Power Enhancement from Solar PV Array Topologies under Partial Shading Condition

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Abstract

In this paper, a detailed study is carried out on the solar photovoltaic (PV) array topologies under various shading patterns. The aim of this study is to investigate the mismatch effect losses in PV modules for non uniform irradiations. The shading causes not only power losses, but also non-linearity of P-V characteristics. Under partial shaded conditions, the P-V and I-V characteristics exhibit extreme non-linearity along with multiple load maxima. In this paper, the investigations of the optimal layout of PV modules in a PV array are worked out to provide maximum output power under various shaded conditions. Three type of solar PV array topologies e.g. Series-parallel (SP), Total cross tied (TCT) and Bridge link (BL) are considered for various types of shaded patterns. The modeling of solar PV array for various types of topologies is done in MATLAB/Simulink environment. The extensive results have been taken on these topologies for partial shading patterns and analyzed, which proves the TCT topology performance is better as compared to other topologies for most of the shading patterns.

1. INTRODUCTION

The electrical power demand is increasing exponentially due to its various advantages in domestic as well as commercial applications. Today, the power supply is dependent on the fossil fuels e.g. diesel, petrol and coal etc., but possibility of unavailability of enough energy resources is major problem in near future, because the limited storage of fossil fuels. In this context, it is forced to the researcher for exploring more sustainable energy sources to generate the electrical power. [1] The renewable energy (RE) is best available option to fulfill the demand of electrical power. [2]

The photovoltaic (PV) system is currently one of the best promising RE source for distribution power generation. The PV system is beneficial and preferable to human being due to various advantages features e.g. no environmental effects and economic, clean and require low maintenance. [3] The PV system converts directly 30-40% of solar energy into the electrical energy only. It is a big challenge to enhance the power generation through PV system, so various advance maximum power point techniques (MPPT) are investigates in literature e.g. Perturb and observe (P and O), Fuzzy logic and Neuro-fuzzy based MPPT techniques [4,5]. Furthermore, the connections of solar PV arrays e.g. series, parallel, series-parallel (SP), bridge link (BL) and total cross tied (TCT) etc. are discussed in literature.

The authors of [6] proposed an algorithm and analyze the effect of non-uniform changing shadows (a passing cloud) on the output power of solar PV arrays. Each solar array is composed of a matrix of individual solar cells or solar modules interconnected in series and parallel. Bypass switches and diodes are also modeled. The authors in [7], proposed a novel algorithm to track the global power peak under partially shaded conditions. In order to accelerate the tracking speed, a feed forward control scheme for operating the dc–dc converter is also proposed. The authors of [8] proposed a concept that the initial voltage tracking function (IVTF) has been introduced to assign new initial voltage for tracking the absolute MPP when the PV array is at shaded conditions. The authors [9,10] proposed various types of solar PV topologies e. g. 2 x 6 (SP, BL and TCT), 6 x 2 (SP, BL and TCT), 4 x 3 (SP, BL and TCT), 3 x 4 (SP, BL and TCT) for performance investigation under the of non-uniform irradiance.

With the motivation of above literature review, in this paper a performance analysis of PV array topologies e.g. SP, BL and TCT are considered for various shading patterns to test the mismatch effect losses in PV modules.

The present paper is organized as follows. In Section II, the mathematical modeling of PV system is described. In Section III, the modeling of PV array topologies are proposed. Furthermore, in Section IV, partial shading patterns are proposed for performance evaluation. The results and discussion are presented in Section V and Section VI concludes this paper.

2. MATHEMATICAL MODELING OF PV SYSTEM

Solar PV array is formed by connecting various PV cells in SP, BL, TCT connections to enhance electrical power from installed array. Considering only a single solar cell; it can be modeled by utilizing a current source, a diode and two resistors and the electrical equivalent circuit is shown in Fig. 1 as,

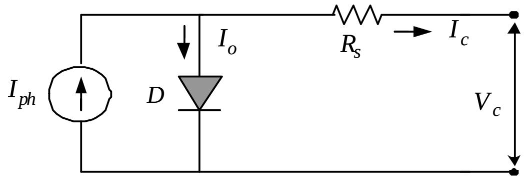

Fig.1: Equivalent circuit diagram of single diode solar cell

Solar PV cell voltage (V_C) is the function of current (I_{ph}) solar irradiation, can be expressed as,

$$V_C = \frac{AkT_C}{e}\ln\left(\frac{I_{ph}+I_o-I_c}{I_o}\right) - R_s I_c \qquad (1)$$

The Eq. (1) gives the PV voltage, which is then multiplied by the number of the PV cells to design a PV array connected in SP, BL and TCT connections.

The operating temperature T_c of PV cell varies with solar irradiation level S_c, ambient temperature T_a. These effects are shown with temperature coefficients for voltage and current (C_{TV} and C_{TI}) for PV cell respectively in Eq. (2) [11] as,

$$C_{TV} = 1+\beta\left(T_a - T_x\right) \text{ and } C_{TI} = 1+\frac{\gamma_T}{S_C}\left(T_x - T_a\right) \qquad (2)$$

The effect of irradiation level (S_x) on the voltage and photo current can be determined with the help of constants, C_{SV} and C_{SI}, which are the correction factors. The correction factors C_{SV} and C_{SI} are helpful to determine the effect of irradiation level (S_x) on the cell voltage and photocurrent. These can be expressed in Eq. (3) [11] as,

$$C_{SV} = 1+\beta_T\alpha_S\left(S_x - S_c\right) \text{and } C_{SI} = 1+\frac{1}{S_c}\left(S_x - S_c\right) \qquad (3)$$

Where, reference solar irradiation and new irradiation level are represented by S_c and S_x respectively. The correction factors C_{TV}, C_{TI}, C_{SV} and C_{SI} are helpful to determine the new values of the PV cell voltage V_{cx} and photocurrent I_{phx}, can be expressed in Eq. (4) as,

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$V_{cx} = C_{TV} C_{SV} V_C$ and $I_{phx} = C_{TI} C_{SI} I_{ph}$ (4)

3. MODELING OF PV ARRAY TOPOLOGIES

The efficiency of PV system is always depends upon irradiation, temperature, aging, dust particles e.g. sand and ash etc. New various topologies are investigated and utilized to enhance the performance of PV array. [12] In this context, various solar PV array topology e.g. SP, TCT and BL are considered for different shading patterns to analyze and enhancement the efficiency of PV module. Therefore, study of PV array behavior is more important in partial shading situation. The effect of partial shading can be reduced the performance of PV array. [13] A major solution of this types shading problem can be overcome by altering or changing the interconnection of solar PV array, so SP and BL topologies are containing less number of interconnections in comparison to the TCT topology PV array. [14]

In this paper, 4 x 4 PV array is simulated for proposed topologies e.g. SP, BL and TCT are shown in Fig. 2. All the topologies of PV array are designed in MATLAB/Simulink environment. [15]

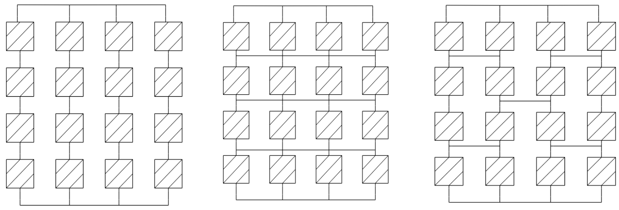


Fig.2: Solar PV array interconnection topologies.

4. ANALYSIS OF SHADING PATTERNS

For determining the impact of shading on solar PV performance, three different shading patterns are considered. Each patterns having four cases a, b, c and d. In all patterns, two types of irradiation level (350W/m^2 and 1000W/m^2) are taken for performance investigation in Fig. 3 as,

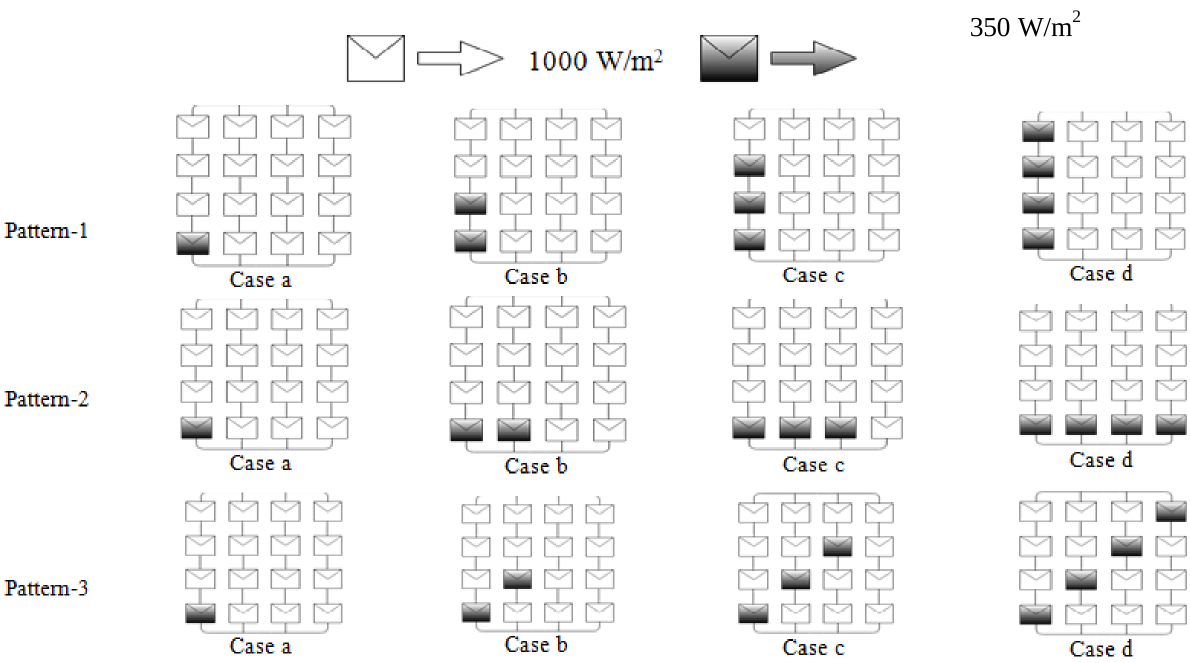


Fig.3: Proposed shading patterns on various topologies of PV array

5. RESULTS AND DISCUSSION

The performance of PV array is analyzed under various shading patterns. Four shading conditions are considered for each of three patterns. Following cases are proposed to assess the effect of shading effect on the considered topologies as,

Case 1: Effect of partial shading (pattern 1-a) on SP, TCT and BL topology

Case 2: Effect of partial shading (pattern 1-b) on SP, TCT and BL topology

Case 3: Effect of partial shading (pattern 1-c) on SP, TCT and BL topology

Case 4: Effect of partial shading (pattern 1-d) on SP, TCT and BL topology

Case 5: Effect of partial shading (pattern 2-a) on SP, TCT and BL topology

Case 6: Effect of partial shading (pattern 2-b) on SP, TCT and BL topology

Case 7: Effect of partial shading (pattern 2-c) on SP, TCT and BL topology

Case 8: Effect of partial shading (pattern 2-d) on SP, TCT and BL topology

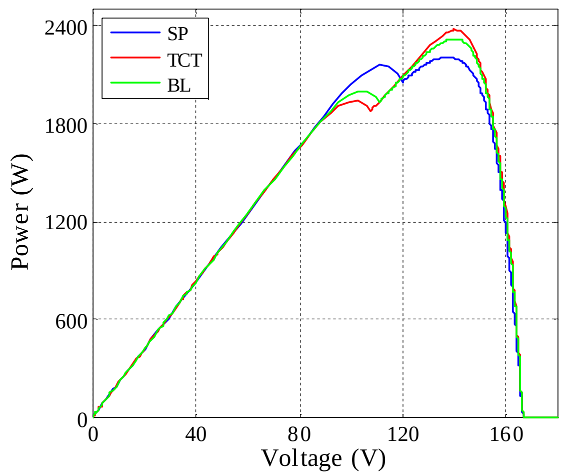
Case 9: Effect of partial shading (pattern 3-a) on SP, TCT and BL topology

Case 10: Effect of partial shading (pattern 3-b) on SP, TCT and BL topology

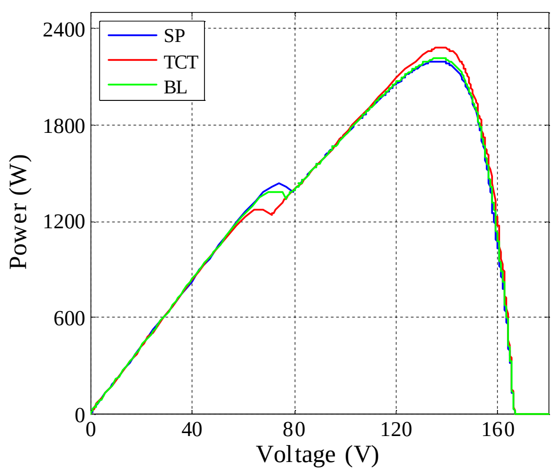
Case 11: Effect of partial shading (pattern 3-c) on SP, TCT and BL topology

Case 12: Effect of partial shading (pattern 3-d) on SP, TCT and BL topology

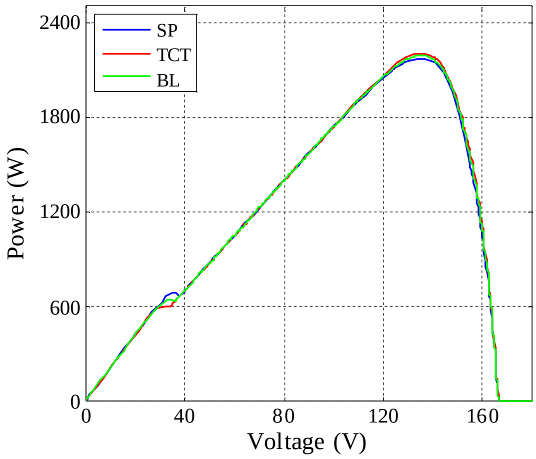
The P-V characteristics of solar PV array for case 1 to case 4 for shading pattern '1' are given in fig. 4a-4d. For the shading case 'a', two MPP are observed on the P-V curve. The local MPP is very close to the global MPP. The effect of shading is quite significant on the power output, which is observed in fig. 4a. The power at global MPP is obtained as 2207 W, 2372 W and 2319 W for SP, TCT and BL topology respectively. The P-V characteristics of shading case 'b' are shown in fig. 4b. It is notice from the figure that local MPP is at a distance from the global MPP and effect of shading on the power curve is not so pronounce as in case 'a'. The power at global MPP is observed as 2197 W, 2279 W and 2213 W for the SP, TCT and BL topology. The P-V characteristics for shading case 'c' and case 'd' are shown in fig. 4c and fig. 4d respectively. The effect of shading is decreasing from case 'a' to case 'd' and it is almost zero for the case 'd' for all the considered SP, TCT and BL topology. The power at global MPP for these two cases are noticed as 2170 W, 2203 W, 2186 W and 2138 W, 2139 W , 2139 W for case 'c' and case 'd' respectively.



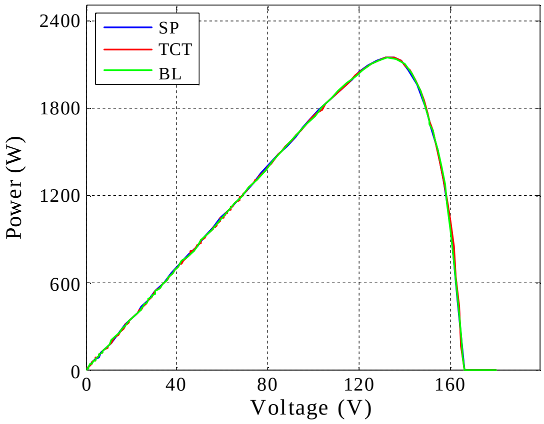
(a)



(b)



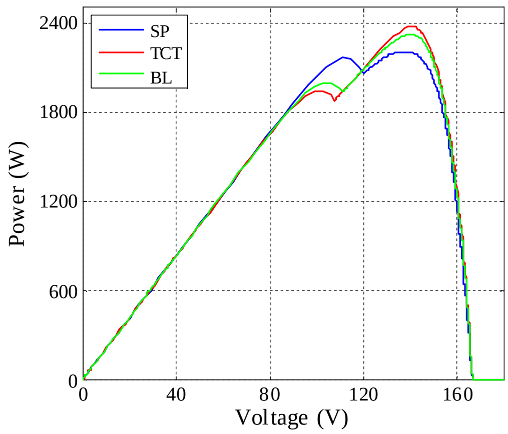
(c)



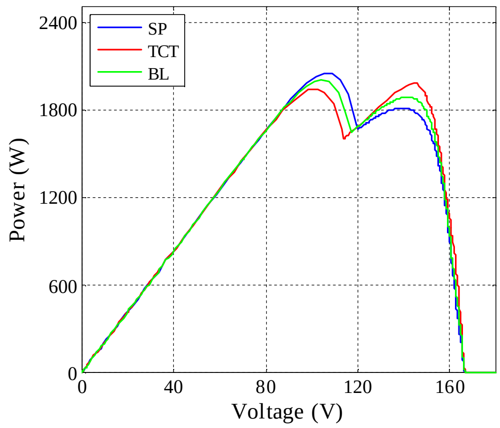
(d)

Fig. 4: (a)-(d) Effect of shading patterns (Case: 1-4) on P-V characteristics for SP, TCT and BL topologies.

The P-V characteristics of PV array for case 5 to 8 for shading pattern '2' are given in Fig. 5a-5d. For the shading case 'a', two MPP are observed on the P-V curve .The local MPP is very close to the global MPP and the effect of shading is quite significant on the power output, which is observed in Fig 5a. The power at global MPP is obtained as 2207 W, 2372 W and 2319 W for SP, TCT and BL topology respectively. The P-V characteristic of shading case 'b' is shown in Fig 5b. it is notice from the figure that local MPP is at a distance from the global MPP and effect of shading on the power curve is not so pronounce as in case 'a'. The power at global MPP is observed as 2049 W, 1976 W and 2001 W for the SP, TCT and BL topology. The P-V characteristic for shading case 'c' and case 'd' are shown in fig. 5c and 5d respectively. The effect of shading is decreasing from case 'a' to case'd' but global MPP are still exiting for all the considered SP, TCT and BL topology. The power at global MPP for two cases are noticed as 1987 W, 1939 W, 1939 W and 1941 W, 1941 W and 1942 W for case 'c' and case 'd' respectively.



(a)



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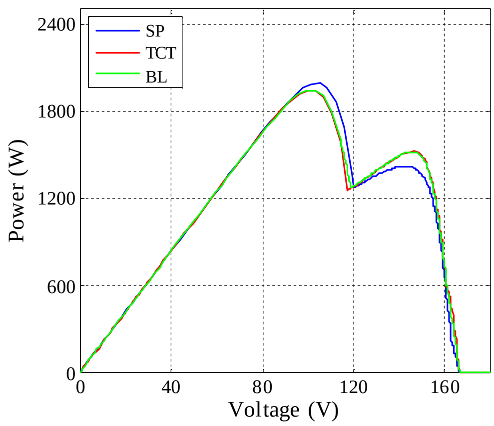

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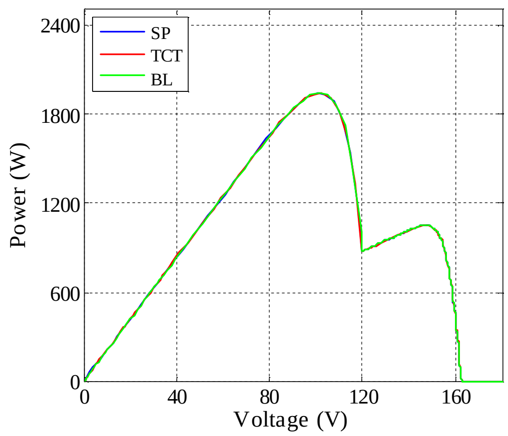
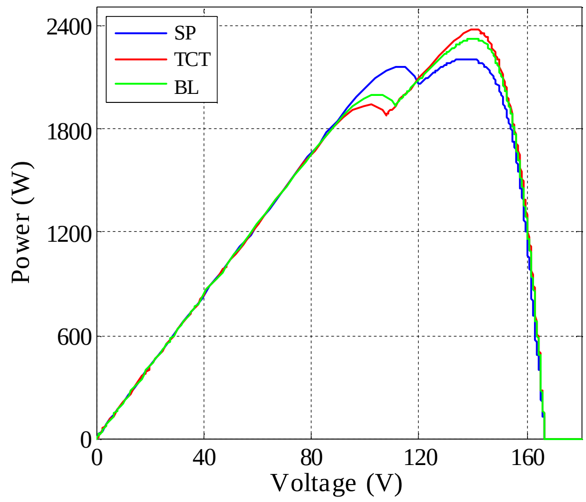


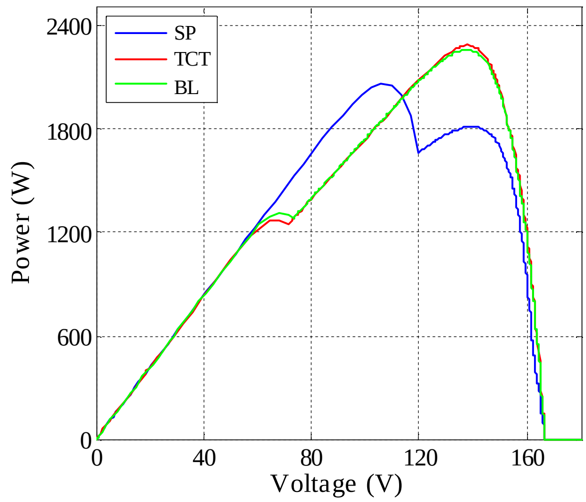
(d)

Fig.5 : (a)-(d) Effect of shading patterns (Case: 5-8) on P-V characteristics for SP, TCT and BL topologies.

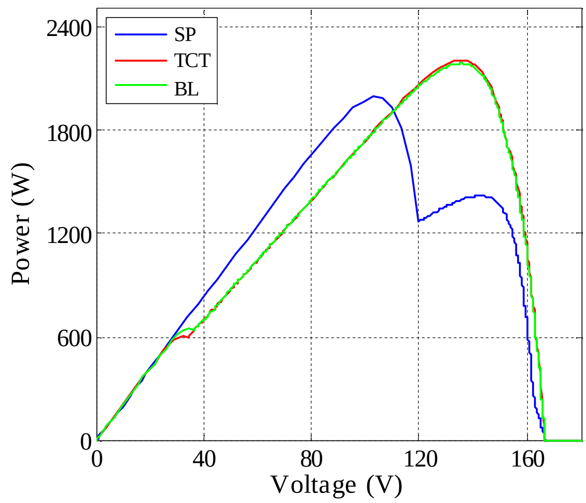
The P-V characteristics of solar PV array for case 9 to case 12 for shading pattern ‘3’ are given in fig 6a-6d. For the shading close case ‘a’ two MPP are observed on the curve. The local MPP is very close to the global MPP. The effect of shading is quite significant on the power output, which is observed in Fig 6a. The power at global MPP is obtained as 2207 W, 2372 W and 2319 W for SP, TCT and BL topology respectively. The P-V characteristics of shading case ‘b’ are shown in fig. 6b. It is notice from the fig. that local MPP is at a distance and the effect of shading on P-V characteristic no large on TCT and BL topology in comparison of S P topology. The power at global MPP is observed as 2051 W, 2279 W and 2255W for SP, TCT and BL topology. The P-V characteristics for shading case ‘c’ and case‘d’ are shown in fig 6c and fig 6d respectively. The effect of shading is decreasing from case ‘a’ to case‘d’. But the shading effect on the TCT topology is not disturbing the P-V characteristics. The power at global MPP for these two cases are noticed as 1987 W, 2204 W, 2186 W and 1942 W, 2138 W, 2139 W for case ‘c’ and case ‘d’ respectively.



(a)



(b)



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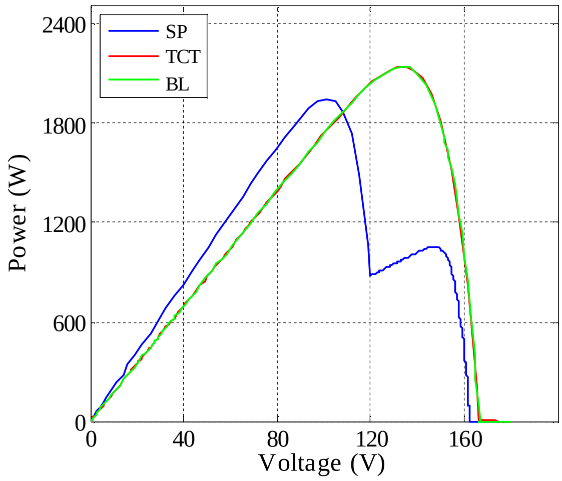

(d)

Fig.6: (a)-(d) Effect of shading patterns (Case: 9-12) on P-V characteristics for SP, TCT and BL topologies.

The maximum power and voltage for the discussed cases 1-12 are summarized in Table I. It is noticed from this study that TCT topology provides the better power as compared to other considered SP and BL topology for the considered shading patterns and cases.

Table-1: Simulation Results : Power, and Voltage and of Various Topologies

	SP		TCT		BL		Best Topology
Cases	P(watt)	V(volt)	P(watt)	V(volt)	P(watt)	V(volt)	
1	2207	138	2372	140	2319	139.4	TCT
2	2197	137.4	2279	138.2	2213	137.5	TCT
3	2170	136	2203	136.4	2186	136	TCT
4	2138	132.6	2139	133	2139	132.6	SP/TCT/BL
5	2207	138	2372	140	2319	139.4	TCT
6	2049	107.8	1976	102.4	2001	104	SP
7	1987	103.5	1939	101	1939	101	SP
8	1941	100.6	1941	100.6	1942	100.6	SP/TCT/BL
9	2207	138	2372	140	2319	139.4	TCT
10	2051	105.9	2279	138.2	2255	138.2	TCT
11	1987	103.5	2204	136.4	2186	136.4	TCT
12	1942	101.4	2138	135	2139	133	TCT/BL

6. CONCLUSION

In this paper the performance of PV array topologies for various shading patterns have simulated and analyzed. Three solar array topologies SP, TCT and BL have considered for this study to assess the effect of shaded patterns of vertical, horizontal and diagonal. The effect of shading pattern on these topologies is resulting into increase of non-linear effect and causing multiple maxima for most of the cases. For vertical progress of shading (pattern 1), TCT has exhibited better performance and produces more power. For horizontal progress shading (pattern 2), TCT performs better for case ‘a’ and ‘d’ whereas SP performs better for shading case ‘b’ and ‘c’. In case of diagonal progress of shading (pattern 3), TCT topology has exhibited better performance.

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