Performance Analysis of Various Interconnection Schemes of Solar Photovoltaic Array under Partial Shading Condition

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Abstract:

Partial shading ruins the performance of solar photovoltaic systems by adversely affecting the insolation received by solar photovoltaic cells. Among several proposed techniques to reduce partial shading effect, one is to alter interconnections schemes. Several interconnections scheme have been reported in literature i.e. Series-parallel (SP), Bridge-linked (BL), Total-cross-tied (TCT), Honey-comb (HC) configuration etc. In this paper these interconnected schemes are investigated in order to suggest best topology for various shade patterns. In addition the result of each configuration is also given in terms of characteristics curves.

Keywords: Global maximum power point, MPP, Partial shading, Solar cell.

1. Introduction

Solar photovoltaic system usage has increased from last many years. However, their performance depends on insolation, temperature, partial shading condition, place where solar photovoltaic system is installed etc. Among these factors partial shading is considered to be the most. Partial shading is the condition when some of the cells/ modules/ arrays receives less insolation due to falling leaves of trees, dirt, bird litters, nearby building, pole etc.[13,14]. At this condition, output of shaded cells fall down and this debris the output performance of whole photovoltaic system as I_{sc} decreases due to less insolation. The current-voltage curves dip due to reduction in short circuit current and so dissipation of power takes place in this condition. But under uniform shading condition the power-voltage characteristics of solar photovoltatic cedes single power maximum. However, at the time of non-uniform insolation superior photocurrent continues to operate unshaded cells because at that time current must be equal for all series connected solar photovoltaic cell. Therefore, the shaded photovolatic cells conduct through large current [1,2,7,8]. The voltage at which the shaded cells operate in this condition is reverse voltage. So, it consume power during this period and thus extracted maximum power from whole solar photovoltaic arrray decreases. Hence high bias voltage causes avlanche breakdown that turn thermal breakdown of the cell. This creates hot spot problem in solar photovoltaic system. To step aside hot spot problem, bypass diodes are used. These are connected in anti-parallel to solar photovoltaic arrays to restrict the reverse voltage and then limit the power loss in shaded cells. This bypass diode limits the reverse voltage to less than the breakdown voltage of photovoltaic cells when reverse voltage across the shaded cells increases[5]. At partial shading condition, when bypass diodes add an alternate current path, cells of a module does not follow the same current. Therefore, power will be consumed by these cells instead to generate and this dissipation of power creates hotspot problem under partial shading condition. To reduce this effect bypass diodes are used in anti-parallel to the cell but it is difficult to differentiate between local and global (at which maximum power can be recorded) maximum power point [3, 15].

Another method to overcome partial shading effect is reconfiguration technique. In this technique shaded modules are reconfigured through modules in adaptive bank. Thus, it provides constant output power even if modules are shaded. But the drawback of this technique is, it has high cost and is not helpful to compensate all shaded cells [5].

Many architectures to reduce the effect of partial shading are also defined in literature i.e. centralized architecture, parallel connected microconverter, series connected microconverter and microinverters. Among all these architecture centralized is conventional inverter architecture . But it cannot track global maximum power point of individual photovoltaic modules. Hence this architecture is not suitable under shading and mismatching losses[5]. For parallel architecture, modules are connected through dc-dc converter from central inverter. Series connected microconverter architecture tracks maximum power point of individual modules through dc-dc converter then connected to central inverter[5]. Central inverter is not used in microinverter architecture and permits maximum power point techniques for individual modules.

Different PV array topologies are also facilitative to overwhelm the problem of partial shading which is described in the following section.

2. Interconnection Schemes

Several topologies of solar photovoltaic are investigated viz. Series-parallel (SP) fig.1(a), Total-cross-tied (TCT) fig.1(b), Bridge-linked (BL) fig.1(c) and Honey-comb (HC) fig.1(d). It is important to study the behavior of these configurations for different shading patterns. In SP configuration, modules are first connected in series to generate required current and then in parallel fashion to meet required voltage [12]. TCT configuration is derived form of SP configuration in which modules are first connected in parallel and then these parallel connections are connected in series fashion to generate required power [6]. BL is modified configuration of TCT and thus some of the ties from TCT is removed [9]. The modification in BL configuration is made to form a new configuration called HC configuration. It is designed by the inspiration of honeycomb hexagon shape, in this case obliquely hatched blocks has a parallel combination of two cells while unhatched blocks show a single cell [10]. In HC configuration selection of ties is an important factor hence ties can be connected in variant of two, four and six modules [4]. However, TCT has so many ties; BL has fewer ties and SP has least number of ties [5]. In literature TCT is reported to perform under partial shading condition [11]. It is important to study about short circuit current, open circuit voltage to draw electrical performance of solar cell.

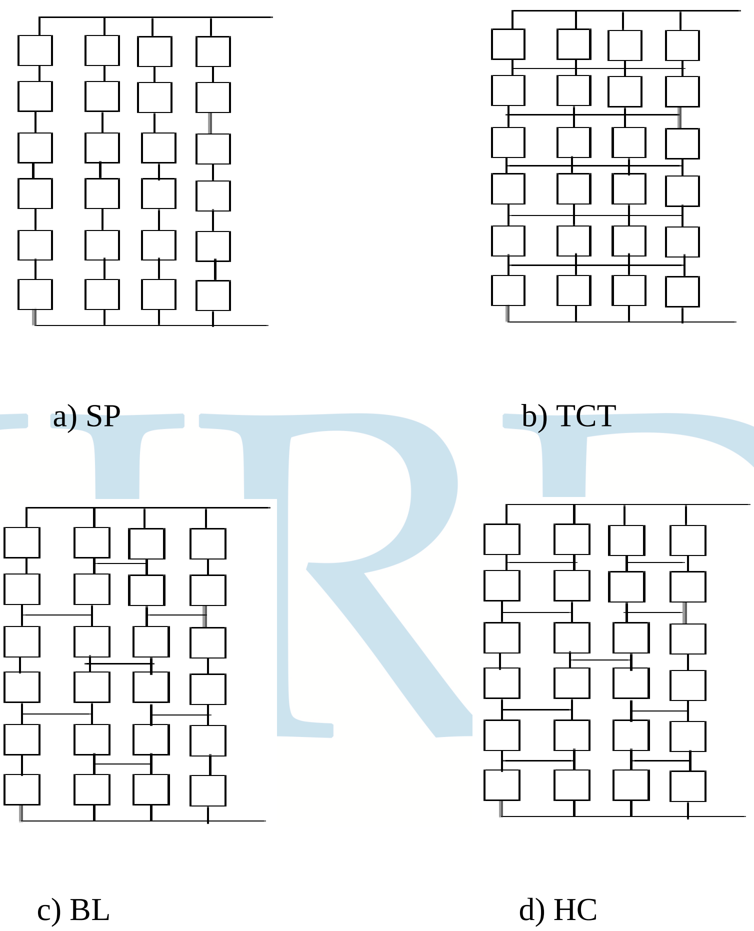


Fig.1 : Some interconnection schemes

3. System Model

3.1 Model of Single Solar Cell/ Array

In this paper already existing model of single solar cell is used for the characteristics curve. Bypass diode is also used in all simulated results to eliminate hot-spot problem. The simulated model of single solar cell is shown together with the I-V characteristics curve (fig.3.1) and power-voltage characteristics curve (fig.3.2). The data for single solar cell is taken from MATLAB/SIMULINK and is shown in Table I.

TABLE I. Data for single solar cell

Parameter	**Value**
Short-circuit current, I_{sc}	7.34 A
Open-circuit voltage, V_{oc}	0.6 V
Irradiance, I_r	1000 W/m^2
Quality factor, N	1.5
Energy gap, E_g	1.11 eV
Fixed circuit temperature	25°C

The output power of single solar cell is not enough to drive load. Therefore, it is required to connect several solar cells in series and parallel to form modules and then collection of one or more such modules are used to form array [16]. However, it is remarkable to embody these cells in assorted configuration. In this paper, 6*4 PV array is simulated considering of 24 modules to draw the characteristics curve for 1000 W/m^2 irradiation is shown in Fig. 4.

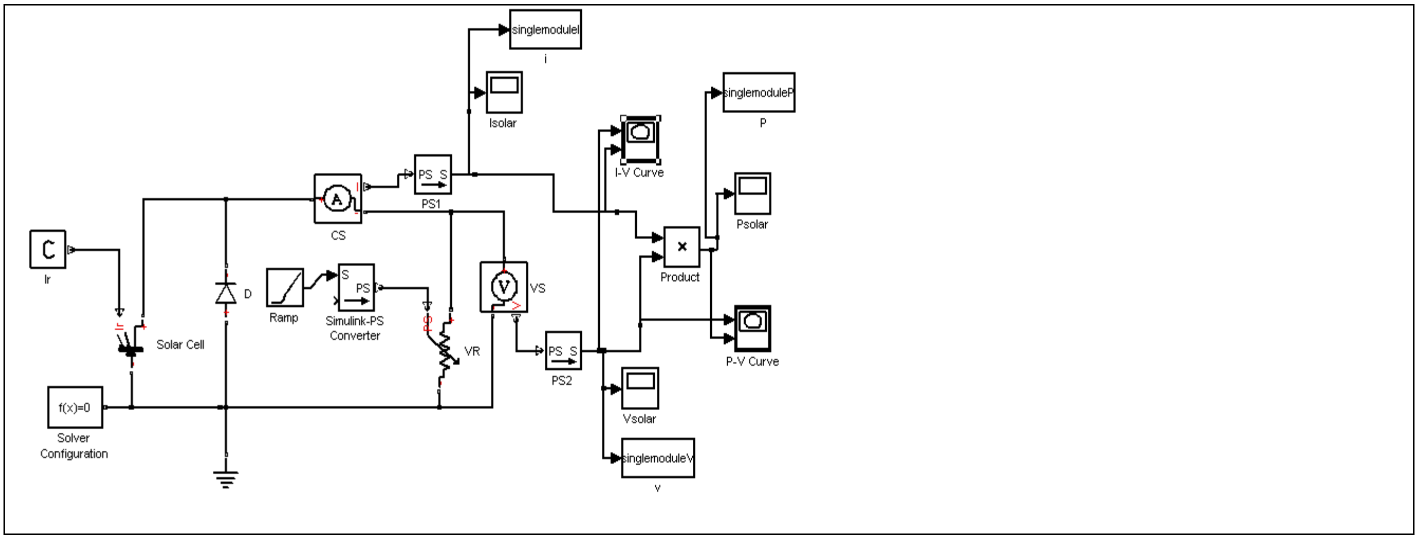
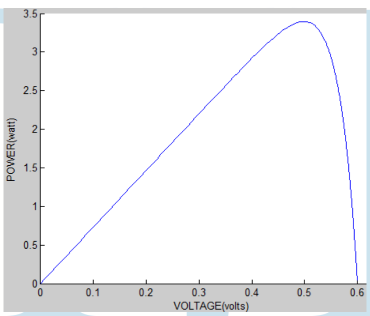
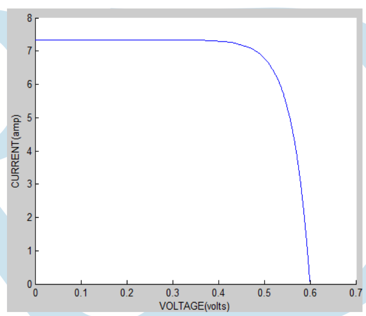


Fig.2 : Model of single solar cell in MATLAB/SIMULINK





a) P-V characteristics b) I-V characteristics

Fig.3 : Characteristics of single solar cell

Power-voltage curve and current-voltage curve for 6*4 PV array performing on 1000 W/m^2 irradiation is shown in Fig.5(a) and 5(b) respectively.

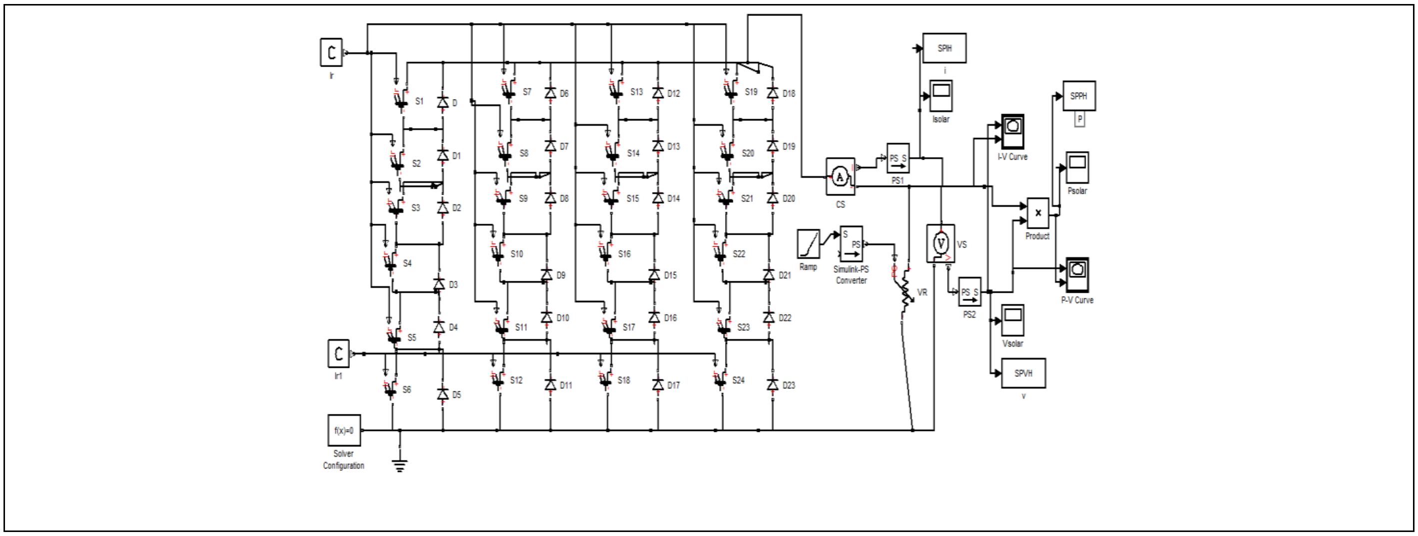
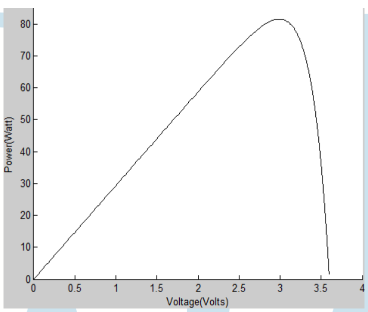
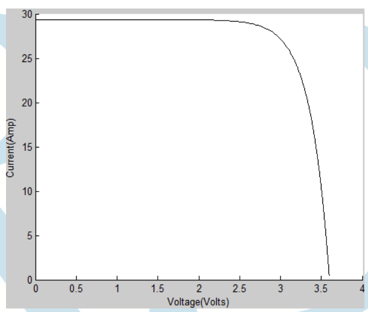


Fig4 :Model of 6*4 PV array in MATLAB/SIMULINK



a)P-V characteristics

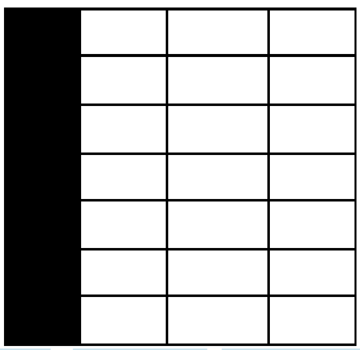


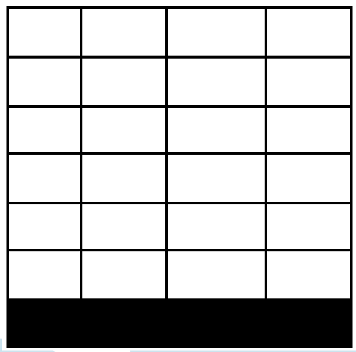
b)I -V characteristics

Fig.5 : Characteristics of solar 6*4 PV array

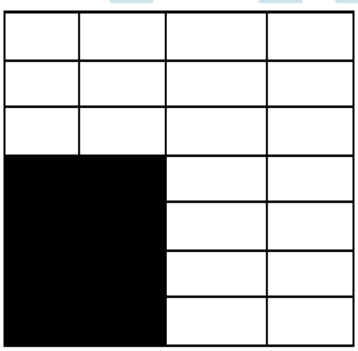
3.2 Shading Patterns

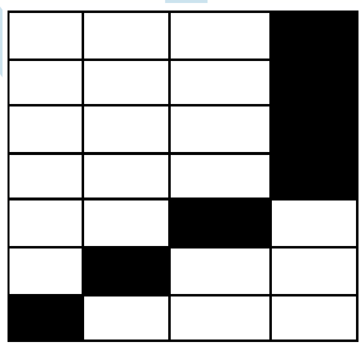
In this paper various configurations to deal with the problem of partial shading are considered under various partial shading scenarios. Thus combination of 24 solar cells is simulated for SP, TCT, BL and HC configurations. In this configuration 6 cells are connected in series to form a string and then these strings are connected in parallel as shown in fig. 4. The simulated modules of these configurations are compared for various shading pattern in order to find best topology for these shade patterns. Various shades patterns are considered for this study i.e. left most column shaded fig. 6(a), bottom row shaded fig. 6(b), quarter array shaded fig. 6(c), randomly assumed shade pattern-I fig. 6(d), randomly assumed shade pattern-II fig. 6(e), randomly assumed shade pattern-III fig. 6(f). For these six shading patterns mentioned above, the MPP power, MPP voltage, MPP current are calculated from characteristics and best topology is suggested based on the results and observations for these shade scenario.



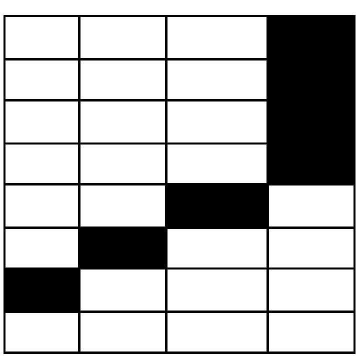


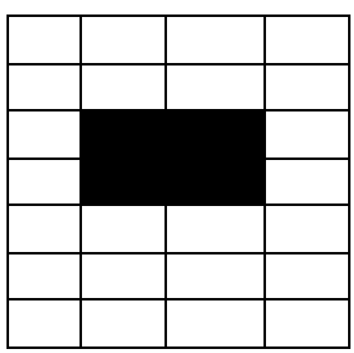
a) Left most columns shaded b) Bottom row shaded





c) Quarter array shaded d) Randomly shaded pattern-I





(e) Randomly shaded pattern-II (f) Randomly shaded pattern- III

Fig.6 : Various Shading Pattern

3.3 Results and Discussion

The results for different configuration under various partial shading patterns is shown in Fig.6(a) to Fig.6(f) in terms of I-V and P-V characteristics of each configuration shown through Fig.7.1 to Fig.7.6 below. Irradiation is taken as 500 W/m^2 for these shaded cells.

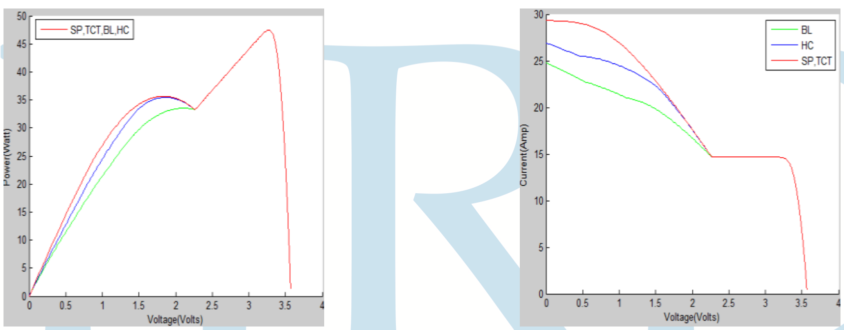


Fig.7.1 : P-V and I-V Characteristics for left most columns shaded

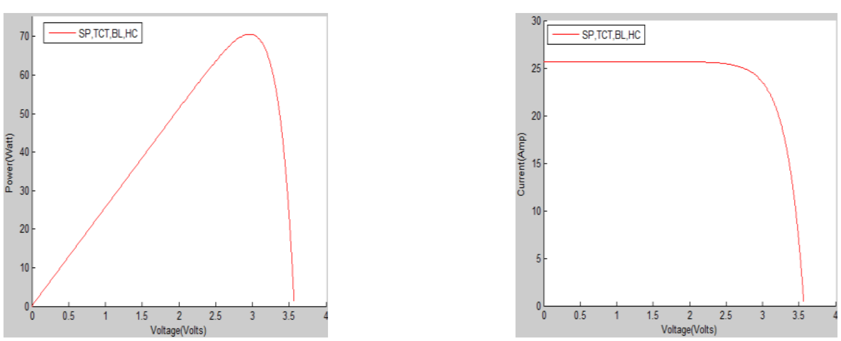


Fig.7.2 : P-V and I-V Characteristics for bottom row shaded

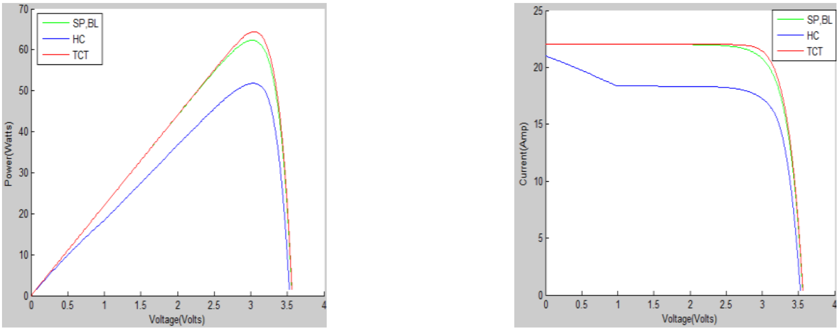


Fig.7.3 : P-V and I-V Characteristics for quarter array shaded

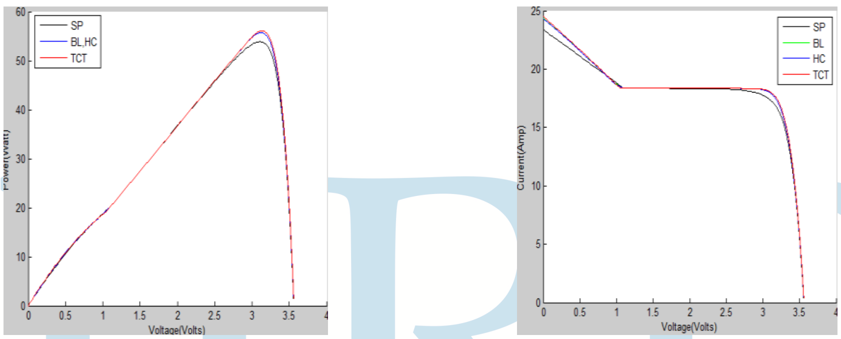


Fig.7.4 : P-V and I-V Characteristics for randomly shaded pattern-I

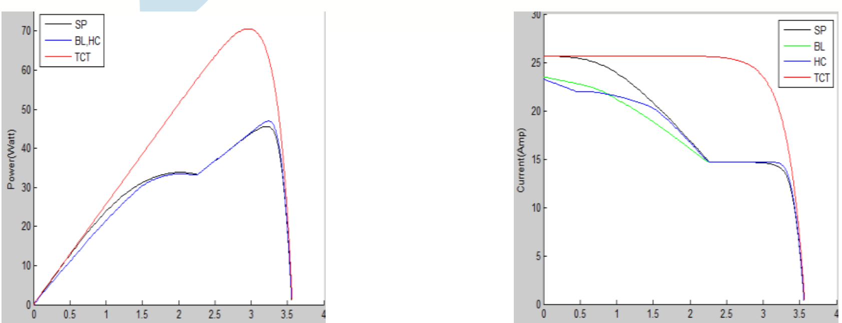


Fig.7.5 : P-V and I-V Characteristics for randomly shaded pattern-II

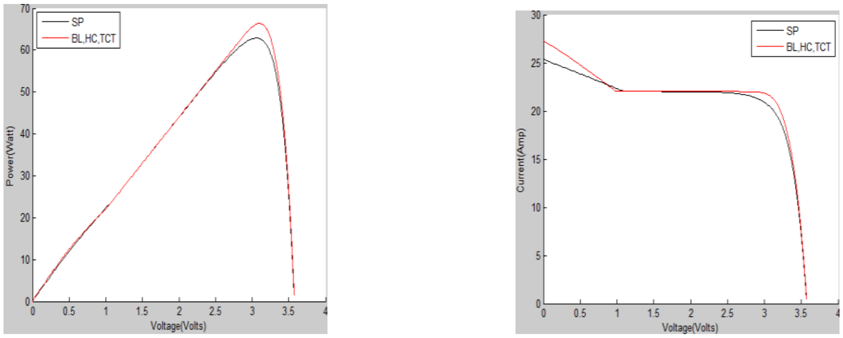


Fig.7.6 : P-V and I-V Characteristics for randomly shaded pattern-III

These results accentuates that in shading pattern shown in Fig.6(a) and 6(b) MPP power is equal for all topologies. So in these partial shading conditions any topology can suggest. However it is better to favor SP configuration as it has less number of ties. Results mentioned for shading pattern as shown in Fig.6(c), 6(d) and 6(e) TCT is performing better according to its power-voltage curve shown in Fig.7.3, 7.4 and 7.5. According to result for shading pattern of Fig.6(f) TCT, BL and HC have same performance shown in Fig.7.6. Here, BL configuration is suggested because it has less number of connections compared to TCT.

4. Conclusion

In this paper different configuration like SP, TCT, BL and HC configuration is simulated with the help of MATLAB/SIMULINK and their performance is compared under various partial shading conditions. It is reported in literature that TCT performs better under partial shading condition. But in some of the cases interconnection can be altered to decrease the number of ties. The consequences of less number of ties are decreased cabling losses along with reduction in connection time. In some of the partial shading condition SP and BL is also supposed to be better in comparison to TCT.

5. References

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