AN IMPROVED MPPT SCHEME FOR PV SYSTEMS UNDER UNSTABLE SHADED CONDITIONS

P. Vinishza[1], P. Maruthupandi[2] and N. Devarajan[3]

[1]PG Scholar-P.E.D Department of Electrical Engineering Government College of Technology
[2]Department of Electrical Engineering Government College of Technology
[3]Head of the Department Department of Electrical Engineering Government College of Technology
E-mail: [1]vinipugal@gmail.com, [3]pandi@gct.ac.in, drdevarajan@gct.ac.in

Abstract—*The objective of this paper is to implement a modified Maximum Power Point Tracker (MPPT) into the pre-existing system to obtain a better output with reduced oscillations during partial shaded conditions. The panel output under shaded conditions drops significantly, with multiple local maximum power points. The conventional MPPT cannot track the Global maximum power Point accurately. The main contribution is the improvement of perturb and observe method by providing a memory unit which will alter the maximum power point before the switching pulse is given to the converter. The panel works initially with Perturb and Observe MPPT algorithm. Further the model is developed with a combination of P&O and Maximum-Voltage-Unit-Guided MPPT Algorithm. Experimental results prove the proposed method is able to track the Global MPP faster with increased power output at partial shaded conditions.*

Index terms: *Photovoltaic, Partial Shaded Conditions, Maximum Power Point Tracking (MPPT), Maximum-Voltage-Unit-Guided (MVUG)*

1. INTRODUCTION

Photovoltaic (PV) power generation has an important role to play due to the fact that it is a green source. Also they can be installed in places, such as roofs and deserts and can produce electricity for remote locations, where there is no electricity network. The latter type of installations is known as off-grid facilities. The capital cost for PV power generation is more expensive than other methods. Increasing the efficiency in PV plants so that the power generated increases, reduces consequently the cost of the power generated [1]. A Solar cell or photovoltaic cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage or resistance vary when exposed to light. Solar cells are the building blocks of photovoltaic modules otherwise known as solar panels. Multiple solar cells in an integrated group constitute a solar photovoltaic panel or solar photovoltaic module.

Solar cells are usually connected in series in modules, creating an additive voltage. Connecting cells in parallel yields a higher current. However shadow effects may cause substantial power loss. Presently the best achieved conversion rate is around 21.5%. In order to achieve maximum power output from the panel Maximum Power Point Tracking Algorithms are used. Improving the efficiency of the PV panel and the inverter is not easy as it depends on the technology available, it may require better components, which can increase drastically the cost of the installation. Instead, improving the tracking of the maximum power point(MPP) with new control algorithms is easier, not expensive and can be done even in plants which are already in use by updating their control algorithms, which would lead to an immediate increase in PV power generation and consequently a reduction in its price [2].MPPT algorithms are necessary because PV arrays have a non linear voltage-current characteristic with a unique point where the power produced is maximum. This point depends on the temperature of the panels and on the irradiance conditions. Both conditions change during the day and are also different depending on the season of the year. Furthermore, irradiation can change rapidly due to changing atmospheric conditions such as clouds. It is very important to track the MPP accurately under all possible conditions so that the maximum available power is always obtained. Conventional MPPT algorithms used are P&O, Incremental conductance, hill climbing algorithms and ripple correction [3]. In [4], an improved P&O technique based on hysteresis band and auto-tuning perturbation step, but there is trade-off between dynamic response and steady state due to the selection of '*dV*'. On the other hand, the magnitude of the intrinsic oscillations around the MPP in steady state was larger, yielding a reduced average PV power conversion in steady state. Since low power converters can operate with frequencies of hundreds of kHz, a satisfactory trade-off between fast transient responses and steady state performance was obtained with a small perturbation step size. The efficiency was about 94.32% than P&O which was around 89.84%. in [5],performance of the solar arrays under partial shaded conditions is analysed. The existing schemes were unable to extract maximum power under those conditions. A novel algorithm was designed based on the PV panel behaviour at various conditions. The proposed algorithm works in conjunction with a dc-dc converter which uses the reference voltage information to shift operation towards the MPP. The tracking time was found to be about one-tenth as compared to the conventional controller. In [6], the characteristics of a PV panel under partial shading conditions are analysed. The algorithm implemented was P&O and a one diode model of a PV cell was used with different irradiation and temperature values. A PWM signal is used for generation of the pulse. A Perturb and Observe based boost converter was modelled and successfully simulated using simulink. In [7], a sub-routine was proposed which calculated the MPP at various point nearer to previously stored MPP. Since the subroutine was called only when the certain conditions were satisfied, blind scanning was avoided. The usage of voltage sensors helped to easily obtain the panel readings for calculation. The proposed algorithm was developed and verified using PLECS simulation. In [8], a subroutine in addition with the normal P&O algorithm which stored the previously tracked maximum power point and then calculated the peaks at left and right of the MPP is used. This helped in easy tracking of the MPP, since the area of scanning was too large, there was significant wastage in the amount of energy produced. Moreover, the sub-routine only allowed for the calculation of the peak values while the MPP was found using P&O algorithm whose output was not optimal. The control unit of the proposed global MPPT system was built with a Texas Instrument Digital Signal Processor TMS320F2812 microcontroller. The simulation and experimental results verified that the proposed method determined the presence of partial shading and guaranteed convergence to global MPP.

In this paper, a new method to track the GMPP is proposed. The paper is organised as follows. The section II explains the modelling of the solar cell. The section III describes the Perturb and Observe algorithm. The section IV explains the improved proposed Maximum-Voltage-Unit-Guided (MVUG) MPPT algorithm. The results are presented in section V. The work is summarised in section VI

2. EQUATION MODEL OF SOLAR CELL

The PV module represents the fundamental power conversion unit of a PV generator system. The output characteristics depend on the solar insolation, the cell temperature and the output voltage of the PV module. Since it has non-linear characteristics, it is necessary to model it for the design and simulation of Maximum Power Point Tracking (MPPT) necessary for PV applications.

Iph = Photocurrent (A)
Iscr = Short circuit current at 25°C and 1000W/m^2
= 2.55 A
Ki = Short circuit current co-efficient = 0.0017A/°C
T = Module operating temperature in Kelvin
λ = PV module illumination (W/m^2)
q = Electron charge = 1.6 x 10^{-19} C
Voc = Open circuit voltage
Ns = Number of cell in series
K = Boltzmann constant = 1.3805 x 10^{-33} J/K
A = Ideality factor = 1.6
Np = Number of cell in parallel
Vpv = Output voltage of the PV module (V)
Rs = Series resistance of the module.

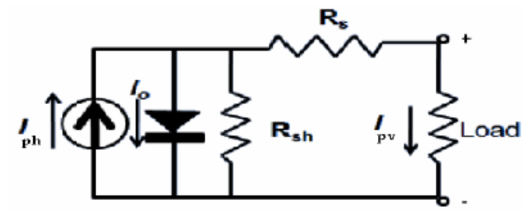

Fig. 1: Diode model of solar cell

The solar cell is modelled using the equation (1)-(4)

The module photo-current

$$\mathrm{Iph} = [\mathrm{Iscr} + \mathrm{Ki}(\mathrm{T} - 298)] * \lambda/1000 \qquad (1)$$

The Module reverse saturation current

$$\mathrm{Irs} = \mathrm{Iscr}/[\exp(\mathrm{qVoc}/\mathrm{NsKAT})] - 1 \qquad (2)$$

The Module saturation current

$$\mathrm{Io} = \mathrm{Irs}\ [\mathrm{T}/\mathrm{Tr}]^3 \exp\ [\mathrm{q}*\mathrm{Ego}/\mathrm{Bk}\{1/\mathrm{Tr}-1/\mathrm{T}\} \qquad (3)$$

The PV module current

$$\mathrm{Ipv} = \mathrm{Np} * \mathrm{Iph} - \mathrm{Np} * \mathrm{Io}[\exp\left\{\mathrm{q} * \frac{\mathrm{Vpv} + \mathrm{IpvRs}}{\mathrm{NsAKT}}\right\} - 1] \quad (4)$$

The electrical characteristic of the PV cell is generally represented by the current verses voltage (I-V) curve and power verses voltage (P-V) curve. The maximum current of the module is the short-circuit current which is the current that is measured with output terminals shorted (zero voltage).The maximum voltage of the module is the open-circuit voltage which is the voltage that is measured with output terminals open (zero current). The power output of the panel is the product of the voltage and current outputs.

Fig. 2 and 3 shows the I-V and P-V Characteristics curve.

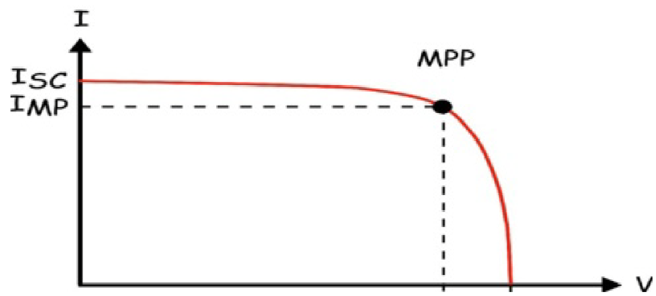

Fig. 2 I: V Characteristics Curve

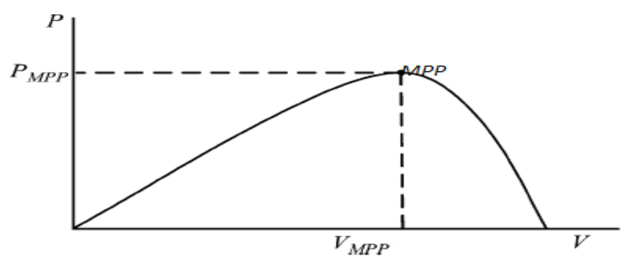

Fig. 3 P-V Characteristics Curve

3. PERTURB AND OBSERVE MPPT ALGORITHM

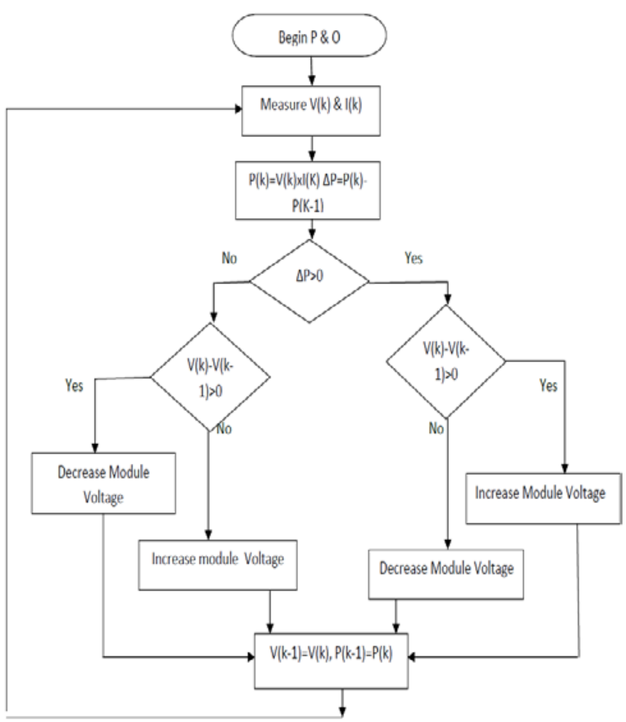

Fig. 4: Perturb and Observe

The conventional method usually used is the P&O MPPT algorithm. Fig. 4 shows the flowchart of the P&O MPPT algorithm. The perturb and observe(P&O), as the name itself states the algorithm is based on the observation of the array output power and on the perturbation (increment or decrement) of the power based on increments of the array voltage or current. In this method a slight perturbation is introduced in the system. This perturbation causes the power of the PV module to change. If the power increases due to the perturbation then the perturbation is continued in that direction. After the peak power is reached the power at the next instant decreases and hence after that the perturbation reverses. When the steady state is reached the method oscillates around the peak point. In order to keep the power variation small the perturbation size is kept very small [12].The operating voltage of the PV system is perturbed by a small increment of ΔV, and this resulting change in ΔP. If ΔP is positive, the perturbation of the operating voltage needs to be in the same direction as that of the increment. On the contrary, if ΔP is negative, the obtained system operating point moves away from the MPPT and the operating voltage needs to move in the opposite direction of the increment [11].

4. IMPROVED PROPOSED MPPT ALGORITHM

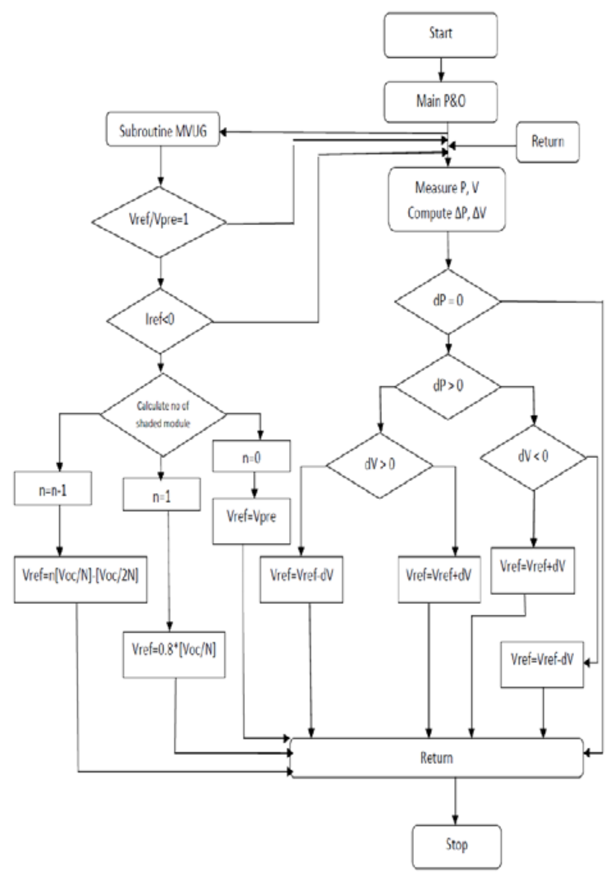

Fig. 5: MVUG MPPT

The MVUG MPPT relies on voltage measurements on each substring of PV module. The substring with the highest voltage is set as the guiding unit and the global maximum power point (GMPP) is determined based on it. The proposed method can be implemented in any of the existing configurations, with the only additional requirement being the voltage sensors across each substring, i.e., across each bypass diode of the modules. Normally, when the solar irradiance on each of the cells is equal, the magnitude of the current source Iph is the same in all the substrings. If the irradiance on the substrings is sun equal due to partial shading, then the magnitude of the current source corresponding to the substring with low irradiance decreases. In the absence of the bypass diode this situation will lead to reverse current, large reverse bias and power dissipation in the shaded cells. However, with the bypass diodes the difference between the current from the shaded and unshaded substrings flows through the bypass diode of the shaded substring avoiding the reverse bias and power dissipation. The voltage output of the bypassed substring, and therefore the power, both reduce to close to zero as long as the difference in Iph among the different substrings is significant. This leads to multiple LMPP, depending on the level of shading and how many substrings are bypassed.

The searching for the GMPP starts by detecting two criteria. The first is the ratio of the voltages of the different units. When it is not close to one, it indicates a partial shading situation. Then the algorithm checks if there is a sudden change in the PV module current. If there is a large current change and if the voltage ratio is not equal to one, then the inverter will determine that a partial shading situation occurs. But if there is only a large current change with the voltage ratio is close to one, then this is an irradiance change without partial shading. If the voltage ratio is not close to one and the current change is not obvious, the PV has been in the partial shading before this cycle. Therefore, if the two criteria are not met at the same time, the inverter will go into the first stage operation [6]. The flowchart of the MVUG subroutine is shown in Fig. 5. The algorithm initially measures the voltage and current of panels. The algorithm then checks if the two criteria is satisfied. In case the two criteria are not satisfied the algorithm sets the reference value as calculated by equation (5) and moves the program control back to P&O algorithm.

$$Vref = Voc - [\frac{Voc}{2*N}] \quad (5)$$

Where

Vref = Reference Voltage of the panel

Voc = Open Circuit Voltage

N = Total number of panel

In case the two cases are satisfied then the algorithm recognizes that a partial shading condition has occurred. The panel then calculates the maximum power with the current and voltage measured by the main program. The voltage value as measured by the voltage sensor is compared and according to the number of panel that has been shaded the new reference voltage is calculated by equation (6), (7) and (8).

$$Vref = n\left[\frac{Voc}{N}\right] - \left[\frac{Voc}{2N}\right] \quad (6)$$

$$Vref = 0.8 * \left[\frac{Voc}{N}\right] \quad (7)$$

$$Vref = Vx \quad (8)$$

The equation (6) is used when n = n-1. The equation (7) is used when one panel is shaded. The equation (8) is used no panel is shaded, i.e., It goes back to the main program. This happens when the panel searches for a global MPP during an interrupt call.

5. SIMULATION RESULTS

The simulation circuit for the mathematical model of the PV module is shown in Fig. 6 and equation model of the system is shown in Fig. 7.

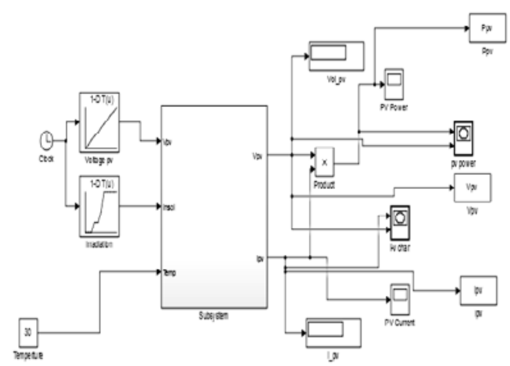

Fig. 6 PV Module

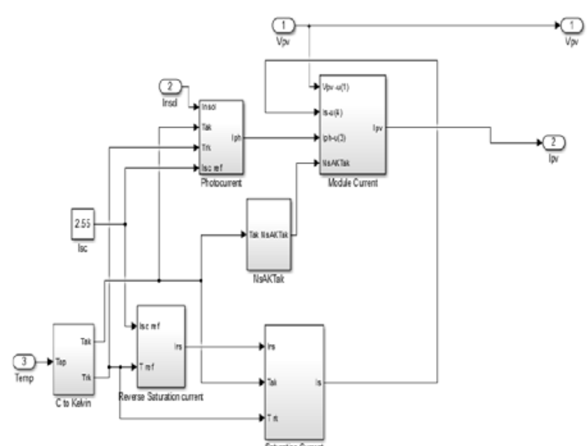

Fig. 7: Shows the equation model of the PV module.

The detailed specifications of the 36W solar module are shown in table 1.

Table 1: Electrical Characteristics Data Sheet of 36W Module

Rated Power	36.08 W
Voltage at Maximum Power (Vmp)	16.56V
Current at Maximum Power (Imp)	2.25A
Open Circuit Voltage (Voc)	21.24V
Short Circuit Current (Iscr)	2.55A
Total Number of Cells in Series (Ns)	36
Total Number of Cells in Parallel (Np)	1

The table 2 summarises the result obtained voltage, current and power when the irradiation level is varied from 1200W/m^2 to 500W/m^2 and then again to 1000W/m^2.

Table 2: Simulation Results of the Panel

IRRADIANCE(W/M2)			(V)	(A)	(W)
Level 1	Level 2	Level 3			
1200	1200	1200	18.61	0.353	12.46
1200	500	1200	17.45	0.35	12.25
1000	1000	1000	17.10	0.34	12.36

From the table it can be inferred that the power falls down then rises up according to the irradiation level.

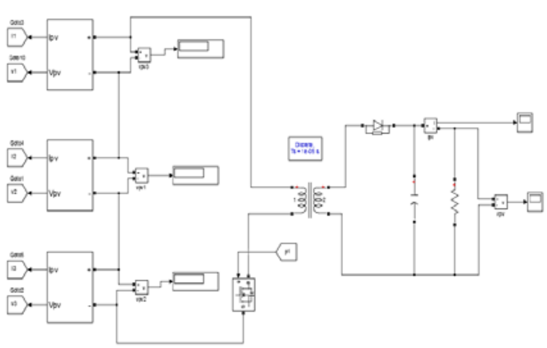

Fig. 8: Simulation Circuit with P&O Algorithm

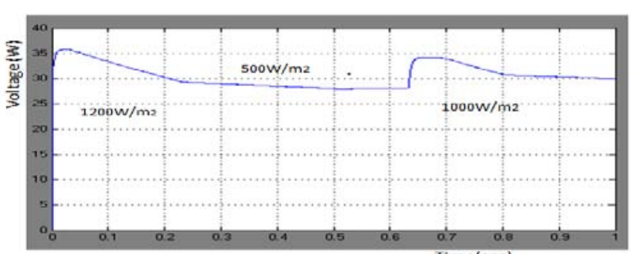

Fig. 9: Output Waveform of PV Module with P&O Algorithm

Table 3 Simulation Results with P&O Algorithm

IRRADIANCE(W/M2)			(V)	(A)	(W)
Level 1	**Level 2**	**Level 3**			
1200	1200	1200	35.61	0.35	12.46
1200	500	1200	35.45	0.35	12.65
1000	1000	1000	35.10	0.34	12.36

Fig. 9 shows the simulation result of a PV panel with P&O MPPT algorithm. The Curve is obtained when the irradiation level is reduced to 500W/m^2 from 1200w/m^2 and the raised up to 1000w/m^2. The values of the solar module using P&O MPPT algorithm alone is tabulated in table 3

From Table 3, it can be seen that there is a significant variation in the power output when the irradiation level is changed.

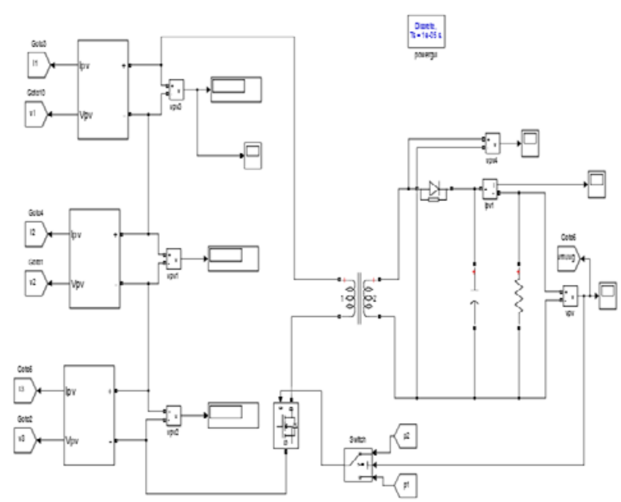

Fig. 10: Shows the simulation circuit with MVUG and P&O algorithm.

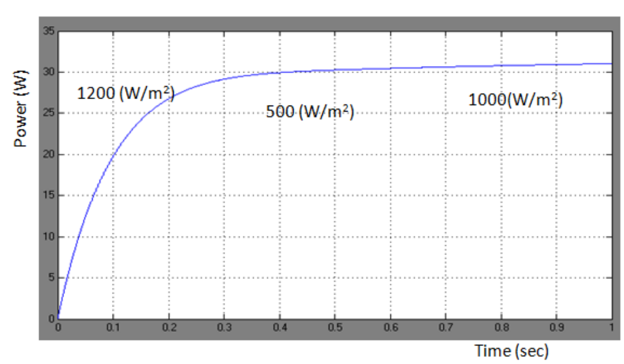

Fig. 11: Output Waveform of PV Module with MVUG Algorithm

Fig. 11 shows the output waveform for the same irradiation changes. It can be seen that the MVUG comes into action only when partial shading occurs which is denoted by the fall of irradiation from 1200w/m^2 to 500w/m^2.

The simulation results are summarized in table 4. The power is calculated only when there is fall in irradiation level. Hence the power output in the first case is not obtained for MVUG subroutine. After the subroutine is called there is significant rise in the power output as compared to the P&O algorithm.

Table 4: Simulation Result of MVUG with P&O Algorithm

IRRADIANCE(W/M2)			(V)	(A)	(W)
Level 1	Level 2	Level 3			
1200	1200	1200	22.96	0.389	-
1200	500	1200	22.05	0.333	30.5
1000	1000	1000	22.19	0.349	31.5

The simulation result of P&O and MVUG with P&O MPPT is compared in Fig. 12. The waveform shows a smooth variation in the output whereas P&O exhibits sudden surge in the output during irradiation change.

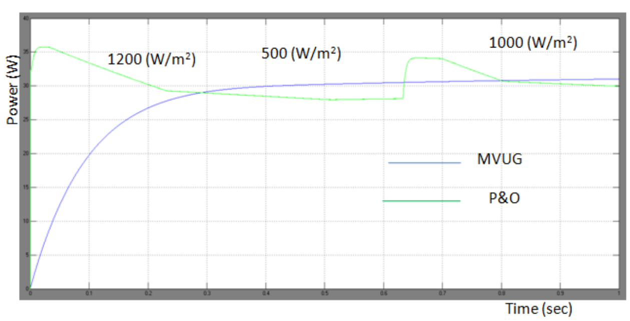

Fig. 12: Output Waveform of PV Module with MVUG and P&O

Table 5: Comparison of P&O and MVUG with P&O Algorithm

IRRADIANCE (W/M2)			POWER (W) - P&O	POWER (W)- MVUG
Level 1	Level 2	Level 3		
1200	1200	1200	35.56	-
1200	500	1200	28	30.5
1000	1000	1000	34	31.5

The Table 5 gives the Power Output comparison. From the table, there is a significant rise in the power when partial shading occurs. This shows that implementation of MVUG is favorable and helps in obtaining improved performance during unstable shading conditions.

6. CONCLUSION

A 36W module was mathematically modelled and simulated in the Matlab / Simulink platform using SimElectronics system blocks to compare the characteristics of a PV module under normal and shaded conditions.

The behaviour of the panel was initially analysed with P&O MPPT algorithm. To enhance the performance of the panel under shaded conditions, a developed MPPT algorithm having MVUG as subroutine was added to the pre-existing system.

The output reveals the module to exhibit improved performance with reduced oscillations under unstable shaded conditions. The usage of the flyback converter allows stepping up of the voltage to any desired level. Moreover the time taken for the algorithm to reach its maximum power point is found to be faster than the conventional methods.

The comparison of the proposed system with the conventional system shows the implementation to be cost effective. Based on the anlaysis of the results, the system employing P&O with MVUG MPPT algorithm is found to exhibit improved performance under partial shaded condition. The main advantage of using this algorithm is that it can be easily incorporated into the pre-existing system.

REFERENCES

[1] Tom Markvart and Luis Castaner, “Practical handbook of Photovoltaics – Fundamental and Applications”

[2] Mukund R. Patel, 2006, “Wind and Solar Power System – Design, analysis and operation”, Taylor and francis.

[3] H. Patel and V. Agarwal, March 2008, “MATLAB-based modelling to study the effects of partial shading on PV array characteristics,” IEEE trans. Power Electron., Vol.23, no. 1, pp. 302-310.

[4] Surya Kumari J. And Dr. Sai Babu Ch., “Design and Investigation of Improved Perturb and Observeee MPPT algorithm for Photovoltaic system” , Journal of Electrical Engineering.

[5] H.Patel and V.Agarwal, October 2012, “Maximum power point tracking scheme for PV systems operating under partially shaded conditions”, IEEE Transactions. Ind. Electron., Vol55, no.4,pp.532-546.

[6] Alex Joseph, Kamala J, 2014, “ PV array characteristics analysis under partial shaded and modelling of P & O MPPT applied boost converter using Matlab/simulink”, IEEE.

[7] Tong Yao, Raja Ayyanar, 2013, “Maximum-Voltage-Unit-Guided MPPT Algorithm for Improved Performance under partial shading”, IEEE, Arizona State University, Tempe, AZ.

[8] Kai chen, Shulin tain, Yuhua cheng, Libing Bai, July 2014, “An Improved MPPT Controller for Photovoltaic system under Partial Shading Conditions”, IEEE Tansactions on Sustainable Energy, Vol.5, No.3.

[9] N. Pandiarajan and Ranganath Muthu, Jan 2011, “Mathematical Modelling of photovoltaic module with Simulink”, International conference on Electrical Energy Systems (ICEES).

[10] M.G. Villalva, J.R. Gazoli, E.R. Filho, May 2009, “Comprehensive approach to modelling and simulation of photovoltaic arrays”, IEEE Transactions on Power Electronics, Vol.24, no.5, pp.1198-1208.

[11] David Sanz Morales, “Maximum Power Point Tracking Algorithms for Photovoltaic Applications”, Aalto University.

[12] Sridhar Sholapur, K.R. Mohan, T.R. Narsimhagowda, Jul-Aug 2014,“ Boost converter topology for PV systems with perturb and observe MPPT algorithm”, IOSR Journal of Electrical and Electronics Engineering (IOSR - JEEE), Vol-9, Iss 4, Ver II, pp 50 -56.

[13] Kok Soon Tey and Saad Mekhilef, October 2014, “Modified Incremental conductance Algorithm for Photovoltaic system under partial shaded conditions and load variations”, IEEE Transactions on Industrial Electronics, Vol.61, No.10.

[14] Mohan, Undeland, Robbins, 2003, “Power Electronics – converter, Applications and Design”, 3rd Edition John Wiley & Sons Ltd.

[15] Mohammad shadmand, Robert S. Balog, Haitham Abu Rub, 2014, “Maximum Power Point Tracking using Model Predictive Control of a Fly Back converter for Photovoltaic applications”, IEEE Transactions on industrial Electronics.

[16] C. Liu, B. Wu and R. Cheung, 2004, “Advanced Algorithm For MPPT Control Of Photovoltaic Systems”, Canadian Solar Buildings Conference Montreal, August 20-24, Refereed Paper.