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Low cost Dynamic Switching Technique for Improving the Power in Partially Shaded Photo Voltaic Array

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Abstract

Shading of PV panel is inevitable, this greatly reduces the power generated from the PV module. In the proposed idea, switches connecting the PV modules changes the connections periodically. As the connecting pattern of the PV module changes the shading is cornered and thus the power is enhanced .Using this idea we can go for any size of the PV module. Results are obtained with different shading environment of PV module and it is proved that the dynamic switching technic is superior that the existing types.

***Keywords**:* Partial shading, Photovoltaic, Dynamic switching, Su Do Ku, Total Cross Tied

1. Introduction

Energy demand increases day by day. Role of Renewable power sources unavoidable, because of depletion of fossil fuels. Solar energy is promising source among the other renewable resources. Renewable energy is eco-friendly as it is available free of cost and clean and green. [1, 2].In PV module cells converts the photons of the insolation into electricity. Power produced from PV module can be used for standalone and grid connected systems [3-7].Current ratting of the Photo Voltaic module increased by connecting PV module as Parallel and the Voltage ratting of PV module can be increased by connecting in series. PV module power output is based on the solar insolation [8, 9].

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Shading of the PV module is due to passing of clouds, shadows of building and trees which is undesirable, because it reduces the power generation of the unit and also it may lead to hot spots which makes the module as permanent unusable. [10, 11].In addition to that, harmful multiple peaks are produced [12, 13].

Due to multiple peaks not only poor performance but also apply MPPT technique is difficult [14-15].The optimization techniques like evolutionary algorithms on the other hand has its own drawbacks of realization of hardware realization [16-18].

.A number of techniques have been discussed [19-20] to reduce the partial shading. More number of methods are discussed by many authors [21-24, 27]. Recent research paper Su Do Ku aided reconfiguration for analyzing the performance of PV system for varying shading pattern validate that the quest on dynamic switching technique for

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improving power in partial shaded photo voltaic module methodology has not depleted [27].

This paper proposes the Dynamic Switching Technique (DST), for reshuffling of PV module achieved by changing the connection under partial shaded environment to improve the power.

Section II explains about the TCT PV modelling of array. Further the proposed DST is implemented in partially shaded environment to enhance power from PV module. The outcomes are conferred in section III. In section IV decision is given.

2. Description About System

Model of a PV Cell

Equivalent circuit of a Photo Voltaic is revealed in Figure 1 is taken from [27].By employing Kirchhoff's current law for Figure 1 the output current equation is written as

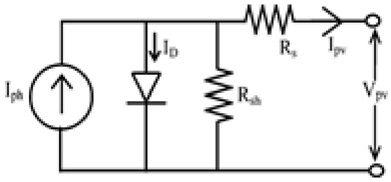


Figure 1. Photo Voltaic cell equivalent circuit.

$$I_m = I_{ph} - I_o\left[\exp\left(\frac{V_{pv} + I_m R_s}{A}\right) - 1\right] - \left[\left(\frac{V_{pv} + I_m R_s}{R_{sh}}\right)\right] \quad (1)$$

$A = \frac{nkT}{q}$, component temperature

$$I_{ph} = I_{sco}\left(\frac{G}{G_0}\right)\left(1 + \alpha_1\left(T - T_0\right)\right)\frac{\left(R_s + R_{sh}\right)}{R_{sh}} \quad (2)$$

I_m	Module current
I_{ph}	Photoelectric current
I_0	Saturation current
V_{ph}	PV voltage
k	Boltzmann's constant
q	Electric charge
n	Number of series connected cells
R_s	Series resistance
R_{sh}	Shunt resistance
I_{sco}	Short circuit current
α_1	Module's temperature coefficient

3. TCT Configured PV Array

TCT, a prominent existing reconfiguration technique attained from Series-parallel (SP) structure by joining cross ties of every row through junctions is taken for primitive study. A typical TCT configuration having (9x9) 81 PV modules is shown in Figure 3.

Table 1. PV Specification at 1000 W/m^2 @ 25^{o}C

PV Power	80
Open circuit	2.2
Short circuit	4.7
Nominal	1.8
Nominal	4.4

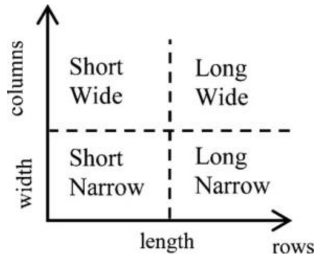


Figure 2. Different Shading Conditions

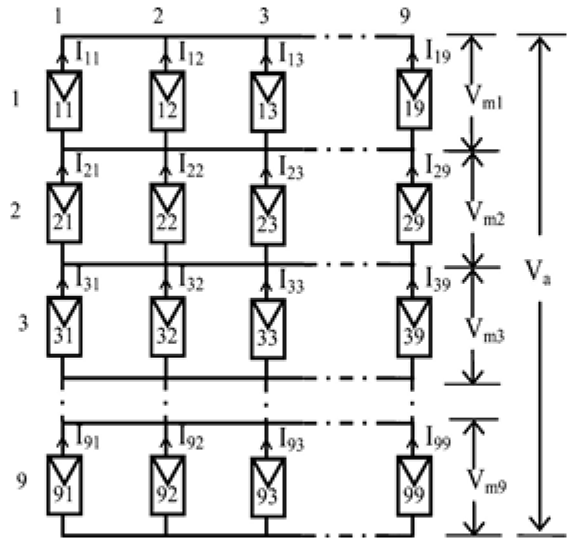


Figure 3. TCT Configuration of PV Array

In TCT formation, voltage across the ties are equal and the array voltage V_a is sum of the voltages from V_{m1} to $V_{m9.}$ The total current enter into the load from the PV array is the currents leaves from the load. The current generated by each module is

$$I = K\, I_m \qquad (3)$$

I_m is module current, on G0 = 1000W/m^2 and $K = G/G_{0.}$

The TCT configuration is proven to be superior to SP configuration as it delivers more power for a stipulated shading pattern [28].

4. Dynamic Switching Technique (DST)

PV panels are connected in matrix (m x n) format to Arduino input module. Each of the PV can power based on the insolation falling on that. This voltage of the PV panels are acquired using Arduino AT mega processor which help us to monitor and control the PV panels at optimal power level. Basically, acquiring voltage in all PV panel will exceed the voltage limitation of AT mega. So, a well define timed acquisition has to be planned accordingly. All the panels are connected to AT mega but acquisition will be computed from the software based on the timing sequence. Data from the PV panels are collected, analyzed and monitored continuously. This data give an idea to build an optimal switching technique as shown in Figure4. For a 3*3 panel arragements. AT mega has its digital I/O module to control the switching operation. The output will be in term of binary values to control the digital relay circuit. The relay is been enhanced with the PV panel acquisition unit. So, the shadow portion will be arranged as shown in matrix to enhance the power. Which guarantee the maximum output power from the PV Panels as the partially shaded panels are arranged in descending order as shown in matrix, the power improves even in the partially shaded environment [27].

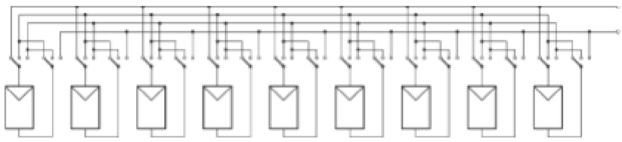


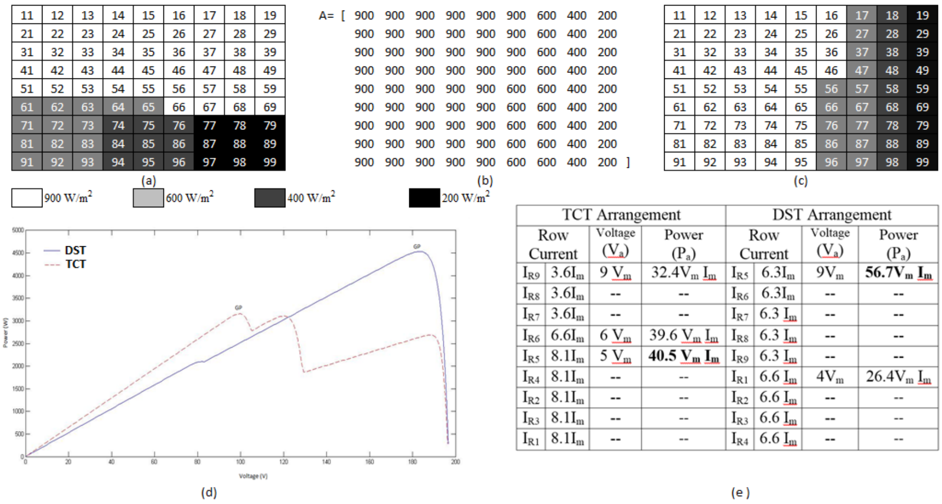
Figure 4. DST Configuration for 9 PV Array

Unlike The reconfiguration technique discussed in [25] the proposed DST technique is low cost as it uses only ardino to arrange the PV panels in descending order as shown in matrix to improve the power. Based on the tolerance value set in the ardino the panels are arranged in descending order thus improves power which proved in the last table.

This low cost DST can be implemented in any number of PV panel size. For a higher range of PV systems the DST chooses the appropriate Arduino and it improves the power by arranging the panels in descending order. In PV panels DST uses switches [25] to enhance the power. As the DST runs for every 5 minutes, It collects the value of voltages of each panel and it stores in an array variable of A[row][column] and it arranged in an descending manner shown in fig b. In this way the shading of panels can be arranged in the right side shown in fig to enhance the power which is proven in the table V for every change in insolation conditions. In order to cross check the proposed DST technique, four different shading conditions as shown in Figure2 were considered as SW Case, SN Case, LW Case and LN Case respectively. The shading circumstances are defined [27] based on photo voltaic length and width as shown in Figure 4.

5. Results and Outcome

To validate the outcome of DST technique a 9 * 9 matrix is taken and the Global Peak is shown in fig 12(d) for both TCT and DST for 4 different conditions For verifying DST technique, square matrix of order 9 is taken and the Global Peak shown in Figure 5(d) is calculated of TCT and DST for 4 different cases. It is verified that the proposed DST technique is best suited for all kinds of partial shaded environments. SW (Short Wide) Case:



TCT Arrangement				DST Arrangement			
Row Current		Voltage (V_a)	Power (P_a)	Row Current		Voltage (V_a)	Power (P_a)
I_{R9}	$3.6I_m$	$9\ V_m$	$32.4V_m\ I_m$	I_{R5}	$6.3I_m$	$9V_m$	**$56.7V_m\ I_m$**
I_{R8}	$3.6I_m$	--	--	I_{R6}	$6.3I_m$	--	--
I_{R7}	$3.6I_m$	--	--	I_{R7}	$6.3\ I_m$	--	--
I_{R6}	$6.6I_m$	$6\ V_m$	$39.6\ V_m\ I_m$	I_{R8}	$6.3\ I_m$	--	--
I_{R5}	$8.1I_m$	$5\ V_m$	**$40.5\ V_m\ I_m$**	I_{R9}	$6.3\ I_m$	--	--
I_{R4}	$8.1I_m$	--	--	I_{R1}	$6.6\ I_m$	$4V_m$	$26.4V_m\ I_m$
I_{R2}	$8.1I_m$	--	--	I_{R2}	$6.6\ I_m$	--	--
I_{R3}	$8.1I_m$	--	--	I_{R3}	$6.6\ I_m$	--	--
I_{R1}	$8.1I_m$	--	--	I_{R4}	$6.6\ I_m$	--	--

Figure 5. (a) TCT configuration (b) DST configuration (c) Shading effect in DST configuration (d) PV characteristics of the array for TCT and DST configuration for Short Wide case (e) Comparison of DST and TCT for SW (Short Wide) Case

V array with different insolation categories [27] such as 900W/m^2, 600 W/m^2, 400 W/m^2 and 200 W/m^2 are taken into account. The effect of shading is shown in Figure 5 (a). The value of $K_{11}=G_{11}/G_0$ .G_{11} is to be taken as solar irradiance of panel numbered in 11 where current produced from that panel is represented as I_{11} . Under Standard Test Conditions, current produced by the panel is Im.

$$I_1 = K_{11}I_{11} + K_{12}I_{12} + K_{13}I_{13} + K_{14}I_{14} + K_{15}I_{15} + K_{16}I_{16} + K_{17}I_{17} + K_{18}I_{18} + K_{19}I_{19}.$$

In the Figure 5 (a) first 5 rows have the same insolation of 900W/m^2.

$$I_1 = I_2 = I_3 = I_4 = I_5 = 9 \times 0.9I_m.$$

The rows 6, 7, 8 and 9 are subjected to different shading shown in Figure 5 (a)

$$I_6 = 5\times 0.6I_m + 4\times 0.9\ I_m$$

$$I_7 = I_8 = I_9 = 3\times 0.6I_m + 3\times 0.4I_m + 3\times 0.2I_m$$

As the current produced in the rows are differs there by multiple peaks in the PV characteristics shown in Figure 5 (e). Omitting the small changes in every row voltage, array voltage $V_a = 9\ V_m$ if no panel is bypassed and $V_a = 8\ V_m + V_d$ where V_d is the diode current. Since V_d is negligible compared to V_a, it is neglected. The power produced by the array $P_a = I_mV_a = I_m\ (9V_m)$. It is noted that power produced reaches its peak 3348 W corresponding at 109.4V [27].

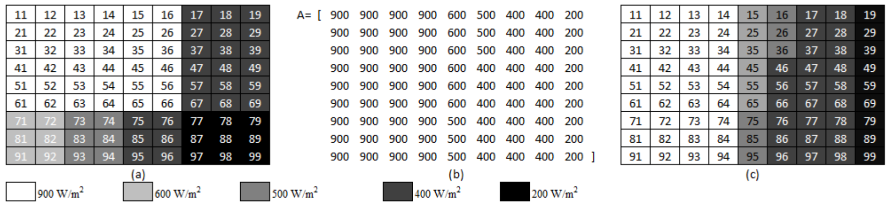
In order to validate the suggested DST, the Photo Voltaic array is exposed to the same shading arrangement shown in Figure 5 (b).

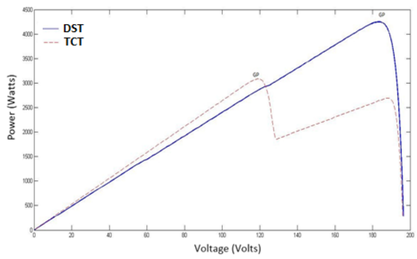
The currents are

$$I_1 = I_2 = I_3 = I_4 = 6 \times 0.9\ I_m + 1 \times 0.6\ I_m + 1 \times 0.4\ I_m + 1 \times 0.2\ I_m$$

$$I_5 = I_6 = I_7 = I_8 = I_9 = 5 \times 0.9\ I_m + 2 \times 0.6\ I_m + 1 \times 0.4\ I_m + 1 \times 0.2\ I_m$$

The value of row currents and voltages are mentioned in Figure 5 (e).It is clearly evident that the DST shifts the location of GP there by power generated by the array improved from 3348W to 4543W which is higher than TCT by 26.30 % as shown in Figure 5(d). The enhancement of Photo Voltaic power of a DST arrangements outcome to the whole array as shown in Figure 5 (c). LW (Long Wide) Case:





(d)

TCT Arrangement				DST Arrangement			
Row Current		Voltage (V_a)	Power (P_a)	Row Current		Voltage (V_a)	Power (P_a)
I_{R7}	$3.6I_m$	$9V_m$	$32.4V_mI_m$	I_{R7}	$5.5I_m$	$9V_m$	**$49.5V_mI_m$**
I_{R8}	$3.6I_m$	--	--	I_{R8}	$5.5I_m$	--	--
I_{R9}	$3.6I_m$	--	--	I_{R9}	$5.5I_m$	--	--
I_{R1}	$6.6I_m$	$6V_m$	**$39.6V_mI_m$**	I_{R4}	$5.6I_m$	$6V_m$	$33.6V_mI_m$
I_{R2}	$6.6I_m$	--	--	I_{R5}	$5.6I_m$	--	--
I_{R3}	$6.6I_m$	--	--	I_{R6}	$5.6I_m$	--	--
I_{R4}	$6.6I_m$	--	--	I_{R1}	$5.7I_m$	$3V_m$	$17.1V_mI_m$
I_{R5}	$6.6I_m$	--	--	I_{R2}	$5.7I_m$	--	--
I_{R6}	$6.6I_m$	--	--	I_{R3}	$5.7I_m$	--	--

(e)

Figure 6. (a) TCT Configuration (b) DST Configuration (c) Shading Effect in DST Configuration (d) PV Characteristics of the Array for TCT and DST Configuration for Long Wide Case (e) Comparison of DST and TCT for LW(Long Wide) Case

In this Long Wide instance 5 different shading environment is exposed for Photo Voltaic array as shown in Figure 6 (a). Current in every row is

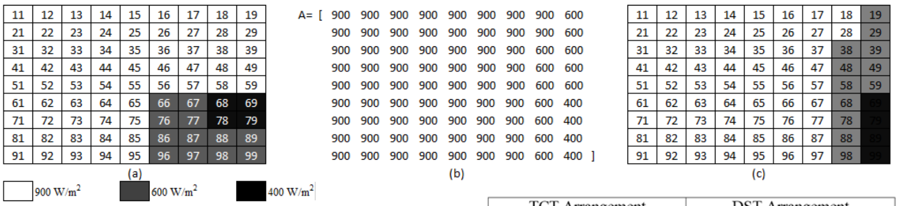
$$I_1 = I_5 = I_9 = 4 \times 0.9\ I_m + 1 \times 0.6\ I_m + 3 \times 0.4\ I_m + 1 \times 0.2\ I_m$$

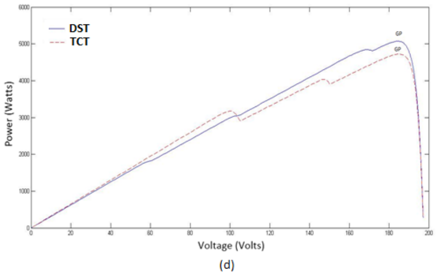
$$I_2 = I_6 = I_7 = 4 \times 0.9\ I_m + 1 \times 0.5\ I_m + 3 \times 0.4\ I_m + 1 \times 0.2\ I_m$$

$$I_3 = I_4 = I_8 = 4 \times 0.9\ I_m + 1 \times 0.6\ I_m + 1 \times 0.5\ I_m + 2 \times 0.4\ I_m + 1 \times 0.2\ I_m$$

The value of row currents and voltages are mentioned in Figure 6 (e) .It is clearly evident that the DST shifts the location of GP there by power generated by the array improved from 3244W to 4286W which is higher than TCT by 24.31 % shown in Figure 6(d). The enhancement of Photo Voltaic power of a DST arrangements outcome to the whole array as shown in Figure 6 (c). SN (Short Narrow) Case:

In this case the PV range shading is done by 3 types of insolations exposed in Figure 7 (a). Figure 7 (e) clearly explains the power generated by TCT and DST .It can be distinguished that the shading pattern the DST enhances power from 4711W to 5079W .The power enchancement is 7.25% as compared with the TCT .The rearrangement of modules as per the DST is shown in Figure 7(c).



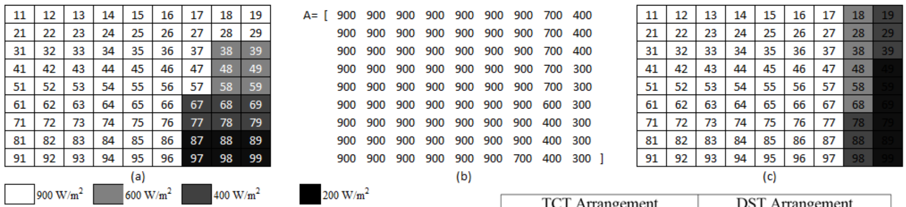


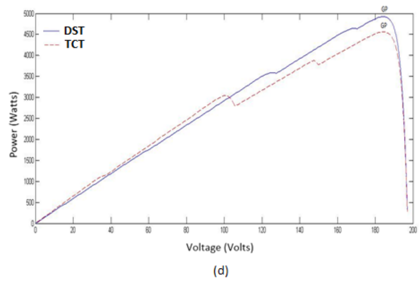
TCT Arrangement				DST Arrangement			
Row Current		Voltage (V_a)	Power (P_a)	Row Current		Voltage (V_a)	Power (P_a)
I_{R8}	$6.1I_m$	$9V_m$	**$54.9V_mI_m$**	I_{R6}	$7.3I_m$	$9V_m$	**$65.7V_mI_m$**
I_{R9}	$6.1I_m$	--	--	I_{R7}	$7.3I_m$	--	--
I_{R6}	$7.3I_m$	$7V_m$	$51.1V_mI_m$	I_{R8}	$7.3I_m$	--	--
I_{R7}	$7.3I_m$	--	--	I_{R9}	$7.3I_m$	--	--
I_{R5}	$8.1I_m$	$5V_m$	$40.5V_mI_m$	I_{R3}	$7.5I_m$	$5V_m$	$37.5V_mI_m$
I_{R4}	$8.1I_m$	--	--	I_{R4}	$7.5I_m$	--	--
I_{R3}	$8.1I_m$	--	--	I_{R5}	$7.5I_m$	--	--
I_{R2}	$8.1I_m$	--	--	I_{R1}	$7.8I_m$	$2V_m$	$15.6V_mI_m$
I_{R1}	$8.1I_m$	--	--	I_{R2}	$7.8I_m$	--	--

(e)

Figure 7. (a) TCT Configuration (b) DST Configuration (c) Shading Effect in DST Configuration (d) PV Characteristics of the Array for TCT and DST Configuration for Short Narrow Case (e) Comparison of DST and TCT for SN (Short Narrow) Case

LN (Long Narrow) Case:





TCT Arrangement				DST Arrangement			
Row Current		Voltage (V_a)	Power (P_a)	Row Current		Voltage (V_a)	Power (P_a)
I_{R8}	$6.3I_m$	$9V_m$	**$56.7V_mI_m$**	I_{R7}	$7.0I_m$	$9V_m$	**$63V_mI_m$**
I_{R9}	$6.3I_m$	--	--	I_{R8}	$7.0I_m$	--	--
I_{R6}	$6.6I_m$	$7V_m$	$46.2V_mI_m$	I_{R9}	$7.0I_m$	--	--
I_{R7}	$6.6I_m$	--	--	I_{R4}	$7.3I_m$	$6V_m$	$43.8V_mI_m$
I_{R3}	$7.7I_m$	$5V_m$	$38.5V_mI_m$	I_{R5}	$7.3I_m$	--	--
I_{R4}	$7.7I_m$	--	--	I_{R6}	$7.3I_m$	--	--
I_{R5}	$7.7I_m$	--	--	I_{R1}	$7.4I_m$	$3V_m$	$22.2V_mI_m$
I_{R1}	$8.1I_m$	$2V_m$	$16.2V_mI_m$	I_{R2}	$7.4I_m$	--	--
I_{R2}	$8.1I_m$	-	--	I_{R3}	$7.4I_m$	--	--

(e)

The shading pattern and the insolation values are shown in Fig15.The current in each row for both TCT and DST method is shown in Figure 8 (e). Power generated by the DST method increases the power by 4.51% as compared with TCT arrangement.

Figure 8. (a) TCT Configuration (b) DST Configuration (c) Shading Effect in DST Configuration (d) PV Characteristics of the Array for TCT and DST Configuration for Long Narrow Case (e) Comparison of DST and TCT for LN (Long Narrow) Case

Table 2

CASE	Peak Power (W)			Power Enrichment (%)	
	TCT Structure	Su Do Ku Structure	DST Structure	TCT & Su Do Ku	TCT & DST
1	3348	4532	4543	26.12	26.30
2	3244	4083	4286	20.54	24.31
3	4711	5045	5079	06.60	07.25
4	4703	4879	4928	03.60	04.57

6. Conclusion

This paper proposes low cost Digital Switching Technique (DST) for a Photo Voltaic power generation when shaded environment conditions. In DST as the switching of the panel dynamically varies with the varying insolation on the PV panels and thus power is improved. The physical position of the module need not be changed for each shading environment. The DST shows better performance than TCT and Su Do Ku [27] as given in table II.

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