Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.18576/amis/13S113

Enhanced power generation using index squaring and calcudoku methods for partial shaded photovoltaic system

R L Helen Catherine[1,*] , *A Soundarrajan*[2] *and R L Josephine*[3]

[1]Electrical and Electronics Engineering, Dr. MCET, Anna University,Pollachi, Tamilnadu - 642002, India.
[2]Electrical and Electronics Engineering, PSG College of Technology, Coimbatore, Tamilnadu- 641004, India.
[3]Electrical and Electronics Engineering, National Institute of Technology ,Trichy, Tamilnadu 620015, India.

Received: 22 Jan 2019, Revised: 21 Feb. 2019, Accepted: 8 Mar. 2019
Published online: 1 Aug. 2019

Abstract: We present the comparison of the solar PV array efficiency using four different methods such as Total Cross Tied (TCT), Minimum Distance Average (MDA), Index Squaring Method (ISM) and Calcudoku method (CM). TCT and MDA are considered as conventional method and each method is discussed for the four different cases such as Short Narrow (SN), Short Wide (SW), Long Narrow (LN), and Long Wide (LW) respectively. The PV array is configured using the ISM in which they are arranged according to their impact of shading approach for various irradiances. CM uses a mathematical puzzle- based approach for PV array reconfiguration to improve their array currents. The proposed techniques for reconfiguration of PV arrays can improve PV power under different partial shading conditions. The performance of PV arrays for the mentioned methods are discussed and analyzed. The efficiency of the PV panels are compared using the Monte Carlo technique for various irradiance values and the results of the comparisons are presented to show the best suited techniques with respect to their power enhancement.

Keywords: Solar photovoltaics, partial shading, Index square method (ISM), Calkudoku method (CM), Montecarlo estimation.

1 Introduction

Solar power is one of the emerging technologies in recent years. It is invented particularly to power the satellites and space station to decrease the use of non-renewable energy and in recent times solar panels are also used for household needs too. The solar panel installation ranges from few KW (off grid system) to MW (solar power station). But the major problem being faced in solar power station is partial shading due to movement of clouds, shadow of towers, buildings etc.

Due to the partial shading of solar panels, the strings current of solar panel gets affected. To reduce the factors that affect the solar panel efficiency, different techniques such as maximum power point tracking, PV architecture, array reconfiguration[1,2,3], convertor topologies and so on are used among various techniques. Some of the commonly used inter connection schemes are series parallel, TCT,MDA and bridge linked.TCT& MDA are conventional inter connection scheme used in recent days. To improve the efficiency of the solar power plants, two methods are proposed namely Index Squaring Method (ISM) and Calcudoku method (CM) [4,5].

In this paper Section 2 deals with system description of TCT, ISM arrangement is based on squaring the index of the matrixes and arranging them in ascending order. CM uses calcudoku puzzle to reconfigure the solar panels. All the proposed methods[6]are compared with respect to TCT and MDA for four cases such as Short Wide (SW), Short Narrow (SN), Long Wide (LW), Long Narrow (LN). For all these cases, array current equations, interconnection schemes, global peak curve, shading pattern are explained in MDA, ISM and Calcudoku. Section 3 shows the comparison and the performance of all four methods with different solar irradiance using Monte Carlo technique.

The performances of all the three methods are analysed [7,8,9,10]. The results of all the methods are compared using the Monte Carlo method that relies on the random sampling and discrete uniform distribution. The

* Corresponding author e-mail: helencatherinephd@gmail.com

results obtained are compared with their variance values calculated from the Monte Carlo technique and the suitable results are achieved [11,12,13,14,15].

2 System Description

2.1 Total Cross Tied (TCT)

TCT configuration is a simple series-parallel connection across each row in a mxn matrix, where all the panels in the column are connected in series and each panel in a row isnotes the number of column in which the panels are connected Fig 1 shows the TCT arrangement pattern. The current generated by each module with respect to the irradiance value is given by

$$I = KI_m \quad (1)$$

Where I_m is the current generated by the module and $k = G/G_0$ where $G_0 = 1000W/m^2$ at null partial shading condition Hence, the solar irradiation is directly proportional to the current generated by the panel. The voltage across the panel is given by the sum of voltages of the row in a mxn matrix and is given by equation 2.

$$V = \sum_{m=1}^{9} V_{mp} \quad (2)$$

Where V is the voltage across PV array and the V_{mp} implies the voltage of other panels in m^{th}row. Applying Kirchhoff's law, the array current equation at each row is given by the following expression 3.

$$I = \sum_{m=1}^{9} (I_{mn} - I_{(m+1)n}) = 0, m = 1,2,3,...,8 \quad (3)$$

The power generated by the PV array is the product of nominal voltage and nominal current generated by the panels with respect to the solar irradiance. Thus, the power obtained in each row is given by the following expression 4.

$$P = I_m V \quad (4)$$

Table 1: Solar panel specification

PV power	80W
Open circuit Voltage	22V
Short circuit current	4.7A
Nominal Voltage	18V
Nominal Current	4.4A

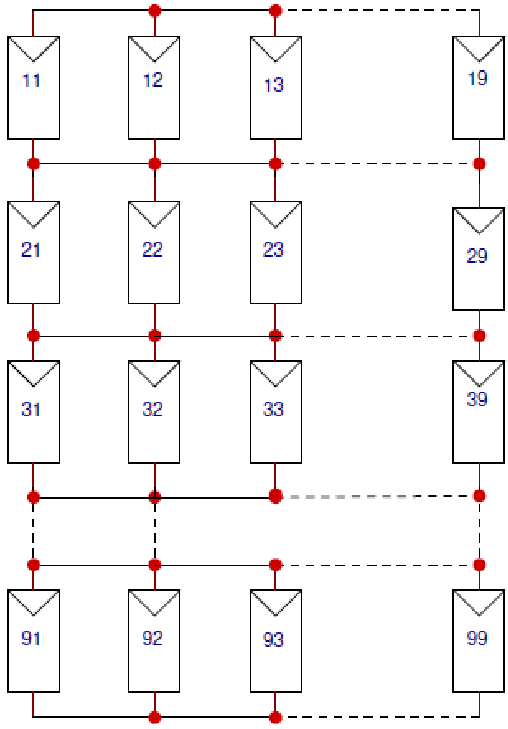

Fig. 1: *TCT arrangement pattern*

2.2 Minimum Distance Average (MDA)

Consider a mxn matrix, where $m = 1,2,3..i$ and $n = 1,2,3,4..j$, let us consider a 9x9 matrix.The distance from one panels to other panels are calculated by equation (5).

$$D_{ij} = \sqrt{(l_j - l_i)^2 + (w_j - w_i)^2} \quad (5)$$

Using equation 5 and considering each panel as origin, the distance of other panels are calculated. The distance values are added and divided with the total number of panels present in an array. Thus the distance average (DA) value are obtained based on equation 6.

$$DA = \sum_{j=1}^{n} \frac{D(i,j)}{N} \quad (6)$$

All these values are compared and the least value panel is taken as radix panel and that is placed in the right-side bottom of the array. Assuming radix panel as origin, the distance of other panels are calculated with respect to the distance values and the panels are arranged in ascending order filled in column wise. The steps shows the determination of MDA fixation of panels.
Step 1: Calculate distances between the solar panels to every other solar panels in the network.
Step 2: Assume each panel in the matrix as origin and

calculate the distance value from 5.
Step 3: Calculate the DA of every solar panels to other panels from 5.
Step 4: Compare the DA values in which the least value is assumed as radix panel.
Step 5: Now assuming radix panel as origin the distance between the other panels are calculated.
Step 6: The radix panel is placed at the right-side bottom of the matrix.
Step 7: With referencing to the distance values, the panels are arranged in ascending order as shown in Fig.1.
The array current equations of $9X9$ matrix is given for the irradiance values such as 900 W/m^2 and 600 W/m^2 in each partial shading condition i.e., SN, SW, LN and LW following with the power comparison with TCT and the proposed methods along with a graphical representation of location of global peak (GP) for MDA methods discussed in section 3.

Table 2: *Distance of all panels 9X9 PV array*

Panel	D	Panel	D	Panel	D	Panel	D	Panel	D
45	1	47	2.236	83	3.605	69	4.123	21	5
65	1	43	2.236	87	3.605	49	4.123	29	5
56	1	73	2.828	27	3.605	22	4.242	89	5
54	1	77	2.828	23	3.605	82	4.242	81	5
44	1.414	37	2.828	32	3.605	88	4.242	11	5.657
46	1.414	33	2.828	72	3.605	28	4.242	19	5.657
66	1.414	25	3	78	3.605	93	4.472	99	5.657
64	1.414	85	3	38	3.605	97	4.472	91	5.657
35	2	58	3	15	4	17	4.472		
75	2	52	3	95	4	13	4.472		
57	2	24	3.162	59	4	31	4.472		
53	2	84	3.162	51	4	71	4.472		
34	2.236	86	3.162	14	4.123	79	4.472		
36	2.236	26	3.162	94	4.123	39	4.472		
76	2.236	42	3.162	96	4.123	12	5		
74	2.236	62	3.162	16	4.123	92	5		
63	2.236	68	3.162	41	4.123	98	5		
67	2.236	48	3.162	61	4.123	18	5		
*D-Distance									

2.2.1 *Cabling*

According to the different techniques proposed the physical location of the panels remains the same but electrical connection of the each panels change according to MDA algorithm. For example, panels 12, 33, 42, 91 are connected in a string similarly panels 51, 22, 53, 93 are connected in a string with reference to the shading pattern as shown in Fig 2 panel 45 implies panel location i.e. 4^{th} row $5th$ column, similarly the other panels of their respective panel location are connected in their following string. This connection is done as mentioned for all m rows of the PV array and by doing so the shaded panels are equally dispersed in the mxn array resulting in increase of power generation in a solar PV array.
The distance average of all the panels with respect to its origin are tabulated in 2.The panel with minimum distance is considered as radix panel; here panel 55 is taken as radix panel. Thus considering radix panel as origin and the panel distance values are arranged in an ascending order and they are tabulated in Table 3 and are arranged in 9x9 matrix as shown in Fig 2.

Table 3: *Distance of all panels with respect to min-panel*

panel	D	panel	D	panel	D	panel	D	panel	D
11	6.237	31	5.276	51	4.943	71	5.276	91	6.238
12	5.683	32	4.649	52	4.293	72	4.649	92	5.683
13	5.276	33	4.188	53	3.814	73	4.189	93	5.276
14	5.027	34	3.908	54	3.522	74	3.908	94	5.027
15	4.943	35	3.814	55	3.424	75	3.814	95	4.943
16	5.027	36	3.908	56	3.522	76	3.908	96	5.027
17	5.275	37	4.188	57	3.814	77	4.188	97	5.276
18	5.683	38	4.649	58	4.293	78	4.649	98	5.683
19	6.238	39	5.276	59	4.943	79	5.276	99	6.238
21	5.683	41	5.026	61	5.027	81	5.683		
22	5.086	42	4.382	62	4.382	82	5.083		
23	4.649	43	3.908	63	3.908	83	4.649		
24	4.382	44	3.619	64	3.619	84	4.382		
25	4.293	45	3.522	65	3.522	85	4.292		
26	4.382	46	3.619	66	3.619	86	4.382		
27	4.648	47	3.908	67	3.908	87	4.649		
28	5.086	48	4.382	68	4.382	88	5.086		
29	5.683	49	5.027	69	5.027	89	5.683		
*D-Distance									

2.3 *Index Squaring Method (ISM)*

In a mxn matrix each element has its own index i,j in which 'i' indicates row and 'j' indicates column. It is used to identify an element easily in the following mxn matrix. According to ISM method, the indices i and j are squared and added with respect to the equation 7.

$$P_{ij} = i^2 + j^2 \tag{7}$$

The index squaring values are arranged in ascending order and the values are tabulated in the table with respect to those values the panels are arranged in the following mxn matrix from top to bottom (column wise) as shown in Fig 3.
Step 1: Identify the indices of all the panels.
Step 2: Square i and j values of each panel.
Step 3: Add the squares of i and j values of each panels with respect to equation 7 and the values are tabulated as shown in Table 4.
Step 4: Compare the Index square values of the panel and arrange it in ascending order (column wise) as shown in Table 20.
Step 5: With reference to the index square values the

Table 4: *Index squares of all panels 9x9 array*

Panel	Index squares	Panel	Index squares	Panel	Index squares	Panel	Index squares	Panel	Index squares
11	2	31	29	51	26	71	50	91	82
12	5	32	32	52	29	72	53	92	85
13	10	33	34	53	34	73	58	93	90
14	17	34	34	54	41	74	65	94	97
15	26	35	37	55	50	75	74	95	106
16	37	36	37	56	61	76	85	96	117
17	50	37	40	57	74	77	100	97	130
18	65	38	40	58	89	78	117	98	145
19	82	39	41	59	106	79	130	99	162
21	5	41	41	61	37	81	63		
22	8	42	45	62	40	82	38		
23	13	43	45	63	45	83	73		
24	20	44	50	64	52	84	74		
25	29	45	50	65	61	85	85		
26	40	46	50	66	72	86	98		
27	53	47	52	67	85	87	113		
28	68	48	52	68	100	88	128		
29	85	49	53	69	117	89	145		

Table 5: *Index square panel arranged in ascending order*

Panel	Index squares	Panel	Index squares	Panel	Index squares	Panel	Index squares	Panel	Index squares
11	2	52	29	72	53	19	82	87	117
12	5	44	32	37	58	91	82	69	117
21	5	35	34	73	58	29	85	96	117
22	8	53	34	56	61	67	85	88	128
13	10	16	37	65	61	76	85	79	130
31	10	61	37	18	65	92	85	97	130
23	13	26	40	74	65	58	85	89	145
32	13	62	40	47	65	85	85	98	145
14	17	45	41	81	65	39	90	99	162
41	17	54	41	28	68	93	90		
33	18	36	45	82	68	49	97		
24	20	63	45	66	72	94	97		
42	20	17	50	83	73	77	98		
34	25	55	50	38	73	68	98		
43	25	71	50	57	74	86	98		
15	26	46	52	75	74	59	106		
51	26	64	52	48	74	95	106		
25	29	27	53	84	74	78	117		

panels are arranged in ascending order in mxn matrix from top to bottom as shown in Fig 3.
The panels in 9x9 matrix are subjected to two different irradiance values such as 900 W/m^2 and 600 W/m^2in each partial shading condition ie. SN, SW, LN and LW In regard to power comparison with the proposed configuration along with a graphical representation that reveals the location of global peak for ISM method.

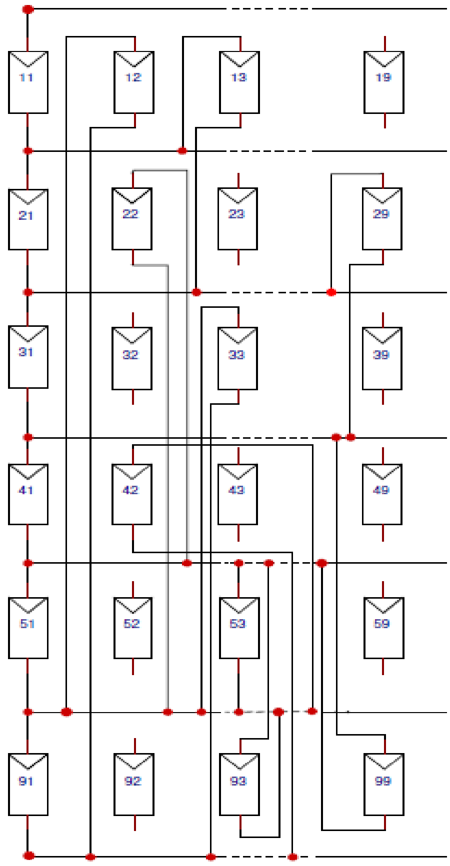

Fig. 2: *MDA arrangement pattern*

2.3.1 *Cabling*

According to ISM configuration the physical location of the panels remains the same but electrical connection of the module changes according to ISM algorithm. For example, panels 91, 12, 33 are connected in a string similarly panels 11, 52, 19are connected in a string with reference to the Fig.3,11 implies panel location i.e.1st row 1^{s}t column, similarly the other panels of their respective panel location are connected in their following string. This connection is done as mentioned for all 'm' rows of the PV array and by doing so the shaded panels are equally dispersed in the mxn array resulting in increase of power generation in a solar power plant.

2.4 Calcudoku Method (CM)

Calcudoku is a logic-based number placement puzzle, where a number must not be repeated more than once, both in row and column for a given arithmetic or logical condition, and the number ranges from 1 to n, here n denotes the number of rows or column. For this method

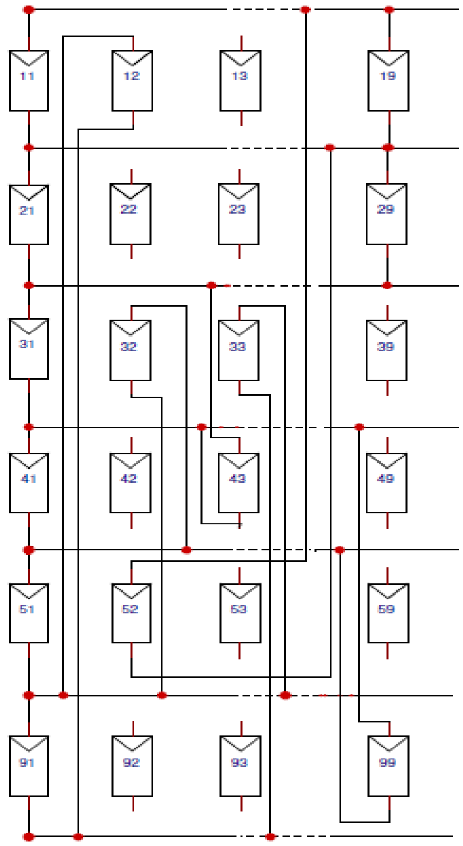

Fig. 3: *ISM arrangement pattern*

The number of rows and column are equal, thus it is applicable only for square matrix configuration.In this method the array current equations of 9x9 matrix is given for the irradiance values such as 900 W/m^2 and 600 W/m^2 for each partial shading conditions i.e. SN, SW, LN and LW.

2.4.1 *Cabling*

According to CM configuration, the physical location of the panels remain the same but electrical connections of the module changes according to CM algorithm. For example, panels 31, 22, 19 are connected in a string similarly 41, 93, 23 are connected in a string with reference to the Fig 4, Here 71 implies panel location i.e.7th row 1st column, similarly the other panels of their respective panel location are connected in their following string. This connection is done as mentioned for all m rows of the PV array and by doing so the shaded panels are equally dispersed in the mxn array resulting in increase of power generation in a solar power plant. The proposed methods are verified for four different shading condition i.e. Short wide, Long wide, Short narrow and Long narrow. The shading pattern are represented in section 3 along with the array current equation, power calculation and its graphical representation which provides the location of global peaks to all the proposed methods for each shading conditions. Finally TCT, MDA, ISM, ICM are compared using Monte Carlo estimator technique, which provides the results by their respective variance values. Thus the PV array characteristics are obtained for each shading condition for both conventional and proposed methods and their results are shown in section 3.

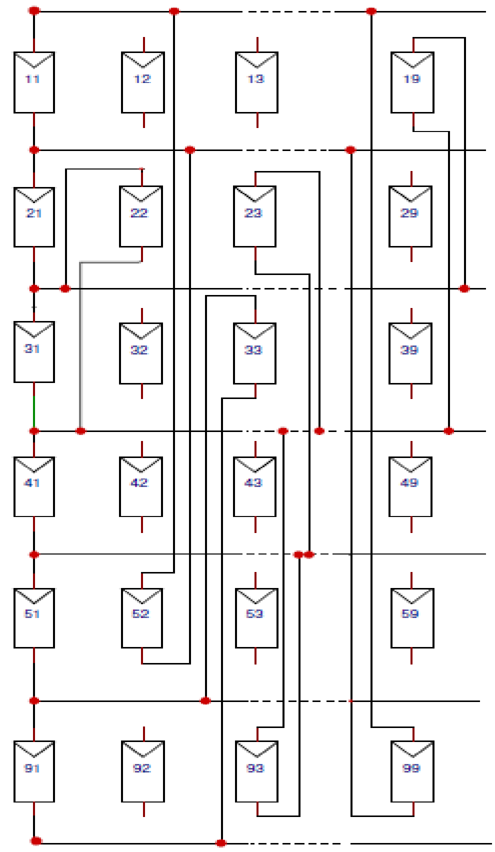

Fig. 4: *CM arrangement pattern*

3 Results and Discussion

This section deals with the performance and comparison of the proposed methods for four shading pattern namely SN, SW, LW and LN with the array current equation, power calculation and location of GP in PV characteristics graph. The theoretical results are verified from Monte Carlo estimator technique using MATLAB/ Simulink environment and the following graph is obtained for each shading pattern and the results are presented.

3.1 Case 1: Short Wide

3.1.1 *Shading Pattern*

Tthe shading pattern for short wide arrangement of TCT, MDA, ISM and CM are tablulated in tables 6, 7, 8 and 9 respectively

$900W/m^2$	$600W/m^2$

Table 6: *TCT*

11	12	13	14	15	16	17	18	19
21	22	23	24	25	26	27	28	29
31	32	33	34	34	36	37	38	39
41	42	43	44	45	46	47	48	49
51	52	53	54	55	56	57	58	59
61	62	63	64	65	66	67	68	69
71	72	73	74	75	76	77	78	79
81	82	83	84	85	86	87	88	89
91	92	93	94	95	96	97	98	99

Table 7: *MDA with Shade dispersion*

45	75	47	52	83	95	69	13	21
65	57	43	24	87	59	49	31	29
56	53	73	84	27	51	22	71	89
54	34	77	86	23	14	82	79	81
44	36	37	26	32	94	88	39	11
46	76	33	42	72	96	28	12	19
66	74	25	62	78	16	93	92	99
64	63	85	68	38	41	97	98	91
35	67	58	48	15	61	17	18	55

3.1.2 *Array Current Equation*

The array current equations for the irradiance values of 900 W/m^2 and 600 W/m^2 are represented for Short wide shading pattern of MDA, ISM and CM where k= 0.9 for 900 W/m^2 and 0.6 for 600 W/m^2, from equation 3 the array current given is given as

Table 8: *ISM with Shade dispersion*

11	14	52	54	72	28	19	93	87
12	33	44	36	37	82	91	49	69
21	24	35	63	73	66	29	94	96
22	42	53	17	56	83	67	77	88
13	34	16	55	65	38	76	68	79
31	43	61	71	18	57	92	86	97
23	15	26	46	74	75	58	59	89
32	51	62	64	47	48	85	95	98
41	25	45	27	81	84	39	78	99

Table 9: *CM with shade dispersion*

71	12	63	44	25	96	57	38	89
81	62	53	14	45	36	97	28	79
21	82	13	54	35	66	77	98	49
61	92	83	24	55	46	17	78	39
41	32	93	74	65	16	87	58	29
51	42	23	84	95	76	37	18	69
91	72	33	64	15	26	47	88	59
31	22	73	94	85	56	67	48	19
11	52	43	34	75	86	27	68	99

$I_{R1} = K_{11}I_{11} + K_{12}I_{12} + K_{13}I_{13} + K_{14}I_{14} + K_{14}I_{14} + K_{15}I_{15} + K_{16}I_{16} + K_{17}I_{17} + K_{18}I_{18}$

$$I_R1 = 9x0.9I_m = 8.1I_m$$

$I_{R2} = K_{21}I_{21} + K_{22}I_{22} + K_{23}I_{23} + K_{24}I_{24} + K_{25}I_{25} + K_{26}I_{26} + K_{27}I_{27} + K_{28}I_{28} + K_{29}I_{29} = 8.1I_m$
$I_{R3} = K_{31}I_{31} + K_{32}I_{32} + K_{33}I_{33} + K_{34}I_{34} + K_{35}I_{35} + K_{36}I_{36} + K_{37}I_{37} + K_{38}I_{38} + K_{39}I_{39} = 8.1I_m$

After Reconfiguration(MDA)
$_{R1} = K_{45}I_{45} + K_{47}I_{47} + K_{75}I_{75} + K_{52}I_{52} + K_{83}I_{83} + K_{95}I_{95} + K_{69}I_{69} + K_{13}I_{13} + K_{21}I_{21} = 7.2I_m$
$_{R2} = K_{65}I_{65} + K_{57}I_{57} + K_{43}I_{43} + K_{24}I_{24} + K_{87}I_{87} + K_{59}I_{59} + K_{49}I_{49} + K_{31}I_{31} + K_{29}I_{29} = 7.5I_m$

After Reconfiguration (ISM)
$I_{R1} = K_{11}I_{11} + K_{41}I_{41} + K_{52}I_{52} + K_{54}I_{54} + K_{72}I_{72} + K_{28}I_{28} + K_{19}I_{19} + K_{93}I_{93} + K_{87}I_{87} = 7.2I_m$
$I_{R2} = K_{12}I_{12} + K_{33}I_{33} + K_{44}I_{44} + K_{36}I_{36} + K_{37}I_{37} + K_{82}I_{82} + K_{49}I_{49} + K_{91}I_{91} + K_{69}I_{69} = 7.5I_m$

After Reconfiguration (CM)
$I_{R1} = K_{71}I_{71} + K_{12}I_{12} + K_{63}I_{63} + K_{44}I_{44} + K_{25}I_{25} + K_{96}I_{96} + K_{57}I_{57} + K_{38}I_{38} + K_{89}I_{89} = 6.9I_m$
$I_{R2} = K_{81}I_{81} + K_{62}I_{62} + K_{53}I_{53} + K_{14}I_{14} + K_{45}I_{45} + K_{36}I_{36} + K_{97}I_{97} + K_{28}I_{28} + K_{79}I_{79} = 6.9I_m$

From equation 3 the array current equations for the irradiance values of $900W/m^2$ and 600 W/m^2 are represented for Short wide shading pattern of MDA , ISM and CM, The global peak values for CM, ISM, MDA, TCT are 4918W, 4705W, 4491W, 3849W respectively.

The power enhancement percentage with respect to TCT configuration is tabulated in Table 26 for the four shading patterns. Secondly, the power calculation of TCT , MDA, ISM, CM are calculated from expression and are tabulated in Table 10, following with the location of GP in PV characteristics graph. The least array current values in a string of TCT, MDA, ISM, CM are $5.4I_m$, $6.3I_m$, $6.6I_m$ and $6.9I_m$. Comparing the least array current values of the three proposed methods, CM seems to be efficient than ISM, MDA and TCT; ISM is efficient than MDA and TCT; finally MDA is efficient than TCT configuration. From Table 10 the global peak of CM is greater than ISM, Further ISM is greater than MDA and MDA is greater than TCT configuration. This shows that CM, ISM, MDA has the capability of extracting maximum power with high efficiency when compared to TCT configuration in shortwide condition. In Fig 6. the PV characteristics of CM, ISM, MDA and TCT is plotted in a graph in that the maximum power value plotted in the graph is noted as Global peak(GP).

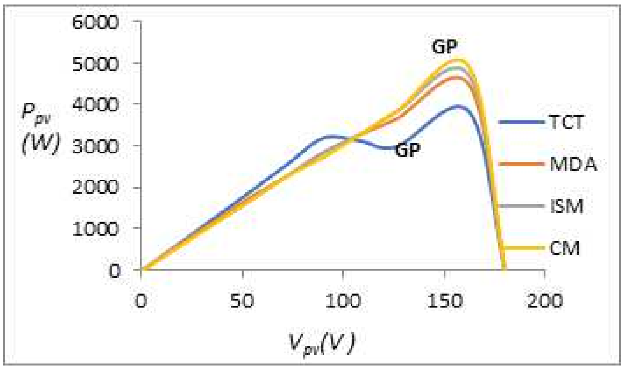

Fig. 5: *PV array characteristics of TCT,MDA, ISM and CM method*

Table 10: *Location of GP in TCT, MDA, ISM and CM*

TCT ARRANGEMENT				MDA ARRANGEMENT			
Row current in the order in which panels are bypassed		Voltage (V)	Power (W)	Row current in the order in which panels are bypassed		Voltage (V)	Power (W)
IR9	$5.4I_m$	$9\ V_m$	$48.6V_mI_m$	IR7	$6.3I_m$	$9V_m$	$56.7V_mI_m$
IR8	$5.4I_m$	-	-	IR8	$6.3I_m$	-	-
IR7	$5.4I_m$	-	-	IR4	$6.6I_m$	$7V_m$	$46.2V_mI_m$
IR6	$6.6I_m$	$6\ V_m$	$39.6V_mI_m$	IR3	$6.9I_m$	$6V_m$	$41.4V_mI_m$
IR5	$8.1I_m$	$5V_m$	$40.5V_mI_m$	IR1	$7.2I_m$	$5V_m$	$36V_mI_m$
IR4	$8.1I_m$	-	-	IR6	$7.2I_m$	-	-
IR3	$8.1I_m$	-	-	IR2	$7.5I_m$	$3V_m$	$22.5V_mI_m$
IR2	$8.1I_m$	-	-	IR5	$7.5I_m$	-	-
IR1	$8.1I_m$	-	-	IR9	$7.8I_m$	V_m	$7.8V_mI_m$
ISM ARRANGEMENT				CM ARRANGEMENT			
Row current in the order in which panels are bypassed		Voltage (V)	Power (W)	Row current in the order in which panels are bypassed		Voltage (V)	Power (W)
IR6	$6.6I_m$	$9V_m$	$56.7V_mI_m$	IR1	$6.9I_m$	$9V_m$	$62.1V_mI_m$
IR8	$6.6I_m$	-	-	IR2	$6.9I_m$	-	-
IR3	$6.9I_m$	$7V_m$	$46.2V_mI_m$	IR4	$6.9I_m$	-	-
IR9	$6.9I_m$			IR5	$6.9I_m$	-	-
IR1	$7.2I_m$	$5V_m$	$36V_mI_m$	IR7	$6.9I_m$	-	-
IR4	$7.2I_m$	-	-	IR3	$7.2I_m$	$4V_m$	$28.8V_mI_m$
IR5	$7.2I_m$	-	-	IR6	$7.2I_m$	-	-
IR7	$7.2I_m$	-		IR8	$7.2I_m$	-	-
IR2	$7.5I_m$	$1V_m$	$7.8V_mI_m$	IR9	$7.2I_m$	-	-

$900W/m^2$	$600W/m^2$

Table 11: *TCT*

11	12	13	14	15	16	17	18	19
21	22	23	24	25	26	27	28	29
31	32	33	34	34	36	37	38	39
41	42	43	44	45	46	47	48	49
51	52	53	54	55	56	57	58	59
61	62	63	64	65	66	67	68	69
71	72	73	74	75	76	77	78	79
81	82	83	84	85	86	87	88	89
91	92	93	94	95	96	97	98	99

3.2 Case 2: Long Wide

3.2.1 *Shading Pattern*

The shading pattern for long wide arrangement of TCT, MDA, ISM and CM methods are shown in the tables 11, 12, 13 and14 respectively.

3.2.2 Array Current Equation

Under conventional configuration (TCT)

$I_{R1} = K_{11}I_{11} + K_{12}I_{12} + K_{13}I_{13} + K_{14}I_{14} + K_{14}I_{14} + K_{15}I_{15} + K_{16}I_{16} + K_{17}I_{17} + K_{18}I_{18} = 8.1I_m$

$I_{R2} = K_{21}I_{21} + K_{22}I_{22} + K_{23}I_{23} + K_{24}I_{24} + K_{25}I_{25} + K_{26}I_{26} + K_{27}I_{27} + K_{28}I_{28} + K_{29}I_{29} = 8.1I_m$

After Reconfiguration(MDA)

$I_{R1} = K_{45}I_{45} + K_{47}I_{47} + K_{75}I_{75} + K_{52}I_{52} + K_{83}I_{83} + K_{95}I_{95} + K_{69}I_{69} + K_{13}I_{13} + K_{21}I_{21} = 6.6I_m$

$I_{R2} = K_{65}I_{65} + K_{57}I_{57} + K_{43}I_{43} + K_{24}I_{24} + K_{87}I_{87} + K_{59}I_{59} + K_{49}I_{49} + K_{31}I_{31} + K_{29}I_{29} = 6.6I_m$

After Reconfiguration (ISM)

$I_{R1} = K_{11}I_{11} + K_{41}I_{41} + K_{52}I_{52} + K_{54}I_{54} + K_{72}I_{72} + K_{28}I_{28} + K_{19}I_{19} + K_{93}I_{93} + K_{87}I_{87} = 6.6I_m$

Table 12: *MDA with Shade dispersion*

45	75	47	52	83	95	69	13	21
65	57	43	24	87	59	49	31	29
56	53	73	84	27	51	22	71	89
54	34	77	86	23	14	82	79	81
44	36	37	26	32	94	88	39	11
46	76	33	42	72	96	28	12	19
66	74	25	62	78	16	93	92	99
64	63	85	68	38	41	97	98	91
35	67	58	48	15	61	17	18	55

Table 13: *ISM with Shade dispersion*

11	14	52	54	72	28	19	93	87
12	33	44	36	37	82	91	49	69
21	24	35	63	73	66	29	94	96
22	42	53	17	56	83	67	77	88
13	34	16	55	65	38	76	68	79
31	43	61	71	18	57	92	86	97
23	15	26	46	74	75	58	59	89
32	51	62	64	47	48	85	95	98
41	25	45	27	81	84	39	78	99

Table 14: *CM with shade dispersion*

71	12	63	44	25	96	57	38	89
81	62	53	14	45	36	97	28	79
21	82	13	54	35	66	77	98	49
61	92	83	24	55	46	17	78	39
41	32	93	74	65	16	87	58	29
51	42	23	84	95	76	37	18	69
91	72	33	64	15	26	47	88	59
31	22	73	94	85	56	67	48	19
11	52	43	34	75	86	27	68	99

$I_{R2} = K_{12}I_{12} + K_{33}I_{33} + K_{44}I_{44} + K_{36}I_{36} + K_{37}I_{37} + K_{82}I_{82} + K_{49}I_{49} + K_{91}I_{91} + K_{69}I_{69} = 7.2I_m$

After Reconfiguration (CM)

$I_{R1} = K_{71}I_{71} + K_{12}I_{12} + K_{63}I_{63} + K_{44}I_{44} + K_{25}I_{25} + K_{96}I_{96} + K_{57}I_{57} + K_{38}I_{38} + K_{89}I_{89} = 6.6I_m$

$I_{R2} = K_{81}I_{81} + K_{62}I_{62} + K_{53}I_{53} + K_{14}I_{14} + K_{45}I_{45} + K_{36}I_{36} + K_{97}I_{97} + K_{28}I_{28} + K_{79}I_{79} = 6.6I_m$

Array current equations are represented for long wide shading pattern and the least array current values are compared. The least array current value for CM, ISM, MDA, TCTis $6.3I_m$, $6.3I_m$, $6.0I_m$, and $5.4I_m$. From Table 15 the global peak of TCT, MDA, CM and ISM are known from the PV curve that is plotted and represented in Fig 8. The GP values of CM, ISM, MDA, TCT .Hence comparing the values of least array current and GP, CM and ISM are equal and are efficient than MDA and MDA is efficient than TCT configuration.

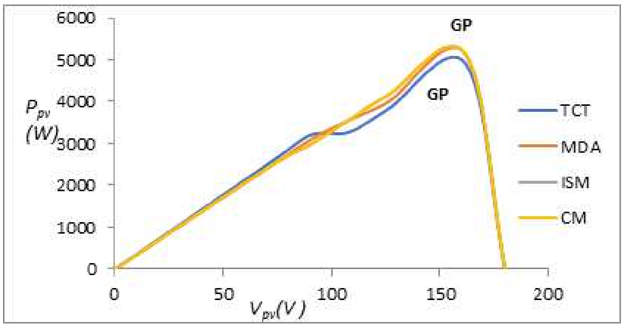

Fig. 6: *PV array characteristics of TCT,MDA, ISM and CM method*

Table 15: *Location of GP in TCT, MDA, ISM and CM*

TCT ARRANGEMENT				MDA ARRANGEMENT			
Row current in the order in which panels are bypassed		Voltage (V)	Power (W)	Row current in the order in which panels are bypassed		Voltage (V)	Power (W)
IR9	$6.9I_m$	9 V_m	$62.1V_mI_m$	IR4	$7.2I_m$	$9V_m$	$64.8V_mI_m$
IR8	$6.9I_m$	-	-	IR7	$7.2I_m$	-	-
IR7	$6.9I_m$	-	-	IR8	$7.2I_m$	-	-
IR6	$6.9I_m$	-	-	IR6	$7.2I_m$	$6V_m$	$45V_mI_m$
IR5	$8.1I_m$	$5V_m$	$40.5V_mI_m$	IR1	$7.5I_m$	$5V_m$	$39V_mI_m$
IR4	$8.1I_m$	-	-	IR2	$7.5I_m$	-	-
IR3	$8.1I_m$	-	-	IR3	$7.8I_m$	-	-
IR2	$8.1I_m$	-	-	IR5	$7.8I_m$	-	-
IR1	$8.1I_m$	-	-	IR9	$7.8I_m$	-	-
ISM ARRANGEMENT				CM ARRANGEMENT			
Row current in the order in which panels are bypassed		Voltage (V)	Power (W)	Row current in the order in which panels are bypassed		Voltage (V)	Power (W)
IR4	$7.2I_m$	$9V_m$	$64.8V_mI_m$	IR3	$7.2I_m$	$9V_m$	$64.8V_mI_m$
IR5	$7.2I_m$	-	-	IR9	$7.2I_m$	-	-
IR3	$7.5I_m$	$7V_m$	$52.5V_mI_m$	IR1	$7.5I_m$	$7V_m$	$52.5V_mI_m$
IR6	$7.5I_m$			IR2	$7.5I_m$	-	-
IR9	$7.5I_m$	-	-	IR6	$7.5I_m$	-	-
IR1	$7.8I_m$	$4V_m$	$31.2V_mI_m$	IR4	$7.8I_m$	$4V_m$	$31.2V_mI_m$
IR2	$7.8I_m$	-	-	IR5	$7.8I_m$	-	-
IR7	$7.8I_m$			IR7	$7.8I_m$	-	-
IR8	$7.8I_m$	-	-	IR8	$7.8I_m$	-	-

3.3 Case 3: Short Narrow

3.3.1 Shading Pattern

The shading pattern for shot narrow arrangement of TCT, MDA, ISM and CM methods are shown in the tables 16, 17, 18 and19 respectively.

$900W/m^2$	$600W/m^2$

Table 16: TCT

11	12	13	14	15	16	17	18	19
21	22	23	24	25	26	27	28	29
31	32	33	34	34	36	37	38	39
41	42	43	44	45	46	47	48	49
51	52	53	54	55	56	57	58	59
61	62	63	64	65	66	67	68	69
71	72	73	74	75	76	77	78	79
81	82	83	84	85	86	87	88	89
91	92	93	94	95	96	97	98	99

Table 17: *MDA with shading pattern*

45	75	47	52	83	95	69	13	21
65	57	43	24	87	59	49	31	29
56	53	73	84	27	51	22	71	89
54	34	77	86	23	14	82	79	81
44	36	37	26	32	94	88	39	11
46	76	33	42	72	96	28	12	19
66	74	25	62	78	16	93	92	99
64	63	85	68	38	41	97	98	91
35	67	58	48	15	61	17	18	55

Table 18: *ISM with shading pattern*

11	14	52	54	72	28	19	93	87
12	33	44	36	37	82	91	49	69
21	24	35	63	73	66	29	94	96
22	42	53	17	56	83	67	77	88
13	34	16	55	65	38	76	68	79
31	43	61	71	18	57	92	86	97
23	15	26	46	74	75	58	59	89
32	51	62	64	47	48	85	95	98
41	25	45	27	81	84	39	78	99

3.3.2 Array Current Equation

Under Conventional Configuration (TCT)
$I_{R1} = K_{11}I_{11} + K_{12}I_{12} + K_{13}I_{13} + K_{14}I_{14} + K_{14}I_{14} + K_{15}I_{15} + K_{16}I_{16} + K_{17}I_{17} + K_{18}I_{18} = 8.1I_m$
$I_{R2} = K_{21}I_{21} + K_{22}I_{22} + K_{23}I_{23} + K_{24}I_{24} + K_{25}I_{25} + K_{26}I_{26} + K_{27}I_{27} + K_{28}I_{28} + K_{29}I_{29} = 8.1I_m$

After Reconfiguration(MDA)
$I_{R1} = K_{45}I_{45} + K_{47}I_{47} + K_{75}I_{75} + K_{52}I_{52} + K_{83}I_{83} + K_{95}I_{95} + K_{69}I_{69} + K_{13}I_{13} + K_{21}I_{21} = 7.8I_m$
$I_{R2} = K_{65}I_{65} + K_{57}I_{57} + K_{43}I_{43} + K_{24}I_{24} + K_{87}I_{87} + K_{59}I_{59} + K_{49}I_{49} + K_{31}I_{31} + K_{29}I_{29} = 7.8I_m$

After Reconfiguration (ISM)
$I_{R1} = K_{11}I_{11} + K_{41}I_{41} + K_{52}I_{52} + K_{54}I_{54} + K_{72}I_{72} + K_{28}I_{28} + K_{19}I_{19} + K_{93}I_{93} + K_{87}I_{87} = 7.8I_m$
$I_{R2} = K_{12}I_{12} + K_{33}I_{33} + K_{44}I_{44} + K_{36}I_{36} + K_{37}I_{37} + K_{82}I_{82} + K_{49}I_{49} + K_{91}I_{91} + K_{69}I_{69} = 7.8I_m$

Table 19: *CM with shading pattern*

71	12	63	44	25	96	57	38	89
81	62	53	14	45	36	97	28	79
21	82	13	54	35	66	77	98	49
61	92	83	24	55	46	17	78	39
41	32	93	74	65	16	87	58	29
51	42	23	84	95	76	37	18	69
91	72	33	64	15	26	47	88	59
31	22	73	94	85	56	67	48	19
11	52	43	34	75	86	27	68	99

After Reconfiguration (CM)
$I_{R1} = K_{71}I_{71} + K_{12}I_{12} + K_{63}I_{63} + K_{44}I_{44} + K_{25}I_{25} + K_{96}I_{96} + K_{57}I_{57} + K_{38}I_{38} + K_{89}I_{89} = 7.5I_m$
$I_{R2} = K_{81}I_{81} + K_{62}I_{62} + K_{53}I_{53} + K_{14}I_{14} + K_{45}I_{45} + K_{36}I_{36} + K_{97}I_{97} + K_{28}I_{28} + K_{79}I_{79} = 7.5I_m$

Table 8 show the least array current values of CM, ISM, MDA, TCT as $6.9I_m$, $7.2I_m$, $7.2I_m$, and $7.2I_m$ respectively.The GP of TCT, MDA, ISM, CM are 4918 W, 5132 W, 5132 W, 5132 W respectively as shown in Fig 7. Comparing the least array current values and GP values CM, ISM and MDA are equally efficient and in turn more efficient than TCT configuration for under short narrow condition.

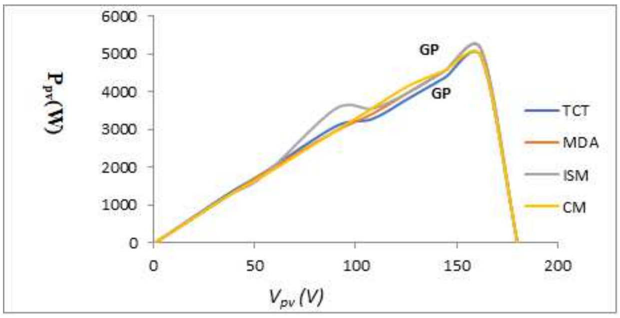

Fig. 7: *PV array characteristics of TCT,MDA, ISM and CM methods*

3.4 Case 4: Long Narrow

3.4.1 Shading Pattern

The shading pattern for long narrow arrangement of TCT, MDA, ISM and CM methods are shown in the tables 21, 22, 23 and24, respectively.

Table 20: *Location of GP in TCT, MDA, ISM and CM*

TCT ARRANGEMENT				MDA ARRANGEMENT			
Row current in the order in which panels are bypassed		Voltage (V)	Power (W)	Row current in the order in which panels are bypassed		Voltage (V)	Power (W)
IR9	$6.9I_m$	$9\ V_m$	$62.1V_mI_m$	IR2	$7.2I_m$	$9V_m$	$64.8V_mI_m$
IR8	$6.9I_m$	-	-	IR4	$7.2I_m$	-	-
IR7	$6.9I_m$	-	-	IR7	$7.2I_m$	-	-
IR6	$6.9I_m$	-	-	IR8	$7.2I_m$	-	-
IR5	$7.8I_m$	$5V_m$	$39V_mI_m$	IR5	$7.5I_m$	$5V_m$	$37.5V_mI_m$
IR4	$7.8I_m$	-	-	IR6	$7.5I_m$	-	-
IR3	$7.8I_m$	-	-	IR1	$7.8I_m$	$3V_m$	$23.4V_mI_m$
IR2	$8.1I_m$	$2V_m$	$16.2V_mI_m$	IR3	$7.8I_m$	-	-
IR1	$8.1I_m$	-	-	IR9	$7.8I_m$	-	-
ISM ARRANGEMENT				CM ARRANGEMENT			
Row current in the order in which panels are bypassed		Voltage (V)	Power (W)	Row current in the order in which panels are bypassed		Voltage (V)	Power (W)
IR4	$7.2I_m$	$9V_m$	$64.8V_mI_m$	IR4	$6.9I_m$	$9V_m$	$62.1V_mI_m$
IR5	$7.2I_m$	-	-	IR5	$7.2I_m$	$8V_m$	$57.6V_mI_m$
IR9	$7.2I_m$	-	-	IR9	$7.5I_m$	$7V_m$	$52.5V_mI_m$
IR2	$7.5I_m$	$6V_m$	$45V_mI_m$	IR2	$7.5I_m$	-	-
IR3	$7.5I_m$	-	-	IR3	$7.5I_m$	-	-
IR6	$7.5I_m$	-	-	IR6	$7.5I_m$	-	-
IR7	$7.5I_m$	-	-	IR7	$7.5I_m$	-	-
IR1	$7.8I_m$	$2V_m$	$15.6V_mI_m$	IR1	$7.8I_m$	$2V_m$	$15.6V_mI_m$
IR8	$7.8I_m$	-	-	IR8	$7.8I_m$	-	-

$900W/m^2$	$600W/m^2$

Table 21: *TCT*

11	12	13	14	15	16	17	18	19
21	22	23	24	25	26	27	28	29
31	32	33	34	34	36	37	38	39
41	42	43	44	45	46	47	48	49
51	52	53	54	55	56	57	58	59
61	62	63	64	65	66	67	68	69
71	72	73	74	75	76	77	78	79
81	82	83	84	85	86	87	88	89
91	92	93	94	95	96	97	98	99

Table 22: *MDA with shading pattern*

45	75	47	52	83	95	69	13	21
65	57	43	24	87	59	49	31	29
56	53	73	84	27	51	22	71	89
54	34	77	86	23	14	82	79	81
44	36	37	26	32	94	88	39	11
46	76	33	42	72	96	28	12	19
66	74	25	62	78	16	93	92	99
64	63	85	68	38	41	97	98	91
35	67	58	48	15	61	17	18	55

Table 23: *ISM with shading pattern*

11	14	52	54	72	28	19	93	87
12	33	44	36	37	82	91	49	69
21	24	35	63	73	66	29	94	96
22	42	53	17	56	83	67	77	88
13	34	16	55	65	38	76	68	79
31	43	61	71	18	57	92	86	97
23	15	26	46	74	75	58	59	89
32	51	62	64	47	48	85	95	98
41	25	45	27	81	84	39	78	99

Table 24: *CM with shading pattern*

71	12	63	44	25	96	57	38	89
81	62	53	14	45	36	97	28	79
21	82	13	54	35	66	77	98	49
61	92	83	24	55	46	17	78	39
41	32	93	74	65	16	87	58	29
51	42	23	84	95	76	37	18	69
91	72	33	64	15	26	47	88	59
31	22	73	94	85	56	67	48	19
11	52	43	34	75	86	27	68	99

3.4.2 Array Current Equation

$I_{R1} = K_{11}I_{11} + K_{12}I_{12} + K_{13}I_{13} + K_{14}I_{14} + K_{14}I_{14} + K_{15}I_{15} + K_{16}I_{16} + K_{17}I_{17} + K_{18}I_{18} = 8.1I_m$

$I_{R2} = K_{21}I_{21} + K_{22}I_{22} + K_{23}I_{23} + K_{24}I_{24} + K_{25}I_{25} + K_{26}I_{26} + K_{27}I_{27} + K_{28}I_{28} + K_{29}I_{29} = 8.1I_m$

After Reconfiguration(MDA)

$I_{R1} = K_{45}I_{45} + K_{47}I_{47} + K_{75}I_{75} + K_{52}I_{52} + K_{83}I_{83} + K_{95}I_{95} + K_{69}I_{69} + K_{13}I_{13} + K_{21}I_{21} = 7.8I_m$

$I_{R2} = K_{65}I_{65} + K_{57}I_{57} + K_{43}I_{43} + K_{24}I_{24} + K_{87}I_{87} + K_{59}I_{59} + K_{49}I_{49} + K_{31}I_{31} + K_{29}I_{29} = 7.8I_m$

After Reconfiguration (ISM)

$I_{R1} = K_{11}I_{11} + K_{41}I_{41} + K_{52}I_{52} + K_{54}I_{54} + K_{72}I_{72} + K_{28}I_{28} + K_{19}I_{19} + K_{93}I_{93} + K_{87}I_{87} = 7.8I_m$

$I_{R2} = K_{12}I_{12} + K_{33}I_{33} + K_{44}I_{44} + K_{36}I_{36} + K_{37}I_{37} + K_{82}I_{82} + K_{49}I_{49} + K_{91}I_{91} + K_{69}I_{69} = 7.8I_m$

After Reconfiguration (CM)

$I_{R1} = K_{71}I_{71} + K_{12}I_{12} + K_{63}I_{63} + K_{44}I_{44} + K_{25}I_{25} + K_{96}I_{96} + K_{57}I_{57} + K_{38}I_{38} + K_{89}I_{89} = 7.5I_m$

$I_{R2} = K_{81}I_{81} + K_{62}I_{62} + K_{53}I_{53} + K_{14}I_{14} + K_{45}I_{45} + K_{36}I_{36} + K_{97}I_{97} + K_{28}I_{28} + K_{79}I_{79} = 7.5I_m$

Fig 8 shows the array currents of all the methods. Among all the four methods, ISM and CM performs well when compared to MDA and TCT (with respect to global peak points).In few case ISM and CM performs similar to MDA configuration more than TCT configuration. In all the cases the proposed methods perform better than TCT method.

Table 25: *Power calculation for all the four cases*

Case	Maximum Power				Power Enhancement (%)		
	TCT	MDA	ISM	CM	MDA	ISM	CM
LN	4198	5132	5132	4918	18.2	18.2	NC
LW	3849	4277	4491	4704	10	14.3	18.17
SW	3849	4491	4705	4918	14.3	18.2	21.73
SN	4918	5132	5132	5132	4.17	18.2	18.2
*NC (No change)							

Table 26: *Array currents of all methods*

S.NO	TCT (I_m)	ISM (I_m)	MDA (I_m)	CM (I_m)
SW	5.4	6.6	6.3	6.9
SN	6.9	7.2	7.2	7.2
LW	5.4	6.3	6	6.6
LN	6.9	7.2	7.2	6.9

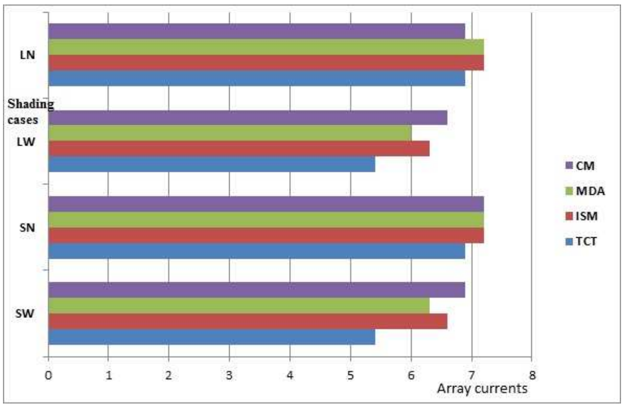

Fig. 8: *Array currents for TCT,MDA, ISM,CM methods*

3.5 Monte Carlo Estimator (MCE)

A Monte Carlo method is based on the analogy between probability and volume. The mathematics of measure formalizes the intuitive notion of probability, associating an event with a set of outcomes and defining the probability of the event to be its volume or measure relative to that of a universe of possible outcomes. Monte Carlo uses this identity in reverse, calculating the volume of a set by interpreting volume as a probability. Evaluating the function f at n of these random points and averaging the results produces the Monte Carlo estimate.

$$g_n(X) = \frac{1}{n}\sum_{i=0}^{n} f[X_i] \quad (8)$$

where N is the number of samples in each matrix $f[X_i]$ is a sample matrix framed from the array current analysis $g_n(X)$ is called the Monte Carlo estimator (MCE) of $f[X_i]$

Mean of MCE is

$$E(g_n(X)) = E\Big[\frac{1}{n}\sum_{i=0}^{n} g(X_i)\Big] = \frac{1}{n}\sum_{i=0}^{n} E\big[g(X_i)\big] = E(g(X)) \quad (9)$$

Variance of MCE is

$$Var(g_n(X)) = Var\Big(\frac{1}{n}\sum_{i=0}^{n} g(X_i)\Big) \quad (10)$$

$$= \frac{Var(g(X))}{n} \quad (11)$$

$$= \frac{1}{n}\sum_{x\in X}\big[g(x) - E(g(x))\big]^2 f_x dx \quad (12)$$

The values of the mean and variance are calculated using expression 9 and 10, for all the four cases such as SN, SW, LN and LW, from which a graph is plotted as shown in Fig 9.

Table 27: *Variance of MCE for SW with respect to various irradiances*

Solar Irradiance	SW			
	TCT	MDA	ISM	CM
1000	1.735	0.295	0.0925	0.0625
750	0.9633	0.1659	0.052	0.0352
500	0.4337	0.0738	0.0231	0.0156
250	0.1084	0.0184	0.0058	0.0039

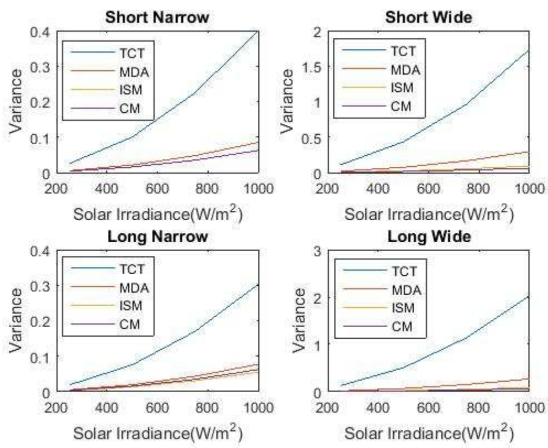

Fig. 9: *Variance of MCE for a proposed TCT, ISM, CM and MDA method*

4 Conclusion

The least array current values of CM, ISM, MDA, TCT are 6.9Im,7.2Im,7.2Im, and 7.2Im respectively the GP of

TCT,MDA,ISM and CM as 4198W, 5132W,5132W,5132W respectively. The power enhancement for LN is 18.2% for ISM. For LW , the proposed ISM is14.3% and CM is about 18.17%. For SW the proposed CM has the power enhancement value is about 21.73% is greater.Comparing the least array current values and GP values it is found that ISM and MDA are equally efficient and in turn more efficient than TCT and CM, and TCT and CM are equally efficient under long narrow condition. Further Monte Carlo analysis shows that the proposed ISM and CM techniques improves PV power under various solar irradiances.

References

[1] Josephine Rathinadurai Louis, SujaShanmugam., Karunabika Gunasekar. Effective utilization and efficient maximum. IET Renew. Power Generation, 10, (3), 1-8 (2015).

[2] Rani.BJ,Elango.GS,NagamaniC. Enhanced Power Generation from PV array under partial shading conditions by shade dispersion using Su Do Ku Configuration. IEEE Trans Sustain Energy, 4, 574-602, (2013).

[3] Patel H and Agarwal V. Maximum power point tracking scheme for pv systems operating under partially shaded conditions.IEEE Trans. Ind. Electron., 55, 1689–1698 (2008).

[4] Gao, L., Dougal, R.A., Liu, S., et al.: ‘Parallel-connected solar PV system to address partial and rapidly fluctuating shadow conditions’, IEEE Trans. Ind. Electron, 2009., 56, (5), pp. 1548-1556.

[5] Kaushika, N, Gautam, N.K. Energy yield simulations of interconnected solar PV arrays. IEEE Trans. Energy Convers,18, 127-13 (2003).

[6] Velasco-Quesada G, Guinjoan-Gispert, F, Pique-lopez, R.Electrical PV array reconfiguration strategy for energy extraction improvement in grid connected systems. IEEE Trans. Ind. Electron., 56, 4319-4331(2009).

[7] B. Patnaik, P. Sharma, E. Trimurthulu, S. P. Duttagupta, and V.Agarwal.Reconfiguration strategy for optimization of solar photovoltaicarray under non-uniform illumination conditions. in Proc.PHOTOVOL. SPECIAL. CONF. (PVSC),001859–001864 (2011)

[8] JazayeriMoein.,UysalSener, JazayeriKian.Comparative study of different photovoltaic array topologies under Partial Shading Conditions.in Proc.IEEE Conference on PES T&D, 1-5, (2014).

[9] Ibraheem, S Khatoon, Jalil, M.F. Feasibility Analysis of Solar Photovoltaic Array Configurations under Partial Shading Conditions. in Proc. IEEE India Conference (INDICON),1-6, (2015).

[10] NamaniRakesh, N,VenkataMadharavan, K, Ajith, T, RajendraNaik, G, Nagarjun Reddy, R.A New Technique to enhance output power from Solar PV array for different Partial Shading Conditions. in Proc. IEEE International Conference on ELECTRON DEVICES AND SOLID STATE CIRCIUTS (EDSSC) ,4799-8364, (2015).

[11] Rubinstein, R.Y., Dirk, P., ‘Simulation and the Monte Carlo method,’ (*John Wiley & Sons*, New York, 2nd edn, 2007.)

[12] Fishman, G.S.: ‘Monte Carlo:concepts, algorithms and application,’ (*Springer-Verlag*, New York, 1996, 1st edn.)

[13] Hammersely, M., Handscomb, DC.: ‘Monte Carlo Methods’(1975, 2ndedn.) Doucet., Arnaud., Freitas., Nando de., Gordon, Neil.: “Sequencial Monte Carlo Methods in Practice,” (Springer, 2001.)

[14] Paul Glasserman.: ‘Monte Carlo methods in Financial engineering’, (Springer, New York, 2003.)

[15] Patel, H., Agarwal, V.: ‘MATLAB based modelling to study the effects of partial shading on PV array characteristics,’ *IEEE Trans. Energy Convers.*, 2008, 2, (1), pp. 302-310.

Helen Catherine R L has received her Bachelor of Engineering degree in Electrical & Electronics Engineering from Sri Ramakrishna college of engineering in the year 2010. And completed PG in power electronics form Anna University, Coimbatore. she is pursuing phd Part time in PSG college of technology. Area of interest includes Control system, Power electronics, Renewable energy sources.

A Soundaarajan has received his Diploma in Electronics & Electronics Engineering and completed his doctorate from Anna University and At present he is working as an Professor, Department of EEE in PSG college of technology, Coimbatore. His areas of interests are applied electronics, Electrical Drives, Power Systems, Renewable Energy Sources, and Networks.

R L Josephine has received her M tech in National Institute of Technology, Trichy. Completed her doctorate from Anna University. And at present she is working as Assistant professor, Department of Electrical Engineering, National Institute of Technology, Trichy. Her Area of interest includes Renewable energy, computing techniques,Power electronics.