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Genetic Algorithm Based PV Array Reconfiguration for Improving Power Output under Partial Shadings

G. Meerimatha*‡, B. Loveswara Rao**,

*, **Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation,Vaddeswaram, Guntur, A.P, INDIA.

(gmeerimatha2k9@gmail.com, loveswararao@kluniversity.in)

‡Corresponding Author; G. Meerimatha, KLEF, Tel: +91-9440333831,

gmeerimatha2k9@gmail.com

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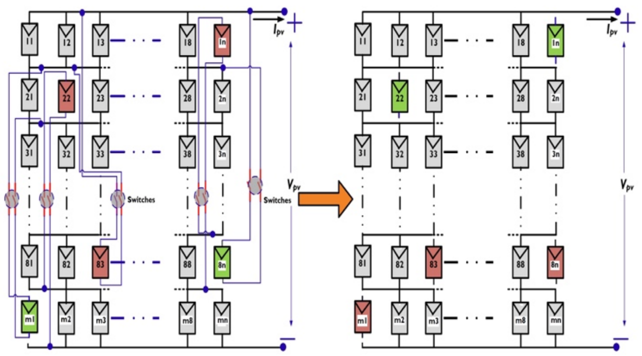
Abstract-The behavior of the Photovoltaic (PV) system may change with respect to climatic conditions. Partial shading is a significant one, the most prominent one, and the problem has been worked out so far in the literature. The impact of partial shading demolishes the PV power output and manifests multiple peak points in the PV characteristics. One of the most effective techniques suggested in the literature to overcome this issue is the electrical array reconfiguration. This paper proposed an electrical array reconfiguration method based on Genetic Algorithm (GA) for Total-Cross-Tied (TCT) array to minimize Partial Shading Conditions (PSCs) and increase power production. The physical positions of the modules in the TCT array are constant in this work, but their electrical connections are altered depending on levels of irradiance. The proposed algorithm produces a TCT array connection pattern, thus spreading shading effects over the array, and increasing the power output. This method is tested under different shading conditions on 6x6 size of array and compared with existing reconfiguration methods. The performance of the proposed method is also investigated through Shadow Loss (SL), Fill-Factor (FF), and Efficiency estimation.

KeywordsPartial shading conditions; Electrical array reconfiguration; TCT array; Genetic algorithm.

1. Introduction

Generating electricity using traditional approaches entails a range of issues, such as increasing production cost due to the import of fossil fuel, and growing environmental challenges, such as the threats of climate change associated with fossil fuel power generation, resulting in the quest for alternative methods of generating electricity using renewable sources such as solar, wind, tidal, etc [1]. Solar energy is the most accessible, completely free, and environmentally friendly among renewable energy sources. While there are many advantages, the PV efficiency, however, still struggling to get an improvement. There have been mentioned in literature; many issues reduce the efficiency of the PV system [2]. Among them, one of the most critical factors is the Partial Shading Condition (PSCs), which arises due to different reasons, such as moving objects and passing clouds. Because of PSCs, multiple maximum power points (MPP) appear in the output PV characteristics and a decline in power output. Therefore it is necessary to implement an approach to mitigate issues concerning PSCs. One of the foremost methods is the PV module interconnection [3]. As literature stated that connecting PV modules in various fashions such as simple-series (SS), parallel (P), series-parallel (SP), total-cross-tied (TCT), bridge-link (BL), and honey-comb (HC) within the array could reduce the native effect of PSCs and improved the power output. Several authors have been studied the importance of PV array interconnections under the impact of PSCs [4-6]. In [7], the authors investigated the performance of SS, SP, TCT, BL, and HC array interconnections under PSCs. In this work, 6×6 size of array is chosen and made the connection between modules in different styles. The performance of each connection is obtained by measuring the various parameters such as global power, fill-factor, and efficiency. The results of the paper stated that the TCT array improved the power output under the effect of shadings. Although the literature stated that the TCT connection structure reduced the impact of PSCs and improved the power output of the array [8], however, TCT has one major drawback of limiting the output array current based on the number of modules shaded in a row. As a result, their exhibits multiple peak points in output

PV characteristics. Among multiple peak points, one global peak (GP), which generates the highest power output under PSCs. A maximum power point tracking (MPPT) is available in the present literature to track that global peak. Various papers [9-10] reported that the MPPT could skip the right GP and follow the path of local peaks, this would add an extra loss to the PV system, and a technique is needed to mitigate the effect of PSCs in the TCT array. Reconfiguration is a method that can distribute the shading effects from one row to another to mitigate the partial shading effect in the TCT array [11]. The reconfiguration approach can be divided into dynamic and static methods. In static, the electrical connections between modules are fixed in TCT array, but the physical placements of the modules are changed. The change in the locations can distribute the shading effects across the array. In [12-13], the authors proposed Sudoku and Optimal Sudoku puzzle patterns to relocate the location of PV modules in the 9×9 TCT array in order to distribute shading impacts over the array. The proposed methods enhanced the maximum power of the TCT array under PSCs. In [14], skyscraper based puzzle pattern is proposed for the TCT to gain the efficiency of the PV system. This method is tested on 6×6 size of array under various grouping shading conditions. The results stated that the skyscraper pattern improved the array power generation as compared to other PV arrays. As per the literature, the static method increases the power generation from the TCT array under PSCs. However, this method requires more wiring and area for installation. Also, this method can't be able to distribute shading effects equally over the array; as a result, still their exhibits multiple peak points on PV characteristics [15].



(a)(b)

Fig. 1. Proposed GA Structure: (a) TCT array under PSCs, (b) Shading distribution using GA.

In dynamic reconfiguration or electrical array reconfiguration (EAR), the physical locations of PV modules don't change, but their electrical connections are altered to distribute PSCs. In [16], the authors proposed the EAR method for 3×3 TCT array to improve the output current by distributing shading effects equally. In this work, the connection between modules in the array is altered to identify the best connection scheme that can distribute shading effects and improve the output current. In [17], an adaptive method is proposed to reduce the irradiance mismatch index (IMI) in TCT array under PSCs. This method contains a fixed portion, adaptive portion and a switching matrix [21]. The switching matrix connects the adaptive part modules to the fixed part to mitigate the irradiance mismatch and maintain the identical row currents. In [18], a novel electrical array reconfiguration approach is proposed based on optimization to retain identical current in each row of the TCT array. The physical positions of the modules are fixed in this system, but their electrical relations are altered based on irradiance. The optimization identifies the shading effect and generates the new connection pattern to distribute shading impacts over the array equally. Previous attempts in the literature to fix a partial shading problem in the PV array include; (i) physical relocation, (ii) electrical array reconfiguration. Among them, the EAR approach is more efficient than physical relocation to spread shading effects in each row of the TCT array and to maintain identical currents. In EAR, finding the right combination of electrical switching is a challenging job. Hence, the application of optimization methodology is one of the potential alternative ways of resolving the above problem appropriately.

Therefore, this paper proposed a novel electrical array reconfiguration based on genetic algorithm (GA) for the TCT array to spread shading effects and increase power capability. The physical positions of PV modules are fixed in this work, but their electrical connections are altered on the basis of shading effects. Unlike static methods, this proposed method distributes shading effects in each row equally and maintains identical currents; as a result, it reduces the multiple peak points on PV characteristics and enhances the power generation of the TCT array. This proposed GA method is tested on 6×6 size of the array and numerically validated with existing reconfiguration methods like TCT and Skyscraper [14] under PSCs. Further, the shadow loss (SL), fill-factor (FF), and efficiency are obtained for each shading condition. Figure.1 shows the proposed electrical array reconfiguration topology. Figure.1(a) shows TCT array is affected by the partial shadings, and these shadings are distributed with the help of GA method (refer in Fig.1(b)). In Fig.1 (b), it can be observed that the connections between PV modules are changing without modifying their physical locations.

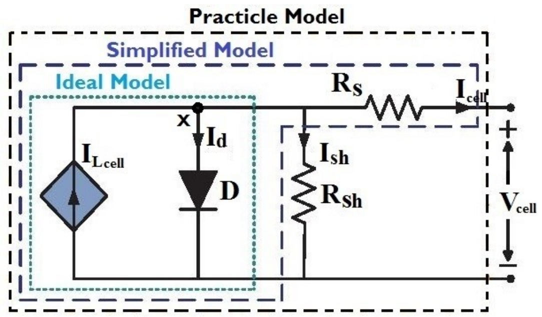


Fig. 2. Practical PV cell model.

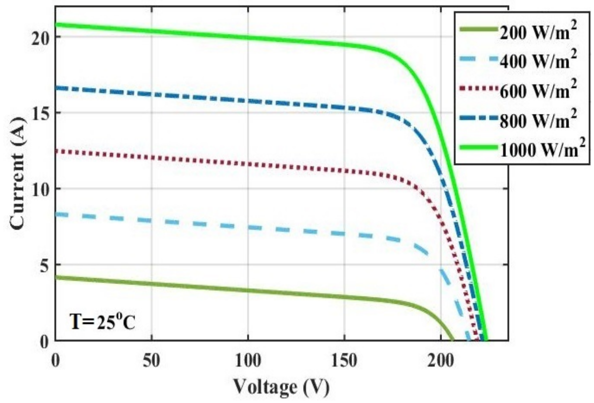
2. Photovoltaic (PV) System modeling

Considerable PV cells in both parallel and series layouts are connected together in a module to improve the levels of current and voltage in the photovoltaic system [20]. The designing and analysis of a PV system is starting with modeling of a single PV cell [12]. The one diode PV cell model is used in this paper for analysis of PV module and array. The practical view of one diode solar cell model is shown in Fig.2.

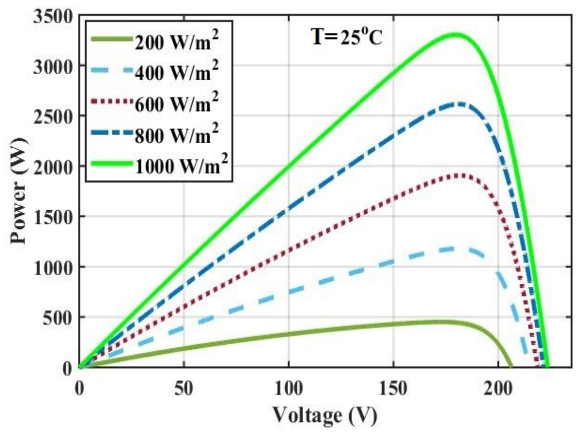
The group of assembled solar PV cells can compose a PV module. Equation (1) define the PV module output current[14], $I_m = I_{ph} - I_d\left[exp\left(\frac{q(V_m+I_mR_s)}{nkT}\right) - 1\right] - \left(\frac{V_m+I_mR_s}{R_{sh}}\right)$ (1)Production of a PV array is by connecting the PV modules in series and parallel. The output functions of the PV array can be summarized as[16],

$$I_a = N_{pp}\left\{I_{ph} - I_0\left[\exp\left(\frac{V_a+I_aR_s}{V_tN_{ss}}\right) - 1\right]\right\} - \left(\frac{V_a+I_aR_s}{R_p}\right) \quad (2)$$

The above collection of equations can also be used to display the output characteristics of the PV array under various irradiations and temperatures, as can be seen, respectively, in Fig.3 and Fig.4. The standard test condition (STC) specifications for the PV module are given in Table 1.



(a)



(b)

Fig. 3. (a) I-V characteristics, (b) P-V characteristics of 5×4 PV array at different irradiations.

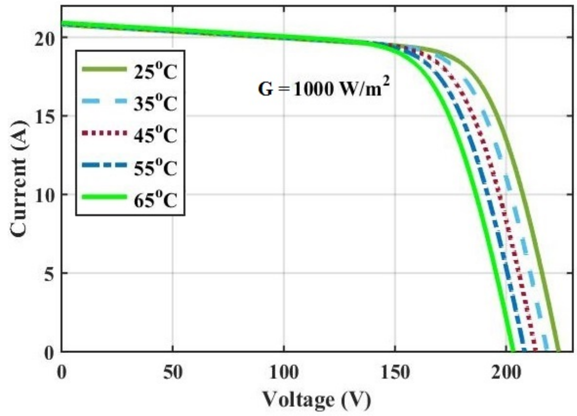
3. TCT PV array Modeling

In order to form TCT array, first compose SP connection by arranging many strings in parallel. Later, each row in a string connected with a tie-line to form a TCT array [19]. The general layout of the TCT connection, as shown in Fig.5. Figure.5 shows $m\times n$ PV modules connected in TCT fashion, where 'm' is a row and 'n' is a column. In this paper, 36 PV modules are partitioned into six rows and six columns to conduct this study. The TCT array voltage can define by applying Kirchhoff's Voltage Law (refer from [22]) in Fig.5.

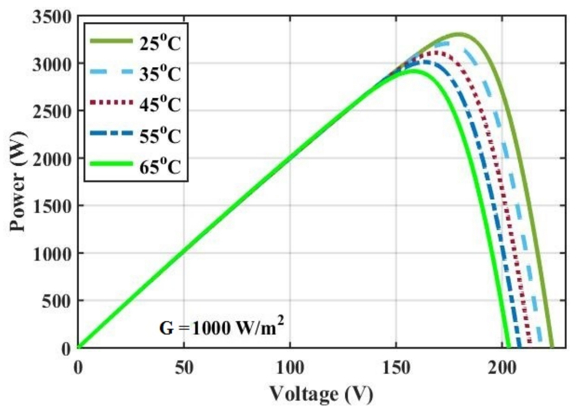
$$V_a = \sum_{i=1}^{6} V_{mi} \quad (3)$$

Where V_{mi} is module voltage with respect to i^{th} row. The array current can be described by the sum of parallel-connected individual module currents in a single row which can be calculated using KCL at each node;

$$I_a = \sum_{j=1}^{6}\left(I_{ij} - I_{(i+1)j}\right) \quad (4)$$



(a)



(b)

Fig. 4. (a) I-V characteristics, (b) P-V characteristics of 5×4 PV array at different temperature.

Table 1. Modeling parameters of the PV module

Parameters	Ratings
Maximum Power (P_{mp})	170.05W
Open-Circuit Voltage (V_{oc})	44.2 V
Short-Circuit Current (I_{sc})	5.2 A
Current at MPP (I_{mp})	4.75 A
Voltage at MPP (V_{mp})	35.8 V
PV Module Area	62.2inc×31.9inc

4. Proposed GA Technique

Genetic Algorithm (GA) is an iterative technique of optimization that provides the maximization or minimization of a problem solution. This is based on Darwin's fittest survival theory. The GA algorithm can be used for specific problems such as a problem with many possible solutions. The electrical array reconfiguration problem has several possible combinations to distribute partial shading effects. Among these, finding the best connection pattern is necessary using GA that can able to increase the power generation of the array. This EAR problem concentrated mainly on maximizing the PV array's power production by minimizing the differences in row currents of the TCT array. The efficacy of GA in any issue of optimization depends primarily on two key factors:

(i) Generation of Population

(ii) Fitness evaluation function

The problem of array reconfiguration is assumed as a problem of optimization and is solved for each population by evaluating the fitness function, given in equation (5).

$$Maximize(\text{Fitness(i)}) = \text{Sum(P)} + \left(\frac{W_e}{E_e}\right) + \left(W_p \times P_a\right) \quad (5)$$

Where,

- Fitness (i) = Population of i^{th} iteration.
- $Sum(\text{P}) = \sum_{i=1}^{6} I_k V_k$

Where, V_k and I_k are the voltage and current across k[th] row of the TCT array.

(iii) $E_e = \sum_{i=1}^{6} \left| I_m - I_k \right|$

Where I_m is maximum generated current at each row of the array.

(iv) P_a= PV module power.

(v) W_e and W_p are the weights assumed for E_e and P_a.

The selection of parameters is an important issue in the application of GA since it directly affects the global optimum convergence rate. This phenomenon of converging to local optimum cannot be completely removed but can be largely reduced by allocating parameter limitations. In the whole activity, the limits of the parameters are applied solely by the method of trial and error. In the GA technique, there is a drawback to the convergence of the local optimum point instead of the global optimum if the parameters are fixed to absolute specified values. Hence to make the algorithm convergence, some parameters are assigned to specific values, and the rest are assigned randomly.To solve this optimization problem various factor are assumed at the initial stage of the algorithm, which includes size of the population and number of iterations are set to be 100 and 800, respectively way that each iteration calculates the fitness of

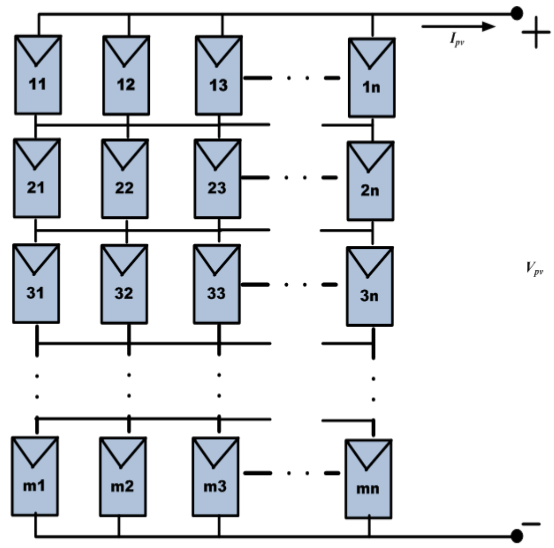


Fig. 5. TCT PV array Interconnection.

the population and compared with previous power output, then ensures that algorithm converged at global optimum.It is observed from the algorithm that in 10 trials, the GA code for the given problem converges to the global optimum almost seven times, taking due account of all the above factors. The convergence rate of the algorithm depends on the fitness function's capacity to determine the best elements within the population. Fig.6 displays the flowchart for the proposed GA algorithm.

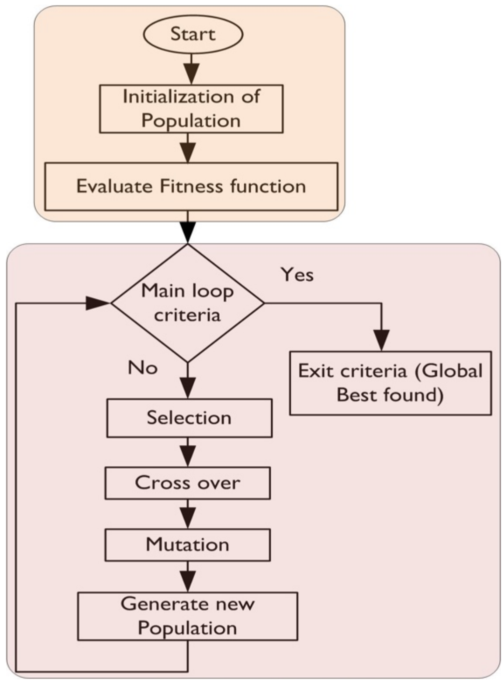


Fig.6. Proposed genetic algorithm for PV array reconfiguration.

4.1. Description of PSCs

In this paper, three artificial shading conditions are created, which includes column-wise, row-wise, and center type conditions. In each shading, the proposed method compared with existing reconfiguration techniques by obtained various parameters such as shadow loss, fill-factor, and efficiency. The mathematical representation for these parameters is given in [14].

5. Results and Discussions

This paper proposed a genetic algorithm based electrical array reconfiguration method to distribute PSCs equally to maintain identical currents in each row of the TCT array. The proposed method tested on 6×6 size of the array and compared with existing TCT and Skyscraper methods using artificially created shading conditions. In each shading, the location of the global peak is identified based on theoretical calculations and validated using MATLAB-SIMULINK.

5.1. Column-Wise Shading

In column-wise shading, the first two columns, half of the PV modules are subjected to partially shaded by 40% of irradiance, and the other modules are shaded by 60% of irradiance, respectively, as shown in Fig.9. The remaining columns of the modules are consumed 100% of irradiance. Figure.9 shows the shading distribution patterns of skyscraper and the proposed GA method. In order to find the location of the global peak for all reconfiguration methods, it is required to evaluate the current and voltage across each row in Fig.9. From the figure, it can be observed that the modules in a row are connected in parallel. Thus, a row's maximum possible current output is equal to the sum of the individual modules 'current limit values. Therefore, the current of the first-row limit is determined as:

$$I_{R1} = k_{11}I_{11} + k_{12}I_{12} + k_{13}I_{13} + k_{14}I_{14} + k_{15}I_{15} + k_{16}I_{16} \quad (6)$$

Where $k_{ij}= (G_{1j}/G_o)$, where G_{1j} is the actual irradiance falls on a module and G_o is the standard irradiance. Assume that all PV modules would generate identical currents. Hence, it can be written as,

$$I_{11}=I_{12}=I_{13}=I_{14}...=I_{16}=I_m \quad (7)$$

To find the location of GP for TCT array (refer in Fig.7(a)), the calculated row currents are as follows; Two modules in the 1st row are consumed same solar insolation ($400\ W/m^2$). The current in the first row is calculated,

$$I_{R1}= 2\times0.4I_m+ 4\times I_m \quad (8)$$

The 2nd and 3rd row consumed solar insolation is identical with respect the first row; therefore, the calculated currents for the second and third-rows are given;

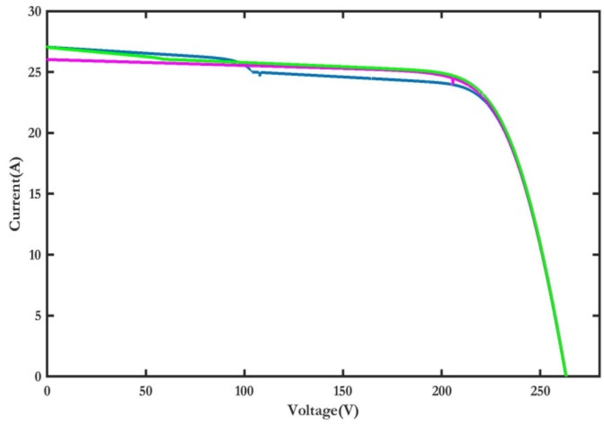
$$I_{R2}= I_{R3} = 2\times0.4I_m+ 4\times I_m \quad (9)$$

Similarly, the 4th, 5th and 6th rows of the first two modules are consumed same solar insolation (600 W/m^2). And the rest of the modules are uniformly irradiated, so the current in these rows can be calculated as follows.

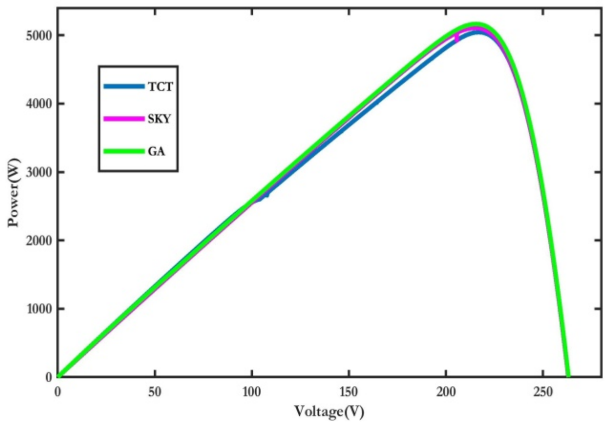
$$I_{R4}= I_{R5}= I_{R6} \quad (10)$$

$$I_{R4}= 2\times0.6\, I_m+ 4I_m \quad (11)$$

However, the voltage across each row is the same if none of the rows are bypassed. The estimated current and voltage across each row in the TCT array are given in Table 2. Similarly, the estimated current and voltage across each row for the skyscraper and proposed GA methods are also presented in Table 2.



(a) I-V characteristics



(b) P-V characteristics

Fig.7. Performance characteristics for Column-wise shading.

From the table, it is noticed that the proposed GA method distributed the shading effects equally in each row of the array and maintained identical currents. Hence, the proposed GA method enhanced the global power output as compared to the TCT and skyscraper [14] methods under column-wise shading condition. The obtained global power is validated using Simulink by plotting the I-V and P-V features (refer in Fig.7). Furthermore, the shadow loss, fill-factor and efficiency parameters are also measured and shown diagrammatically in Fig.8. From the observation of column shading, it is noted that, compared to the TCT and skyscraper [14] methods, the proposed GA method increased the power generation by 6.8% and 1.9%, respectively.

5.2. Row-Wise Shading

In row-wise shading, the last two rows, half of the PV modules are subjected to partially shaded by 40% of irradiance, and the other modules are shaded by 60% of irradiance, respectively, as shown in Fig.10. Figure.10 shows the shading distribution patterns of skyscraper and the proposed GA method. In order to find the location of the global peak for all reconfiguration methods, it is required to evaluate the current and voltage across each row in Fig.10.The estimated current and voltage across each row for the TCT, skyscraper and the proposed GA method are presented in Table 3. From the table, it is noticed that the proposed GA method distributed the shading effects equally in each row of the array and maintained identical currents. Hence, the proposed GA method enhanced the global power output as compared to the TCT and skyscraper methods under row-wise shading condition. The obtained global power is validated using Simulink by plotting the I-V and P-V features (refer in Fig.12). Furthermore, the shadow loss, fill-factor and efficiency parameters are also measured and shown diagrammatically in Fig.13. From the observation of row shading, it is noted that, compared to the TCT and Skyscraper [14] methods, the proposed GA method increased the power generation by 23.8% and 2.8%, respectively.

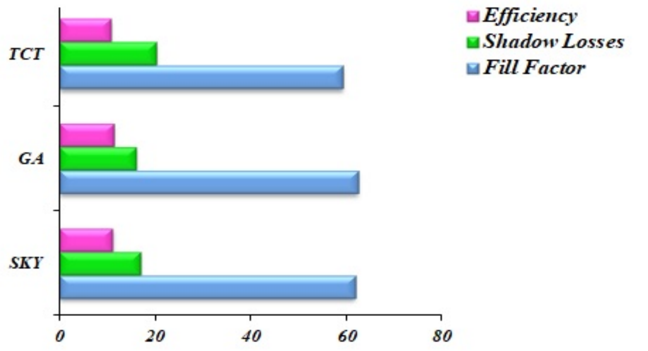


Fig.8. Estimated parameters for column-wise shading.

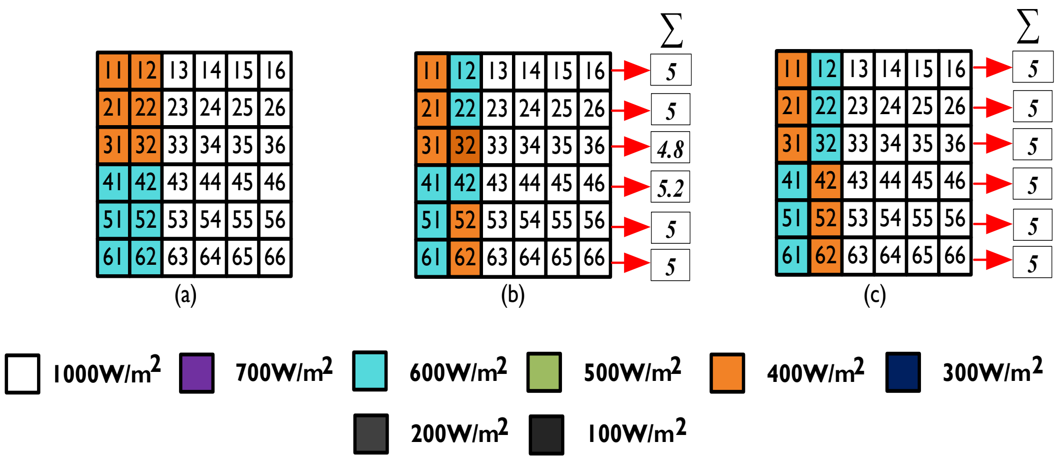


Fig.9. Column-wise shading: (a) TCT, (b) Skyscraper and (c) Distributed GA reconfiguration.

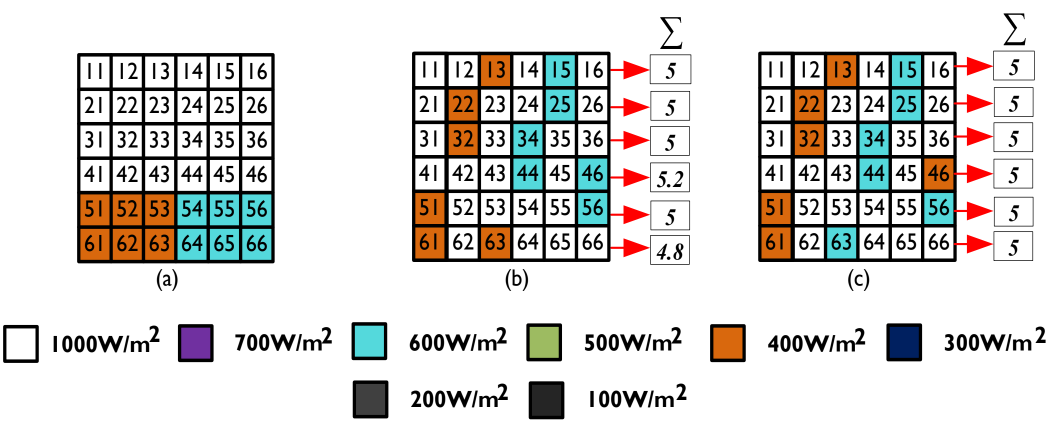


Fig.10. Row-wise shading: (a) TCT, (b) Skyscraper and (c) Distributed GA reconfiguration.

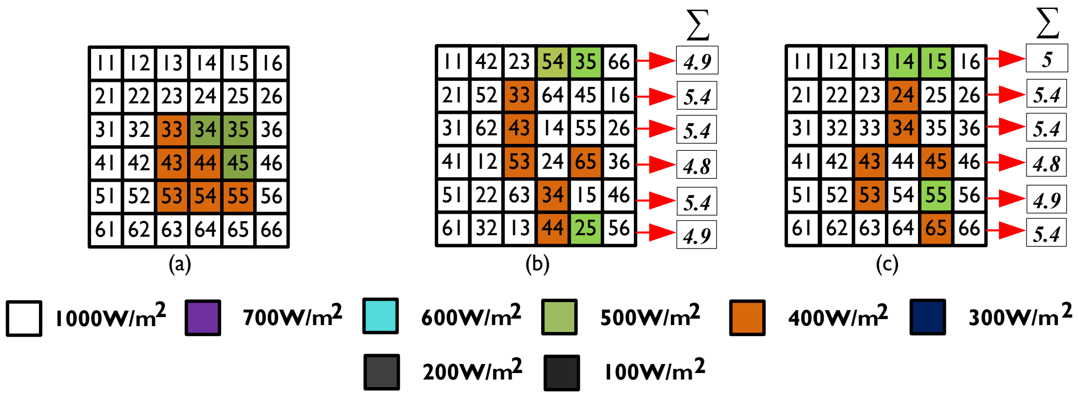


Fig.11. Center type shading :(a) TCT, (b) Skyscraper and (c) Distributed GA reconfiguration

Table 2. Estimated Global location for TCT, Skyscraper [14] and GA under column-wise shading

TCT				SKY [14]				GA			
Row currents		V_a	P_a	Row currents		V_a	P_a	Row currents		V_a	P_a
I_{row6}	$5.2I_m$	$3V_m$	$15.6\ V_m.I_m$	I_{row6}	$5I_m$	$5V_m$	$25V_m.I_m$	I_{row6}	$5I_m$	$6V_m$	$30V_m.I_m$
I_{row5}	$5.2I_m$	$3V_m$	$15.6\ V_m.I_m$	I_{row5}	$5I_m$	$5V_m$	$25V_m.I_m$	I_{row5}	$5I_m$	$6V_m$	$30V_m.I_m$
I_{row4}	$5.2I_m$	$3V_m$	$15.6\ V_m.I_m$	I_{row4}	$5.2I_m$	V_m	$5.2V_m.I_m$	I_{row4}	$5I_m$	$6V_m$	$30V_m.I_m$
I_{row3}	$4.8I_m$	$6V_m$	$28.8\ V_m.I_m$	I_{row3}	$4.8I_m$	$6V_m$	$26V_m.I_m$	I_{row3}	$5I_m$	$6V_m$	$30V_m.I_m$
I_{row2}	$4.8I_m$	$6V_m$	$28.8\ V_m.I_m$	I_{row2}	$5I_m$	$5V_m$	$25V_m.I_m$	I_{row2}	$5I_m$	$6V_m$	$30V_m.I_m$
I_{row1}	$4.8I_m$	$6V_m$	$28.8\ V_m.I_m$	I_{row1}	$5I_m$	$5V_m$	$25V_m.I_m$	I_{row1}	$5I_m$	$6V_m$	$30V_m.I_m$

Table 3.Estimated Global location for TCT, Skyscraper [14] and GA under row-wise shading

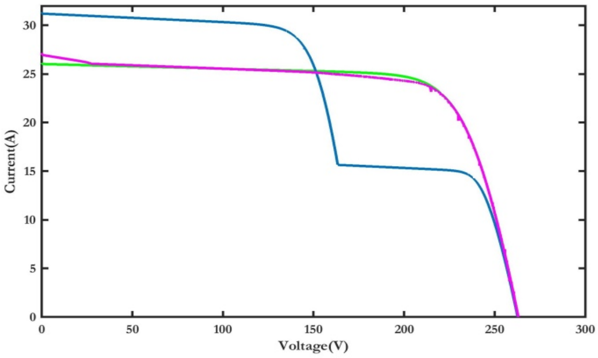
TCT				SKY [14]				GA			
Row currents		V_a	P_a	Row currents		V_a	P_a	Row currents		V_a	P_a
I_{row6}	$3I_m$	$6V_m$	$18\ V_m.I_m$	I_{row6}	$4.8I_m$	$6V_m$	$26V_m.I_m$	I_{row6}	$5I_m$	$6V_m$	$30\ V_m.I_m$
I_{row5}	$3I_m$	$6V_m$	$18\ V_m.I_m$	I_{row5}	$5I_m$	$5V_m$	$25V_m.I_m$	I_{row5}	$5I_m$	$6V_m$	$30\ V_m.I_m$
I_{row4}	$6I_m$	$4V_m$	$24\ V_m.I_m$	I_{row4}	$5.2I_m$	V_m	$5.2V_m.I_m$	I_{row4}	$5I_m$	$6V_m$	$30\ V_m.I_m$
I_{row3}	$6I_m$	$4V_m$	$24\ V_m.I_m$	I_{row3}	$5I_m$	$5V_m$	$25V_m.I_m$	I_{row3}	$5I_m$	$6V_m$	$30\ V_m.I_m$
I_{row2}	$6I_m$	$4V_m$	$24\ V_m.I_m$	I_{row2}	$5I_m$	$5V_m$	$25V_m.I_m$	I_{row2}	$5I_m$	$6V_m$	$30\ V_m.I_m$
I_{row1}	$6I_m$	$4V_m$	$24\ V_m.I_m$	I_{row1}	$5I_m$	$5V_m$	$25V_m.I_m$	I_{row1}	$5I_m$	$6V_m$	$30\ V_m.I_m$

Table 4. Estimated Global location for TCT, Skyscraper [14] and GA under center type shading

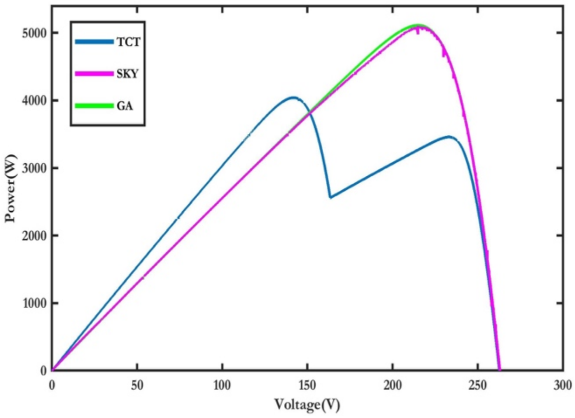
TCT				SKY [14]				GA			
Row currents		V_a	P_a	Row currents		V_a	P_a	Row currents		V_a	P_a
I_{row6}	$6I_m$	$3V_m$	$18\ V_m.I_m$	I_{row6}	$4.9I_m$	$2V_m$	$9.8\ V_m.I_m$	I_{row6}	$5.4I_m$	$6V_m$	$32.4\ V_m.I_m$
I_{row5}	$4.2I_m$	$6V_m$	$25.2\ V_m.I_m$	I_{row5}	$5.4I_m$	$5V_m$	$27\ V_m.I_m$	I_{row5}	$4.9I_m$	$4V_m$	$19.6\ V_m.I_m$
I_{row4}	$4.2I_m$	$6V_m$	$25.2\ V_m.I_m$	I_{row4}	$4.8I_m$	$2V_m$	$9.6\ V_m.I_m$	I_{row4}	$5.4I_m$	$6V_m$	$32.4\ V_m.I_m$
I_{row3}	$4.2I_m$	$6V_m$	$25.2\ V_m.I_m$	I_{row3}	$5.4I_m$	$6V_m$	$32.4\ V_m.I_m$	I_{row3}	$4.8I_m$	$3V_m$	$14.4\ V_m.I_m$
I_{row2}	$6I_m$	$3V_m$	$18\ V_m.I_m$	I_{row2}	$5.4I_m$	$6V_m$	$32.4\ V_m.I_m$	I_{row2}	$5.4I_m$	$6V_m$	$32.4\ V_m.I_m$
I_{row1}	$6I_m$	$3V_m$	$18\ V_m.I_m$	I_{row1}	$4.9I_m$	$5V_m$	$24.5\ V_m.I_m$	I_{row1}	$5I_m$	$5V_m$	$25\ V_m.I_m$

5.3. Center type Shading

In this condition, 9 PV modules are partially shaded in the center of 6×6 PV array, as shown in Fig.11. The consumed solar irradiance of these PV modules is varied from 20%-80%. Figure.11 shows the shading distribution patterns of skyscraper and the proposed GA method. In order to find the location of the global peak for all reconfiguration methods, it is required to evaluate the current and voltage across each row in Fig.11. The estimated current and voltage across each row for the TCT, skyscraper and proposed GA method are presented in Table 4. From the table, it is noticed that the proposed GA method distributed the shading effects equally in each row of the array and maintained identical currents. Hence, the proposed GA and Skyscraper [14] methods enhanced the global power output as compared to the TCT array under center type shading condition. The obtained global power is validated using Simulink by plotting the I-V and P-V features (refer in Fig.14). Furthermore, the shadow loss, fill-factor and efficiency parameters are also measured and shown diagrammatically in Fig.15. From the observation of center shading, it is noted that, compared to the TCT and Skyscraper [14] methods, the proposed GA method increased the power generation by 16% and 3.9%, respectively.



(a)I-V characteristics



(a) P-V characteristics

Fig. 12. Performance characteristics for row-wise shading.

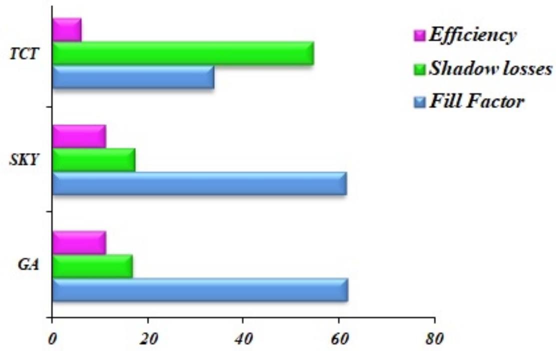
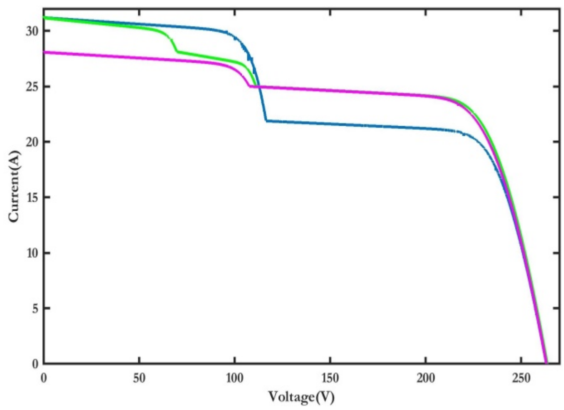


Fig. 13. Estimated parameters for row-wise shading.

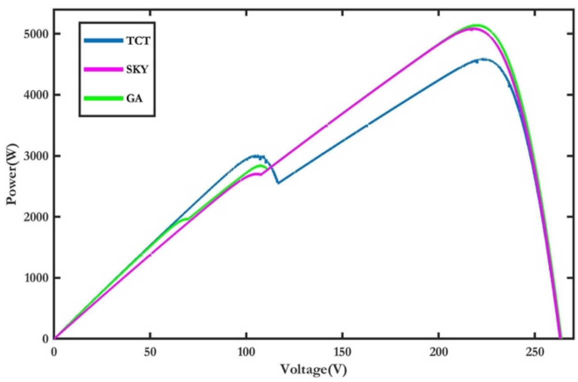
The proposed algorithm adequately finds the best connection matrix for TCT array to distribute shadings effectively and minimizethe differences in row currents. For better understanding, various reconfiguration methods have been compared in a wheel chart diagram (refer in Fig.16) by including different parameters; (A) number of parameters acquired, (B) payback period, (C) complexity of the algorithm, (D) number switching elements, (E) sensors availability (F) complexity of the wiring. In this chart, it can be observed that the proposed method required less sensors and robust algorithm as compared to other methods. The wheel chart can be comprehended as follows. The diagram covering the inner diameter of the wheel is the most suitable approach with higher suggestions, while the approaches covering the outer diameter are less adaptable to PV array reconfiguration.

6. Comparative Study on Reconfiguration Methods

Electrical array reconfiguration improved the power generation of the TCT array by minimizing the differences in row currents by distributing shading effects from one row to another row [24]. The variation of this method is reported in [14]. In this process, PV modules physical positions are changed based on skyscraper pattern without altering their electrical connections to spread shading effects on a 6×6 TCT array. This procedure enhanced the power output of the PV array. In this method, however, it is difficult to achieve the row current minimization, as a result of their exhibits multiple peak points in PV characteristics.Similarly, the Arrow-SuDoKu reconfiguration method is suggested for the 6×6 TCT array to distribute various PSCs across the array [15].The drawback of this method is that it requires more wiring and area for installation. The increment in wiring may cause a voltage drop in the PV system. Also, it is time taking process.To overcome these issues, a genetic algorithm optimization-based reconfiguration is proposed in this paper. In this work, the location of modules is fixed, and their electrical connections are altered only one time for shading conditions.



(a)I-V characteristics



(b)P-V characteristics

Fig. 14. Performance characteristics for center type shading.

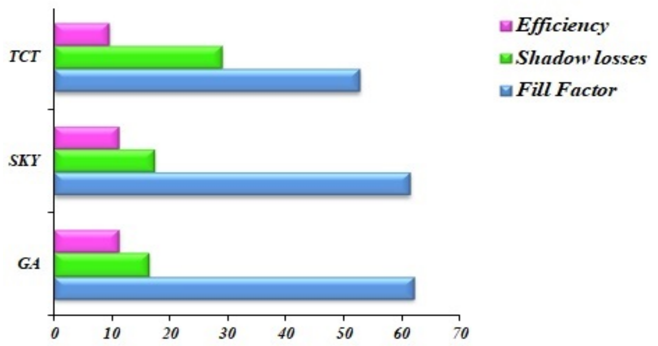


Fig. 15. Estimated parameters for center type shading.

6.1 Extension of large array sizes

The proposed GA reconfiguration method can extend to any size of the PV arrays such as 4×4, 9×9, and 16×16, etc., for effective shading distributions and improved power output.

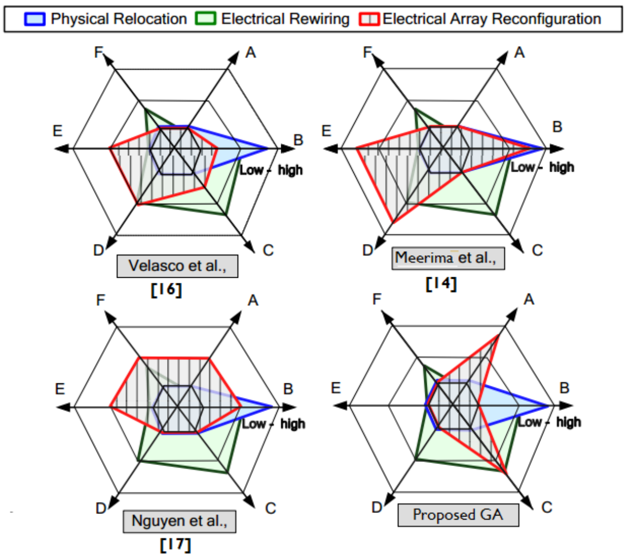


Fig. 16. wheel chart diagram for various reconfiguration methods.

7. Conclusion

- In order to spread shading effects and increase power efficiency, this paper proposed a genetic algorithm-based electrical array reconfiguration for 6×6 TCT array.
- The physical positions of the modules in the TCT array are fixed in this system, but their electrical relations are altered based on shading effects.
- This is a one-time connection pattern to distribute any shading equally in each row and maintain identical currents.
- The validation of the proposed method has been done with other existing TCT and Skyscraper methods under various PSCs by obtained FF, shadow loss and efficiency.
- Based on the results, it is observed that the proposed GA method reduced the multiple peak points on PV characteristics and improved the power output as compared to other methods.

Acknowledgements

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Appendix: V_m: Photovoltaic module Voltage (V); *Im:* Photovoltaic module Current (A); V_a: Total PV array voltage (V); I_a: Total PV array current (A); V_T: Thermal voltage of diode (V); I_{ph}: Photon generated current; I_d: Diode current, I_0: Reverse saturation current; R_s, R_p: Parasitic resistances of a PV cell; N_{ss}, N_{pp}: Series and parallel connected modules; G, G_r: Actual and Reference Irradiance; A: Ideality factor; α: Shading factor, n: Ideality factor, K: Boltzmann's constant 1.38×10^{-23} J/K; q: Electron charge 1.6×10^{-19} C; i,j: Row and column index.

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