An Approach to improve the Performance of Total Cross-tied connected PV array in Partial shading condition

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Abstract: ***Due to the partial shading condition (PSC) in solar PV systems, performance degrades to a large extent. To overcome from this problem bypass diode is used which creates the problem of multiple local maxima. Therefore, total cross-tied (TCT) connection is introduced in the literature, which improves the performance of PV systems in PSC without using bypass diode. But the performance improvement in TCT connection is also limited. Because for some particular shading pattern the efficiency cannot be improved beyond a certain limit. In line with this, an algorithm is proposed in this paper through which the performance of a PV array can be improved. Here, the performance of a PV array is improved by distributing the shading effect on the entire PV array, which reduces the mismatch losses and to enhance the power output of the PV array.***

Keywords: Photovoltaic; Equalizer; Solar Irradiance; Shading Effect; Mismatch losses.

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1. Introduction

Nowadays, the increase in global energy demand and the pursuit of most countries to ensure their energy security through the development of alternative energies, come in the forefront the solar energy. Photovoltaic system represents one of the best alternative resources in the field of electricity generation due to its increasing use. Moreover, the use of such kind of energy is not only economical and inexhaustible, but also its maintenance is low, noiseless and lesser hazardous for environment in comparison to other type of energy. It is green energy by excellence.

Photovoltaic systems are highly susceptible to partial shading. The maximum power of a photovoltaic system can reduce drastically when partial shading takes place. The susceptibility of partial shading can be based on the partial shading pattern, shading heaviness, and the configuration employed in connecting all the photovoltaic modules in the photovoltaic system. Under a fixed configuration and partial shading pattern, the maximum power of a partially shaded system is tacitly assumed to decrease a constant rate as the shading heaviness increases. This tacit assumption is based on the functionality of a photovoltaic system that relies on solar irradiance to generate electrical power.

Photovoltaic effect is the production of electricity by conversion of solar photons into electricity by semiconductor such as silicon. Among the factors that have a significant impact on the operation of photovoltaic system the most notable are temperature, solar intensity, partial shade and configuration of PV strings. Therefore, the MPP method is required to guarantee the generation of the highest power from PV module. In recent years, various methods have been proposed for tracking MPP.

Normally the maximum power point MPP of the PV array under uniform isolation is only the single power peak [1]. However, the frequently the PV array get shadowed partially and the PV characteristic exhibits multiple local maxima, only one of them corresponds to the Global Maximum Power Point (GMPP), whereas the Multiple Power Point Tracking (MPPT) method mentioned above may fail to track the GMPP. In order to overcome this problem, it is necessary to develop a special GMPPT method able to track the global MPP under partial shading condition. Among all conventional solar photovoltaic array configuration Total-Cross-Tied solar array configuration has greater output power under uniform irradiance condition (un-shaded case) but reduced array power under non-uniform irradiance cases (shading case). To improve the performance of Total-Cross-

Tied array configuration under shading condition the photovoltaic module in the Total-Cross-Tied connection are rearranged or repositioning is done with the reference of the existing photovoltaic module in total cross-tied (TCT) configuration to new optimal locations within a TCT array configuration with shade dispersion technique [9,10]. While rearranging the photovoltaic module repositioning is done on the base of puzzle pattern without altering the electrical connection among modules in the solar photovoltaic array. The shading of PV module is dispersed by changing the position of PV module to optimal position within solar photovoltaic array so that the performance of conventional TCT configuration will be improved. Our main objective is to demonstrate a novel approach for shaded dispersion, on 6×6 PV array is considered for TCT configuration under four different shading conditions. We have found out the power voltage characteristic of 6×6 PV array for TCT in different shading condition and the respective graph have been studied. An equivalent model of PV module is taken into reference. It consists of a current source, a diode and a series shunt resistance. We have designed various algorithm and patterns for the respective configuration which are shading pattern for short and narrow, shading pattern for long and narrow, shading pattern for short and wide and shading pattern for long and wide. For this analysis, MATLAB/Simulink software is used for modelling and simulation of 6×6 PV array configurations. The mathematical representation of shading condition and proposed model is described briefly, and the required comparison are also been noted down respectively.

This paper will approach a novel approach to distribute shading effect over the entire array to improve the power output under different shading condition. In this approach only the physical location of the PV module is changed, without changing the electrical connection of the modules.

We have considered a 6×6 PV array configuration considered for TCT connection under four different shading configurations. We have designed various algorithms and patterns for the proposed configuration which are:

- Shading pattern for short and wide
- Shading pattern for long and wide
- Shading pattern for long and narrow
- Shading pattern for short and narrow

2. Methods

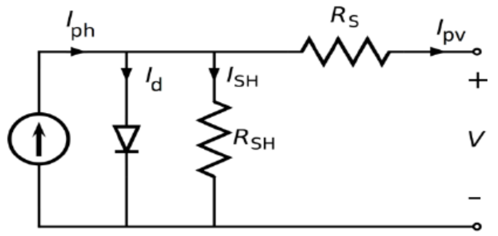
An equivalent model of a PV module is shown in Fig. 1(a) [2]. It consists of a current source, a diode, and series and shunt resistances. The current-voltage relation of the PV module is given in eqn.(1).

$$I = I_{ph} - I_0\left\{e^{\frac{V_{ph}+I_m R_s}{n_s V_t}} - 1\right\} - \frac{V_{ph}+I_m R_s}{R_{sh}} \quad \text{....(1)}$$

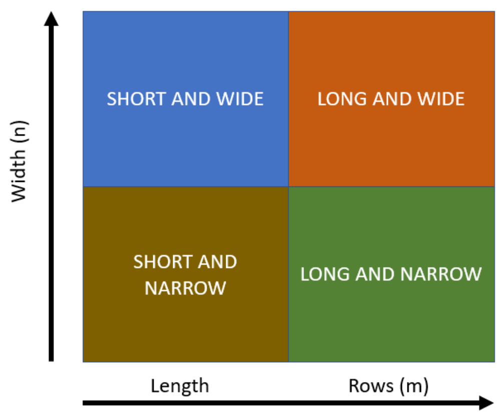
where I_m is the current generated by the module, I_{ph} is the photo-generated current, I_o is the dark saturation current, V_{pv} is the output voltage, R_s and R_{sh} are the series and parallel resistances respectively, N_s is the number of cells are connected in series, V_t is the junction thermal voltage which is given by

$$V_T = \frac{KTA}{q} \quad \text{.... (2)}$$

where 'k' is the Boltzmann's constant, T is the junction operating temperature, 'A' is the diode quality (ideality) factor and 'q' is the charge of an electron.



(a)



(b)

Fig. 1: (a) Equivalent circuit of a PV module
(b) Different types of shading condition.

In TCT configuration, the voltages of all nodes and the sum of currents in different junctions are equal [2]. In BL configuration, every four modules are connected to each other in the form of a rectifier bridge in which at first two modules are connected in series and then in parallel to each other.

Considering the datasheet values of a 85 W PV module provided by the manufacturer, short circuit current = 5.17 A, open circuit voltage = 21.9 V, voltage at MPP = 17.90, current at MPP = 4.84 A, and number of cells in series = 36.

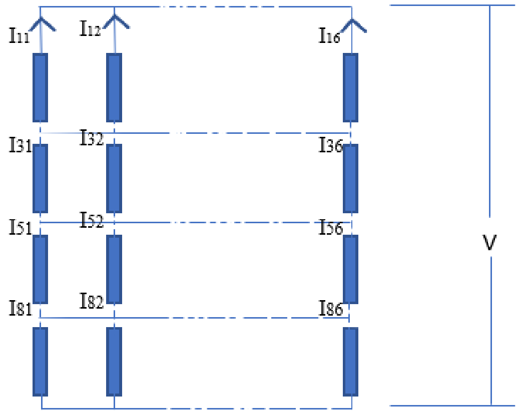


Fig. 2: TCT Configuration of PV Array.

Fig. 2 shows an 8 × 6 PV array of TCT configuration. A series-parallel PV array by connecting ties across each row of the junction is called as TCT configuration. The PV array involves eight rows and six columns, so that the total numbers of modules are forty-eight. The current produced by a module depends on the irradiation G, is given as

$$I = KI_m = \left(\frac{G}{G_{stc}}\right) * I_m \quad \ldots\ldots\ldots\ldots\ldots(3)$$

Table 1: Location of GMPP in TCT

	*I_R	Voltage (V)	Power (P) (W)
IR8	$3I_m$	$8V_m$	$24.0V_mI_m$
IR7	$3I_m$	$7V_m$	$21VmIm$
IR6	$4.2I_m$	$6V_m$	$25.2V_mI_m$
IR5	$5.4I_m$	$5V_m$	$27V_mI_m$
IR4	$5.4I_m$	$4V_m$	$21.6V_mI_m$
IR3	$5.4I_m$	$3V_m$	$16.2V_mI_m$
IR2	$5.4I_m$	$2V_m$	$10.8V_mI_m$
IR1	$5.4I_m$	V_m	$5.4V_mI_m$

where I_m is the current generated by the module at standard condition irradiation G_{STC} = 1000 W/m2 and temperature = 25^{O}C. Using Kirchhoff's voltage law, the voltage of the array can be calculated as:

$$V = \sum_{X=1}^{N}(X - 1) \quad \ldots.\ (4)$$

where V_{mx} is the voltage of the x^{th} row of the PV array.

2.1 Mathematical Representation

To demonstrate a novel approach for shade dispersion, an 8 × 6 PV array is considered for TCT connection under four different shading conditions. Power-voltage characteristics of a 8 × 6 PV array for TCT in different shading conditions, are presented and discussed in this section.

In shading condition, four different types of solar irradiation such as, 900 W/m2, 700 W/m2, 500 W/m2, and 300 W/m2 are received by the modules of PV array. It is necessary to find the current across each row of the PV array to determine the location of GMPP. The shading pattern for different configurations in shading condition is shown in Fig. 3.

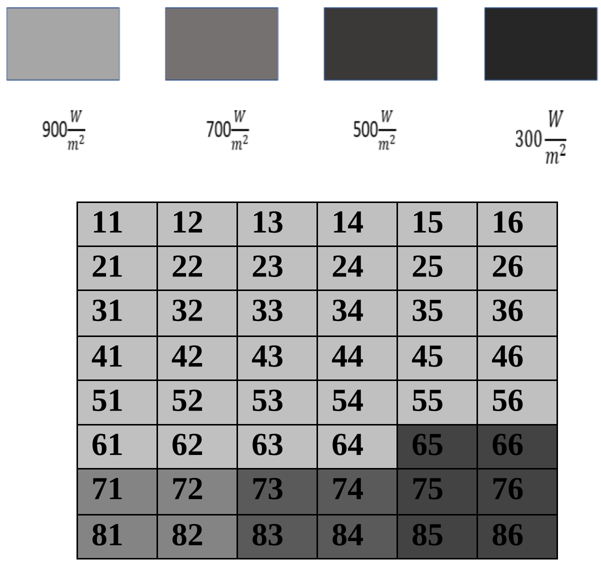


Fig. 3: Shading Pattern for TCT Configuration

The current across the first row in TCT configuration will be written as:

I_{R1}=6*(900/1000) I_M=5.41I_M

As the PV modules in rows 2, 3 and 4 receive the same solar irradiation (900 W/m2) as in row 1, the current across rows 2, 3, 4, and 5 are same as calculated for row 1.

$I_{R5} = I_{R4} = I_{R3} = I_{R2} = I_{R1}$

$I_{R6} = 4 \times 0.9I_m + 2 \times 0.3I_m = 4.2I_m$

$I_{R7} = 2 \times 0.7I_m + 2 \times 0.5I_m + 2 \times 0.3I_m = 3.0I_m$

$I_{R8} = I_{R7}$

* I_R is the row current of the PV modules which are bypassed in increasing order

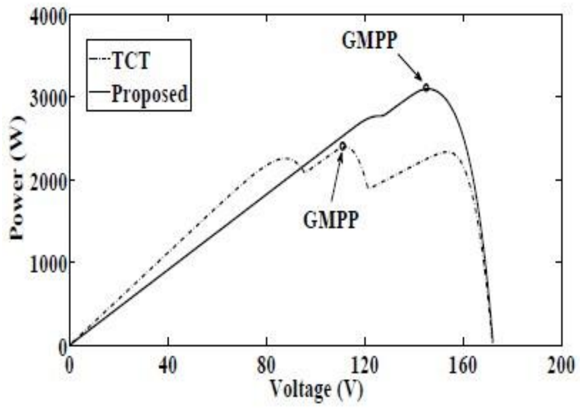


Fig. 4: Power-Voltage curve for shading condition.

2.2 Proposed Methodology

The PV modules of the same row in the TCT configuration move to different location in the proposed configuration of the array, without changing the physical position. Therefore, it enables to decrease the shading effect in the same row, and enhance the current in the same row, and the power generation by a PV array is increased under partial shading condition. The voltage and current equations of the proposed configuration remain same as in the TCT configuration because the electrical connection of a PV array is unchanged. For the practical implementation of the proposed configuration for the enhancement of the power generation in shading condition, the modules of a PV array in TCT configuration need to be rearranged once only because of the same configuration holds effective for any shading condition. Fig. 3 (b) shows four different shading conditions, such as Short and Wide (SW), Short and Narrow (SN), Long and Wide (LW), and Long and Narrow (LN), and these are considered to verify the proposed configuration.

2.3 System Design

In a novel approach for shade dispersion, an 6 × 6 PV array is considered for TCT connection and Proposed model under four different shading conditions. This section provides details about the design of the scattered configuration which give us Maximum output from all different shading condition. The location of GMPP, calculated theoretically and simulated using MATLAB, is verified for both TCT and the proposed configuration.

The main objective of the proposed configuration is to distribute the shading effect over the entire array. In this configuration, the row position of a 6×6 PV array is arranged by using the digits 1 to 6 as shown in Table IV. The proposed configuration of a PV array is achieved by using the following steps:

(i) 6x6 array consist of 36 module which can 2be arranged in a sequence to achieve maximum output from the array.

(ii) Divide the 36 modules into 6 parts that is 36/6=6, 6 modules can be distinguished into 6 parts.

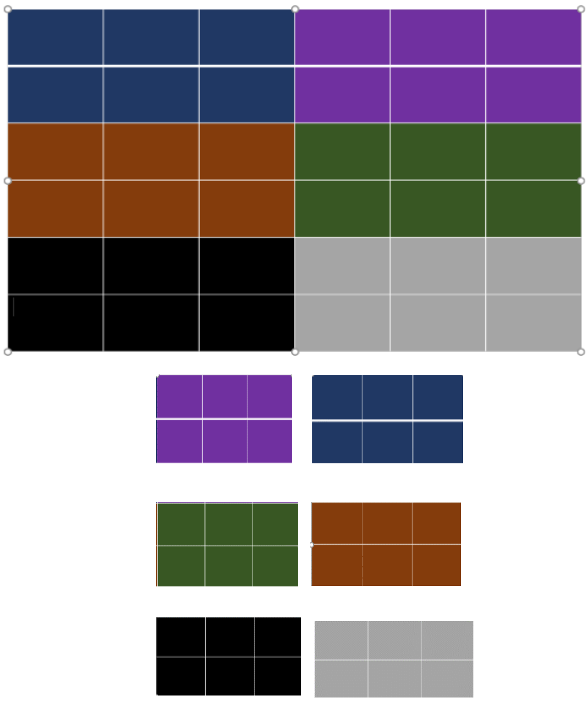


Fig. 4.1: Represent 1 part which contains 6 modules each.

(iii) 6 different colours represent 6 modules distinguish into 6 parts.

(iv) Write the digits 1 to m in the ascending order from first row of 1st cell to 3rd cell of 3rd column and from 2nd row of 1st cell to 3rd cell of 3rd column.

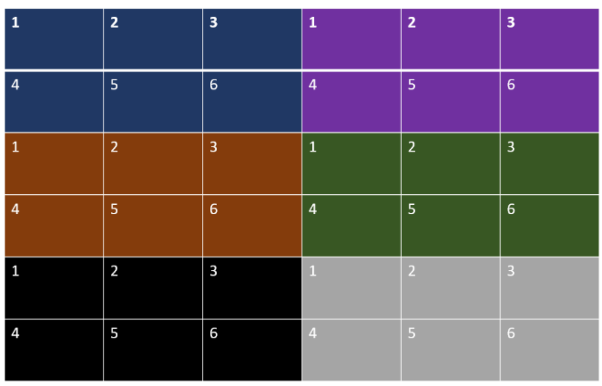


Fig. 4.2: PV Module Configuration

(v) Here m = 6 is an even number, so the first row in the 1st cell to the 3rd column will be filled up in ascending order as given in Fig. 4.2.

From 1 to 3 and the rest 3 will be placed in 2nd row 1st cell to 3rd cell of 3rd column in order.

(vi) In this particular sequence the rest of the part will be arranged such as 1st row 4th cell to 6th cell of 6th column and 2nd row 4th cell to 6th cell of 6th column, 3rd row of 1st cell to 3rd cell of 3rd column, etc. as shown in Fig. 4.2.

(vii) To provide ultimate scattering of module, we will rearrange the numbered sequence into a single column such as modules 1 to 6 present in 1st cell to 3rd cell of 2nd and 1st row to 3rd column will be moved to column 1 as shown in Fig. 4.3.

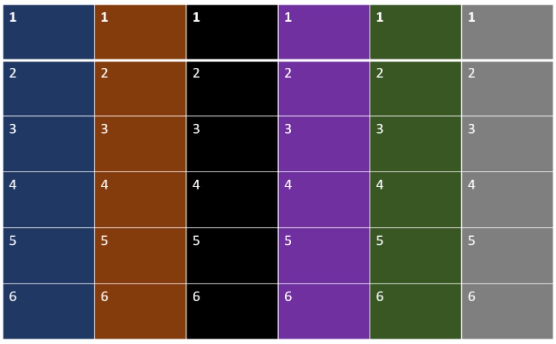


Fig. 4.3: Modified PV Module Configuration.

2.4 Analysis of Different Shading Pattern

To demonstrate a novel approach for shade dispersion, a 6× 6 PV array is considered for TCT connection under four different shading conditions. Power-voltage characteristics of a 6 × 6 PV array for TCT in different shading conditions, are presented and discussed in this section.

In Shading condition, fix different types of solar irradiation such as, 900 W/m2, 11 W/m2, 12 W/m2, 10 W/m2 and 0 W/m2 are received by the modules of PV array. It is necessary to find the current across each row of the PV array to determine the location of GMPP. The shading pattern for different configurations in shading condition is shown in figures 5.1, 5.2, 5.3 & 5.4.

The following 4 shading conditions are considered:

- Short and narrow
- Long and narrow
- Short and wide
- Long and wide

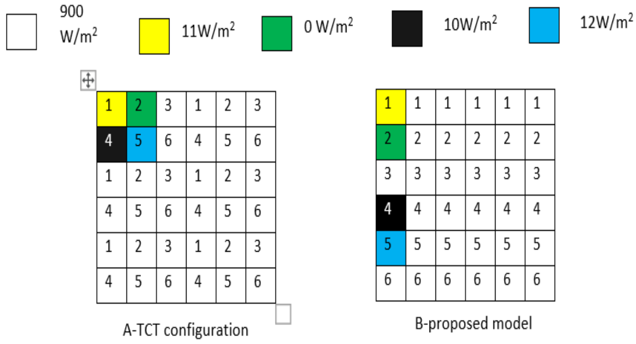


Fig. 5.1: Short & wide

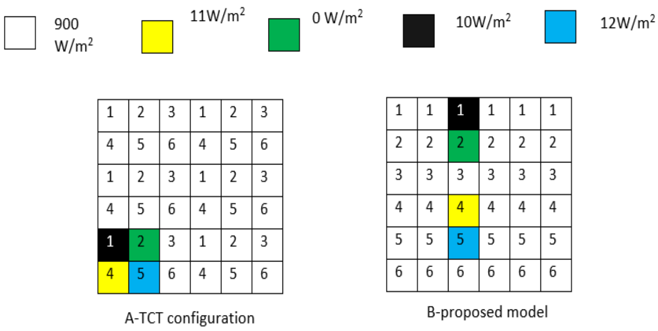


Fig. 5.2: Short & narrow

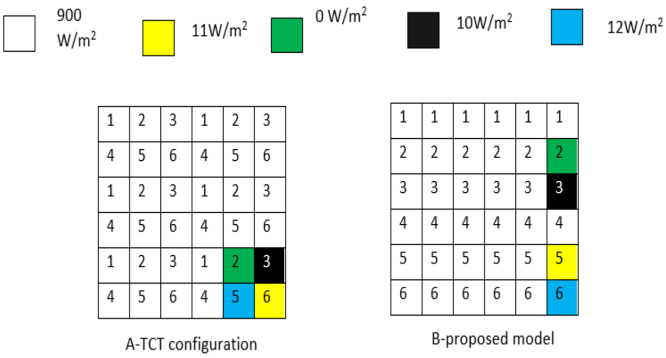


Fig. 5.3: Long & narrow

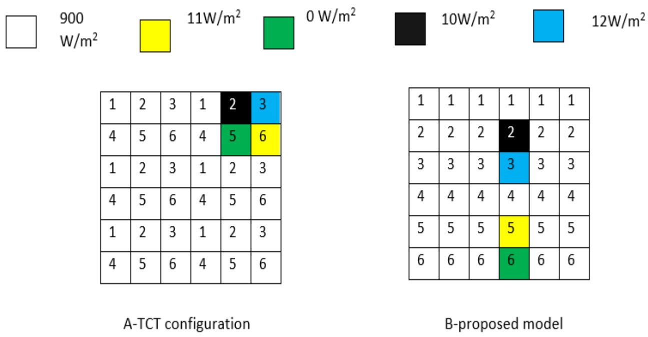


Fig. 5.4: Long & wide

2.5 Output

To demonstrate a novel approach for shade dispersion, an 6 × 6 PV array is considered for TCT connection and Proposed model under four different shading conditions. The location of GMPP, calculated theoretically and simulated using MATLAB, is verified for both TCT and the proposed configuration. Power-voltage and Current-Voltage characteristics of a 6 × 6 PV array for TCT and the proposed configuration in different shading conditions, are presented and discussed in this section.

The following figure represent the current and voltage generation for shading pattern of short and wide from Fig. 5.1 after performing simulation in MATLAB.

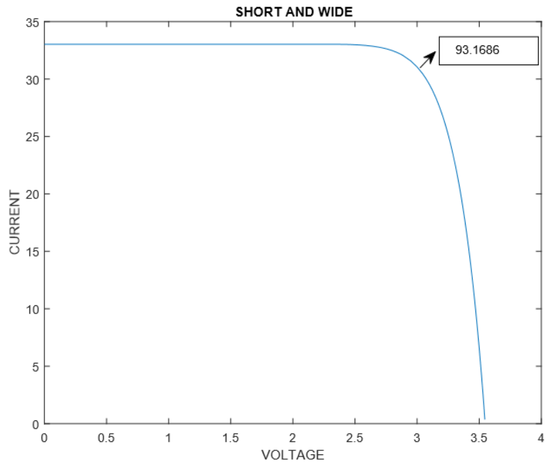


Fig. 6.1: Current-Voltage Curve for Shading Conditions of Short and Wide.

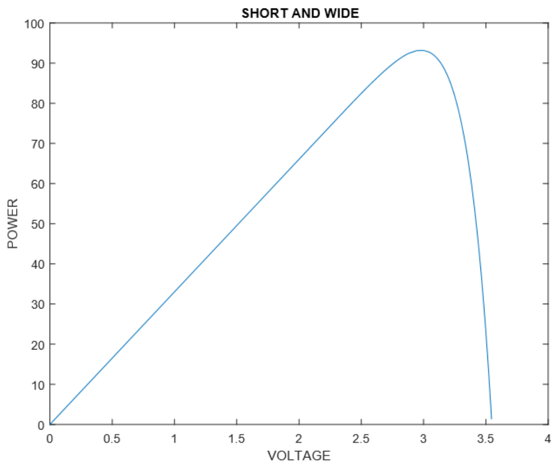


Fig. 6.2: Power-Voltage curve for shading conditions of short and wide.

The following figure represent the current and voltage generation for different shading condition of long and wide from fig. 5.4 after performing simulation in MATLAB.

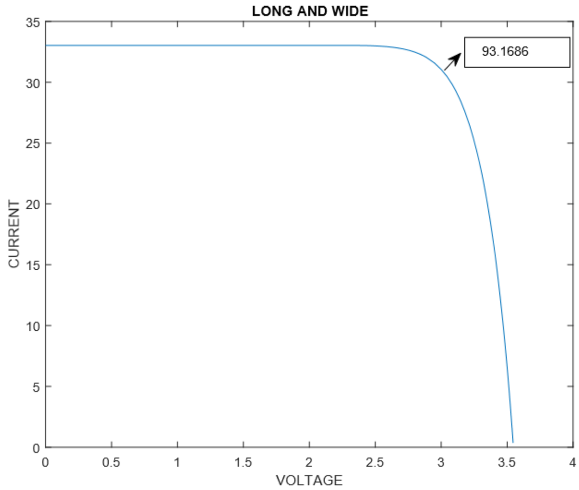


Fig. 6.3: Current-Voltage Curve for Shading Conditions of Long and Wide.

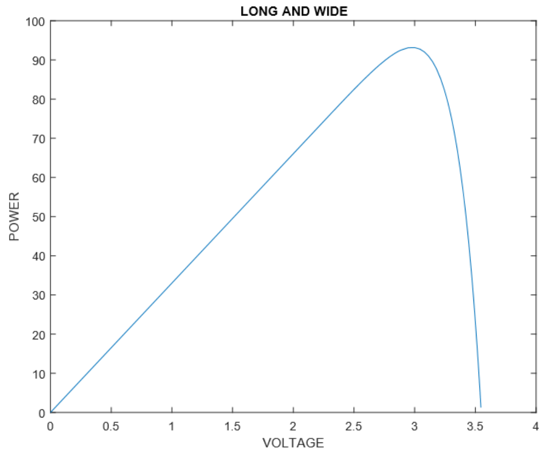


Fig. 6.4: Power-Voltage curve for shading conditions of long and wide.

The following figure represent the current and voltage generation for different shading condition of short and narrow from fig. 5.2 after performing simulation in MATLAB.

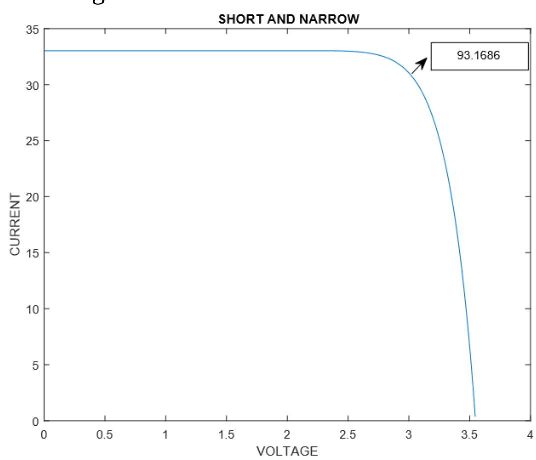


Fig. 6.5: Current-Voltage Curve for Shading Conditions of Short and Narrow.

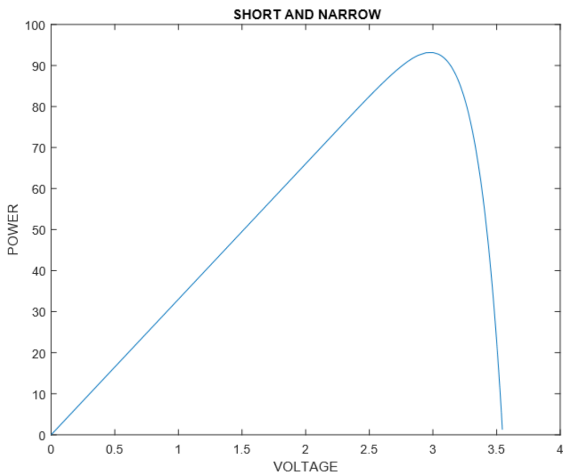


Fig. 6.6: Power-Voltage Curve for Shading Conditions of Short and Narrow.

The following figure represent the current and voltage generation for different shading condition of long and narrow from fig. 5.3 after performing simulation in MATLAB.

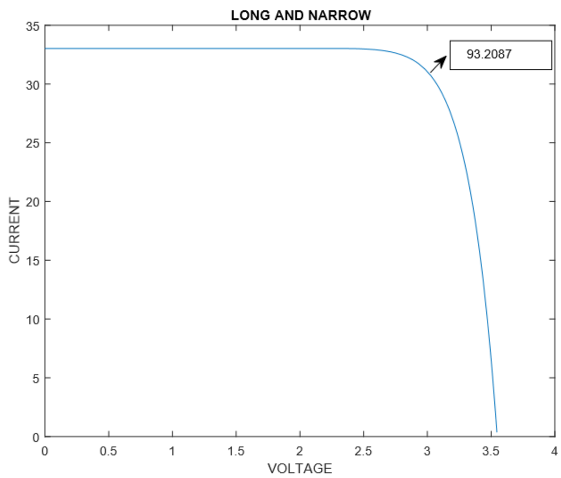


Fig. 6.7: Current-Voltage Curve for Shading Conditions of Long and Narrow

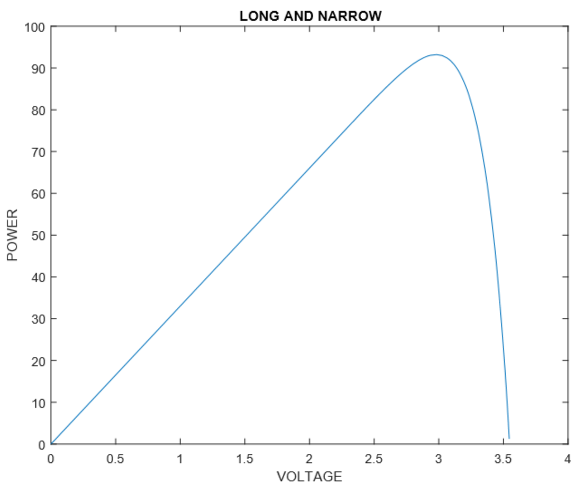


Fig. 6.8: Power-Voltage Curve for Shading Conditions of Long and Narrow.

3. Results

Applying the algorithm in 6×6 modules of TCT (total cross tied) PV arrays which was mentioned above in the system design & analysing those 6×6 modules in 4 different shading condition in MATLAB, it has been observed that maximum power point is observed in the power-voltage & current- voltage curve as shown in Fig.6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8.

The power difference can be observed in the following table between normal TCT connections and proposed algorithm for new configuration.

Table 2: Power differences

Shading condition	TCT Configuration (watt)	Proposed configuration (watt)	Efficiency (%)
Short & wide	80.1498	93. 1686	13.97
Short & narrow	80.161	93.168	13.95
Long & wide	63.0243	93.1686	32.35
Long & narrow	80.1608	93.20	13.98

4. Conclusion

The power voltage characteristic of the array is simulated by using MATLAB, are presented for four different shading condition in the TCT and the proposed configuration is smoother and contains a smaller number of local maxima, hence the accurate tracking of GMPP is simpler. It is demonstrated that, for the PV array, there is a significant power improvement in the proposed configuration with respect to the TCT configuration. Hence, the approach presented in this project will help the PV plant promoters to extract more power during partial shading of a PV array. The power voltage characteristic for the proposed configuration is to smoother and contains a smaller number of local maxima.

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