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Enhancement of Power and Performance of 9x4 PV Arrays by a novel arrangement with shade dispersion

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Abstract
Demand for green energy is increasing day by day in all sectors. It has become all time high now a days. Researchers are therefore, trying to improve the performance of renewable energy resources like PV Array Solar cell. Performance of a solar cell can be improved with different number of PV array matrix and different shade dispersion arrangement. In this paper, a new model of the Photo Voltaic Array configuration of 9x4 PV Arrays has been presented and their performance has been studied in the MATLAB / Simulink platform.

Keywords: *Photovoltaic arrays,Renewable energy sources (RES), 9x4 PV Arrays, Partial shading, shade dispersion arrangement.*

INTRODUCTION

Declination of fossil fuels with ever increasing environmental pollution is a real concern of today’s time. This has compelled the tremendous growth of Renewable Energy Sources (RES) research to balance the growing demand for energy. Solar is one of the most attractive renewable energy sources for power distribution. Solar energy is a cleaner source of energy and does not responsible for any pollution as well as global warming. For this reason, solar energy systems are correspond to future investment for conserving of non-renewable energy sources and environmental protection.

Scientists are busy on improving the Photo Voltaic (PV) cell technology which is the fundamental block for converting solar energy into electrical energy. PV cell operates based on the the principle of photoelectric phenomenon. Compared to other sustainable power sources it is more reliable, safe, low cost and required minimal maintenance. However, there are some issues with PV cell. Since the PV cell works on sun light, shading is a real concern for PV cell. Efficiency of a solar panel is highly affected by shading. Even partial shading affects a solar panel's efficiency. Because in partial shading condition the operational temperature increases. It can reach upto 150˚C, where as the safe operating temperature of a PV cells is approximately 85 ° C. This over heating phenomenon creates local over heating (hotspot) which is the most frequently occurred phenomenon and can seriously damages the PV cell. This is a most frequent phenomenon occurred in solar panel which limits the operation life of PV cells. Moreover, partial shading also affects the efficiency of the PV modules. To mitigate the partial shading problem a large number of researchers are working on proper arrangement of the PV modules. Photo diodes are arranged in series and parallel arrangement. The photon current flowing through each series connected PV cells must be equal in order to improve the efficiency of a PV array, which is not the case in partial shading condition. Since, in partial shading condition the shaded cell is in reverse biased condition which behaves as a resistance. To avoid this situation, diodes are connected across shaded PV cells in order to carry the current of reverse bias. Hence, the reverse bias current, and formation of hotspot on the PV cells can be avoided. However, power consumption increases and additional cost needed for it. A shadow upon the solar panel also affects the various parameters like irradiance;

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temperature levels etc. In partial shadow condition solar panel receive unbalance solar irradiation. Hence, the PV arrays depict few peaks in P-V and I-V curve.

Partial shading condition occurs due to the shadow of cloud, tree, buildings upon solar panel; even snow or dust may create partial shedding. Partial shadow effect can be minimized by a new configuration of PV array design. Different modules of PV array are interconnected increase the power output of the array. Therefore, PV cell arrangement has a major role in the efficiency contribution. Various configuration of PV array design is available in the literature like, Total cross tied (TCT), Honey- comb (HC),Bridge-link (BL),Series-parallel (SP), for different shading pattern etc [1]. A PV module is configured with a number of interconnected PV cell. Usually, 36 cells are connected in series. The connection of PV cells depends on the PV module voltage (series) / current (parallel) rating. The electrical properties of the PV cells should be same.

This paper introduced a new model for Photo Voltaic array configuration, and its efficiency has been studied. To improve the efficiency of the partially shedded PV system is the real challenge. Local and global maximum power points (MPPs) should be monitored to determine the shedding effect. Due to the different solar irradiation obtained by the PV array during the partial shading condition as received during no shading period, the power generated by the PV system is reduced during the partial shading. Due to its simplicity and cost-effectiveness, the commonly used traditional incremental conductance and perturb & observe [2] MPP tracking (MPPT) has a significant implementation.

Solar PV modules performance depends on the level of solar radiation and certain environmental factors. In designing the solar PV cells, several changes can be made using the study and analysis of the power plant if necessary.

This paper proposes a new PV system design to enhance PV system performance under partial shading conditions. This design uses different PV modules rearrangement techniques. In the presence of different shading patterns, the performance analyses of the PV array (9x4) with the proposed configuration and some other configurations have been performed.Detailed comparative studies have also carried out to show the superiority of the proposed configuration with different configurations. The MATLAB / Simulink software is used to model photo voltaic module with different configurations.

The remaining paper is structured in the following manner. Section 2 addresses PV cell modeling. Section 3 describes different configurations used for the PV array to manage partial shading condition. Section 4 introduces a new configuration for the photovoltaic array. Section 5 analyzes the PV array for different configurations. Section 6 provides a conclusion.

I. MATHEMATICALMODELING OF PHOTO VOLTAIC CELL

Solar photovoltaic cell works on the principle of energy conservation and electrical energy transfer from heat and light energy. This is the PV array's fundamental building block.A single PV cell is a diode made from a highly doped silicon wafer p-n junction. A large number of p-n junction diodes are connected in various combinations and methods to increase the power generated and make the PV module the desired size and capacity. Power generation of a PV pane depends on sun radiation incident on its floor and temperature. Hence, the electricity generation varies with time to time as well as in seasons. Total radiation incident on an inclined PV panel can be given as follows [2]:

$$I_T=I_bR_b+I_dR_d+(I_b+I_d)R_d \quad (1)$$

Where, $I_d$and $I_b$stands for diffuse radiation normal radiation respectively.

$R_d$and R_r are the tilt factor for diffuseand reflected radiation respectively.

Fig. 1 shows the PV cell's electrical equivalent circuit, where a diode and a resistor are connected with a current source as,

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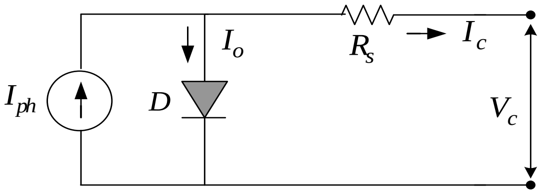


Fig. 1 Equivalent circuit diagram of single diode solar cell

PV array is the interconnection of large number of PV cells [1]. In order to boost the electrical power produced by the PV array, many types of connections are being studied.

The losses in the PV array are known to be zero in ideal condition, but it is not possible to achieve zero losses in realistic condition. As illustrated in Fig. 1, a series of resistors is connected to the PV cell equivalent circuit to reflect internal photovoltaic cell losses [1]. The value of this resistance is zero for a PV cell functioning in the ideal condition.The PV cell's reduction in efficiency is represented through power dissipation across the series resistor. The current passes through the diode connected across the current source as shown in Fig. 1, can be given by Shockley diode equation [2].

Mathematically, Solar PV cell voltage (V_C) depends on solar irradiation and current (I_{ph}), is expressed as,

$$V_C = \frac{AkT_C}{e}\ln\left(\frac{I_{ph}+I_o-I_c}{I_o}\right)-R_sI_c \qquad (2)$$

where, I_d is the diode current,

I_s is the reverse saturation current,

Q = elementary charge,

K = Boltzmann's constant,

N = Ideality factor.

The temperature coefficients for current (C_{TI}) and voltage (C_{TV}) for PV cell can be given by Eq. (3) [2],

$$C_{TV} = 1+\beta(T_a - T_x) \;\&\; C_{TI} = 1+\frac{\gamma_T}{S_C}(T_x - T_a) \qquad (3)$$

The operating temperature T_x depends on ambient temperature (T_a) and solar irradiation level. Two correction factors C_{SV} and C_{SI} are needed to determine the effect of irradiation level (S_x) on the photo current and voltage, as given by Eq. (4) [3],

$$C_{SV} = 1+\beta_T\alpha_S(S_x - S_c) \;\&\; C_{SI} = 1+\frac{1}{S_c}(S_x - S_c) \qquad (4)$$

Where, S_c represents reference solar irradiation and S_x represents new irradiation level. The values of the PV cell voltage V_{cx} and photo current I_{phx}, can be given as Eq. (5),

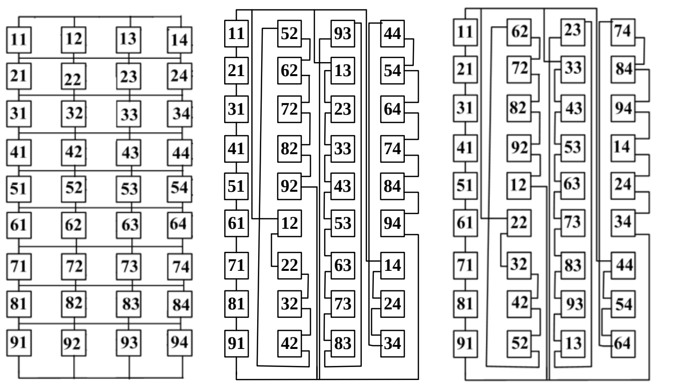
$$V_{cx} = C_{TV}C_{SV}V_C \;\&\; I_{phx} = C_{TI}C_{SI}I_{ph} \qquad (5)$$

II. MODELING OF THE PV ARRAYCONFIGURATION

The efficiency of the PV system is always dependent on irradiation, temperature, aging, particles of dust such as sand and ash etc. in the PV array row modules. New topologies are explored and used to optimize efficiency.In this context, different solar PV array topologies e.g. NS-1, NS-2 and TCT, are considered for different shading patterns to examine and improving the efficiency of PV module. Therefore, in shading situation, the behavior of PV arrays is more important.

The effect of shadings can be reduced the execution of PV array [4, 5]. By changing the interconnection of the solar PV array, a major solution of this type of shading problem can be overcome, so conventional topologies contain less interconnections compared to the TCT [6,7].

In this paper, with proposed topologies such as TCT, NS-1 and NS-2, the 9x4 PV array is simulated as shown in Fig. 2. Both topologies of the PV array are designed in the MATLAB / Simulink environment [8].



(a) TCT-PVF pattern (b) NS-1 pattern (c) NS-2

Fig. 2 Solar PV array topologies.

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The proposed configuration of the 9x4 model is shown in fig. 2, where the first digit is the position of the row and the second digit is the position of the column. Here, the panel position is changed without disturbing the panel's electrical connection.Since the array's electrical configurations do not change with the panel position, for all configurations, the voltage & current equations remain the same [9].

The current generated by PV modules can be given as Eq. (6).

$$I = \left(\frac{G}{G_{STC}}\right) \times I_m \quad (6)$$

Where, I_m is the generated module current. The Array voltage can be expressed as,

$$V = \sum_{n=1}^{4} V_{mn} \quad (7)$$

Where, V_{mn} is the n^{th} row voltage of photo voltaic array.

A solar cell's fill-factor can be determined from the P-V curves. It varies and describes partial shading conditions as,

$$FF = GMPP/Voc \times Isc \quad (8)$$

Where, LMPP is local maximum power points and GMPP is multiple maximum power points [10-13] under partial shaded conditions. In the scenario when the multiple Maximum Power Points (MPPs) are considered that conventional tracking techniques do not give the desired results for tracking the GMPP [14].

The technique of MPPT or Incremental Conductance is used to maximize and optimize the use of the PV array. The principle of summation of instantaneous conductance (Ipv /Vpv) and incremental conductance (AIpv /AVpv) at mostpower factor leads to zero with negative on the right side (*dI/dV<-I/V)* and high-quality on the left side of MPP (*dI/dV>-I/V)* governs this MPPT technique. Using the values, this technique detects the ideal operating point of the PV device:

dI/dV=-I/V   *at MPP*

Power loss in the partially shaded PV array can be expressed as [15],

Power loss = (Maximum power of PV array without PS – GMPP with PS) (9)

III. ANALYSIS OF 9X4 PV ARRAY SHADING PATTERNS

In order to determine the effect of shading on the PV array, two separate shading patterns are considered. Pattern-1 has nine (a-i) cases, but pattern-2 has only four (a-d) cases. Two different levels of irradiation are taken for output analysis on pattern-1 and pattern-2 in all two models (350W / m2 and 1000W / m2) as shown in fig. 3.

Table I gives the values of different parameters of available PV module (for commercial use) at standard test condition (STC).

Table 1. Specifications of photo voltaic module at STC (1000W/m^2 and 25^0C)

Parameters	Values
No. of cell	72
Open circuit voltage	44.2 V
Short circuit current	5.2 A
PV power	170 W
Current at MPP	4.75 A
Voltage at MPP	35.8 V

Arrangements method for NS-1 and NS-2 configurations are depicted in Table 2

Table 2. Arrangement of Digits by using Proposed NS-1 and NS-2 method for 9x4 PV Array

NS-1 Arrangement			
Column 1	Column 2	Column3	Column4
1	3	5	2
2	4	1	3
3	5	2	4
4	1	3	5
5	2	4	1
6	8	10	4
7	9	1	3
8	10	2	4
9	2	4	1

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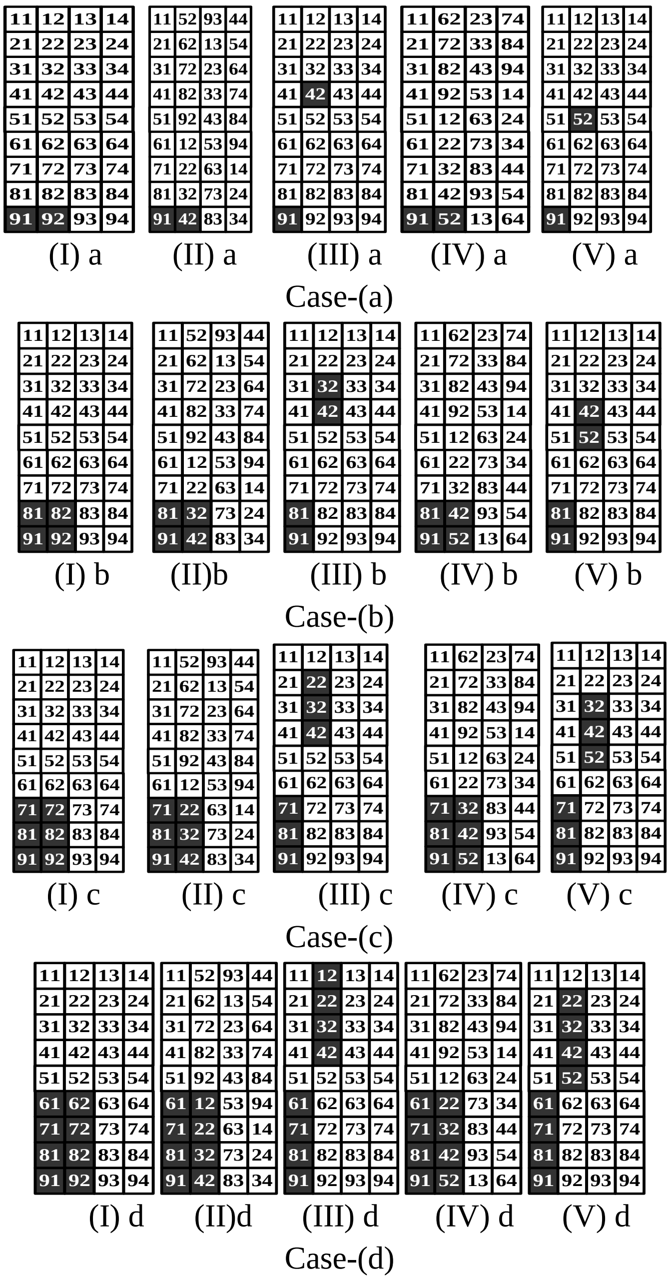
NS-2 Arrangement			
Column 1	Column 2	Column 3	Column 4
1	4	2	5
2	5	3	1
3	1	4	2
4	2	5	3
5	3	1	4
6	9	2	5
7	10	3	1
8	11	4	2
9	3	6	4

Shading cases for 9x4 PV array with all types of configuration is shown below.



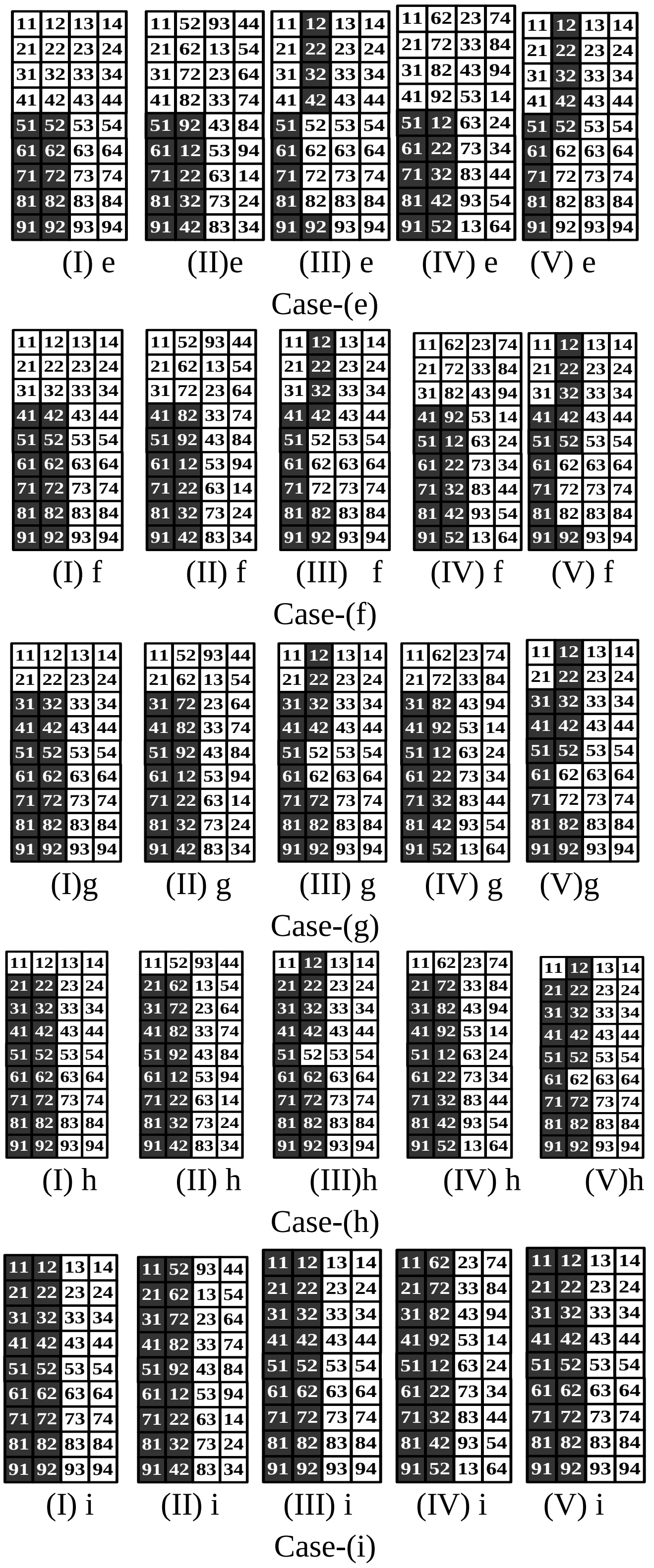


Fig.3 Proposed shading cases of Pattern-I from all types of configurations

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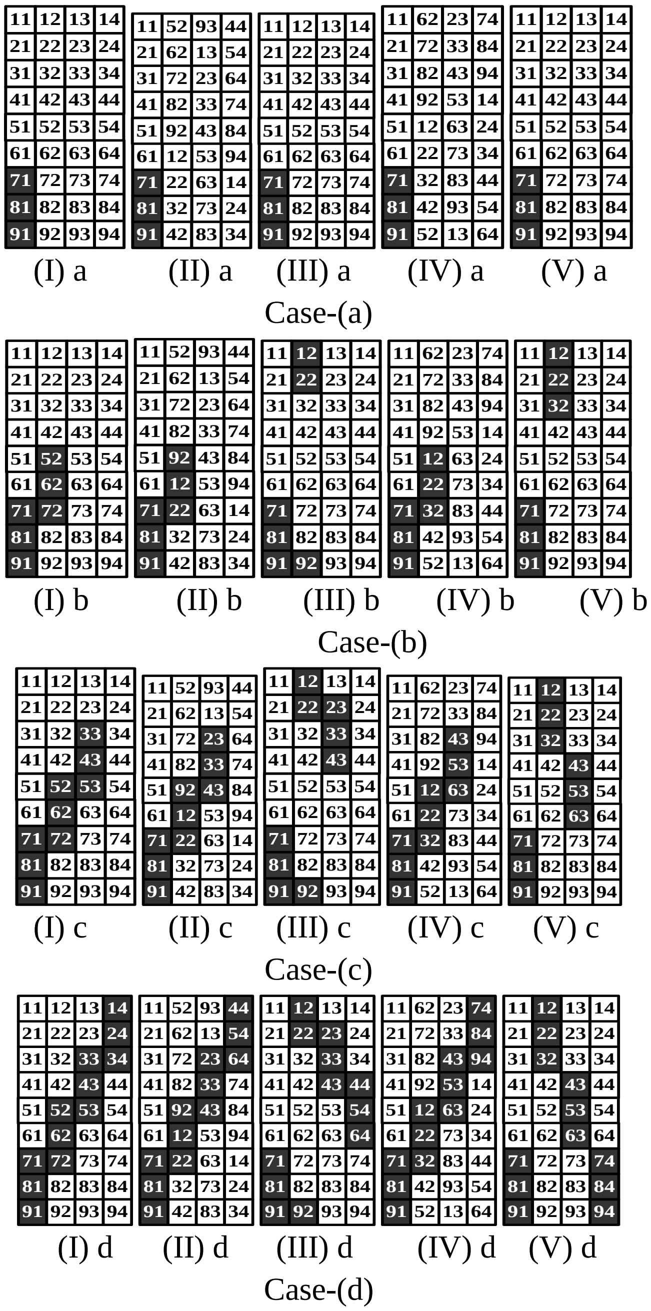

Fig. 4. Proposed shading cases from diagonal on all topologies and shade dispersion arrangement (pattern -2)

IV. RESULTS AND DISCUSSION

Simulation study and performance analysis of PV panel for three different configurations has been done with the help of MATLAB/Simulink platform. The results shown in figure as well as tabular form showed performance analysis for different configuration under different shade patterns.

The cases of Figure 3 for NS-1, NS-2 and TCT are examined. The shadow is in left side and their impact on the configuration of PV array is described by Fig.4(a). It can be observed that there is a space between LMPP and GMPP. In terms of shading shifting the power of both configurations is equal to 3342 W at real PPP. It is clearly observed from the figure that the shadow now shifted to PV array and its impact on P-V profiles are examined. As described in Figure 4 many LMPP's are generated due to shading.

V.I Shading pattern-1 and shade dispersion effects on MPP

The PV modules falling on their surface with the same 1000W/m2 solar irradiation are used in the 1st, 2nd and 3rd row But in the 4th row two modules are receiving 1000W/m2 solar irradiation and 350W/m2 received by two other modules. Therefore, for 4x4 PV (TCT), for case-5a shading pattern-1, the array current can be calculated by as;

Generated currents forfirst, second and third row- are

$$I_{R1} = 4 \times \left(\frac{G}{G_{STC}}\right) I_m = 4 \times \left(\frac{1000}{1000}\right) I_m = I_{R2} = I_{R3} = 4I_m \qquad (9)$$

Fourth row generated current are

$$I_{R4} = 2I_m + \left(\frac{350}{1000} + \frac{350}{1000}\right) I_m = 2.7I_m \qquad (10)$$

Similarly, for shading pattern-1 case-b, c and d, the current generated can be calculated as follows;

Case 5b:

$$I_{R1} = I_{R2} = 4I_m \text{ and } I_{R3} = I_{R4} = 2.7I_m \qquad (11)$$

Case 4c:

$$I_{R1} = 4I_m \text{ and } I_{R2} = I_{R3} = I_{R4} = 2.7I_m \qquad (12)$$

Case 4d:

$$I_{R1} = I_{R2} = I_{R3} = I_{R4} = 2.7I_m \qquad (13)$$

The currents in each row for each shading cases can be calculated as

First and third row-generated currents are

$$I_{R1} = 4 \times \left(\frac{G}{G_{STC}}\right) I_m = 4 \times \left(\frac{1000}{1000}\right) I_m = I_{R3} = 4I_m \qquad (14)$$

Second and fourth row generated current are

$$I_{R2} = 3I_m + \left(\frac{350}{1000} + \frac{350}{1000}\right) I_m = I_{R4} = 3.35I_m \qquad (15)$$

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Similarly for shading pattern-1 case-b,c and d,the generated current can be calculated as;

Case 4b: $I_{R1} = I_{R2} = I_{R3} = I_{R4} = 3.35I_m$ (16)
Case 4c:
$I_{R1} = I_{R3} = 3.35I_m$ and $I_{R2} = I_{R4} = 2.7I_m$ (17)
Case 4d: $I_{R1} = I_{R2} = I_{R3} = I_{R4} = I_{R5} = 2.7I_m$ (18)

The array currents for TCT patterns, respective power and voltages are tabulated in Table II, which clearly shows the before and after the arrangement of modules according to configuration, the location of GP. This increases the photovoltaic array's generated power. With the respect of shading pattern-1, PV array characteristics are plotted in Fig. 5 which shows the power has improved.

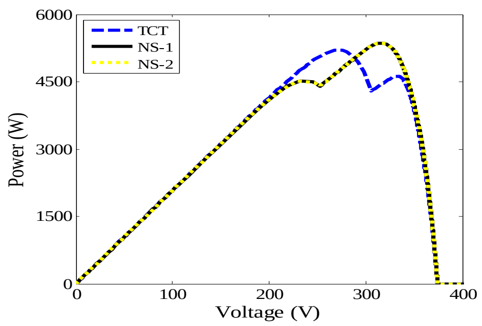

Fig.5 'a' (for case- 4a)

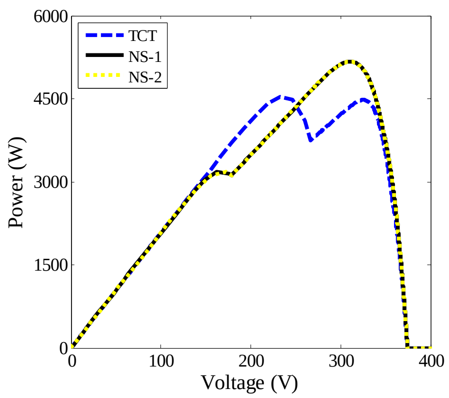

Fig.5'b' (for case- 4b)

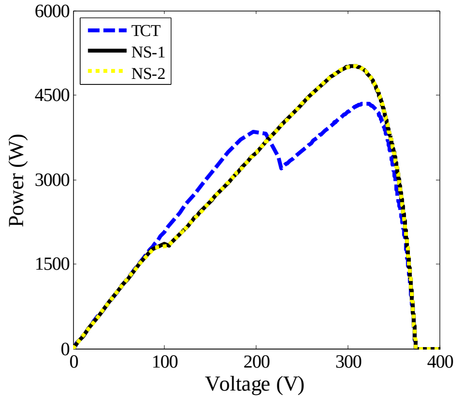

Fig.5 'c' (for case- 4c)

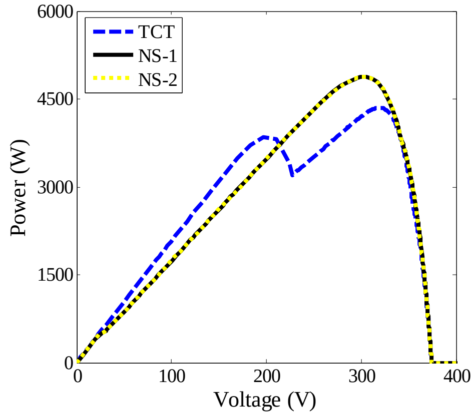

Fig.5 'd' (for case- 4d)

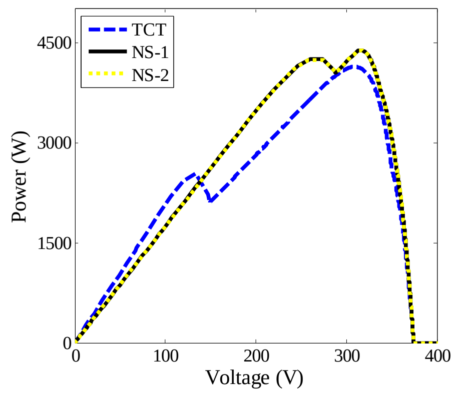

Fig.5 'e' (for case- 4e)

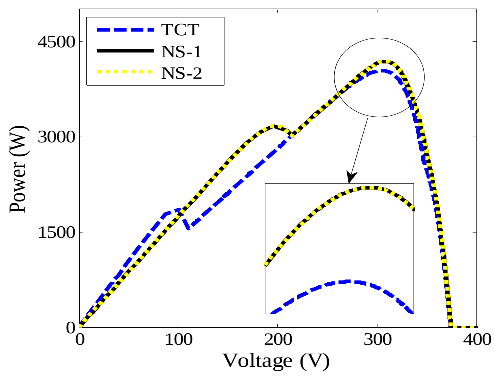

Fig.5 'f' (for case- 4f)

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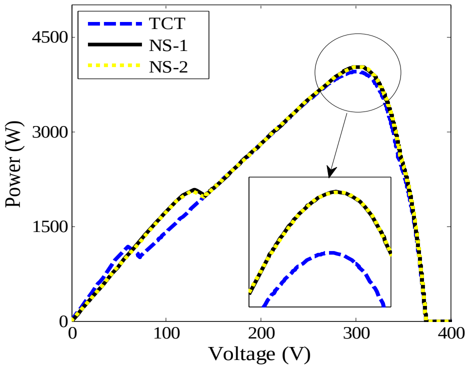

Fig.5 ‘g’ (for case- 4g)

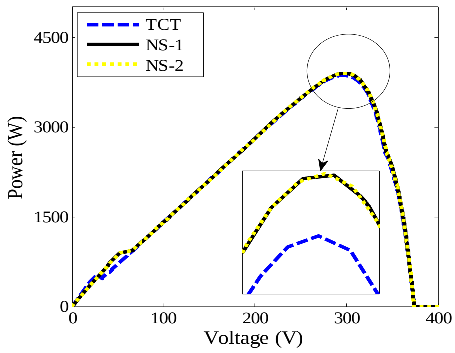

Fig.5 ‘h’ (for case- 4h)

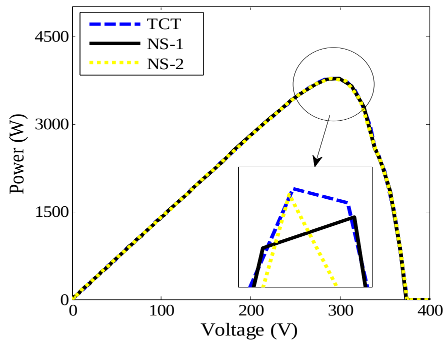

Fig.5 ‘i’ (for case- 4i)

Fig. 5. Effect of shading pattern-1 on PV characteristics of 9x4 PV array for TCT, NS-1 and NS-2 topologies

***V.II** P-V characteristics of 9x4 PV array with shading pattern-2*

Currents, voltages and power output of the PV array are given in Table I for NS1 and NS2 configuration showing increased power generation and the characteristics of the PV Array are shown in Fig. 5(a-d) with the pattern of shading-2.On the P-V curve, two different global and local power points are observed that are very similar to each other. As shown in Fig.5, the shading effect on the output power is very significant.

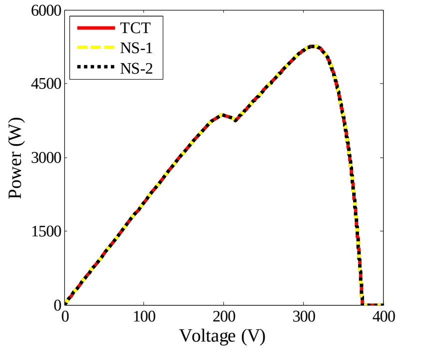

Fig. 6. ‘a’ (for case- 3a)

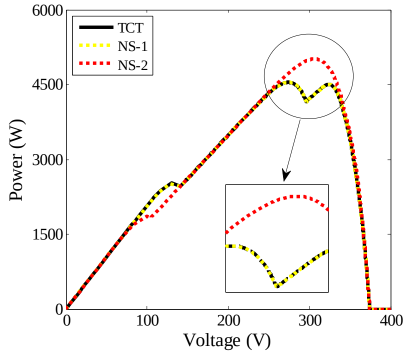

Fig. 6.‘b’ (for case- 3b)

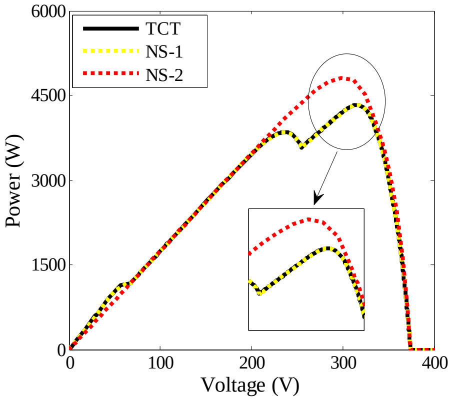

Fig. 6. ‘c’ (for case- 3c)

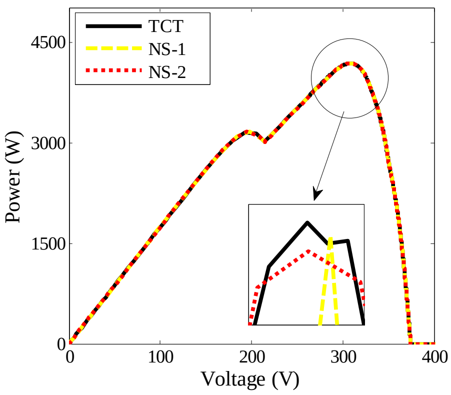

Figure 5.‘d’ (for case- 3d)

Fig. 6. Effect of shading pattern-3 on PV characteristics of 9x4 PV array for TCT, NS-1 and NS-2 topologies

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V.III P-V Effect of shading pattern-1 on power losses and fill factor for 9x4 PV array

The results showthe effectiveness and superiority of the PV array (9x4) with TCT arrangement, simulation result also shows that the configuration consumes more power losses than the other available arrangements. The P-V power loss graph given in Fig.5 (case a-i) depicts that power loss is high for TCT arrangement (case a-d). However, in the case 'e' to 'h' power loss is comparable with other arrangements. In case of 'i' power loss is equal for all configuration is shown in Fig. 5(case i).

Fill factor for 9x4 PV array of all three configurations are almost comparable. Fill factor of TCT is slightly lower in case of a-h. However, it is equal for all arrangements in case of 'i', as shown in fig 6.

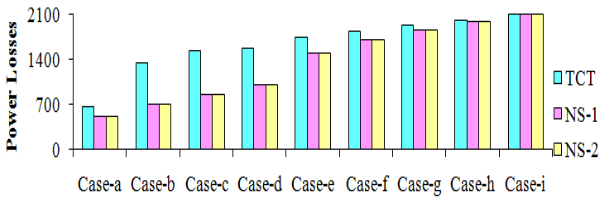

Fig. 7. Effect of shading pattern-1 on power losses for 9x4 PV array

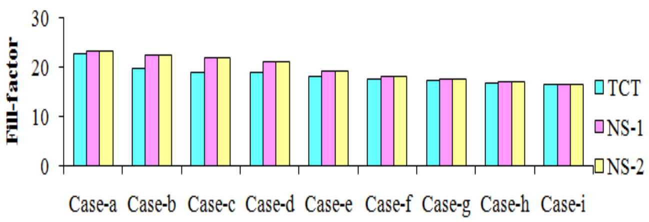

Fig. 8. Effect of shading pattern-1 on fill factor for 9x4 PV array

Table 3: Power at MPP for shading pattern-1 for 9x4 PV array

Shading patterns		NS-1 P (W)	NS-2 P (W)	TCT P (W)	Best Topology
Pattern-1	Case-a	5363	5205	5363	NS-1/NS-2
	Case-b	5170	4528	5170	NS-1/NS-2
	Case-c	5013	4352	5013	NS-1/NS-2
	Case-d	4876	4312	4876	NS-1/NS-2
	Case-e	4385	4134	4385	NS-1/NS-2
	Case-f	4182	4038	4182	NS-1/NS-2
	Case-g	4028	3948	3897	NS-1/NS-2
	Case-h	3897	3864	3897	NS-1/NS-2
	Case-i	3780	3780	3780	ALL

Table 4: Mismatch power losses for shading pattern-1 for 9x4 PV array

Shading patterns		NS-1 P (W)	NS-2 P (W)	TCT P (W)	Best Topology
Pattern-1	Case-a	507	665	507	NS-1/NS-2
	Case-b	700	1342	700	NS-1/NS-2
	Case-c	857	1518	857	NS-1/NS-2
	Case-d	994	1558	994	NS-1/NS-2
	Case-e	1485	1736	1485	NS-1/NS-2
	Case-f	1688	1832	1688	NS-1/NS-2
	Case-g	1842	1922	1842	NS-1/NS-2
	Case-h	1973	2006	1973	NS-1/NS-2
	Case-i	2090	2090	2090	ALL

Table 5: FF for shading pattern-1 for 9x4 PV array

Shading patterns		NS-1	NS-2	TCT	Best Topology
Pattern-1	Case-a	23.33	22.64	23.33	NS-1/NS-2
	Case-b	22.49	19.70	22.49	NS-1/NS-2
	Case-c	21.81	18.93	21.81	NS-1/NS-2
	Case-d	21.21	18.79	21.21	NS-1/NS-2
	Case-e	19.07	17.98	19.07	NS-1/NS-2
	Case-f	18.19	17.56	18.19	NS-1/NS-2
	Case-g	17.52	17.17	17.52	NS-1/NS-2
	Case-h	16.95	16.83	16.95	NS-1/NS-2
	Case-i	16.44	16.44	16.44	ALL

V.IV P-V Effect of shading pattern-2 on power losses and fill factor for 9x4 PV array

The results show the superiority and efficacy of the PV array (9x4) with TCT arrangement, simulation result also shows the configuration consumes more power than the other available arrangements. The P-V power loss graph given in Fig.6 depicts that power loss is low for NS-2 arrangement (case b,c) than other two arrangements. However, in the case 'a' to 'd' power loss s is almost equal for all configuration is shown in Fig. 7.

Fill factor for 9x4 PV array of all three configurations are almost comparable. In fact Fill factor in case 'a' and 'd' equal for all arrangements as shown in fig 6.However, it is equal for all arrangements in case of 'a' and 'd', as shown in fig 8. Fill factor of NS2 is higher in case of 'b' and 'c'.

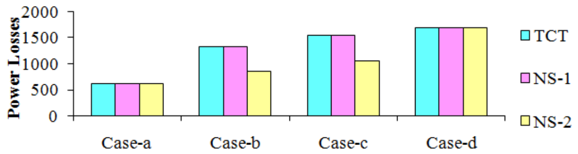

Fig. 9. Effect of shading pattern-2 on power losses for 9x4 PV array

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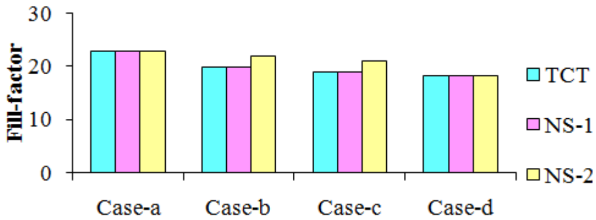

Fig. 10. Effect of shading pattern-2 on fill factor for 9x4 PV array

Table 6: Power at MPP for shading pattern-2 for 9x4 PV array

Shading patterns		NS-1 P (W)	NS-2 P (W)	TCT P (W)	Best Topology
Pattern-3	Case-a	5260	5260	5260	ALL
	Case-b	4545	5013	4545	NS-2
	Case-c	4332	4811	4332	NS-2
	Case-d	4182	4182	4182	ALL

Table 7.Mismatch power losses for shading pattern-2 for 9x4 PV array

Shading patterns		NS-1 P (W)	NS-2 P (W)	TCT P (W)	Best Topology
Pattern-3	Case-a	610	610	610	ALL
	Case-b	1325	1325	857	NS-2
	Case-c	1538	1538	1059	NS-2
	Case-d	1688	1688	1688	ALL

Table 8: FF for shading pattern-32 for 9x4 PV array

Shading patterns		NS-1	NS-2	TCT	Best Topology
Pattern-3	Case-a	22.84	22.84	22.84	ALL
	Case-b	19.77	21.81	19.77	NS-2
	Case-c	18.84	20.93	18.84	NS-2
	Case-d	18.19	18.19	18.19	ALL

V. CONCLUSION

A new configuration for photovoltaic module with 9x4 PV array is proposed in this paper. To evaluate the performance of different PV array configurations, different partial shading patterns are applied to the PV module. Performance analyzes have been carried out for all three configurations. For considered PV array with three different configurations, the obtained voltage, current, power have been considered as output parameters. The shade dispersion effect on PV array with various configurations is also examined. Simulation results show the effectiveness of NS-PVF for the photovoltaic array in 9x4 configuration. Results clearly demonstrate that shading cases on these topologies results in a rise in the non-linear effect and in many cases causing multiple maxima. NS-PVF has shown better performance for all kinds of shading cases.

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