A new model to enhance the power and performances of 4x4 PV Arrays with puzzle shade dispersion

Rabindra Nath Shaw, Pratima Walde, Ankush Ghosh

Abstract*: The conventional resources are getting depleted day by day and as a result there is a need to go deep into the green sources to harvest the natural resources in an eco-friendly manner. There are diverse demanding situations for effective usage of dispensed era like intermittency of renewable sources, power control difficulties, call for uncertainty, and so, that should be addressed for reaching the ability benefits of PV solar systems. Power and performances PV Array solar cell is significantly compromised due to shadow cast upon it. But a partial shadow can be eliminated always and, therefore, this may be considered as a part of life of a PV solar system. Output power of the PV arrays gets reduced because the solar irradiation received by the PV array during the partial shading condition is different as received during no shading condition. A new model for configuration of Photo voltaic array has been presented in this paper and their performance has been studied.

***Keywords*: Photovoltaic arrays, Array configurations, Partial shading, Renewable energy sources (RES).**

I. INTRODUCTION

Renewable energy is a form of energy that is naturally obtained from the environment and from sources that can be replenished naturally. The concern for the day by day reduction of natural occurring fossil fuels and depletion in environmental conditions with increased pollution due to burning of fossils has compelled the tremendous growth in the research going on in the area of exploring RES for supplementing the increased energy demand. Solar and wind energy is the most promising RES for power distribution. The renewable energy sources are cleaner source of energy and they do not dissipate heat to the environment that is responsible for global warming. Residential solar energy systems correspond to an investment in the future of the world, conserving non-renewable energy sources and protecting the environment. Renewables are the fastest growing source of new electricity generation.

Technology in the solar power industry is constantly advancing. Researchers are trying to improve the technology which will intensify in the future. Photo Voltaic (PV) cell is the fundamental unit which convert solar energy into electrical energy. Consequently, innovations in Photo Voltaic cell can potentially increase the effectiveness of solar panels of the solar power systems. PV panels utilized solar energy which is available in abundance in the nature without any cost. Photoelectric phenomenon is basic operating principle for PV cell. Operating and maintenance costs for Photo voltaic system are marginal, practically insignificant, compared with expenditures of other sustainable power source frameworks. PV panels have no rotating parts, with the exception of sun-following mechanical bases; therefore PV systems have less breakage. Researchers have drawn lots of interest on the problem of partial shading and its mitigation as impact of partial shading condition affects the performance and reliability of photovoltaic system. The safe operational temperature limit of PV cells is about 85˚C, but because of partial shading condition, it reaches up to 150˚C which exceeds the safe operational limit. This high temperature causes hot spotting or local over heating which can damage PV modules. Hotspot (local over heating) is the most commonly occurred phenomenon which limits the operation life of PV cells. To produce the desired photon current and terminal voltage, series and parallel connection is used between PV cells. The photon current flowing through each series connected PV cells have to be equal for better performance of PV module. But this is not possible during partial shading condition, in such situation shaded cell get reverse biased and act as a load. Large number of researchers drawn interest on impact of partial shading and its mitigation techniques.

To avoid the reverse breakdown of PV cells due to partial shading condition, a diode is connected across the shaded PV cells to carry the reverse bias current. By diverting the reverse bias current, creation of hotspot on the PV cells can be avoided. These mitigation techniques are very worthwhile to enhance the performance of PV system but cause additional cost, more power consumption and reduce the reliability of the PV system. The efficiency of a photovoltaic system is very low and depends upon various parameters like irradiance; temperature levels etc. In addition to that, a shadow upon the solar panel affect extensively on the efficiency of the Photo Voltaic system. Output of PV arrays is decrease due to partial shading condition. Modules of the photo voltaic array receive unbalance solar irradiation because of partial condition, so the PV arrays exhibit number of different peaks in I-V and P-V curve. During partial shadow

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condition efficiency of the PV array gets tremendously affected. Shedding may happen upon solar panel due to cloud, tree, buildings; even snow or dust may create partial shedding. In our work here, we are trying to increase the efficiency of PV solar system for partial shedding condition by a novel configuration of PV array design. In a PV array, the different modules are interconnected to increase the power output of the array using different interconnection schemes. PV array has very low conversion efficiency, so it is very difficult to improve the performance of PV arrays under shading condition e.g. trees, moving clouds etc. To deal with this issue of PV system different configuration have been developed and analyzed with PV system. The researchers have proposed various configuration of PV array design to restrict the effect of partial shedding like, Honey- comb(HC), Total cross tied (TCT), Bridge-link(BL), Series-parallel(SP) for different shading pattern [1] etc. Various types of connections are studied to increase electrical power received from the PV arraywith various shading pattern. PV module is the interconnection of many PV cells. Different connections are possible for PV cells but normally 36 cells are connected in series. The series/parallel connection of PV cells is depends upon voltage/current rating of PV module. The PV cells should have identical electrical properties. But because of different level of solar irradiation, mismatch of losses occur.

In this paper a new model for configuration of Photo voltaic array has been presented and their performance has been studied. The real challenge is to improve the efficiency of the PV system with partial shedding condition. We need to track local and global maximum power points (MPP) to evaluate the shedding effect. During the Partial shading the generated power by the PV system gets reduced because the solar irradiation received by the PV array during the partial shading condition is different as received during no shading condition. The widely applied conventional incremental conductance and perturb & observe [2] MPP tracking (MPPT) has a significant implementation due to its simplicity and cost effectiveness. MPPT algorithm is a very important part of the implementation of the photovoltaic system.

It is necessary to keep monitoring the performance of the solar power plants so we can analyze the system performance and hence can calculate the efficiency of the solar PV modules based on solar radiation level and some environmental factors. So, with the help of all this data, we can analyze and study the system performance. Several changes can be made in designing the solar PV cells by using the study and analysis of the power plant if needed.

In this paper a new configuration (Su-Do-Ku) for PV system is proposed for improving the performance of PV system during partial shading condition. This configuration utilizes various rearrangement techniques of PV modules i.e., puzzle pattern. The performance analysis of PV array (4x4) with proposed configuration and some other configurations have been done in the presence of different shading pattern. Detailed comparative studies have also been done for different configurations to show the superiority of proposed configuration. Photo voltaic module with different configuration is modeled using the MATLAB/Simulink software.

The rest of paper is structured as follows. Section 2 deals with modeling of PV cell. Different configurations used for the PV array to deal with partial shading condition are introduced in Section 3. A new configuration for photo voltaic array is introduced in Section 4. PV array with different configuration is analyzed in Section 5. Conclusion is given in Section 6.

II. MODELING OF PHOTO VOLTAIC CELL

A photo voltaic module is made up of small cells that work on the principle of energy conservation and transfer of heat and light energy to electrical energy. This cell acts as the basic module of the PV array. This cell is essentially a normal p-n junction diode made using highly doped silicon wafer and works on the principle of conservation and transfer of energy from light to electricity, individual cell can generate electricity and these cells can be combined to increase the generated power of photovoltaic system. Hence, large numbers of cells are joined together using different combinations and methods to increase the generated power and make the PV module of the desired size and capacity. The PV gadget used has a rated capability of two hundred kW working at 250 V. The power a PV panel generates depends upon the quantity of sun radiation incident on its floor and temperature. Both solar irradiance and temperature range according to the vicinity of the sun in the sky. Hence, the seasonality which affects the solar radiation directly has great impact on the electricity generation capability of the PV module. Total radiation incident on an inclined PV panel can be given as follows [2]:

$$I_T=I_bR_b+I_dR_d+(I_b+I_d)R_d \quad (1)$$

Where, I_d stands for diffuse radiation and direct I_b stands for normal radiation.

R_r and R_d are the tilt factor for reflected radiation and diffuse radiation respectively.

Fig. 1 represents the electrical equivalent circuit of a PV cell, where a diode and one resistor connected with a current source as,

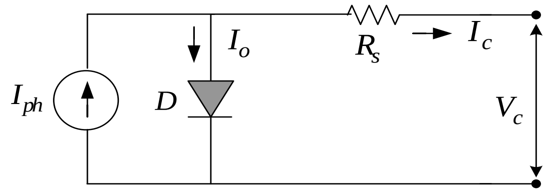


Fig. 1 Equivalent circuit diagram of single diode solar cell

PV array is the interconnection of large number of PV cells [1]. Various types of connections are studied to boost electrical power generated by the photo voltaic array.

In ideal condition the losses occurring in the PV array are considered to be zero, but in practical condition achieving zero losses is not possible. As shown in Fig. 1, a series resistor is connected in the equivalent circuit of PV cell to represent the internal losses of photo voltaic cell [1]. For a PV cell working in the ideal condition the value of this resistance is zero. The efficiency reduction of the PV cell is represented by power dissipation across series resistor. The current passing through the diode connected in parallel across the current source in Fig. 1 can be given by Shockley diode equation [2].

I_s is the reverse saturation current,
I_d is the diode current,
K = Boltzmann's constant,
Q = elementary charge,
N = Ideality factor.

Mathematically, Solar PV cell voltage (V_C) depends on current (I_{ph}) and solar irradiation, is expressed as,

$$V_C = \frac{AkT_C}{e} \ln\left(\frac{I_{ph} + I_o - I_c}{I_o}\right) - R_s I_c \quad (2)$$

The temperature coefficients for voltage (C_{TV}) and current (C_{TI}) for photovoltaic cell can be expressed by Eq. (3) [2],

$$C_{TV} = 1 + \beta(T_a - T_x) \;\&\; C_{TI} = 1 + \frac{\gamma_T}{S_C}(T_x - T_a) \quad (3)$$

The operating temperature T_x depends on solar irradiation level and ambient temperature (T_a). To determine the effect of irradiation level (S_x) on the photo current and voltage, two correction factors C_{SV} and C_{SI} are needed, as given by Eq. (4) [3],

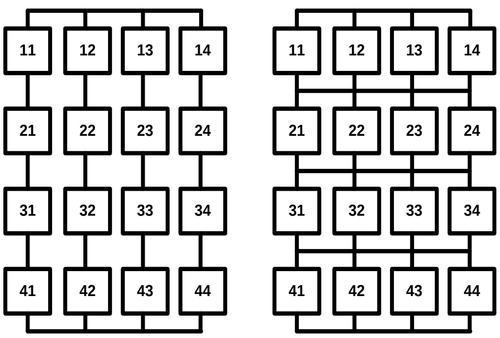
$$C_{SV} = 1 + \beta_T \alpha_S (S_x - S_c) \;\&\; C_{SI} = 1 + \frac{1}{S_c}(S_x - S_c) \quad (4)$$

Where, S_x represents new irradiation level and S_c represents reference solar irradiation. The values of the PV cell voltage V_{cx} and photo current I_{phx}, can be expressed as Eq. (5),

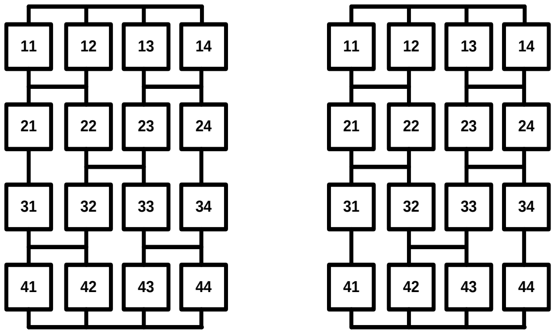
$$V_{cx} = C_{TV} C_{SV} V_C \;\&\; I_{phx} = C_{TI} C_{SI} I_{ph} \quad (5)$$

III. DIFFERENT CONFIGURATIONS OF THE PV ARRAY

In the PV array row modules and column modules are connected in parallel and series respectively. Here we are analyzing the performance of four different configurations SP, BL, HC and TCT.



(a)4x4 SP (b) 4x4TCT



(c) 4x4BL (d) 4x4HC

Fig. 2. Solar PV array interconnection topologies

Fig. 2 depicted four different configurations of PV array interconnection topologies where row modules and column modules are connected in parallel and series respectively. Performances of these configurations can be studied.

The current generated by PV modules can be given as Eq. (6).

$$I = \left(\frac{G}{G_{STC}}\right) \times I_m \quad (6)$$

Where, I_m is the generated module current. The Array voltage can be expressed as,

$$V = \sum_{n=1}^{4} V_{mn} \quad (7)$$

Where, V_{mn} is the n^{th} row voltage of photo voltaic array.

Fill-Factor of a solar cell can be calculated from the P-V curves. It variesin partial shading conditions and expressed as,

FF = GMPP/Voc × Isc (8)

Where, GMPP is multiple maximum power points and LMPP is local maximum power points [5-7] under partial shaded conditions. In the scenario when the multiple Maximum Power Points (MPPs) are considered that conventional tracking techniques do not give the desired results for tracking the GMPP [8].

MPPT Technique or Incremental Conductance technique is used for maximizing and optimizing the utilization of the PV array. The principle of summation of incremental conductance (AIpv /AVpv) and instantaneous conductance (Ipv /Vpv) at most power factor leads to zero with high-quality on the left side of MPP (*dI/dV>-I/V)* and negative on the right side (*dI/dV<-I/V)* governs this MPPT technique. Using the values, this technique detects the ideal operating point of the PV device:

dI/dV=-I/V at MPP

Power loss in the PV array with partial shading conditions can be expressed as [9],

Power loss = (Maximum power of PV array without PS – GMPP with PS) (9)

IV. PROPOSED 4X4PV ARRAY CONFIGURATIONS

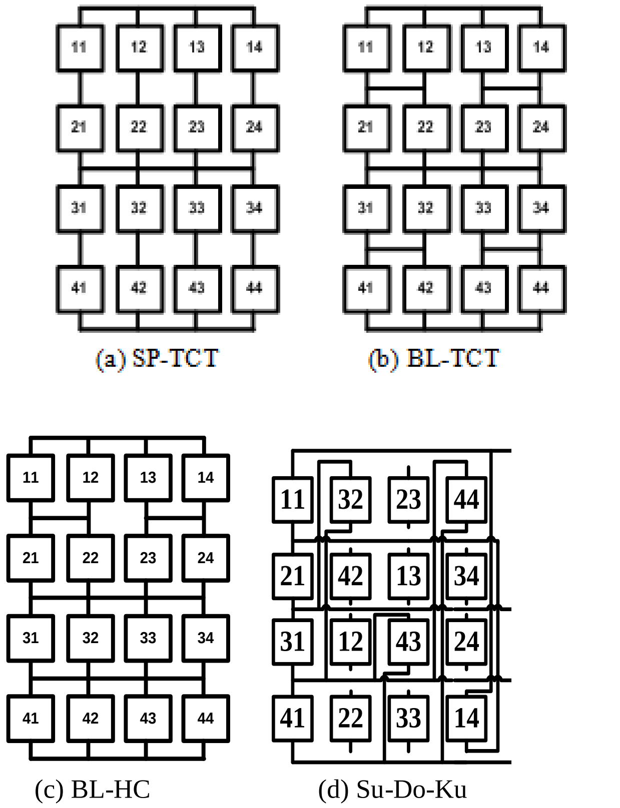
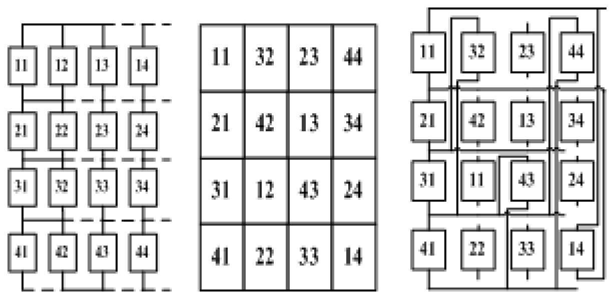


Fig. 3Proposed 4x4 PV Array configurations

IV.I Su-Do-Ku Configured arrangements for 4x4 PV Array

The proposed novel configuration for PV array, Su-Do-Ku is a logic based, combinatorial number-placement puzzle [10]. The whole puzzle areas are called as Grid, it is divided in columns (vertical lines) and rows (horizontal lines) made up of the individual Su-Do-Ku squares. A simple 4x4 puzzle size, so there are only four possibilities to think and shown Fig.10 with the respect of TCT topology arrangement as,



(a) TCT arrangement(b) Su-Do-Ku pattern (c) Su-Do-Ku arrangement

Fig. 4 Su-Do-Ku configuration for PV Array

In the proposed model of Su-Do-Ku configuration is depicted in fig. 4, where first digit represents the row position and second digit denotes the position. Here in first row, third column panel 23 has shifted to the new position (first row third column) but the electrical connection of the panel remains same. In the same way, the new position for panel 44 is first row and fourth column but the electrical connection of the panel remains same. Therefore, the position of the panels is change without disturbing the electrical connection of panel. Since the electrical configurations of the array does not change with position of panel, the voltage & current equations remains the same for all used configuration e.g. SP,TCT, BL [4].

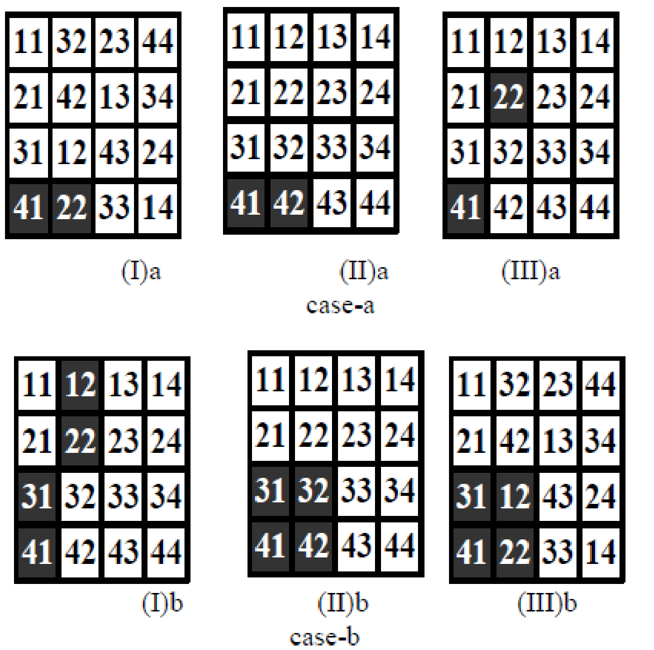
IV.II Analysis of 4x4 PV Array Shading Patterns

Three different shading patterns are considered to determine the impacts of shading on PV array. Each patterns having four cases a, b, c and d but pattern-3 are only two types of cases. In all three patterns, two different of irradiation level ($350W/m^2$ and $1000W/m^2$) are taken for performance investigation on pattern-1, pattern-2 and pattern-3 as depicted in fig.5a, 5b and 5c respectively.

The values of different parameters of available PV module (for commercial use) at standard test condition (STC) are given in Table I;

Table I. Specifications of photo voltaic module at STC ($1000W/m^2$ and 25^0C)

Parameters	Values
PV power	170 W
Short circuit current	5.2 A
Open circuit voltage	44.2 V
Voltage at MPP	35.8 V
Current at MPP	4.75 A
No. of cell	72



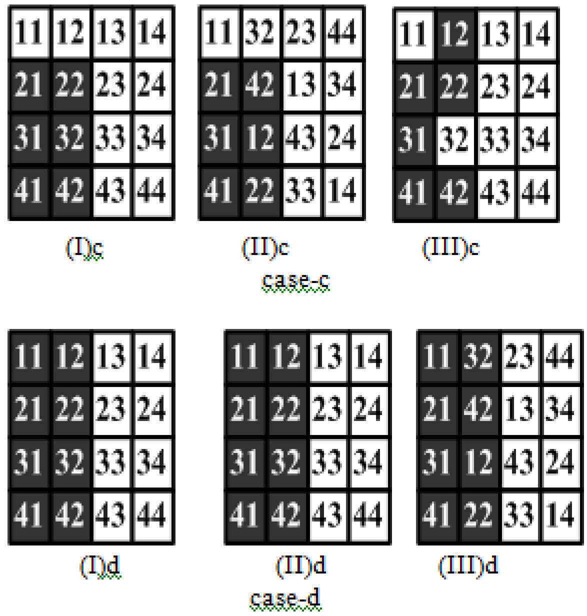


Fig.5a Proposed shading cases from all types of configurations

Pattern-2:

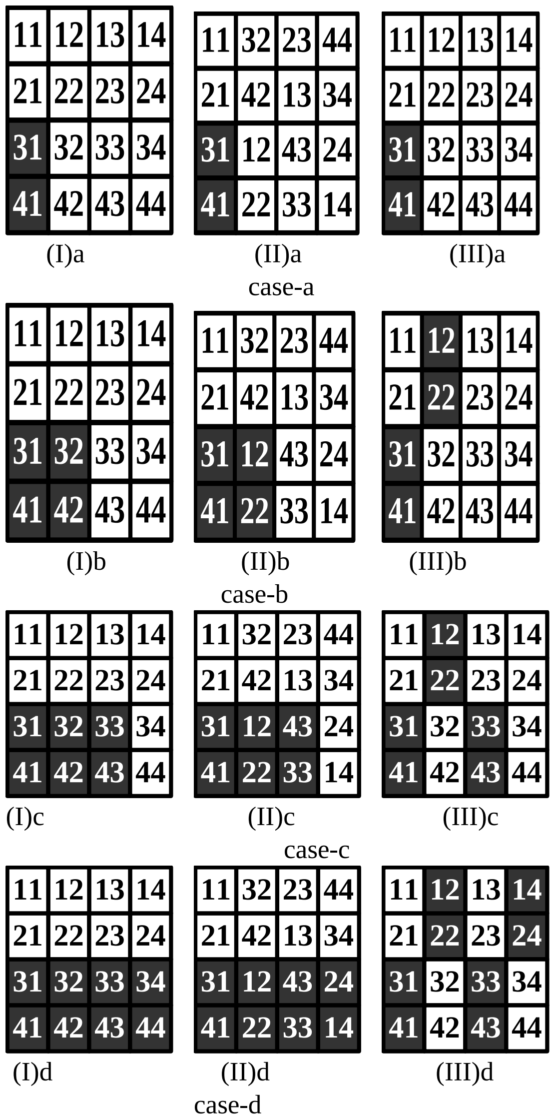


Fig.5b proposed shading cases from all types of configurations

Pattern-3:

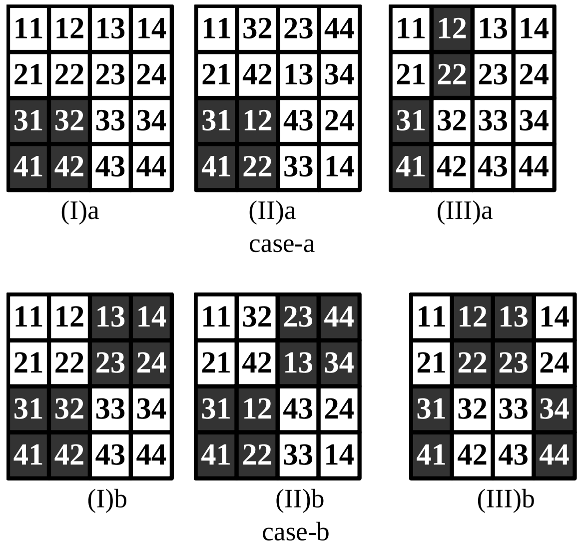


Fig.5c Proposed shading cases from All-8 topologies

V. RESULTS AND DISCUSSION

MATLAB/Simulink is used for simulation study of all configurations namely SS, SP, TCT performance analysis of PV panel with different configuration. Performance analysis for different configuration under various shade patterns have been shown in results in figure as well as tabular form.

V.I Shading pattern-1 and shade dispersion effects on MPP

The PV modules with same solar irradiation of 1000W/m2falling on their surface are used in the 1st, 2nd and 3rd row. But in 4th row, two modules receives solar irradiation of 1000W/m^2 and other two modules are receives 350W/m^2. Therefore, for 4x4 TCT PV, the array current can be calculated by case-5a shading pattern-1 as;

First, second and third row-generated currents are

$$I_{R1} = 4 \times \left(\frac{G}{G_{STC}}\right) I_m = 4 \times \left(\frac{1000}{1000}\right) I_m = I_{R2} = I_{R3} = 4I_m \qquad (9)$$

Fourth row generated current are

$$I_{R4} = 2I_m + \left(\frac{350}{1000} + \frac{350}{1000}\right) I_m = 2.7I_m \qquad (10)$$

Similarly, the current generated by the shading pattern-1 case-b, c and d can be calculated as follows;

Case 5b:

$$I_{R1} = I_{R2} = 4I_m \text{ and } I_{R3} = I_{R4} = 2.7I_m \qquad (11)$$

Case 5c:

$$I_{R1} = 4I_m \text{ and } I_{R2} = I_{R3} = I_{R4} = 2.7I_m \qquad (12)$$

Case 5d:

$$I_{R1} = I_{R2} = I_{R3} = I_{R4} = 2.7I_m \qquad (13)$$

To prove the efficacy of proposed configuration (Su-Do-Ku) for PV array, the arrangement of modules are according to Su-Do-Ku puzzle pattern, the rearrangement of the array is subjected to the same shading pattern-1[Fig. (5a)-(5c)] for each shading cases and currents in each row is calculated as

First and third row-generated currents are

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$$I_{R1} = 4\times\left(\frac{G}{G_{STC}}\right) I_m = 4\times\left(\frac{1000}{1000}\right) I_m = I_{R3} = 4I_m \quad (14)$$

Second and fourth row generated current are

$$I_{R2} = 3I_m + \left(\frac{350}{1000} + \frac{350}{1000}\right) I_m = I_{R4} = 3.35I_m \quad (15)$$

Similarly the generated current on shading pattern-1 case-b,c and d can be calculated as;

Case 5b: $I_{R1} = I_{R2} = I_{R3} = I_{R4} = 3.35I_m$ (16)

Case 5c:

$$I_{R1} = I_{R3} = 3.35I_m \text{ and } I_{R2} = I_{R4} = 2.7I_m \quad (17)$$

Case 5d: $I_{R1} = I_{R2} = I_{R3} = I_{R4} = I_{R5} = 2.7I_m$ (18)

The array currents for Su-Do-Ku and TCT patterns, respective power and voltages are tabulated in Table II, which clearly shows the before and after the arrangement of modules according to Su-Do-Ku puzzle configuration, the location of GP. This increases the generated power of the photo votaic array. PV Array characteristics are plotted in Fig. 6(5a-5d) with the respect of shading pattern-1which shows the power has improved.

Table II: Locations of GMPP on Su-Do-Ku and TCT configuration in shading pattern-1

TCT configuration			Su-Do-Ku configuration		
Case-5a			*Case-5a*		
I_R*	V	P	I_R*	V	P
I_{R4}= 2.7Im	4V_m	10.8V_mI_m	I_{R4}= 3.35Im	4 V_m	13.4 V_mI_m
I_{R3}= 4Im	3 V_m	12 V_mI_m	I_{R3}= 4Im	3 V_m	12 V_mI_m
I_{R2}= 4Im	2 V_m	8 V_mI_m	I_{R2}= 3.35Im	2 V_m	6.7 V_mI_m
I_{R1}= 4Im	V_m	4 V_mI_m	I_{R1}= 4Im	V_m	4 V_mI_m
Case-5b			*Case-5b*		
I_{R4}= 2.7Im	4 V_m	10.8 V_mI_m	I_{R4}= 3.35Im	4 V_m	13.4 V_mI_m
I_{R3}= 2.7Im	3 V_m	8.1 V_mI_m	I_{R3}= 3.35Im	3 V_m	10.05 V_mI_m
I_{R2}= 4Im	2 V_m	8 V_mI_m	I_{R2}= 3.35Im	2 V_m	6.7 V_mI_m
I_{R1}= 4Im	V_m	4 V_mI_m	I_{R1}= 3.35Im	V_m	3.35 V_mI_m
Case-5c			*Case-5c*		
I_{R4}=2.7Im	4 V_m	10.8 V_mI_m	I_{R4}= 2.7Im	4 V_m	10.8 V_mI_m
I_{R3}=2.7Im	3 V_m	8.1 V_mI_m	I_{R3}= 3.35Im	3 V_m	10.05 V_mI_m
I_{R2}=2.7Im	2 V_m	5.4 V_mI_m	I_{R2}= 2.7Im	2 V_m	5.4 V_mI_m
I_{R1}=4Im	V_m	4 V_mI_m	I_{R1}= 3.35Im	V_m	3.35 V_mI_m
Case-5d			*Case-5d*		
I_{R4}=2.7Im	4 V_m	10.8 V_mI_m	I_{R4}= 2.7Im	4 V_m	10.8 V_mI_m
I_{R3}=2.7Im	3 V_m	8.1 V_mI_m	I_{R3}= 2.7Im	3 V_m	8.1 V_mI_m
I_{R2}=2.7Im	2 V_m	5.4 V_mI_m	I_{R2}= 2.7Im	2 V_m	5.4 V_mI_m
I_{R1}=2.7Im	V_m	2.7 V_mI_m	I_{R1}=2.7Im	V_m	2.7 V_mI_m

V.II Effects of shading pattern-2 and shade dispersion on MPP

Currents, voltages and power output of PV array are noted in Table III for Su-Do-Ku and TCT configuration which shows the power generation is increased and the PV Array characteristics plotted in Fig. 7(6a-6d) with the respect of shading pattern-2.

Table III: Locations of GMPP on Su-Do-Ku and TCT configuration in shading pattern-2

TCT configuration			Su-Do-Ku configuration		
Case-6a			*Case-6a*		
I_R*	V	P	I_R*	V	P
I_{R4}= 3.35Im	4V_m	13.4V_mI_m	I_{R4}= 3.35Im	4V_m	13.4V_mI_m
I_{R3}= 3.35Im	3 V_m	10.05 V_mI_m	I_{R3}= 3.35Im	3 V_m	10.05 V_mI_m
I_{R2}= 4 Im	2 V_m	8 V_mI_m	I_{R2}= 4 Im	2 V_m	8 V_mI_m
I_{R1}= 4 Im	V_m	4 V_mI_m	I_{R1}= 4 Im	V_m	4 V_mI_m
Case-6b			*Case-6b*		
I_{R4}= 2.7Im	4 V_m	10.8 V_mI_m	I_{R4}= 3.35Im	4 V_m	13.4 V_mI_m
I_{R3}= 2.7Im	3 V_m	8.1 V_mI_m	I_{R3}= 3.35Im	3 V_m	10.05 V_mI_m
I_{R2}= 4Im	2 V_m	8 V_mI_m	I_{R2}= 3.35Im	2 V_m	6.7 V_mI_m
I_{R1}= 4Im	V_m	4 V_mI_m	I_{R1}= 3.35Im	V_m	3.35 V_mI_m
Case-6c			*Case-6c*		
I_{R4}= 2.05Im	4 V_m	8.2 V_mI_m	I_{R4}= 2.7Im	4 V_m	10.8 V_mI_m
I_{R3}= 2.05Im	3 V_m	6.15 V_mI_m	I_{R3}= 2.7Im	3 V_m	8.1 V_mI_m
I_{R2}= 4Im	2 V_m	8 V_mI_m	I_{R2}= 3.35Im	2 V_m	6.7 V_mI_m
I_{R1}= 4Im	V_m	4 V_mI_m	I_{R1}= 3.35Im	V_m	3.35 V_mI_m
Case-6d			*Case-6d*		
I_{R4}= 1.4Im	4 V_m	5.6 V_mI_m	I_{R4}= 2.7Im	4 V_m	10.8 V_mI_m
I_{R3}= 1.4Im	3 V_m	4.2 V_mI_m	I_{R3}= 2.7Im	3 V_m	8.1 V_mI_m
I_{R2}= 4Im	2 V_m	8V_mI_m	I_{R2}= 2.7Im	2 V_m	5.4 V_mI_m
I_{R1}= 4Im	V_m	4V_mI_m	I_{R1}= 2.7Im	V_m	2.7 V_mI_m

5.3 Effects of shading pattern-3 and shade dispersion on MPP

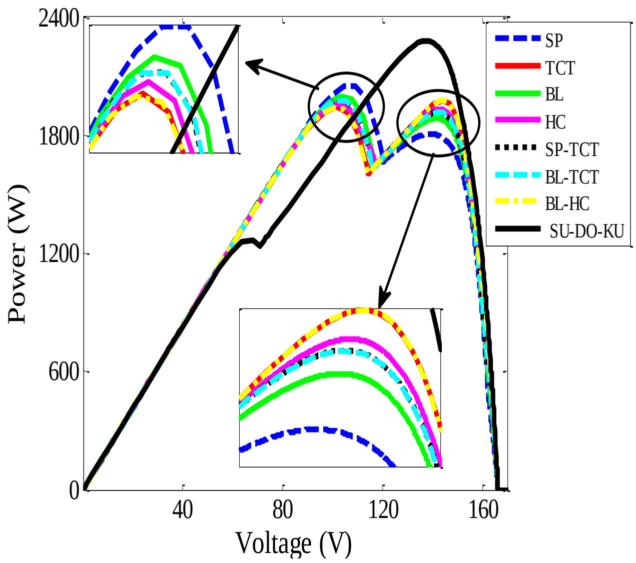
PV array currents, voltages and power for the TCT and Su-Do-Ku configuration are noted in Table IV which shows the location of GP is according to Su-Do-Ku puzzle pattern. The power outputby the array is increased and the PV Array characteristics plotted in Fig. 8(case 7a-7b) with the respect of shading pattern-3.

Table IV: Locations of GMPP on Su-Do-Ku and TCT configuration in shading pattern-3

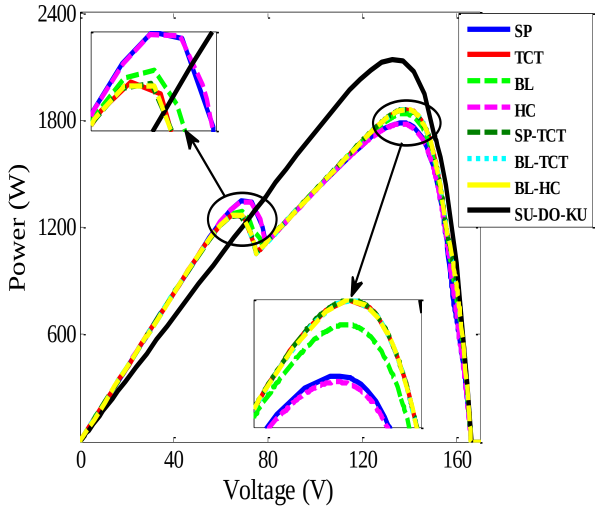
TCT configuration			Su-Do-Ku configuration		
Case-7a			*Case-7a*		
I_R*	V	P	I_R*	V	P
I_{R4}= 2.7Im	4 V_m	10.8 V_mI_m	I_{R4}= 3.35Im	4 V_m	13.4 V_mI_m
I_{R3}= 2.7Im	3 V_m	8.1 V_mI_m	I_{R3}= 3.35Im	3 V_m	10.05 V_mI_m
I_{R2}= 4Im	2 V_m	8 V_mI_m	I_{R2}= 3.35Im	2 V_m	6.7 V_mI_m
I_{R1}= 4Im	V_m	4 V_mI_m	I_{R1}= 3.35Im	V_m	3.35 V_mI_m
Case-7b			*Case-7b*		
I_{R4}= 2.7Im	4 V_m	10.8 V_mI_m	I_{R4}= 2.7Im	4 V_m	10.8 V_mI_m
I_{R3}= 2.7Im	3 V_m	8.1 V_mI_m	I_{R3}= 2.7Im	3 V_m	8.1 V_mI_m
I_{R2}= 2.7Im	2 V_m	5.4 V_mI_m	I_{R2}= 2.7Im	2 V_m	5.4 V_mI_m
I_{R1}= 2.7Im	V_m	2.7V_mI_m	I_{R1}= 2.7Im	V_m	2.7V_mI_m

V.IV P-V characteristics of 4x4 PV array with shading pattern-1

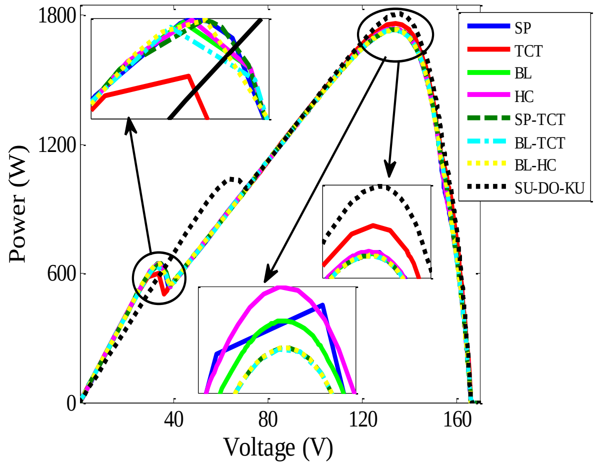
The given results depict effectiveness and superiority of the PV array (4x4) with Su-Do-Ku arrangement, simulation result also suggests that the configuration produces more power than the other available configurations. The P-V characteristics of PV array for shading pattern '1' are given in Fig.6 (case a-d). In the case 'a' shading, the P-V curve with two different MPPs can be observed. Here, local MPP is very close to the global MPP. Here, shading effect is observed on the power output in Fig.6 (case a).The power at global MPP is obtained as 1961 W, 1976 W and 2047 W, 2000 W, 1975 W, 1977 W, 1994 W and 2279 W for HC, TCT, SP,BL Hybrid BL-TCT, SP-TCT, H-6 and Su-Do-Ku topology respectively. In the case 'b' local MPP is at a distance from the global MPP is shown in Fig. 6(case b).



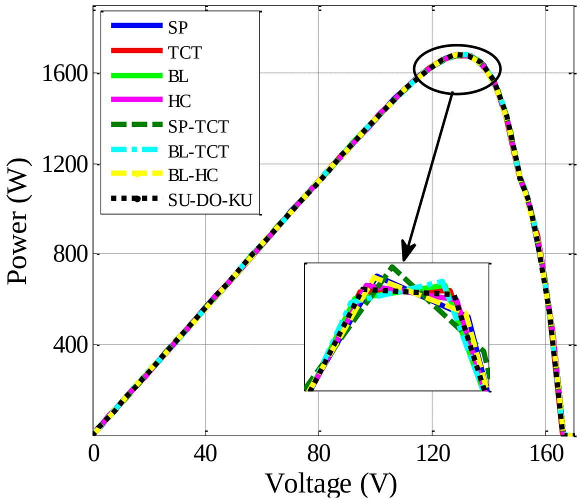
case-a



case-b



case-c



case-d

Fig. 6. Effect of shading cases (a-d) on P-V characteristics for all 4x4 PV array configurations

Table V: Pattern-1simulation results in terms of Power (Watt) and Voltage for different configurations

Topologies	Case-8a		Case-8b		case-8c		Case-8d	
	P	V	P	V	P	V	P	V
SP	2047	108.5	1784	136.3	1735	132	1680	131.5
TCT	1976	144	1860	138.3	1765	134.2	1680	131.5
BL	2000	103.3	1835	138	1734	132.2	1679	131.5
HC	1961	102.3	1778	136.3	1736	132.3	1679	131.5
SP-TCT	1977	104.8	1860	138.3	1732	132.1	1681	131.5
BL-TCT	1975	102.1	1860	138.3	1732	132.1	1680	131.5
BL-HC	1975	103.1	1860	138	1732	132.2	1680	131.5
SU-DO-KU	2279	137.3	2139	133	1806	135.1	1680	131.5
BEST TOPOLOGY	SU-DO-KU						ALL	

The power produced by different PV arrays using global MPP is 1784 W, 1860 W, 1835 W, 1778W, 1860W, 1860W, 1840W and 2139W for the SP, TCT, BL, HC, Hybrid BL-TCT,SP-TCT, BL-HC and Su-Do-Ku topology respectively. The proposed different configurations of the 4x4 PV array compares the power output and voltages with respect to the locations of GMPP as shown in the Table V. similarly, for the shading case studies 'c' and case 'd' the PV characteristics are shown in Fig. 6(case c) and Fig. 6(case d) respectively. The shading effect caused due to partial shading conditions can be seen to decrease from case 'a' to case 'd' and it reaches zero for the case 'd' for all the considered topologies, i.e., TCT, SP, HC,BL, Hybrid BL-TCT, BL-HC, SP-TCT and Su-Do-Ku considered in the proposed work. The power at global maximum power point for these two cases are noticed as 1735 W, 1765 W, 1736 W, 1734W, 1732W, 1732W, 1732W and 1806W for case 'c' and 1680 W, 1680 W, 1679 W, 1679W, 1681W, 1680W, 1680W and 1680W for case 'd' respectively.

***5.5** P-V characteristics of 4x4 PV array with shading pattern-2*

Fig.7 (case a-d) shows the P-V characteristics of array for shading pattern '2'. In the case 'a' shading, two maximum power points global and local are observed on the P-V curve which are very close to each other. As shown in Fig.7 (case a), shading effect is quite significant on the output power.

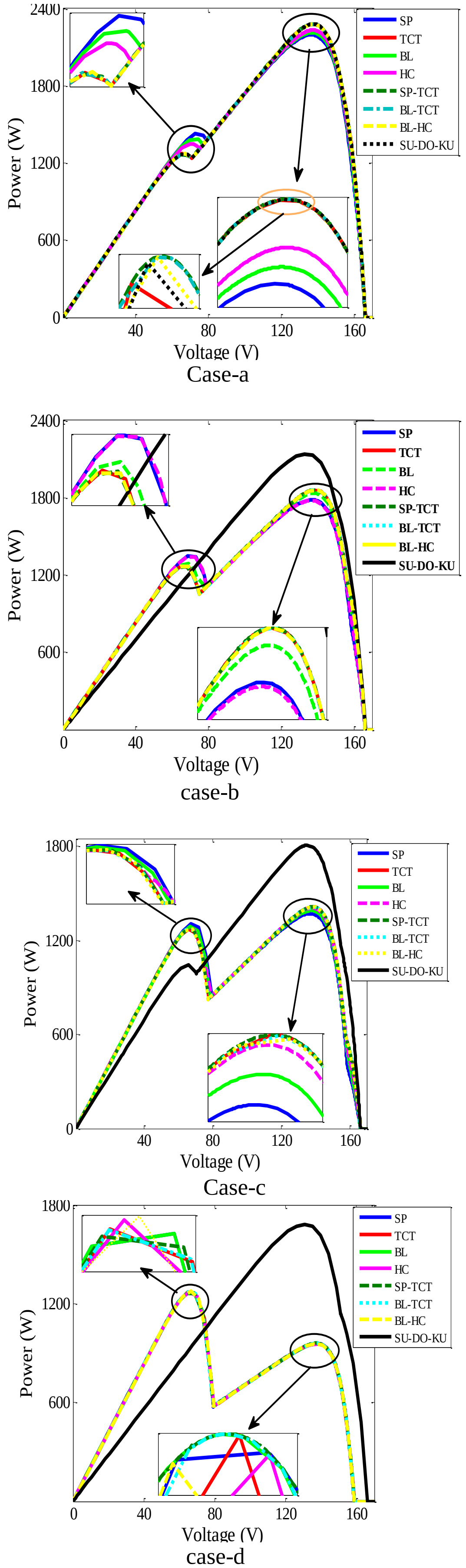


Fig. 7 Effect of shading cases (a-d) on P-V characteristics for all 4x4 PV array configurations

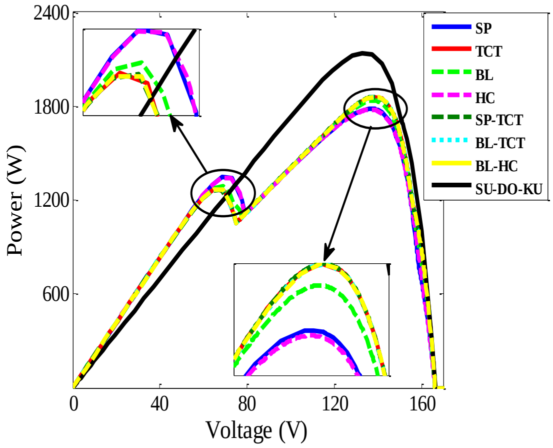
The power produced by different PV arrays using global MPP is 2232 W, 2279 W and 2213 W, 2197W, 2279 W, 2279W, 2279 W and 2279 W for HC, TCT, BL, SP, Hybrid BL-TCT, SP-TCT, BL-HC and Su-Do-Ku topologies respectively. The power output and voltages of 4x4 PV array for different configuration used here are given in Table VI with respect to the locations of GMPP. These results depicts that the 4x4 PV array with proposed Su-Do-Ku arrangement is producing more power compare to other classical configurations. Fig. 8 (case b) shows P-V characteristics for shading case 'b. It is notice from the Fig. 8 (case b) that local MPP is at a distance from the global MPP and effect of shading on the power curve is not so pronounce as in case 'a'. The power at global MPP is observed as 1784 W, 1860 W, 1835 W, 1778W, 1860W, 1840W, 1860W and 2139W for the SP, TCT, BL, HC, Hybrid SP-TCT, BL-HC, BL-TCT and Su-Do-Ku topology. Fig.8 (case c) and Fig.8 (case d) shows the P-V characteristics for shading case 'c' and 'd' respectively. The effect of shading is decreasing from case 'a' to case 'd' and it is almost zero for the case 'd' for all the considered TCT, SP, BL, HC, BL-TCT, SP-TCT, BL-HC and Su-Do-Ku topology. The power at global MPP for these two cases are noticed as 1390 W, 1414 W, 1371 W, 1408W, 1414W, 1414W, 1412W and 1806W for case 'c' and 1268W, 1269W, 1267W, 1267W, 1267W, 1273W, 1269W and 1682W for case 'd' respectively.

Table VI: pattern-2 simulation results in terms of Power (Watt) and Voltage (V) for various configurations

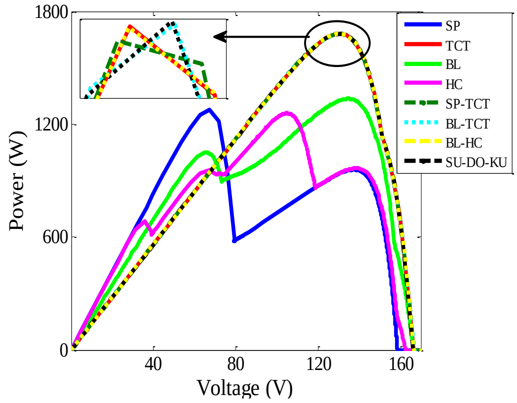
Topologies	Case-6a		Case-6b		case-6c		Case-6d	
	P	V	P	V	P	V	P	V
SP	2197	136.4	1784	136.3	1371	137.4	1268	66.63
TCT	2279	137.3	1860	138.3	1414	138.7	1269	66.63
BL	2213	137.2	1835	138	1390	138.1	1267	66.63
HC	2232	137.1	1778	136.3	1408	137.8	1267	66.63
SP-TCT	2279	137.3	1860	138.3	1414	138.7	1267	66.63
BL-TCT	2279	137.1	1860	138.3	1414	138.7	1267	66.63
BL-HC	2279	137.2	1860	138	1412	138.1	1273	66.63
SU-DO-KU	2279	137.3	2139	133	1806	135.1	1682	131.5
BEST TOPOLOGY	SU-DO-KU		SU-DO-KU		SU-DO-KU		SU-DO-KU	

5.6 P-V characteristics of 4x4 PV array with shading pattern-3

Fig. 8 shows the P-V characteristics of PV array with different configurations (SP, TCT, HC, BL, BL-HC, SP-TCT, BL-TCT and Su-Do-Ku) for case 'a' and 'b' with shading pattern '3'.



case-a



case-b

Fig.8 Effect of shading cases on P-V characteristics for all different configurations

For the shading case '7a' similar to the pattern-2 case '6b', so we discuss the only shading case '7b'. As shown in results two MPP local and global are observed on the P-V curve, which are very close to each other. The effect of shading is quite significant on the power output, which is observed in Fig. The power at global MPP is obtained as 1335 W, 1681 W, 1274 W, 1257W, 1681 W, 1679W, 1681 W and 1681 W for BL, TCT, SP, HC, Hybrid BL-TCT,SP-TCT, BL-HC and Su-Do-Ku topology respectively. Output power and voltages of photo voltaic array with different configurations techniques are compared with respect to the global maximum power point, given in Table VII.

Table VII: pattern-3 simulation results: Power (Watt) and Voltage (V) for different configurations

Topologies	Case-7a		Case-7b	
	P	V	P	V
SP	1784	136.3	1274	67.07
TCT	1860	138.3	1681	131.5
BL	1835	138	1335	134.1
HC	1778	136.3	1257	105
SP-TCT	1860	138.3	1679	131.5
BL-TCT	1860	138.3	1681	131.5
BL-HC	1860	138	1681	135.9
SU-DO-KU	2139	133	1681	131.5
BEST TOPOLOGY	SU-DO-KU		SU-DO-KU	

VI. CONCLUSION

In this paper, a new configuration for photovoltaic arrays is proposed, called Su-Do-Ku configuration. The performance analyses for other classical configurations like SP, BL, TCT,HC, BL-HC, BL-TCT, BL-HC and SP-TCT have also done. The obtained voltage, current, power has been considered performance parameters for considered PV array with different classical and proposed configuration. The shade dispersion effect on PV array with various configurations is also investigated. Different partial shading patterns are applied to photo voltaic module to assess the performance of different PV array configuration. Simulation results show the efficacy of proposed Su-Do-Ku configuration for photovoltaic array. Results clearly show that, the proposed Su-Do-Ku configuration has enhanced the output power and performances and is better than the other configurations with puzzle shade dispersion and different partial shading conditions.

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