Enhancement of PV Array Performance during Partial Shading Condition

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Abstract: The partial shading of photovoltaic array (PV) may be caused by neighbour building, trees, dust and clouds. The effects of partial shading on PV array characteristics are presented and a comparative literature review on methods to mitigate these effects and the drawbacks of this method are provided. A new technique for enhancement the output power of PV array is suggested. Simulation carried out by using MATLAB/Simulink under different irradiance conditions. The results investigated the conducting of bypass diode under partial shading condition and its effect on the output power of the PV array then illustrate the optimization of PV array output power by using a new suggested technique where The output power of the PV array increased by 56% under partial shading condition with using the new proposed technique.

Keywords: Photovoltaic array, Partial shading, Bypass diode, MATLAB, Simulink.

I. INTRODUCTION

A partial shading is a case when the different modules of the array received a different irradiance level. These shadow may be either to predict due to neighbour building, nearby tree or difficult to predict due to clouds or building. Let us assume the connection of three PV modules connected in series to form an array and study the effect on the output power of PV array characteristics in two cases. The first case each module receive irradiance of 1000 w/m^2 as shown in Fig. 1 the P-V characteristic has only one maximum power point(MPP) that equal the summation of MPP for each module (i.e. 3*83.3=250 W) and the second case the first module receive irradiance of 1000 w/m^2 and the second module receive 600 w/m^2 and the third module receive irradiance of 300 W/m^2 as shown in Fig. 2 also the PV system has only one MPP but in this case the PV has Three MPP two local MPP and one global MPP and the global MPP not equal the sum of the power for each module (i.e. 83.3+49.98+24.99=158.27 w) but it equal 110 W that means there are loss in the power of shaded module where the power of shaded module is 44% of unshaded array power, there are three values of short circuit currents of 10, 5 and 3 A and three values of open circuit voltage of 10, 23 and 38V. The partial shading causes the existence of multiple peaks as shown in Fig. 2 and that makes it difficult to track the global maximum peak, the global MPP of the shaded array occurs at relative low voltage compared to unshaded one and the global MPP not equal the summation of the maximum power that every module is able to deliver.
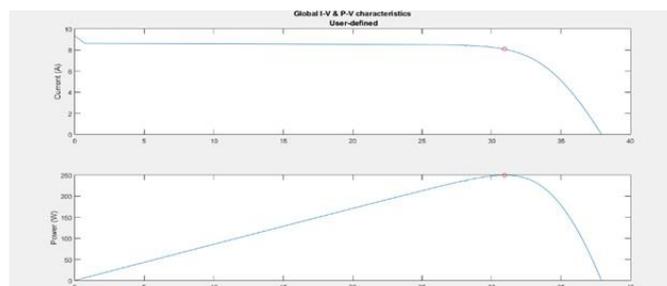
Fig. 1. P_V, I-V characteristic of unshaded array
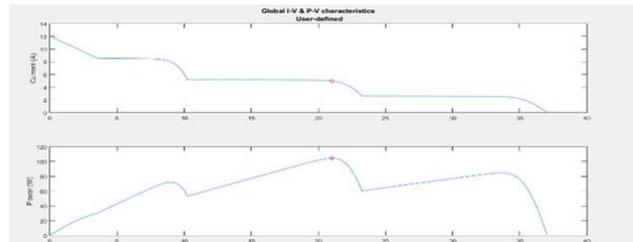
Fig. 2. P_V, I-V characteristic of shaded array

According to this bad impact on the output power of the PV array the partial shading became a key issue. The remaining of the paper coordinated as the following: section 2 Literature review, section 3 modelling of the PV array, section 4 the simulation, section 6 the results and section 7 conclusion.

II. LITERATURE REVIEW

Some literature covered a plenty of techniques to track the global MPP of the PV array under partial shading condition the author [1-3] cover some of this technique and some literature studied the enhancement of the output power of PV array under partial shading condition as:

In [4] studied the effect of the interconnection the array according to the shading pattern. The author made simulation on three interconnection of PV array series-parallel connection (SP) , total cross tie connection (TCT) and bridge linked connection (BL) at a different shading patterns. The author found that the output power of SP connection is greater than the output power of TCT connection when shadow is portended to be progress on last row of horizontal modules, the output power of TCT connection is greater than SP connections when shadow is portended to be progress on left column of vertical modules. The drawbacks of this technique that the shading pattern must be known.

In [5] studied the effect of using DC-DC converter on the performance of PV array. The author used a DC to DC converter (SEPIC converter) to track and improve the MPP of the PV array but the drawbacks of this technique that it increase the loss.

In [6-9] studied the effect of reconfiguration the PV array during the partial shading on the performance of PV array. the author made a laboratory experiment for a 4*4 PV array under partial shading condition made reconfiguration for the PV array by separate the shading modules and this technique improve the performance of PV array but the drawbacks of this technique that the MPP after reconfiguration less than the MPP of unshaded array and also reconfiguration required a controller to take switching action.

III. MODELLING OF PV ARRAY

There are three models of PV array as detected in Table 1. The single diode model assume that the ideality factor of diode has a constant value and this ideality factor is a function of voltage so in High voltage application the single diode model is preferred than the two diode model and in low voltage application the two diode model is preferred in [10]. A single diode model is used in this paper.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Issue 4, April 2017

Table 1. The different models of PV array

Model	Electrical Scheme	Number of parameters
Ideal Model		(3) Iph, lo and a
One diode model		(5) Iph, lo, Rs, Rsh and a
Two diode model		(6) Iph, lo1,lo2, lo, Rs, Rsh and a
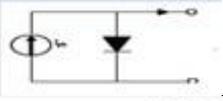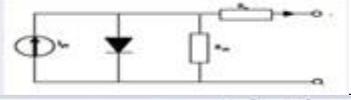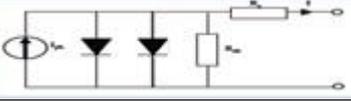
Mathematical Model OF PV Module (five parameter model)

Thermal voltage:

The thermal voltage of a module with N_c cells is given by the Eq. 1

$$\mathrm{Vth} = \frac{KT}{q} \quad (1)$$

Where the k is the Boltzmanns's constant ($1.38*10^{-23}$ J/K), q is the electron charge ($1.6 *10^{-19}$ C) and T is the temperature.

Diode reverse saturation current (Io):

The diode reverse saturation current can be calculated by substituting the open circuit conditions (V=Voc, I=0) as shown in Eq. 2.

$$I_o = \frac{Isc}{\exp\left(\dfrac{Voc}{aNcVth}\right)-1} \quad (2)$$

Where Voc is the open circuit voltage, Isc is the short circuit current, a is the ideality factor of the diode and Nc is the number of cells.

Photovoltaic current (Iph):

The photovoltaic current Ipv depend on the temperature and the solar irradiation as shown in Eq. 3.

$$\mathrm{Iph} = \left(\mathrm{Iph,reference} + Kt\left(\mathrm{T\text{-}Tref}\right)\right)\frac{G}{\mathrm{Gref}} \quad (3)$$

Where Iph, ref is the photovoltaic current at reference irradiance and temperature (1000 w/m^2 and 25°C),G is the incident irradiance (w/m^2), Tref is the reference temperature at normal condition (25°C) and Gref is the reference irradiance or nominal irradiance (1000 w/m^2).

PV Array with By-Pass Diode

The shaded modules of PV array consume power from unshaded module due to the reverse voltage polarity so the MPP of the array reduced. the high reverse voltage polarity of the shaded modules lead to breakdown and cause hotspot so the bypass diode used to limit the reverse voltage less than breakdown voltage but it caused MPP as shown in Fig. 2. The bypass diode are connected parallel to the PV cell as shown in Fig. 3. The bypass diode may be connected to a set of series cells in [11,12].
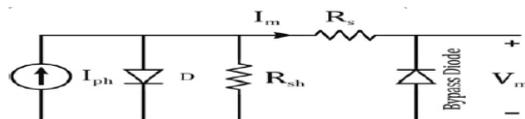
Fig. 3. Equivalent circuit of PV array protected by bypass diode

The Proposed Technique

AS shown in Fig. 4 a battery to improve the performance of the PV array during the partial shading condition is used to compensate the loss of power occurred due to partial shading and also a diode to automatically connect the battery when the partial shading occurs is used. The voltage and ampere-hour of the battery is chosen by calculating the total power and the output voltage of the PV array under unshaded conditions.
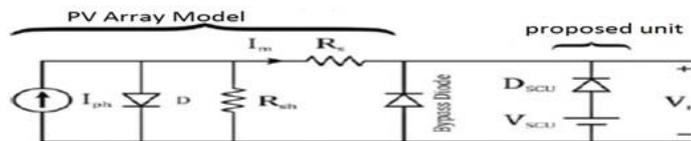
Fig. 4. Proposed PV module technique

IV. THE SIMULATION

The simulated PV array system is consists of 3 modules connect in series and each module consists of 20 solar cells. The PV module's parameters were taken from NERL System advisor (January 2014) and sorted in Table 2 and Fig. 5.

Table 2. The parameters of the PV module

Parameter	Value
I_{MPP}	8.07 A
V_{MPP}	10.32 V
P_{MPP}	83.28 W
$I_{s.c.n.}$	8.62 A
$V_{o.c.n}$	13.30 V
$I_{0.n}$	1.4176 e-
a	10 A 0.99132
Rs	0.098 ohm
Rp	82.11 ohm
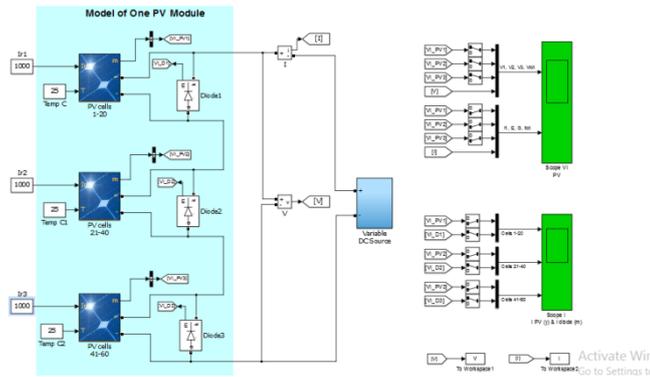
Fig. 5. The simulation of the PV array system

The simulated system exposed to different irradiance conditions:

Uniform Illuminated Condition

The simulated PV array system under uniform illuminated condition where all modules exposed to the same irradiance of 1000 w/m^2.

Partial Shading Condition

The simulated PV array system under partial shading condition where the first module, second module and third module exposed to irradiance of 1000, 600 and 300 w/m^2.

Enhancement of PV Array Performance

The simulated system with the proposed unit as shown in Fig. 6. a lead acid battery is used because the lead acid battery is the most common type of batteries used with PV system due to its deep discharge cycle in [13]. The lead acid battery parameters are shown in Table 3.

Table 3. The parameters of the PV battery

Parameter	Value
Nominal voltage	30 V
Rated capacity	0.4 AH
Fully charged voltage	38.87 V
Nominal discharge current	0.08 A
Internal resistance	0.03
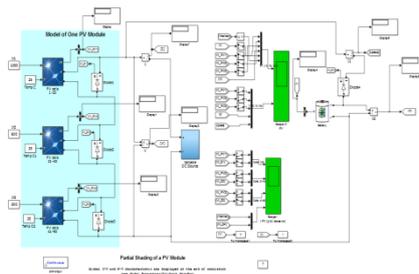
Fig. 6. The simulation of the PV array with proposed unit

V. RESULTS

The array output PV, IV characteristic under different irradiance conditions are simulated and it founded that under uniform irradiance condition the system has a unique MPP that equal the total maximum power of the three modules (3*83.3=250 W) and the short circuit current of each module equal 9 A and the bypass diode current equal zero that means the bypass diode didn't conduct in this case.

In the case of partial shading condition, the system has three MPP one global MPP and two local MPP. The global MPP at relative low voltage and has lower value than the MPP of the system. The MPP reduced to 110 W due to partial shading. There are current passes through bypass diode of the partially shaded modules as shown in Fig. 7 and this causes loss in power.
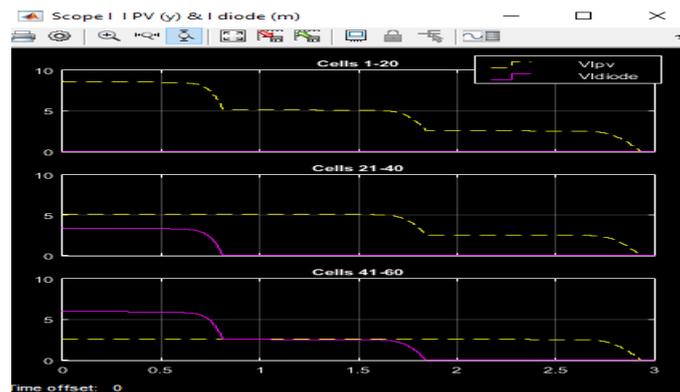
Fig. 7. VI (PV) and VI diode characteristic curves under partial shading condition

In the case of using the proposed unit, the battery operated when the partial shading occurs and substituted the loss of power due to the partial shading and the MPP reach to 250 W like the case of the uniform irradiance, the bypass diode of the shaded modules operated and the diode of the shading control unit operated so there are loss and multiple MPPs as shown in Fig. 8.
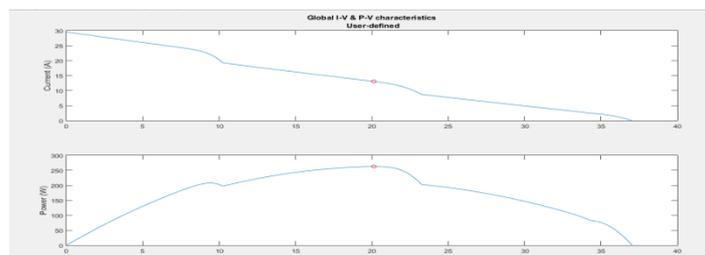
Fig. 8. The PV, IV characteristic of PV array under partial shading condition with the proposed technique

Comparison between the Proposed Technique and the Previous Techniques

The new technique isn't required a complex control system like the other techniques [7,9] where the control in this technique by using the SCU Diode as shown in Fig. 4. The new technique has low loss compared to the other techniques used power electronics for mitigation the effect of partial shading [8]. The new technique has low cost compared to the other techniques in [7-9].

VI. CONCLUSION

A new technique for the mitigation of the partial shading effect is presented. Simulation are carried out under different irradiance condition. The optimization of PV array output power under partial condition is obtained by using a new technique where the output power of the PV array increase by 56% under partial shading condition. The problem of the presence of the multiple MPPs where it cause difficult to detect the MPP but this problem solved in [14]. The main advantages of the new technique that it is required lesser number of sensors and switches and reach high MPP similar to the using of power electronics.

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