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Research Article

Improvement of the Performance of Solar PV Array topologies under various partial shadowing situations

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ABSTRACT

The partial shadowing effect significantly lowers the solar photovoltaic (PV) array's output power. To lessen the impacts of partial shade in PV arrays, several researchers have proposed a variety of array construction and reconfiguration strategies. In order to enhance performance under partial shadowing circumstances (PSCs), this research suggests novel PV array topologies (PVATs).Partial shadowing is a common occurrence for photovoltaic (PV) systems, and it significantly impairs the overall performance and efficiency of solar arrays. A precise understanding of how shadowing affects PV panels at a specific location are necessary for a techno-economic analysis to be correct. Due to a discrepancy in the power outputs from individual panels, the PV array's total efficiency is significantly reduced by partial shade. To improve their efficiency in shadowed areas, a range of tactics may be employed, such as MPPT methods, PV array design, converter circuit topologies, and PV system designs. The performance of several PV array topologies in situations with partial shade is investigated in this study. The building of PV arrays requires a number of electrical connections between PV modules. Several solar array topologies are investigated, including Bridge-Link, Honey-Comb, Total-Cross-Tied, Series, and Series-Parallel.A distinct partial shade pattern is used to mimic each array layout. Standard test circumstances and various partial shadow patterns were used to duplicate and assess the previously specified 4x4 PV array designs. Finding the optimal array arrangement under the shadow pattern was the aim of the inquiry.

Keywords: Series-parallel (S-P), total-cross-tied (T-C-T), bridgelinked (B-L), honey-comb (H-C), partial shading condition (PSCs), global peak point (G-PPP), and mismatch loss,CNN.

INTRODUCTION:

Non-traditional energy sources have been the primary sources of electricity generation for a long time. However, its riches are predicted to be environmentally hazardous and stifling in the near future [1]. Because of this, a lot of scholars are interested in producing electricity utilizing renewable energy sources [2]. The S-P, T-C-T, BL, and H-C array designs are the most common. Numerous factors, including as geometric layout, ambient temperature, and the non-uniform amounts of solar insolation caused by PSCs, influence the effectiveness of traditional installations. Since these designs lead to mismatched power losses and have fewer PPPs in the output characteristics, it is more challenging to determine actual MPPs[3-5]. The T-C-T pattern has fewer PPPs and generates more power than other conventional PV array configurations [7]–[9]. A contemporary, affordable, and useful sustainable energy source is needed in light of the growing demand for power and current environmental changes like global warming and greenhouse gas emissions. The abundance of solar energy has made it a viable long-term energy source. In recent years, it has emerged as one of the most attractive research sources[10]-[11]. It is plentiful, free of pollution, low-maintenance, reliable, and limitless. Its low energy conversion efficiency and high installation cost are some of its drawbacks. Partial shadowing condition (PSC), or the uneven distribution of light, is a major drawback of photovoltaic (PV) systems. A number of factors, including as solar PV size limitations, structural problems, product flaws, and the outcome of uneven irradiance, can lead to PSCs. Lower irradiance absorption is the effect of the PV modules in PSCs absorbing less irradiance than the other modules.8. The current generated in these modules is lower than that of other modules because of the reduced absorption of irradiance. This shift in magnitude causes the PV cell or module to be damaged when the shaded modules begin to absorb the current. One way to protect modules from damage is to connect bypass diodes across the terminals[12]. The several peaks in the PV array's P–V and I–V characteristics, which cause power losses in the system, are another factor contributing to partial shadowing.

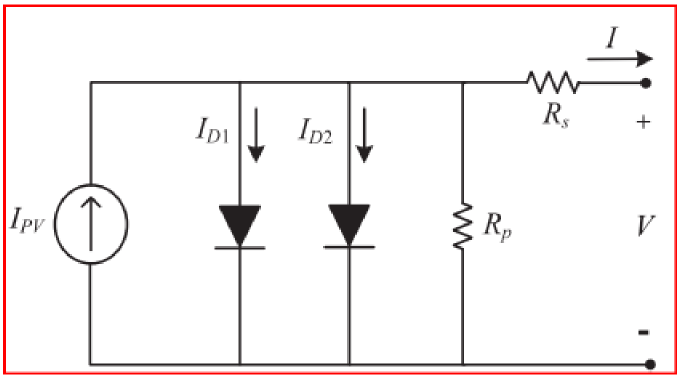

Fig. 1. PV module two-diode circuit model

Compared to other renewable energy sources, solar photovoltaic (PV) sources are widely used worldwide. Interest in using solar PV systems has grown as a result of recent advancements, lower module costs, simpler installation, and longer module lifespans. The poor system conversion efficiency (SCE) of these solar PV systems is a problem. Numerous studies are now being carried out to enhance SCE. The primary determinants of the amount of output electricity generated are "temperature" and solar radiation. Temperature and radiation have a direct and inverse connection with the output power that is produced. As a result, the "temperature" and "irradiation" components are crucial to the power generation process of solar PV systems. "Partial shadowing circumstances (PSC) or non-homogenous irradiation" describes different degrees of irradiance in solar photovoltaic installations. At a fixed temperature, the current study assesses how the output power of solar PV arrays changes with the degree of irradiation [13]. When subjected to homogenous irradiation, a solar PV array's output power has a peak point that represents its maximum power. When irradiation is uneven, peak power generation falls. The difference in produced output power under uniform and non-homogeneous irradiation levels is referred to as "mismatch power loss (MPL)". Solar PV facilities' output power generation and efficiency are decreased by non-homogeneous irradiation [14].

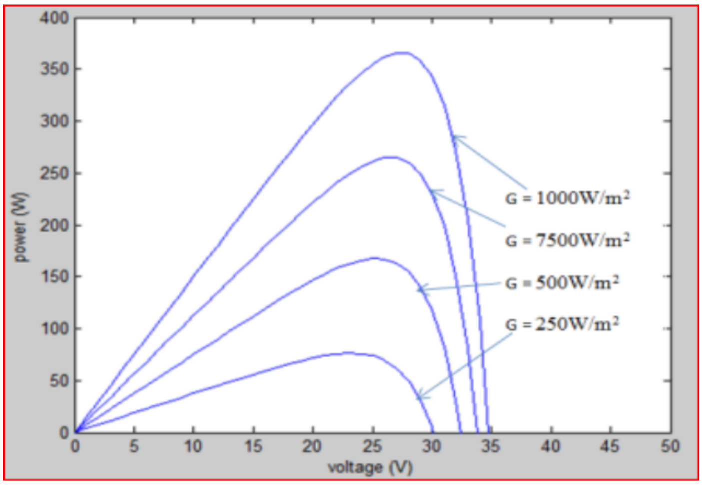

Fig. 2 PV curve with different at different insolation levels and at 25 °C.

Through simulation studies, the capacity of a 4 × 4 test solar PV array to enhance its overall output power is examined. Investigations are conducted on the solar PV array's performance in non-homogeneous irradiance circumstances, such as shadowing patterns. The output power of a 4 x 4 test solar PV array drops in an environment with uneven irradiation. This reduced output power is due to the solar PV array's increased power loss. To accomplish analytical objectives, representative criteria for typical output performance are selected for the current study [15].

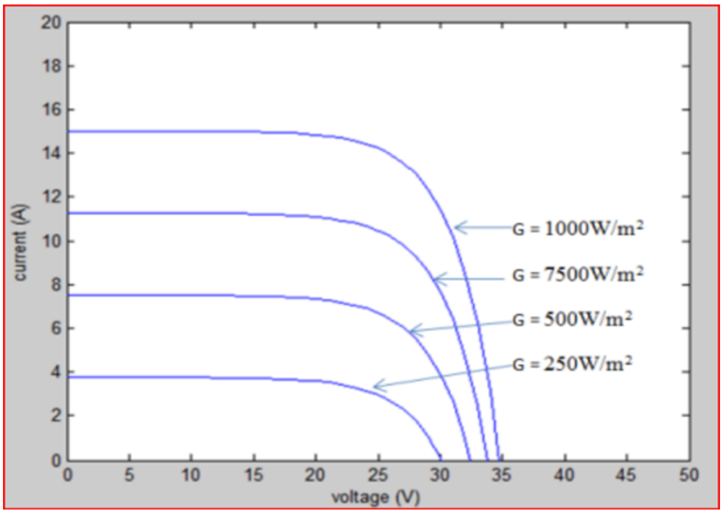

Fig.3 VI curves with different at different insolation levels and at 25 °C.

Two-Diode PV Module Model:

Single-diode and two-diode PV modules are the two varieties now available in the literature[16]. The idea that charge carriers do not recombine in the depletion area is the foundation of the PV module's single-diode concept [17–20]. In a genuine PV cell or module, recombination of charge carriers is a major loss, especially at low voltages. To reproduce this, many diodes are required. As a result, the two-diode PV cell/model that accounts for recombination loss is presented [21]. Fig. 1 shows the electrical equivalent circuit for the two-diode PV module design. Equations (1) through (3) in MATLAB/Simulink provide a mathematical representation of the PV module's two-diode model [22–23].

$$I_{pv} = I_{ph} - I_{0,1}\left[exp\left(\frac{V_{pv}+I_{pv}R_s}{a_1V_{T,1}}\right)-1\right] - I_{0,2}\left[exp\left(\frac{V_{pv}+I_{pv}R_s}{a_2V_{T,2}}\right)-1\right] - \left(\frac{V_{pv}+I_{pv}R_s}{R_p}\right) \quad (1)$$

$$I_{ph} = \frac{G}{G_{STC}}\left[I_{ph,STC} + K_I\Delta_T\right] \quad (2)$$

$$I_{o,1} = I_{o,2} = \frac{I_{SC,STC}+K_I\Delta T}{exp[(V_{OC,STC}+K_V\Delta T)/\{(a_1+a_2)/p\}V_T]-1} \quad (3)$$

Equations (1)–(3) are used to determine the parameters of PV modules. Vpv and Ipv stand for terminal voltage (V) and current, respectively. Voc, ST C, and Isc, ST C stand for open-circuit voltage and short-circuit current under standard test conditions (STC) of 1000W/m2 at 25°C; Iph, ST C, and Iph stand for photo-generated currents at STC and any taken-in isolation.

PV Configurations:

Equalizing the currents produced by various electrical rows is its primary goal. Otherwise, in order to balance the irradiance, the reconfiguration process entails relocating the electrically or physically linked solar PV panels. Techniques for array reconfiguration come into two major categories: static operations and dynamic methods [24].

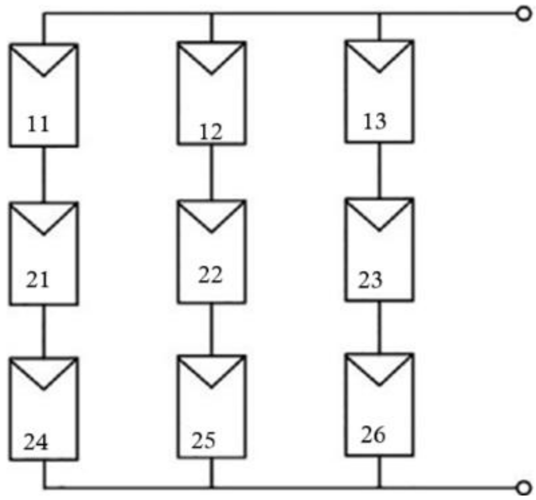

Fig.4 SP configuration

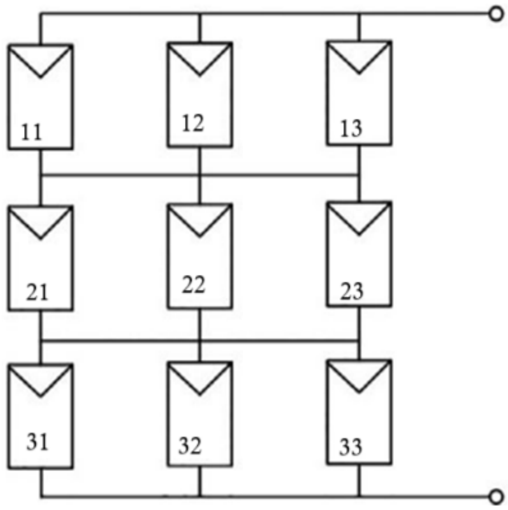

Fig.5 TCT Configuration

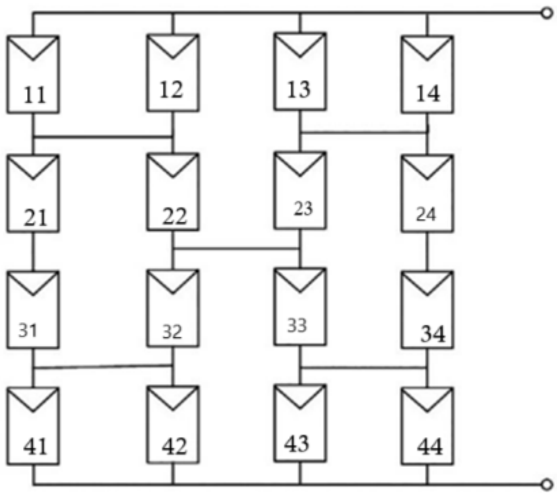

Fig.6 Bridge linked

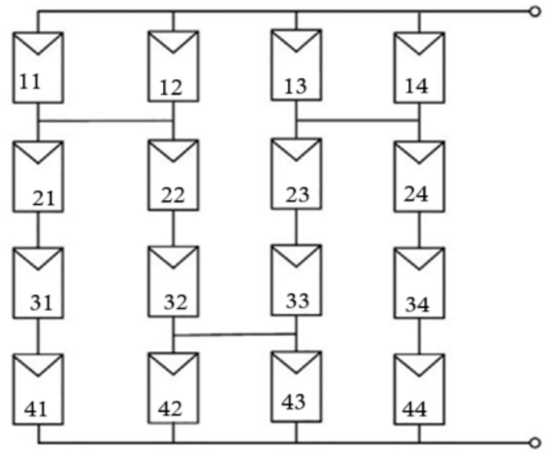

Fig.7 Honey comb

Because of its straightforward design and benefits for cost-effective operations, it is the most often used PV array arrangement. In this design, the necessary voltage is obtained by connecting five modules in series, and the necessary current is produced by connecting five comparable setups in parallel. Mismatch losses are decreased because a series structure has fewer modules coupled than a series structure. The SP topology for a 3 x 3 PV array system is shown in Figure 4[25].Each module in this PV array design is connected by a bridge rectifier structure. A discernible voltage drop occurs under PSCs because several modules are coupled in series in an SP setup. In this arrangement, two modules are connected in series, and then two more modules. The bridge connection arrangement for a 4 × 4 PV array system is shown in Figure 6.This design was inspired by the HC produced by honeycomb bees. The PVs of this PV array arrangement are connected in an HC-like hexagonal layout. The HC architecture for a 4 × 4 PV array system is shown in Figure 7.

Fill Factor (FF):

The fill factor (FF), which is the ratio of the regions filled by the product of the ISC-VOC and IMPP-VMPP rectangles, is displayed in Figure 3. It is computed by dividing the MPP by the total of the short circuit current and open circuit voltage. It demonstrates the I-V curve's confidence. If a cell's I-V curve is square, it is better. It drastically degrades when parasitic resistive elements like shunt and series resistance are added [26].

$$FF=\frac{M_{PP}}{V_{oc}I_{sc}} \tag{4}$$

Darkening one series circuit won't significantly impact the array's overall output, in contrast to a pure series setup. This improves the reliability and redundancy of the array. In order to safeguard each PV string against serious PSCs or short-circuit scenarios, blocking diodes are also linked in series[27]. These diodes stop string current from flowing backward into another string. In commercial and large-scale PV projects, where shading, system reliability, and energy production optimization are critical factors, T-C-T topologies are commonly used. The TCT configuration originates with the SP configuration. Instead of being directly linked to the inverter, the rows of solar modules are "cross-tied" to one another. This suggests that a grid-like pattern is created by some of the rows being connected to one another in series. The cross-tied rows are then connected to the inverter in parallel. Using this parallel connection reduces the impact of shading or underperforming panels. Because the rows are cross-tied, if a piece of the array is shaded, only the affected rows would suffer lower output, leaving the remaining rows unaffected. This means that when one row is darkened or performs poorly, it won't influence the entire array as it could in a traditional series configuration. Because more modules are connected in series during PSCs, the S and S-P configuration is most impacted. In order to improve the electrical characteristics of a PV system, a bridge link is frequently used to connect many PV modules or strings. By altering the BL configuration, a new configuration known as the HC configuration has been produced. The shortcomings of SP and BL topologies could be resolved by modeling an HC PV array configuration. The homes of honey bees were the primary inspiration for the design. Compared to the S, S-P, and B-L PV array layouts, the H-C PV array architecture has fewer series connections and more electrical connections between the PV modules. The I − V & P − V characteristics of the chosen module at various insolation levels and 25 °C are shown in Figures 2 and 3. Table 2 displays this module's power output at 900, 800, 700, and 600 W/m2[28]. A PV system's efficiency is always influenced by temperature, age, dust particles like sand and ash, and radiation. To improve PV array performance, new topologies are being researched and used. [29] In order to assess and improve the efficiency of PV modules, multiple solar PV array topologies—such as SP, TCT, and BL—are taken into consideration for varied shading patterns. Consequently, it is more crucial to research PV array behaviour in partial shadowing. Partial shade may have the effect of lowering the PV array's performance. Modifying or adjusting the solar PV array's connectivity can significantly alleviate this shadowing issue; hence, SP and BL topologies have fewer interconnections than TCT topology PV arrays.

Table 1: PV array shading pattern

Shading Pattern	**Uneven Row**			
	A11	A12	A13	A14
	A21	A22	A23	A24
	A31	A32	A33	A34
Case-1	A41	A42	A43	A44

(a)

Shading Pattern	**Uneven Column**			
	A11	A12	A13	A14
	A21	A22	A23	A24
	A31	A32	A33	A34
Case-2	A41	A42	A43	A44

(b)

300 W/m2	**900 W/m2**	**800 W/m2**	**700 W/m2**	**600 W/m2**	**500 W/m2**	**400 W/m2**	**1000 W/m2**

Fig- 8 Different shade patterns under PSCs are shown by (a) an uneven row and (b) an uneven column.

Table-2 Efficiency of array under uneven row shading condition

Configuration	V_m	I_m	V_{oc}	I_{sc}	Mismatch Loss	P_{max} (W)	FF	$\eta\%$
SP	37.92	20.05	55.47	17.73	98.703	760.296	0.64	11.32
TCT	38.18	19.61	55.52	17.73	97.71	748.71	0.64	13.47
BL	37.21	20.01	55.31	17.52	98.37	744.572	0.64	11.48
HC	37.3	19.89	55.21	1.01	98.21	741.897	0.64	12.24

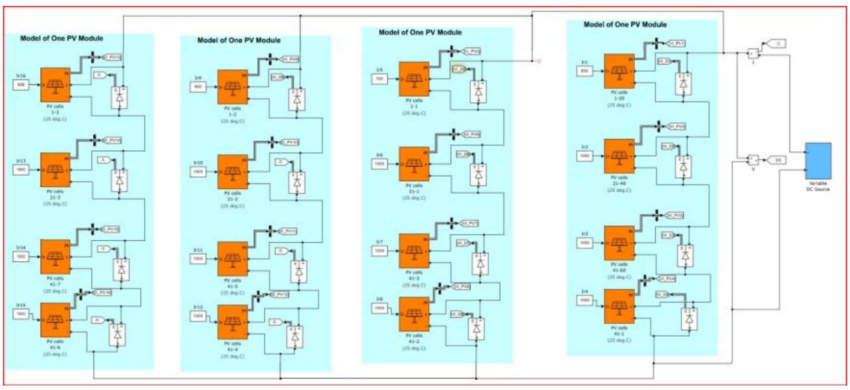

Fig-9 (a) Matlab simulation of 4*4 SP configuration

The proposed 4x4 hybrid configurations shown in Figure 9 (a) are modeled in this section. Modules are arranged in four rows and four columns in each arrangement. (11, 12...., 14); (21, 22,...., 24); (31, 32,...., 34); (41, 42,...., 44); are the numbers assigned to the modules. The module in the third column and fourth row, for example, is identified by the number "43."

The symmetrical elements of any two conventional arrangements are combined with a crosstie in between to create the hybrid configurations. The T-C-T design seen in Figures 4 to 7 [30–33] is replicated by combining the symmetrical S-P and T-C-T layouts.
An array's modules are first put together in an S-P arrangement. Cross-tying is then used to unite the third and sixth rows. This cross-tied connection creates a series link between the S-P and T-C-T configurations by connecting the modules (31, 32,...., 34) and (41, 42,...., 44) at the same node [34–36].

Implementation of TCT configuration In EV charging System:

The Total Cross-Tied (TCT) photovoltaic (PV) configuration (shown in Fig 9 (b)) is a highly efficient interconnection scheme for solar panel arrays, making it an ideal choice for Electric Vehicle (EV) charging systems. Unlike the conventional series-parallel (SP) configuration, the TCT arrangement connects adjacent rows of PV modules through cross-tied connections, reducing power mismatches caused by partial shading, temperature variations, and panel degradation. This results in higher output power, improved reliability, and better fault tolerance, making TCT a superior configuration for EV charging stations where consistent energy supply is crucial. Integrating a TCT-configured PV array into an EV charging system enhances energy harvesting and maximizes power generation. The reduced voltage and current mismatches in the TCT configuration lead to lower power losses and increased conversion efficiency. To further optimize power flow, a Maximum Power Point Tracking (MPPT) algorithm is employed to dynamically adjust the operating point of the PV array. The generated DC power is then processed through a DC-DC converter (such as a boost or buck-boost converter) to regulate the voltage level according to EV battery requirements. Additionally, an energy storage system (ESS), such as a battery bank or supercapacitor, can be integrated to store excess solar energy for uninterrupted charging, even under low sunlight conditions. A grid-tied or standalone hybrid system can be deployed, incorporating smart controllers for optimal power distribution. The enhanced resilience of the TCT configuration ensures higher reliability and efficiency, making it a promising solution for sustainable EV charging infrastructure. As solar energy continues to play a crucial role in clean transportation, TCT-based PV integration can significantly advance the future of eco-friendly EV charging networks.

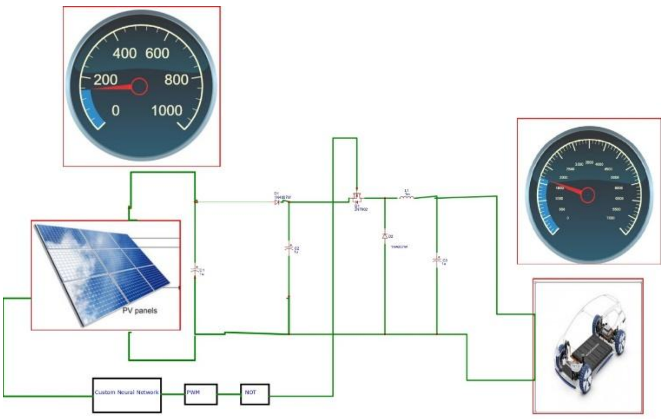

Fig. 9 (b) Design of TCT configuration In EV charging System

RESULTS

For various PSCs, the performance of many current PV setups was examined. Figures 10 through 17 compare the performance of the best PV arrays now in use with those that have been suggested. TCT performs better than any other techniques for UR partial shading in the current PV array topologies.

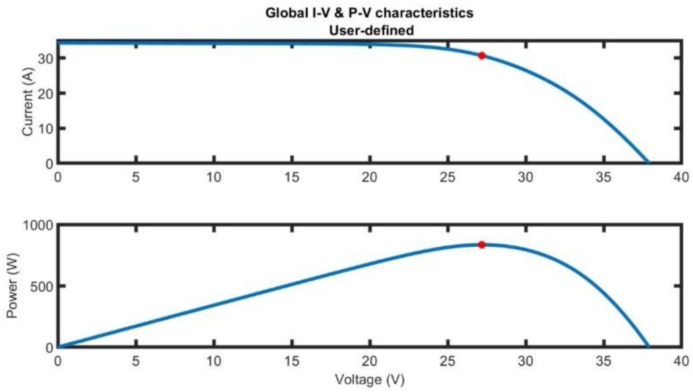

Fig-10 PV and VI features of the PV system's SP setup in the absence of PS condition scenario (1)

According to a summary of studies on interconnection topologies, a higher mismatch power loss (MPL) is the cause of the solar PV array's decreased output power. Alternate connecting strategies can reduce the MPL experienced in solar PV arrays under PSC. Previous researchers have suggested H-C, B-L, and conventional TCT connecting schemes in this direction rather than the previously documented series (S), parallel (P), and S-P connectivity schemes. The idea that the classical TCT connecting design yields very low power loss under non uniform shading conditions has not been widely supported by authors.

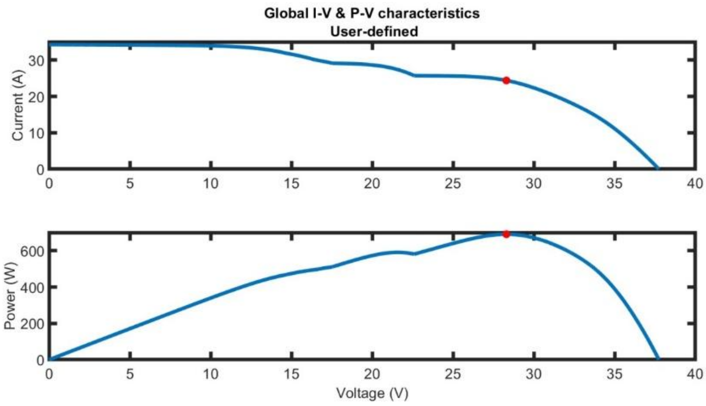

Fig-11 PV and VI characteristics of SP configuration of PV system with PS condition case (1)

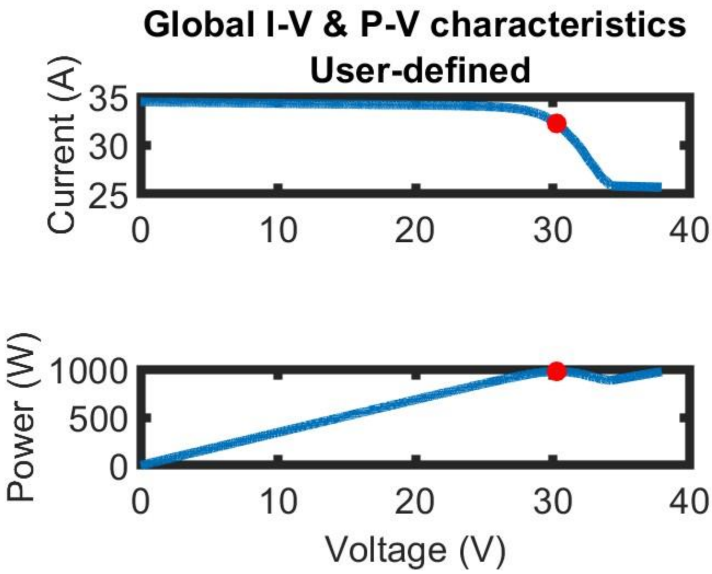

Fig-12 PV and VI characteristics of TCT configuration of PV system with PS condition case (1)

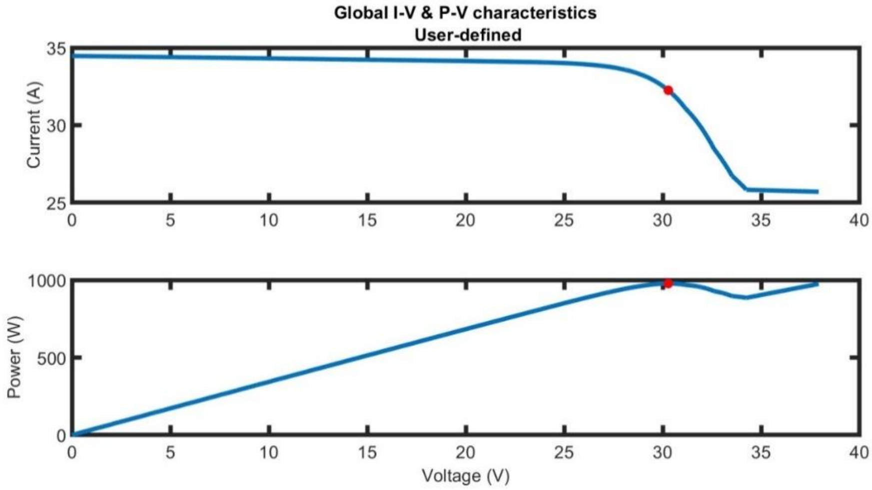

Fig-13 PV and VI characteristics of BL configuration of PV system with PS condition case (1)

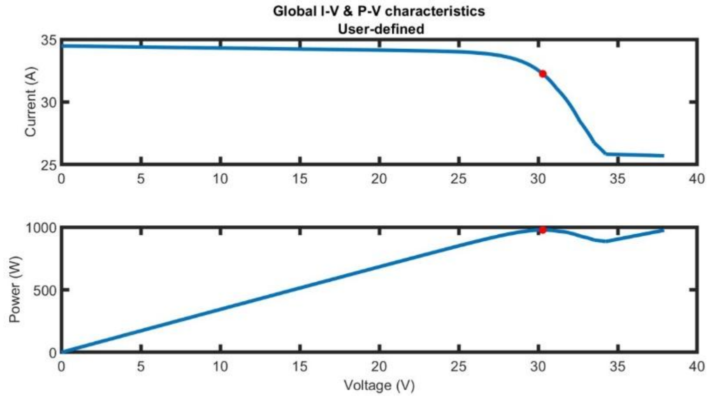

Fig-14 10 PV and VI characteristics of HC configuration of PV system with PS condition case (1)

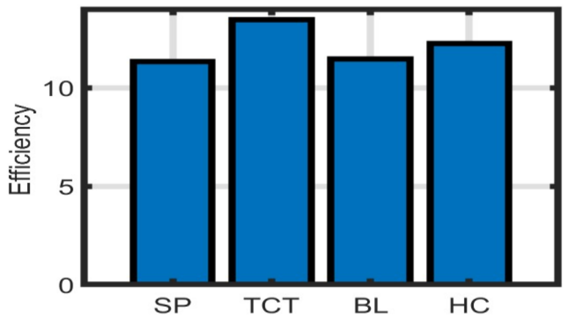

Fig-15 Efficiency of PV array with PS condition case (1)

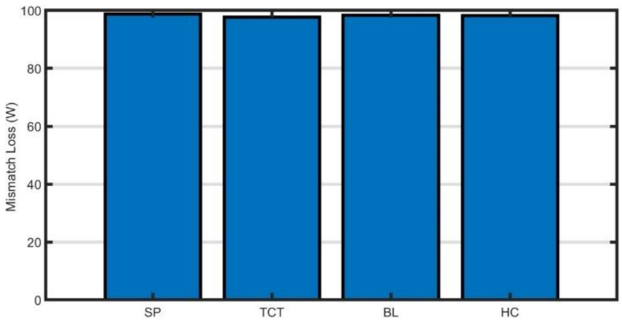

Fig-16 Miss match loss of PV array with PS condition case (1)

Mismatch loss happens because the lowest irradiation level under PSCs determines the PV array's output current. Unlike un-shaded PV panels, shaded ones function in reverse bias. Hot spots therefore develop on the shadowed panels, harming the PV panels and resulting in heat-related power outages. As seen in Fig. 7, a bypass diode is placed across each PV panel to prevent such hot areas. The output power and voltage of this PV array are significantly influenced by PSCs. The full simulation results for each PSC are shown in Table 2. Performance-wise, the proposed TCT, PV outperforms the existing SP design.

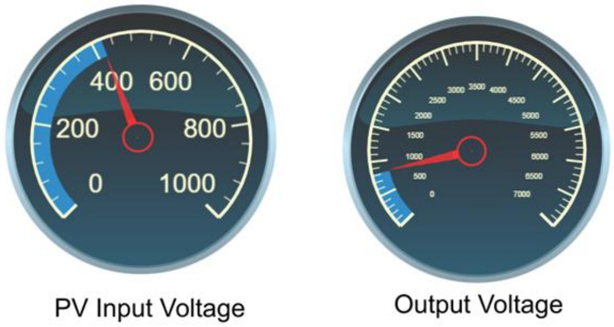

Fig-17 Input output voltage of proposed design

The TCT PV array generates an input voltage of 400V to 500V DC, optimized via CNN control. A DC-DC converter (boost or buck-boost) regulates the output voltage to 700V–800V DC (shown in Fig-17), depending on the EV battery and charging level .

CONCLUSION:

By reducing the mismatching loss under PSCs, the suggested topologies provide more power than the traditional setups. Additionally, the output characteristics have less peaks because to these hybrid arrangements. Less redundancy, fewer connections, less wire loss, and other benefits are features of hybrid setups. For this study, three solar array topologies—SP, TCT, and BL—have been taken into consideration in order to evaluate the impact of vertical, horizontal, and diagonal shadowed patterns. In most situations, the shading pattern's impact on these topologies leads to several maxima and an increase in the non-linear effect. TCT has performed better and generates more power for vertical shading progress. For each of the four partial shade profile scenarios taken into consideration, the output power of the suggested TCT, SP, HC, and BL connectors is higher than that of traditional interconnections. Additionally, fewer ties are needed for the suggested TCT, SP, HC, and BL interconnections than for the classical interconnection. As a result, less wiring is needed for the suggested hybrid connections. For the 4 × 4 test solar PV array, it is found that the output power is further increased when the bypass diode arrangement method is used (across each solar PV module in the array). In conclusion, suggested hybrid interconnection topologies—especially those involving bypass diodes—are novel ways to increase the solar PV array's electrical power production in conditions with non-homogeneous irradiation (partial shadowing).In the case of DSP partial shading, the output power of the suggested hybrid interconnected 4 × 4 SPV array configurations is 23.4% higher than that of the SP interconnection.

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