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An Extended Cross Diagonal View Network Topology for a PV System of Non-Square Dimension under Shading Conditions to Yield Maximal Power

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ABSTRACT

A PV module subjected to decrease in the solar irradiance conditions leads to the reduction of power production. Shading of modules is one of the problems encountered in the system which makes the system less productive. The cause of shading may be of different factors like buildings, clouds etc. Hence, in a PV system, the placement of modules in a grid arrangement is a vital part, which influence greatly in the generation of power. If the position of modules is rightly configured, then the possibility of incidence of solar irradiance on the PV module can be enhanced leading to higher performance of the system. Therefore, the existing conventional series parallel (SP) and total cross tied (TCT) configuration are reinforced with a novel network topology namely extended cross diagonal view (ECDV) is proposed. The design is that the modules electrical connectivity is unaltered whereas the module position is altered. With the proposed topology, different kinds of shading patterns are imposed to carry out the performance analysis. The conventional SP and TCT configuration performance are compared with the proposed method which gave a significant rise in output power. An increase of 20.55% is observed by the proposed ECDV method for the crosswise shading pattern. From the analysis, the proposed method proves to be the most suitable and efficient method for generating maximum power under shading condition in non-square matrix photovoltaic (PV) system.

1. INTRODUCTION

Energy sources comprising conventional and non-conventional, are the vital elements of human life which fulfil the daily energy requirements. Larger dependence on fossil fuels like coal for power generation increases, as the per capita consumption rises gradually every day. Nevertheless, the fossil fuels' exhaustion dismays the world. As the coal reserves lows down, it leads to energy crisis. In addition, conversion of fossil fuels produces greenhouse gases which offer various health effects to the public [1]. Therefore, depletion of coal, increased energy needs and greenhouse gases are the thoughtful concerns to stimulate the effort to exploit renewable energy sources.

Owing to the eco-friendly sustainable nature of certain renewable energy sources, adoption of technology is necessary to harness the energy to the maximum. Amongst, the solar energy is the primary source from which naturally enormous amount of power is available. It has received special consideration as this is the only energy source which is used to obtain electricity directly from the photovoltaic (PV) system.

Solar modules are formed by the interconnection of solar cells serially and parallelly. As the series connection of number of solar cells increases, the output voltage increases, while the increased number of parallel paths gives high output current [2]. Interconnection of several PV modules form a PV system. A PV system has various kinds of configurations [3,4] like series, parallel, series and parallel (SP), total cross tied (TCT), bridge link (BL), honey comb (HC) etc. and are shown in Fig. 1. In a PV system, if the modules of non-identical parameters are interconnected, it is called I-V mismatch [5].

The power generation of PV modules gets affected due to the mismatching of panel rating. Some other reasons of mismatching include different manufactures, varying environmental conditions and partial shading [6]. Partial shading of the modules leads to reduction in power generation and hotspot problems [7]. Protective diodes can overcome the hotspot problems but it creates multiple peaks and power losses. The analyses of different literatures proved that rearranging the location of modules but unaltering the electrical connection is an effective way to spread the shading effect to improve power generation of PV systems [8]. Based on this concept, different modified configurations like sudoku [9], magic square [10], novel structure [11], new shifted arrangement [12], dominance square [13], competence square [14], Sider Web Tie SBT [15] and cross diagonal view (CDV) [16] have been proposed.

The length of DC cable line is the main disadvantage of this configuration. The novel structure [11] arrangement relocates the modules in the row-wise form. Hence the shading gets distributed only along the row, where effective distribution of shade is not achieved. The augmentation of this technique with the conventional TCT produces 13.2% increase in power. Belhaonas et al. [12] arranged the modules are arranged based on new shifted PV array arrangements.

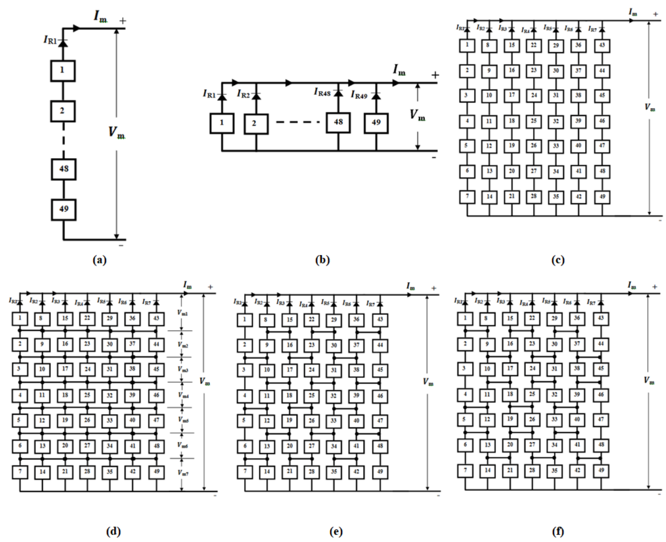


Figure 1. Interconnection of PV modules in a) Series Configuration b) Parallel Configuration c) Series Parallel Configuration d) Total Cross Tied Configuration e) Bridge Linked Configuration f) Honey Comb Configuration

The algorithm eliminates multiple peaks and minimizes usage of protective diodes but highly increases the area occupied by the PV system. The dominance square DS-TCT arrangement introduced by B. Dhanalakshmi & N. Rajasekar [13], carried out the comparative analysis with seven different shading patterns and conventional configurations like TCT, SP, SP-TCT, BL, HC, BL-TCT and BL-HC respectively. It is observed that the DS-TCT is the most efficient among all to spread shading of the modules.

B. Dhanalakshmi & N. Rajasekar [14] proposed a 9 x 9 competence square arrangement that used four shading patterns and examined with DS and TCT configuration. The CS has the advantage of more power production with minimum number of LPPs.

The Sider Web Tie SBT configuration is hosted by Asadi Suresh Kumar and Vyza Usha Reddy [15]. in this SBT 5X5 200W panels are contemplate combined with SP, TCT, BL and Triple-Tied (TT) configuration. It is observed that SBT combined with TCT gives maximum efficiency of 13.098%.

However, some of the drawbacks in the existing methods such as, difficulty of identification of location of the module, limited size of the number of modules, limitation of spreading the shading effect etc. are rectified using cross diagonal view (CDV) arrangement [16]. This configuration spreads the shading throughout the PV system column-wise and row-wise and is implemented for a square matrix PV system only. In this paper, an extended cross diagonal view (ECDV) network topology is proposed for the non-square arrangement of PV systems. The paper concentrated on the analysis of the non-square PV system with three different shading conditions. The proposed ECDV network arrangement is augmented to the conventional SP and TCT configuration to form series parallel extended cross diagonal view (SPECDV) configuration and total cross tied extended cross diagonal view (TCTECDV) configuration by replacing the position of modules while remaining the electrical connection unaltered in a non-square PV system. The power yield of the SP, TCT and the proposed ECDV configuration is analysed and compared under three different shading patterns, interior shading, crosswise shading and border shading and is found that the proposed network topology outperforms the others.

2. PV SYSTEM CONFIGURATIONS

In a PV system, number of modules determines voltage and current with serial-connected and parallel-connected respectively. Literature provides several types of arrangements. The choice is mainly based on simplicity in connection, cost effectiveness, redundancy elimination, minimum usage of number of bypass or blocking diodes and high-power generation. The four major PV system configurations are SP, TCT, BL and HC. Among these four, higher performance of SP and TCT configurations are achieved than BL and HC types. Most of the PV modules arrangements are based on SP and TCT and the manufacturing cost is also nearly same [17].

In the SP type, the modules run series-wise and parallel-wise and is depicted in Fig. 1(c). The module current is,

$$I_{mrc} = K_{rc} I_{mo} \tag{4}$$

Here, r and c are the row and column number respectively. $K_{rc} = {}^{G_{rc}}/_{G_o}$, G_{rc} is the instantaneous irradiance falling on the rth row and cth column modules. I_{mo} is the module operating current generated at STC. I_{mrc} is the rth row and cth column module current. The voltage in each array is,

$$V_{ai} = \sum_{r=1}^{r=n} (V_{mri} + V_d) \tag{5}$$

where V_{ai} is the ith column voltage, n is the total number of rows in the system, V_{mri} is the i^{th} column rth row module voltage, V_d is the blocking diode voltage which is very low and can be neglected. In general, this configuration is less expensive and the simplest.

In the TCT type shown in Fig. 1(d), the column modules are series-connected and the row modules are parallel- connected. Under PSC, based on the irradiance on the module the current in each module will differ but the voltage remains same. A highly shaded module causes a reverse current flow and it acts as load. Otherwise it causes more current flow in the nearby healthy modules, release more amount of heat and power loss takes place. These effects are minimized or eliminated by using bypass and blocking diodes. Blocking diodes block the reverse current flow in an array. In the TCT arrangement, under all operating conditions, the array voltage is the same but the array current is different, which is given as,

$$I_a = \sum_{r=1}^{p}, \sum_{c=1}^{q} I_{mrc} \tag{6}$$

In comparison to the other configurations, TCT has more parallel loops and usage of lesser number of bypass diodes. This higher number of parallel connections makes TCT more reliable with the reduction in mismatch losses and produces more power under PSC. Narendra & Nalin [18] it was stated that the TCT method is the best solution of mismatch losses reduction under partial shading condition which produced 4% increase in output power as compared with SP configuration.

3. METHODOLOGY OF THE PROPOSED EXTENDED CROSS DIAGONAL VIEW ARRANGEMENT

Let the size of the PV system matrix is $n \times m$. If $n = m$, then the first module number is placed at the center of the first row, and the last module number is placed at the center of the last row. The CDV constant is given as,

$$\text{CDV constant} = m(m^2+1)/2 \qquad (7)$$

where m is the size of the PV system matrix. The CDV constant represents the addition of the module numbers in a row or a column or the diagonal. The module number placed at the center of the matrix is equal to the ratio of CDV constant to the number of row or column. The flowchart in Fig. 2 is used to form the ECDV matrix.

In the non-square matrix, the size of the matrix is $n \neq m$. Four cases of PV system sizes arise,

Case 1) The number n is odd and n > m
Case 2) The number n is even and n > m
Case 3) The number m is odd and m > n
Case 4) The number m is even and m > n

3.1. Formation of non-square PV system

The non-square PV system is formed for the four cases. The size of the PV system matrix is $n \times n$ or $m \times m$, whichever is greater.

Case 1: n is an odd number and greater than m,

- Let $n = 7$ and m= 6, the size of PV system is 7×6.
- The conventional arrangement of modules of size $n \times n$ i.e. 7×7 is shown in Fig. 3(a).
- Form the ECDV matrix of size $n \times n$, based on Fig.2.
- Find the ending $(n-m)$ column elements of the conventional configuration and discard them in the ECDV matrix arrangement.
- The circled module in Fig. 3(b) are the eliminated modules and thus the PV system size is 7×6.

Case 2: n is an even number and greater than m,

- Let $n = 6$ and m= 5, the size of PV system is 6×5
- The conventional arrangement of modules of size $[(n+1) \times (n+1)]$, that is 7×7 is given in Fig. 4(a).
- Using the flowchart in Fig. 2, build the ECDV matrix. The size is $[(n+1) \times (n+1)]$.
- In the framed ECDV matrix, discard the ending $[(n+1)-m])$ column and the ending row elements of the conventional arrangement.
- The circled module in Fig. 4(b) are the eliminated modules and thus the PV system size is 6×5.

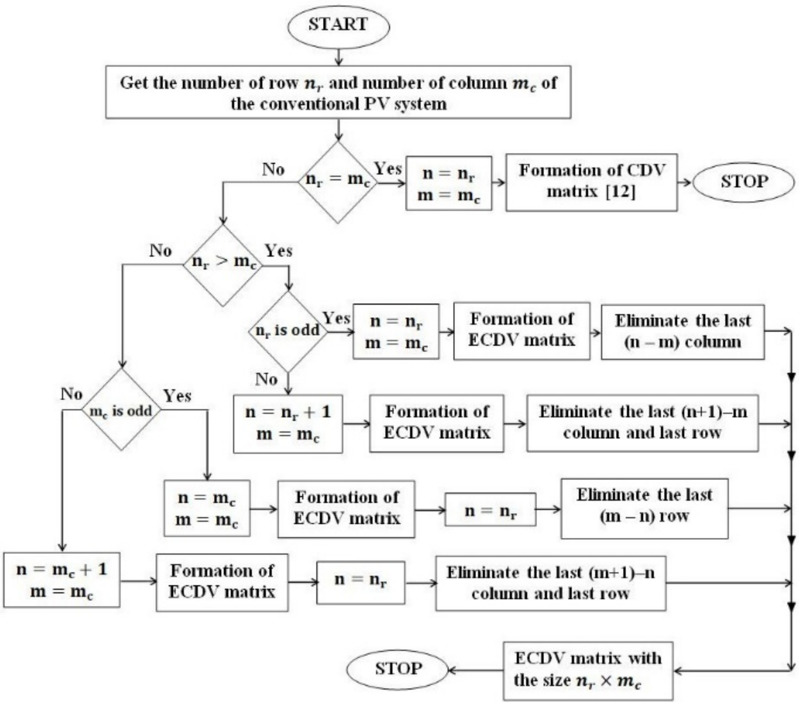


Figure 2. Flow chart for proposed ECDV matrix formation of PV system

(a)

1	8	15	22	29	36	43
2	9	16	23	30	37	44
3	10	17	24	31	38	45
4	11	18	25	32	39	46
5	12	19	26	33	40	47
6	13	20	27	34	41	48
7	14	21	28	35	42	49

(b)

30	39	48	1	10	19	28
38	47	7	9	18	27	29
46	6	8	17	26	35	37
5	14	16	25	34	36	45
13	15	24	33	42	44	4
21	23	32	41	43	3	12
22	31	40	49	2	11	20

Figure 3. Arrangement of modules in non-square matrix with $n = 7$ and $m = 6$: a) Conventional pattern b) Module distribution with ECDV pattern

(a)

1	8	15	22	29	36	43
2	9	16	23	30	37	44
3	10	17	24	31	38	45
4	11	18	25	32	39	46
5	12	19	26	33	40	47
6	13	20	27	34	41	48
7	14	21	28	35	42	49

(b)

30	39	48	1	10	19	28
38	47	7	9	18	27	29
46	6	8	17	26	35	37
5	14	16	25	34	36	45
13	15	24	33	42	44	4
21	23	32	41	43	3	12
22	31	40	49	2	11	20

Figure 4. Arrangement of modules in non-square matrix with $n = 6$ and $m = 5$: a) Conventional pattern b) Module distribution with ECDV pattern

Case 3: m is an odd number and greater than n,

- Let $n = 6$ and m= 7

- The conventional arrangement of modules of size $m \times m$ i.e. 7×7 is given in Fig. 5(a).
- Build the ECDV matrix as given in Fig. 2. The size is $m \times m$.
- Find the ending $(m-n)$ row elements of the conventional arrangement and discard them in the framed ECDV matrix arrangement.
- The circled module in Fig. 5(b) are the eliminated modules and thus the PV system size is 6×7.

Case 4: m is an even number and greater than n,

- Let $n = 5$ and m= 6
- The conventional arrangement of modules of size $[(m+1) \times (m+1)]$ i.e. 7×7 is given in Fig. 6(a).
- Build the ECDV matrix of size $[(m+1) \times (m+1)]$ as in Fig. 2.
- Discard the ending $[(m+1)-n]$ row and the ending column elements of the conventional arrangement in the framed ECDV matrix.
- The circled module in Fig. 6(b) are the eliminated modules and thus the PV system size is 5×6.

Accordingly, the non-square PV system matrix of any size can be devised.

3.2. Size of the non-square PV system

The performance of the extended CDV method is analyzed with a non-square matrix of size 6×7 shown in Fig. 5(a). To develop a 6×7 ECDV topology, initially a 7×7 matrix PV module arrangement is considered. Then, as given in Fig. 2 the 6×7 non-square matrix is formed by eliminating the element numbers 7, 14, 21, 28, 35, 42 and 49 of the 7×7 square matrix. Hence, in the conventional SP and the proposed SPECDV configuration, there are seven arrays each with six modules. The conventional TCT and the proposed TCTECDV configuration has six arrays consisting of forty-two modules. The total PV system output power at STC is 5.887 kW. The current and voltage in each array of the SP and TCT model is 7.997 A and 105.2 V and 55.98 A and 17.53 V respectively.

(a)

1	8	15	22	29	36	43
2	9	16	23	30	37	44
3	10	17	24	31	38	45
4	11	18	25	32	39	46
5	12	19	26	33	40	47
6	13	20	27	34	41	48
7	14	21	28	35	42	49

(b)

30	39	48	1	10	19	28
38	47	7	9	18	27	29
46	6	8	17	26	35	37
5	14	16	25	34	36	45
13	15	24	33	42	44	4
21	23	32	41	43	3	12
22	31	40	49	2	11	20

Figure 5. Arrangement of modules in non-square matrix with $n = 6$ and $m = 7$: a) Conventional pattern b) Module distribution with ECDV pattern

4. INVESTIGATION OF EFFICACY OF THE ECDV METHOD FOR IMPLEMENTATION

4.1. Proposed ECDV augmented to SP configuration

The developed methodology ECDV is examined by implementing various shading patterns to validate the reliable performance.

(a)

1	8	15	22	29	36	43
2	9	16	23	30	37	44
3	10	17	24	31	38	45
4	11	18	25	32	39	46
5	12	19	26	33	40	47
6	13	20	27	34	41	48
7	14	21	28	35	42	49

(b)

30	39	48	1	10	19	28
38	47	7	9	18	27	29
46	6	8	17	26	35	37
5	14	16	25	34	36	45
13	15	24	33	42	44	4
21	23	32	41	43	3	12
22	31	40	49	2	11	20

Figure 6. Arrangement of modules in non-square matrix with $n = 5$ and $m = 6$: a) Conventional pattern b) Module distribution with ECDV pattern

Different shading patterns such as interior shading, crosswise shading and border shading are used for the study. The shading on the solar module, are considered randomly with different levels of solar insolation. This can be 1000 W/m^2, 800 W/m^2, 500W/m^2 and 300W/m^2.

The simulation is carried out using MATLAB/Simulink platform. The determined parameters are the P-V characteristics, the maximum power, the number of blocking diodes to be used and the GP location. The electrical connectivity of the conventional and the proposed arrangement does not vary. The position of location of the modules alone differ. As per the topology, the voltage at which each array operates is almost same as GPP voltage. Therefore, there is reduction in number of blocking diodes and by the involvement of many numbers of arrays power yield becomes high.

The effectiveness of the proposed series parallel extended cross diagonal view (SPECDV) over the conventional SP configuration is examined. The PV system consists of 42 modules.

In the interior shading pattern, there are 16 modules shaded and the degree of shading varies and is shown in the conventional arrangement in Fig. 7. Fig. 8 gives the proposed ECDV topology and indicates how the modules are distributed in the PV system respectively.

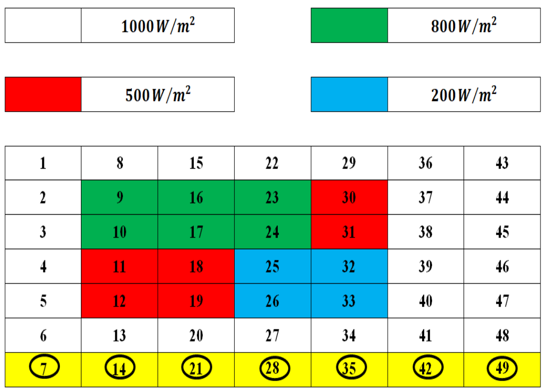


Figure 7. Interior block shading of conventional configuration in a non-square matrix PV system

In accordance with the proposed methodology, three shaded modules numbered 7, 47 and 42 are eliminated. In the SPECDV, the shading effect is distributed to all the arrays and global point is determined at the operating point 7.464A, 98.29V.

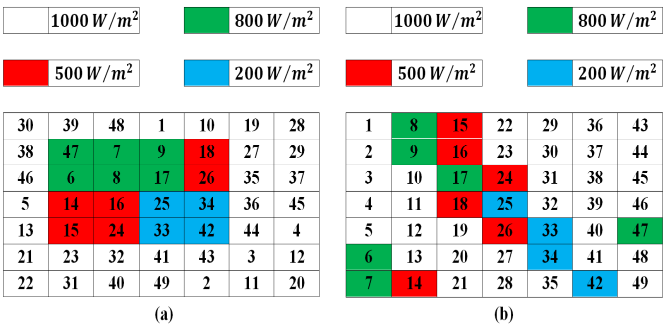


Figure 8. Interior shading pattern a) ECDV network topology, b) Distribution of shaded modules shown in the conventional configuration.

The seven arrays of the proposed ECDV system gives 6 local peak points listed in table 1. The third, fourth and the fifth arrays generate power less than that of the global operating point power.

By blocking these arrays, the proposed SPECDV system yielded a maximal power of 2934.4 W and this is represented by the PV characteristics in Fig. 9. An increase of 6.99% of power is observed in the SPECDV configuration compared with SP configuration.

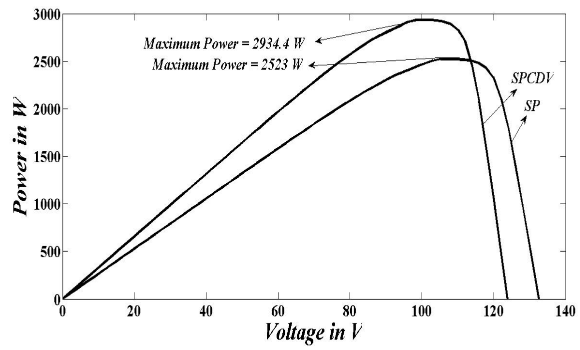


Figure 9. The maximum power P-V characteristics curve of SP and SPECDV configurations in non-square matrix interior shading pattern

Table 1. PV system features of SP and SPECDV configurations with interior shading

	SP Configuration					SPECDV Configuration				
Array Numbe r	Array Current in A	Array Voltage in V	Local Peak Power in W	Maximal Power Yield	Blocking diode used	Array Current in A	Array Voltage in V	Local Peak Power in W	Maximal Power Yield	Blocking diode used
1	7.997	105.2	841	2523	No	7.73	101.7	786.4	2359.2	No
2	6.13	81.02	496.7	2483.5	Yes	7.464	98.29	733.6	2934.4	No
3	6.13	81.02	496.7	2483.5	Yes	5.73	75.83	434.5	2607	Yes
4	5.33	70.46	375.6	2253.6	Yes	5.597	73.98	414.1	2898.7	Yes
5	4.53	60.07	272.1	1904.7	Yes	5.863	77.34	453.5	2267.5	Yes
6	7.997	105.2	841	2523	No	7.997	105.2	841	841	No
7	7.997	105.2	841	2523	No	7.73	101.7	786.4	2359.2	No

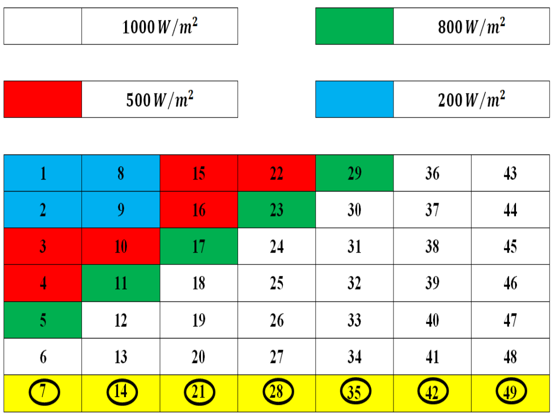


Figure 10. Crosswise shading pattern of conventional configuration in a non-square matrix PV system

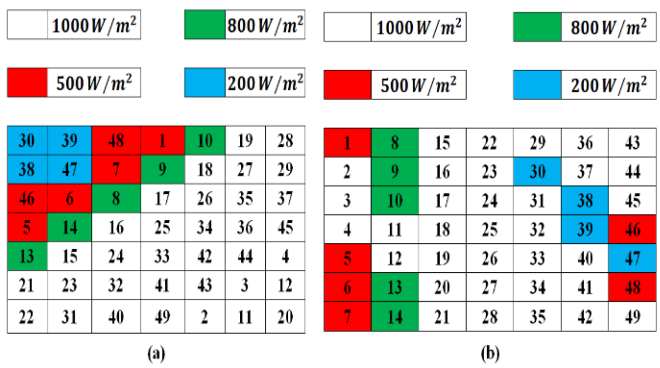


Figure 11. Crosswise shading pattern a) ECDV network topology, b) Distribution of shaded modules shown in the conventional configuration.

Next, the crosswise shading pattern is introduced in the conventional SP. In this pattern of shading, 15 modules are shaded and the intense of shading is shown in Fig. 10 and the proposed ECDV network topology in Fig. 11. The global operating point is obtained at 5.597A, 73.98V and the maximal power that could be produced is 2898.7 W represented in table 2.

Table 2. PV system features of SP and SPECDV configurations with crosswise shading

Array Number	SP Configuration					SPECDV Configuration				
	Array Current in A	Array Voltage in V	Local Peak Power in W	Maximal Power Yield	Blocking diode used	Array Current in A	Array Voltage in V	Local Peak Power in W	Maximal Power Yield	Blocking diode used
1	4.263	56.63	241.4	1689.8	Yes	5.997	79.26	475.3	2376.5	No
2	4.93	65.27	321.8	1930.8	Yes	6.93	91.41	633.5	1900.5	No
3	6.397	84.46	540.3	2701.5	No	7.997	105.2	841	1682	No
4	7.064	93.09	657.6	2630.4	No	7.997	105.2	841	1682	No
5	7.73	101.7	786.4	2359.2	No	6.93	91.25	632.4	2529.2	No
6	7.997	105.2	841	1682	No	5.863	77.34	453.5	2721	No
7	7.997	105.2	841	1682	No	5.597	73.98	414.1	2898.7	No

The conventional SP configuration with the same pattern of shading could harvest 2701.5W is depicted in Fig. 12. The proposed network topology enhances this extracting performance of the PV system by 3.35%.

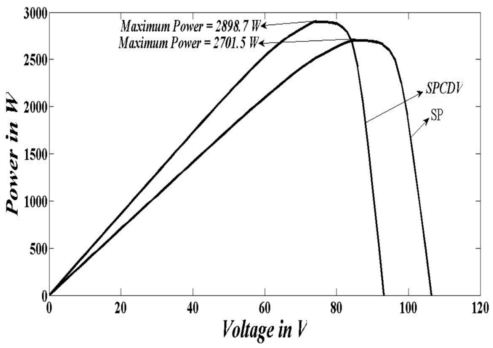


Figure 12. The maximum power P-V characteristics curve of SP and SPECDV configurations in non-square matrix under crosswise shading

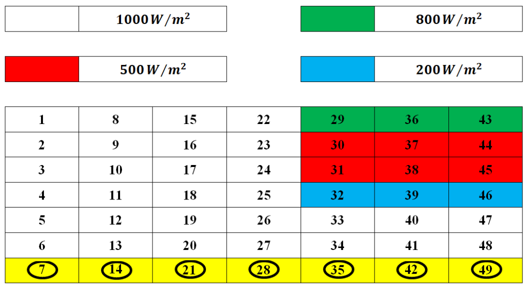


Figure 13. Border shading pattern of conventional configuration in a non-square matrix PV system

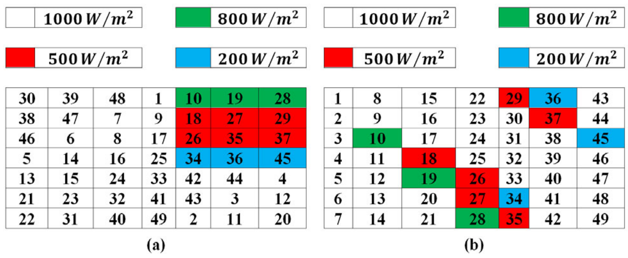


Figure 14. Border shading pattern a) ECDV network topology, b) Distribution of shaded modules shown in the conventional configuration.

Table 3. PV system features of SP and SPECDV configurations with border shading pattern

Array Number	SP Configuration					SPECDV Configuration				
	Array Current in A	Array Voltage in V	Local Peak Power in W	Maximal Power Yield	Blocking diode used	Array Current in A	Array Voltage in V	Local Peak Power in W	Maximal Power Yield	Blocking diode used
1	7.997	105.2	841	3364	No	7.997	105.2	841	841	No
2	7.997	105.2	841	3364	No	7.73	101.7	786.4	1572.8	No
3	7.997	105.2	841	3364	No	6.664	87.9	585.7	2928.5	No
4	7.997	105.2	841	3364	No	6.664	87.9	585.7	2928.5	No
5	5.33	70.55	376	2632	Yes	6.263	82.62	517.5	3622.5	No
6	5.33	70.55	376	2632	Yes	6.263	82.62	517.5	3622.5	No
7	5.33	70.55	376	2632	Yes	6.93	91.25	632.4	1897.2	No

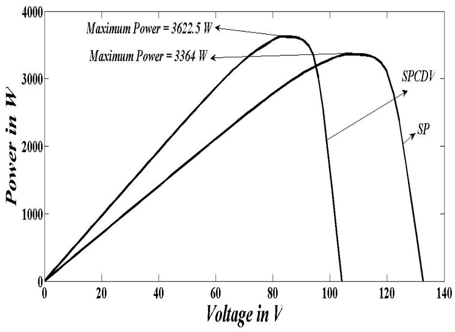


Figure 15. The maximum power P-V characteristics curve of SP and SPECDV configurations in non-square matrix border shading pattern

Then, the border shading pattern is introduced in the conventional SP. The conventional SP and the proposed SPECDV configuration with the border shading pattern are shown in Fig. 13 and Fig. 14 respectively. The shading zone of this pattern is concentrated in the arrays 5, 6 and 7.

All the arrays contribute in power production and the maximal power that could be yielded under this pattern of shading is 3622.5W at the operating point 82.62V and 6.263A is shown in table 3. This represents a rise in power of 4.39% with the conventional SP configuration which gives a maximum power generation of 3364 W shown in Fig. 15.

4.2. Proposed ECDV augmented to TCT configuration

Then, observations on the effectiveness of the proposed total cross tied extended cross diagonal view (TCTECDV) configuration over the conventional TCT is presented. The interior shading pattern in conventional TCT configuration shows the shaded modules present in arrays two, three, four and five. There are no shaded modules in arrays one and six. The process of the proposed methodology is that it does not concentrate the shading effect. Fig. 8(b) depicts how the shaded modules and the effect of shading are distributed to all the arrays. In the TCTECDV, the global point is determined at the operating point 43.98A, 13.82V. The proposed TCTECDV system has four local peak points and could generate a maximum power of 3645.6W and is shown in Fig. 16.

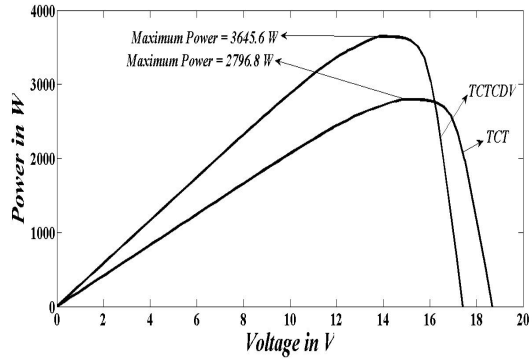


Figure 16. The maximum power P-V characteristics curve of TCT and TCTECDV configurations in non-square matrix interior shading pattern

The maximal power yielded by the proposed TCTECDV configuration is 14.42% greater than conventional TCT and the generated power is listed in table 4.

Table 4. PV system features of TCT and TCTECDV configurations with interior shading pattern

	TCT Configuration					TCTECDV Configuration				
Array Number	**Array Current in A**	**Array Voltage in V**	**Local Peak Power in W**	**Maximal Power Yield**	**Blocking diode used**	**Array Current in A**	**Array Voltage in V**	**Local Peak Power in W**	**Maximal Power Yield**	**Blocking diode used**
1	55.98	17.53	981.2	1962.4	No	50.38	15.8	796.1	2388.3	No
2	47.18	14.82	699.2	2796.8	No	50.38	15.8	796.1	2388.3	No
3	47.18	14.82	699.2	2796.8	No	50.38	15.8	796.1	2388.3	No
4	35.18	11.09	390	2340	Yes	45.58	14.31	652.1	3260.5	No
5	35.18	11.09	390	2340	Yes	43.98	13.82	607.6	3645.6	No
6	55.98	17.53	981.2	1962.4	No	47.98	15.05	722	2888	No

Next, using the crosswise shading pattern, the inspection of the proposed TCTECDV configuration and the conventional TCT is carried out. This shading pattern in Fig. 10, depicts the amount of shading. It is observed that four local peaks occurred and all the arrays contributed its maximum power. The identified maximum power is 3912.6 W with the global operating point is at 45.58A, 14.31V. The maximum power generated in TCT and TCTCDV configurations are illustrated in Fig. 17. The power yield from the conventional TCT arrangement is 2702.8.5W listed in table 5. The performance of proposed topology is boosted by 20.55% revealing its advantage.

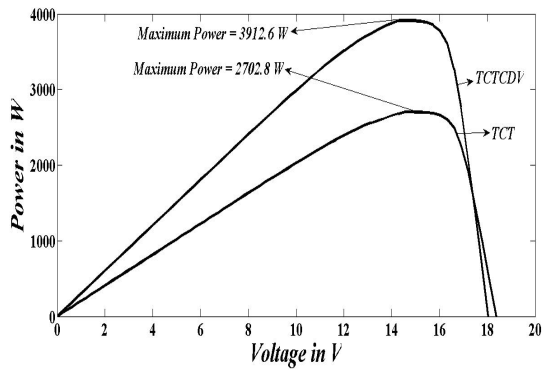


Figure 17. The maximum power P-V characteristics curve of TCT and TCTECDV configurations in non-square matrix under crosswise shading

Then the border shading pattern is applied for the conventional and proposed TCTECDV configuration. The shaded portion of this pattern is shown in Fig. 14 for the ECDV network topology and in the conventional TCT configuration.

Here, all the arrays contributed in generation of power yielding a maximum of 3912.6W with the global operating point at 45.58A and 14.31V shown in table 6.

The corresponding PV characteristics is shown in Fig. 18. However, the conventional TCT configuration could generate a power of 3040.5W as maximum, thus proving the benefit of proposed TCTECDV topology which shows 14.81% higher yield.

Table 5. PV system features of TCT and TCTECDV configurations with crosswise shading

	TCT Configuration					TCTECDV Configuration				
Array Number	**Array Current in A**	**Array Voltage in V**	**Local Peak Power in W**	**Maximal Power Yield**	**Blocking diode used**	**Array Current in A**	**Array Voltage in V**	**Local Peak Power in W**	**Maximal Power Yield**	**Blocking diode used**
1	33.58	10.59	355.7	2134.2	Yes	46.38	14.57	675.7	3378.5	No
2	37.58	11.83	444.5	2222.5	Yes	47.98	15.05	722	2166	No
3	46.38	14.57	675.7	2702.8	No	47.98	15.05	722	2166	No
4	50.38	15.8	796.1	2388.3	No	49.58	15.54	770.4	770.4	No
5	54.38	17.04	926.4	1852.8	No	45.58	14.31	652.1	3912.6	No
6	55.98	17.53	981.2	981.2	No	46.38	14.57	675.7	3378.5	No

Table 6. PV system features of TCT and TCTECDV configurations with border shading

	TCT Configuration					TCTECDV Configuration				
Array Number	**Array Current in A**	**Array Voltage in V**	**Local Peak Power in W**	**Maximal Power Yield**	**Blocking diode used**	**Array Current in A**	**Array Voltage in V**	**Local Peak Power in W**	**Maximal Power Yield**	**Blocking diode used**
1	51.18	16.05	821.6	2464.8	No	45.58	14.31	652.1	3912.6	No
2	43.98	13.83	608.1	3040.5	No	51.98	16.29	846.9	1693.8	No
3	43.98	13.83	608.1	3040.5	No	47.98	15.05	722	2888	No
4	36.78	11.57	425.3	2551.8	Yes	51.98	16.29	846.9	1693.8	No
5	55.98	17.53	981.2	1962.4	No	50.38	15.8	796.1	2388.3	No
6	55.98	17.53	981.2	1962.4	No	45.58	14.31	652.1	3912.6	No

Finally, it is understood that the proposed ECDV network topology augmented to the conventional SP and TCT configurations outperforms the conventional configurations. The maximal power yield performance of the proposed SPECDV and TCTECDV methodology is 6.99% and 20.55% higher than the SP and the TCT configuration respectively. The proposed 6 × 7 size PV system experience three different shading patterns like Interior shading, Crosswise shading and Border shading. The conventional series parallel (SP), total cross tied (TCT) configuration and the proposed series parallel extended cross diagonal view (SPECDV) and total cross tied extended cross diagonal view (TCTECDV) configurations are analysed under these shading conditions and the output power obtained is depicted in Fig. 19. The proposed TCTCDV outperformance with the maximum power of 3912.6 W.

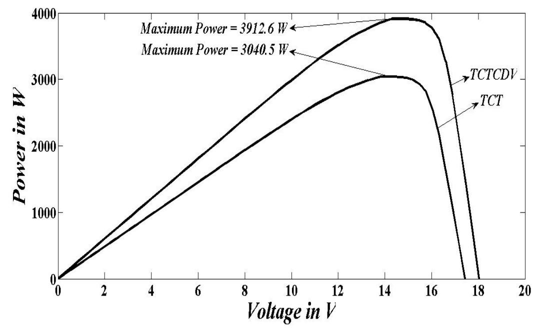


Figure 18. The maximum power P-V characteristics curve of TCT and TCTECDV configurations in non-square matrix border shading pattern

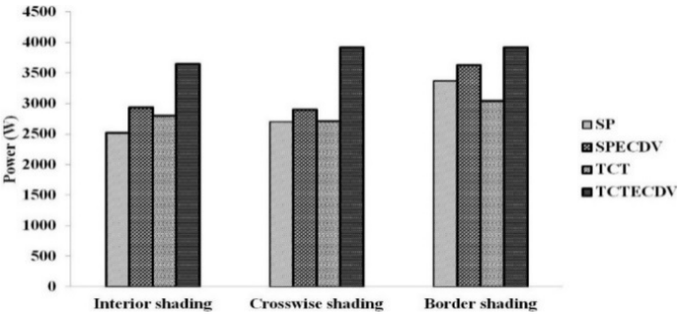
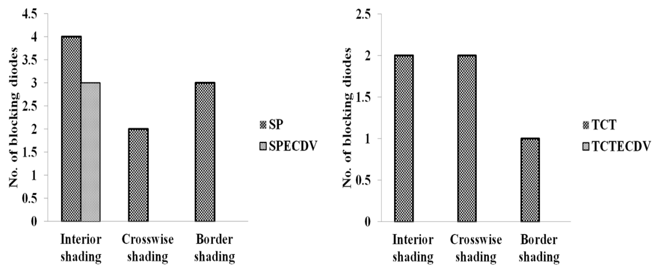


Figure 19. PV system power comparison of the four configurations.

The number of blocking diodes required in all the four configurations of size 6×7 under three different shading conditions is depicted in Fig. 20. It is realized that the blocking diodes requirement is nullified with the proposed configuration except in the interior shading pattern of SPECDV in which it is minimised. The placement of modules by the proposed methodology makes the global operating point and the optimal operating point matches almost resulting in higher power production and elimination of blocking diodes.



(a) (b)

Figure 20. Number of blocking diodes used in 6×7 PV system (a) For SP and the proposed SPECDV configuration (b) For TCT and the proposed TCTECDV configuration

5. CONCLUSIONS

An extended cross diagonal view network topology is proposed in this paper which yields maximum power in the PV system. A non-square matrix PV system is considered under shaded conditions of the PV system. The proposed ECDV arrangement works such that within the dimension of the system, the PV modules are altered in position without making alterations in the electrical connectivity of the modules. This reposition of modules resulted in minimal shading on the arrays, aided each array to contribute in generation of output power and thus minimised the usage of number of blocking diodes in the system. The proposed ECDV augmented to the SP and TCT configuration is compared with the conventional configurations. Simulation result showed that the proposed TCTECDV configuration produces a maximum power with 20.55% increase in power. It is observed from the outcome that the ECDV topology showed the best performance and is successful in maximizing the power under shading conditions of PV systems.

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