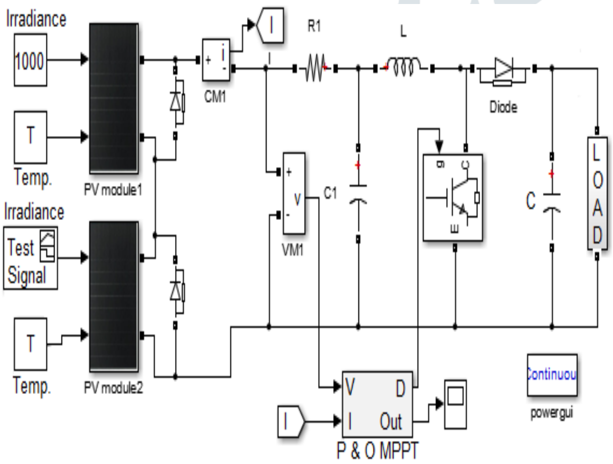


Fig. 11 Simulation model for partial shading observation of P&O

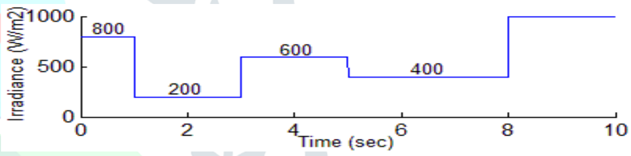


Fig. 12 Test signal for Partial shading analysis

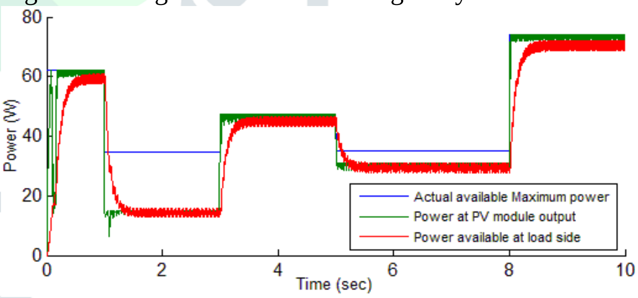


Fig. 13 Output power analysis of PV system under partial shading condition with P&O MPPT as a controller.

V. SIMULATION AND ANALYSIS

The Fig. 13 shows that there is additional 11% power loss due to P&O inability to track Global Maximum Power Point. The same analysis is performed using the practical setup of two series connected PV module with Power condition & logging unit. The Fig. 14 shows the practical setup to do analysis of partial shading for two PV modules. The setup is used to check and verify the simulation result. The resemblance in simulation and practical shows that mathematical model used for partial shading is accurate and can be utilize for the designing of modified MPPT for tackle partial shading condition. The simplest GMPPT (power curve scanning (PSC) technique) is implemented in this paper to find the drawback of simple P&O MPPT [10-11]. In PSC method, the complete curve is scanned in regular interval for identifying GMPP. In this method, P&O act as a secondary MPPT to run the system continuously at LPP until the start of next scan cycle. The Fig. 15 and Fig. 16 show the response of GMPPT and P&O under partial shading conditions. From Fig. 16, it is clear that P&O is helpful for tracking LPP and add on algorithm must be required to locate the LPP point which is actual GMPP. There are various techniques like Power slope detection, DMPPT and PSO etc. for tracking GMPP under partial shading condition.

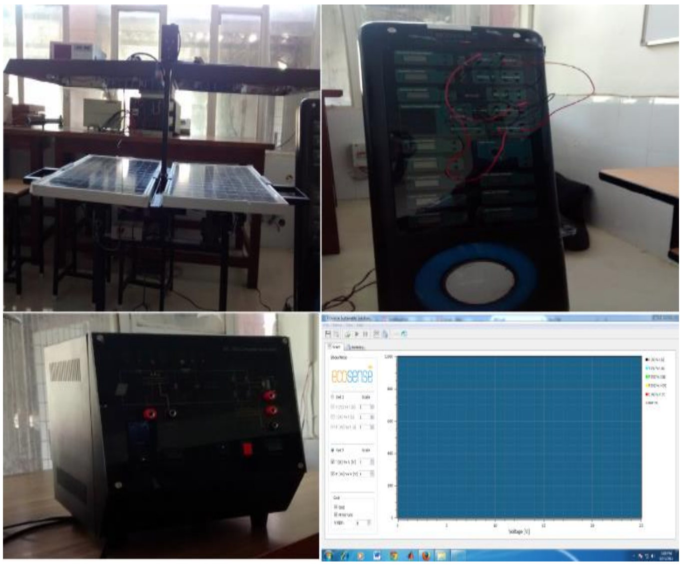


Fig. 14 The experimental setup for solar PV analysis

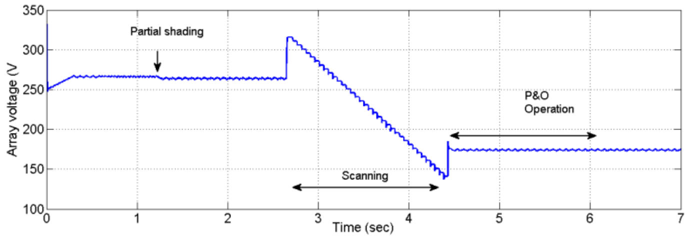


Fig. 15 The output voltage of PV array for the Power Curve Scanning technique

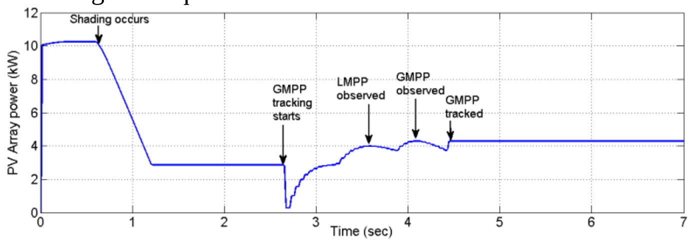


Fig. 16 The output power to show the impact of partial shading on P&O and PSC MPPT

VI. CONCLUSIONS

In this paper, a mathematical model with parameter calculation is presented in detail. The iterative method to calculate the five parameters of single diode model is discussed. The same mathematical model is used to do analysis of partial shading on PV array. It is observed that output power is reduced significantly under partial shading. The results show that simple MPPT controller is not effective in case of uneven radiation. The comparison simulation between Power Curve Scanning GMPPT and P&O is also presented in this paper. It is concluded that by utilizing GMPPT, power output can be increased up to 11%.

This paper helps to check the performance of different advance MPPT controller on the purposed system. The work can be extended to implement the real time GMPPT controller.

REFERENCES

[1] Gyanendra Singh Sisodia 2016. The status of renewable energy research on India, Energy Procedia, vol. 95, pp. 416-423.

[2] 31st Annual Report 2017-2018. Indian Renewable Energy Development Agency Ltd., Available online: https://www.ireda.in/writereaddata/IREDA_Annual_Report_N2017-18.pdf

[3] Samkeliso Shongwe, and Moin Hanif, 2015. Comparative Analysis of Different Single-Diode PV Modeling Methods, *IEEE J. of Photovoltaics*, vol. 5, no. 3, pp. 938-946.

[4] Aissa Chauder, Santiago Silvestre, Nawel Sadaoui, and Lazhar Rahmani, 2012. Modeling and simulation of a grid connected PV system based on the evaluation of main PV module parameters, Simulation Modeling Practice and Theory, vol. 20, Issue 1, pp. 46-58.

[5] Jianbo Bai, Sheng Liu, Yuzhe Hao, Zhen Zhang, Meng Jiang, and Yu Zhang, 2014. Development of a new compound method to extract the five parameters of PV modules, Energy Conversion and Management, vol. 79, pp. 294-303.

[6] Mark D. Yandt, John P. D. Cook, Michael Kelly, Henry Schriemer,and Karin HinzerDynamic, 2015. Real-Time I–V Curve Measurement System for Indoor/Outdoor Characterization of Photovoltaic Cells and Modules, IEEE Journal of Photovoltaics, vol. 5, no. 1, pp. 337-343.

[7] Kun Ding, XinGao Bian, HaiHao Liu, and Tao Peng, 2012. A MATLAB-Simulink-Based PV Module Model and Its Application under Conditions of Nonuniform Irradiance, IEEE Trans. on Energy Conversion, vol. 27, no. 4, pp. 864-872.

[8] S. Kolsi, H. Samet, and M. Ben Amar, 2014. Design Analysis of DC-DC Converters Connected to a Photovoltaic Generator and Controlled by MPPT for Optimal Energy Transfer throughout a Clear Day," Journal of Power and Energy Engineering, vol. 2, pp. 27-34.

[9] Bidyadhar Subudhi, and Raseswari Pradhan, 2013. A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems, IEEE Transactions on Sustainable Energy, vol. 4, no. 1, pp. 89-98

[10] Yi-Hua Liu, Jing-Hsiao Chen, and Jia-Wei Huang, 2015. A review of maximum power point tracking techniques for use in partially shaded conditions, Renewable and Sustainable Energy Reviews, vol. 41, pp. 436-453.

[11] Aleck W. Leedy, Kristen E. Garcia, 2013. Approximation of P-V characteristic curves for use in maximum power point tracking algorithms, 45th Southeastern Symposium System Theory, Waco, TX, USA, pp. 88-93.