Enhancing PV Power Extraction Under Partial Shading Condition with Shade Dispersion Strategy

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ABSTRACT

Improving photovoltaic (PV) system efficiency is a popular field of research. Partial shading (PS) adversely impacts the solar system's output power, which considerably reduces the system's efficiency. As a result, this issue has been the subject of extensive investigation. When sunlight is blocked off of photovoltaic cells in a PV array, panel, or module, it is referred to as shading. Using a method that involves spreading shade throughout the PV array is one of the suggested fixes for this issue. This study compares the performance of a shade dispersion method to different PV array configurations under different partial shading circumstances, and it looks at how effective it is in a 3x3 PV system. MATLAB/Simulink is used for the evaluation. To achieve this, shade dispersion-based TCT (SD-TCT) under various shading scenarios has been compared to the current standard designs, which include series-parallel (SP), Honey-Comb (HC), Bridge-Linked (BL), and Total Cross-Tied (TCT). Based on the global maximum power (GMPP), mismatch power losses, fill factor (FF), percentage power losses (PL %), and PV system efficiency, the efficacy of the shade dispersion technique was assessed. For every partial shading condition (PSC) that was studied, the SD-TCT configuration outperforms the other setups in terms of fill factor and power loss.

1. Introduction

Nowadays, energy consumption of the world is Overcame by traditional, nonrenewable energy sources. Toxic and dangerous chemicals get released from These sources into the atmosphere. As a result, the climate and environment will be badly influenced leading to the worsening of global warming [1]; investigating alternative and renewable energy sources in immediate manner is important to secure environmental preservation, long-term sustainability, and fulfillment of the world's enormous energy demands [2-4], photovoltaic energy systems, also known as PV systems, are a common type of renewable energy. The thriving of photovoltaic technology can be attributed to various factors, including its environmental friendliness, the abundance of solar radiation, and its simple installation method on residential rooftops [5]. The photovoltaic effect, which is the process of turning solar photons into electricity by using semiconductors like silicon, is the basis for solar panel technology [6]. The factors that affect the effectiveness and performance of Systems the most are temperature, solar irradiation, and partial shading (PS) [7, 8].

The photovoltaic (PV) system's Maximum Power Point (MPP) have a great obstacle to be dodged which is the occurrence of PSC[9]. Partially shaded modules are the result of some
of a photovoltaic array's modules being partially shaded by surrounding structures, buildings, clouds, and other things. This leads to the production of multiple power points (MPPs), the greatest of which is the GMPP. It also greatly distorts the power-voltage (P-V) and current-voltage (I-V) curves. As a result, noticeable decrease in the maximum power that the PV array is capable of producing. Other sites refer to PV array's performance data, as Local Maximum Power Points (LMPPs) [10–12].

PSC effect in a solar photovoltaic array can be reduced by different methods and strategies. Such as using a variety of connectors. To do so, the PV array's module connections are modified from the traditional SP structure to a new arrangement, such as TCT, BL, or HC [7], [13]. when some of them are shaded from the sun, the amount of current that modules in a row generate is consequently reduced. As a result, regardless of any obstruction, multiple unique paths are created for the electric current to flow through [3]. Another method to lessen the effect of partial shadowing is to disperse the shadow uniformly throughout the displayed array. As long as the array's shadow pattern doesn't change, dispersion can be accomplished by moving PV modules around without breaking their connections [14]. Various algorithms are used to disperse partial shade in photovoltaic energy systems. Some common algorithms include the Particle Swarm Optimization (PSO) algorithm, the Genetic Algorithm (GA), and the Perturb and Observe (P&O) algorithm for Maximum Power Point Tracking (MPPT) mitigating partial shading effects [15].

The following tactics have been tested by several researchers in an attempt to raise the PV array's efficiency. The optimal energy harvesting under various shade conditions is described by Mayank Kumar [16] utilizing physical relocation and fixed column position modules with fixed electrical connections (PRFCPM-FEC). The algorithm is explained for m x n modules under different shading conditions. The intended configuration is maintained while adjusting module placements without damaging electrical connections. Furthermore, a comparison is made between the suggested pattern arrangement, TCT, and actual physical relocation of modules with fixed electrical connections (PRM-FEC). The array layout improves PSC performance, according to the results.

Under various shadowing situations, Kazerani et al. [17] investigated a variety of techniques, including SP, TCT, BL, half-reconfiguration photovoltaic arrays (HRPVA) and full reconfiguration photovoltaic arrays (FRPVA). The HRPVA composition produced the best outcomes.

For PV arrays of any size, Dhanup S. Pillai et al. [18] assessed a two-phase shadow dispersion technique. Due to its two separate phases, the two-phase approach utilized to relocate PV panels offers excellent shade dispersion. Four shade cases were compared to other approaches found in the literature to validate their involvement in physical relocation. Furthermore, a quantitative comparison between electrical reconfiguration (PSO), popular physical relocation (SuDoKu), and TCT connection procedures is provided for row current computation and bypass impact. According to the findings, the recommended two-phase approach can accomplish fill factors of 72% for short-wide scenarios, 62% for long-wide situations, 81% for short-narrow situations, and 75% for long-narrow conditions. Except for one pattern, the suggested method also produced a minimum power improvement of 700 W when compared to TCT in all shadow scenarios.

Sangram Bana and R.P. Saini [19] tested uniform and non-uniform shadowing on solar photovoltaic modules using various connection techniques. Array size experiments in different shadows were used to calculate the curves of solar system attributes. Different transmissivity meshes were used to create random shading patterns. Bypass diodes also impact the power production of photovoltaic systems. The final analysis identified the optimal module design under partial shadow and uniform insolation. As a conclusion the study recommend the partial shadowing the operation and design of solar systems.

Fabio Viola et al. [20] inspected the economic advantages of executing a reconfiguration system in photovoltaic plants to
promote efficiency and enhance power generation. Cost-effectiveness of this system in different countries were evaluated with diverse incentive structures, giving consideration to factors like installation, shadow projections, incentives, and reconfiguration costs. Financial metrics like Net Present Value (NPV) and payback period are utilized to measure the usefulness of such an investment. The study concluded that the economic benefits of using a reconfiguration system for photovoltaic plants are considerable, especially taking into account the different incentive policies in various countries.

Possibility for static reconfiguration using Magic Su-Do-Ku were investigated by G. Madhusudanan and colleagues [21]. By the effective shadows spreading while maintaining TCT connections, the aim of this creative method was to maximize power generation and PV array performance enhancement in partially shadowed conditions. Consequently, determine the ideal circumstances for generating a substantial amount of electricity at the PV array’s maximum power point (MPP), by examining different shading patterns. The outcome obtained under a variety of shading situations indicates the effectiveness and success of this methodology.

In a groundbreaking study, carried out by Suneel Raju Pendem and Suresh Mikkili [22] Simulations were carried to evaluate the performance of many PV array designs, including Series (S), SP, BL, and HC, under different shading patterns. Simulations were executed on 5*5 PV array systems in MATLAB/Simulink. The HC design performed better than the others, regarding the outcomes, hence it is appropriate for standalone and on-grid PV systems with central inverters.

In this study, shade dispersion strategy-based TCT (SD-TCT) and various solar array configurations, were compared in terms of how well it works to improve the efficiency and performance of the photovoltaic system. The evaluation depends on the highest power produced, efficiency, FF, PL%, and the least amount of mismatch power losses.

2. Photovoltaic Array Modeling

Numerous scholars have previously offered a variety of methods, including single-, double-, and triple-diode models, for simulating PV cells. Figure 1 shows a simplified version of a photovoltaic (PV) cell with a single diode for clarity [21], a mathematical equation of a Photovoltaic solar cell module which characterizes the I-V characteristics is given by:

\[
I_{ph} = \frac{I_{Scr} + k_i(T-298)}{1000} \times \lambda
\]

\[
I_{rs} = \frac{I_{Scr}}{e^{(qV_{oc}/NpKAT)}-1}
\]

\[
I_0 = I_{rs} \left( \frac{T}{T_r} \right)^3 \left( e^{\frac{qV_{oc}}{nkT}} - 1 \right) e^{\frac{q(V+IR_s)}{nkT}}
\]

\[
1 = I_{ph} - I_0 \left( e^{\frac{q(V+IR_s)}{nkT}} - 1 \right) - \left( \frac{V + IR_s}{R_p} \right)
\]


![Figure 1. PV cell single-diode circuit [23]](image)

Figure 2 represents the mathematical representation of a photovoltaic cell using MATLAB/ Simulink. Figure 3 depicts the fundamental block diagram of the system outlined in this study, which has been simulated using Matlab.
This study uses the type 1 soltech 1STH-215-P Solar PV module to mimic multiple array configurations, including SP, HC, BL, TCT, and SD-TCT. The specifications that the system employs for the PV modules are listed in Table 1, and Figures 4(a) and 4(b) show the P-V and I-V characteristics of the PV modules that are used in the system.

**Table 1: PV Module parameter used in the system at STC (1000 W/m² and 25°C)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max power</td>
<td>213.15W</td>
</tr>
<tr>
<td>Max power point current</td>
<td>7.35 A</td>
</tr>
<tr>
<td>Max power point voltage</td>
<td>29 V</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>7.84 A</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>36.3V</td>
</tr>
<tr>
<td>Fill Factor</td>
<td>%74.6</td>
</tr>
<tr>
<td>Number of series Cell</td>
<td>60</td>
</tr>
<tr>
<td>Isc temperature coefficient</td>
<td>0.102</td>
</tr>
<tr>
<td>Temperature coefficient of Voc</td>
<td>-0.36099</td>
</tr>
<tr>
<td>Dimensions</td>
<td>1626<em>964</em>46 mm</td>
</tr>
</tbody>
</table>

**Figure 2. Simulink Model of PV cell**

**Figure 3. Simulink model of PV system**
3. PV Array Configurations

Solar power systems fall into two basic categories: standalone systems, which are typically utilized in rural and remote regions and have a power output of a few kilowatts, and grid-connected systems, which can provide the grid with many megawatts of power[14]. To meet the voltage and current requirements of the electrical network or the power requirements of the loads, solar panels must be assembled and connected to a photovoltaic (PV) array [5], [13]. To evaluate how well the proposed shade dispersion method works to lessen the effects of a partial shadow scenario, it needs to be compared to existing standard setups. With MATLAB/Simulink, four distinct configurations—the SP, HC, BL, and TCT—have been simulated. The P-V and I-V properties of the SD-TCT setup were then compared using these configurations in various partial shadow scenarios. Figure 5 displays every configuration utilized in this paper. Figure 5(a) displays the SP's blueprint, the first step in achieving the desired output voltage is to connect every module in series. Consequently, these series of connections must be combined in parallel at the end of each row. Figure 5(c) shows a graphic illustration of the BL setup. To be more precise, the bridging unit consists of four distinct parts. Connecting identical modules in parallel is the next step after connecting two modules in series within a circuit. Cross ties are employed to link the different bridges that comprise a network. In addition, Figure 5(d) displays the HC arrangement. The bridge's dimensions can be changed to provide an alternative configuration for the HC configuration, which is a modified version of the BL design [4]. In this paper, manually moving the solar panel while maintaining the electrical connections is the preferred method for shade dispersion. Thus, as shown in Figure 5(e), the Shade Dispersion Technique-Based TCT (SD-TCT) is presented. The TCT arrangement is used to create electrical linkages between the PV modules. On the other hand, all PV modules that are physically connected inside an array of PV modules in a series column string are those that belong to an odd-numbered row according to their electrical connection. The modules from even-numbered rows are grouped again after being arranged in a column with all the odd-numbered modules first, followed by the electrical connections. Additionally, the module linked in the first row of a given column moves a certain number of rows following each succeeding column in a sequential fashion.
4. Results and discussion

The purpose of this study is to present simulation results for the five PV array topologies operating under various PSCs. Measured and compared across PV installations in MATLAB/SIMULINK simulations of different partial shade circumstances were GMPP, mismatching power losses, FF, and PL%. On a 3x3 PV array operating in PSCS mode, experiments were conducted to evaluate the effectiveness of various array configurations. To assess the PV system's performance, the study exposed the solar modules to two different partial shade patterns:

The first pattern: Cases I, II, and III in Figure 6 represent what is thought to be progress on the leftmost modules (from top to bottom) where the moving shadow is seen.

The second pattern is represented by examples IV, V, and VI in Figure 6 and is interpreted as progress on the bottommost modules (from left to right).
Initially, to determine whether the HC, TCT, BL, and SD-TCT configurations reduce the amount of electricity produced under normal conditions, they must be contrasted with the conventional connection SP architecture without shade. The measured I-V and P-V characteristics of all possible PV array designs at the same operating conditions (1000 W/m² and 25°C) are displayed in Figures 7, where Figure 7(a) represent I-V characteristics and Figure 7(b) represent I-V characteristics. Table 2 provides information on the maximum power output of a 3x3 solar array. All five array layouts have nearly identical maximum power levels, according to the research, and there is just one notable power peak. The simulation results of PV array configurations under shading cases are represented in Table 3.
The P–V characteristics of several PV array topologies under various partial shading scenarios are shown in Figure 8. Two maximum power points (MPPs) are shown in the P–V curves of all designs in Figure 8(a). The GMPP of the BL and HC versions is 1478.7674W,
whereas the GMPP of the SP configuration is 1448.0332 W. The maximum power of the TCT and SD-TCT configurations is 1567 W.

The shading for case II is looked at in Figure 8 (b). Three MPPs and a GMPP are present in SD-TCT at 1539.341 W. In BL, HC, and TCT setups, two MPPs with a maximum power of 1262.138 W are seen; this is significantly more than the actual GMPP and results in increased shadowing. For the SP configuration, a single MPP with a maximum power of 1294.308 is discovered.

The P-V curves for the partial shadowing condition in instance III are shown in Figure 8(c). In this case, the curves for the SP, HC, BL, and TCT configurations are the same and have two MPPs with a maximum power output of 1262.124 W. In scenario 4, this value is acknowledged as the actual GMPP for the PSCS. Because of its distance from the GMPP, the LMPP may have a stronger shading impact. Three MPPs are detected for the SD-TCT configuration; two of them are LMPPs, while the third is a GMPP with a power value of 1529.237 W.

The outcomes of instance I-V coincide with case I. Figure 8 (d) shows the P-V curves under the partial shadowing situation of case IV.

In Figure 8 (e), the P-V curves for case V are shown. The curves for the SP and BL configurations are the same, with three MPPs. The GMMP is determined to be around 1478 W. Because of its distance from the GMPP, the LMPP may have a greater shading impact. Two MPPs match the P-V curve for the HC and TCT arrangement; the GMPP, located at 1262.138 W, is one of them, and the LMPP is the other. Three MPPs are detected for the SD-TCT configuration; two of them are LMPPs, and the third one, with a power value of 1539.341 W, is a GMPP.

Figure 8(f) displays the P-V curves for case VI's partial shading condition. The P-V curves for the SP, HC, BL, and TCT configurations are the same; two MPPs have emerged, and GMPP is discovered to be at 1262.124 W. In the P-V curve for the SD-TCT configuration, three MPPs have emerged; two of them are LMPPs, and the third is GMPP, which is discovered to be at 1529.235 W.

The GMPP is shown for several PV array topologies in Figure 9. It shows that when it comes to tracking the MPP under PSCS, the SD-TCT method works better than other configurations.
Figure 8. P-V Curve of PV array under shading pattern

Figure 9. GMPP of various PV array configurations

Figure 10 uses bar graphs to display the fill factor of different PV array arrangements, while Figure 11 displays the power losses brought on by mismatches. It is observed that the SD-TCT performs better and demonstrates good results in all scenarios examined in this research by lowering mismatch losses and raising the FF.
Figure 11. Mismatch power losses of various PV array configurations

Figure 12 displays bar graphs representing the percentage power losses (PL%) of the different PV array configurations. PL% is the ratio of the GMP obtained under unshaded conditions to the GMP obtained under shaded conditions. It is seen that the SD-TCT performs better than all other configurations and demonstrates good results by lowering the percentage power losses in cases II, III, and VI. TCT and SD-TCT are equally effective in terms of percentage power losses in Cases I, IV, and V, while also outperforming the alternative design.

Figure 13 displays bar graphs illustrating the efficiency of different PV array configurations. It is observed that in all instances examined in this study, the SD-TCT consistently outperforms and demonstrates favourable outcomes by enhancing the efficiency of the PV system.
5. Conclusions

The SP, HC, BL, TCT, and SD-TCT PV array topologies, among others, have all been the subject of extensive research and analysis. On the above-specified setups, two different partial shade patterns for the solar modules have been investigated. The resulting metrics have been used to assess and contrast their performance, including GMPP, mismatch power loss, FF, and percentage power loss. The findings of the thorough simulation have been examined. Out of all the partial shading scenarios studied, the results show that SD-TCT exhibits the lowest power loss, maximum fill factor (FF), and best performance ratio. In the circumstances of partial shadowing that were studied, the efficiency of the photovoltaic energy system improved. Concerning examples I, II, III, IV, V, and VI, the shade dispersion technique specifically produced percentage improvements of 8%, 19%, 21%, 8%, 6%, and 21%, respectively. The SD-TCT method used in this research does not incur any additional economic costs, as the basic idea is based on changing the locations of solar panels within the photovoltaic system itself while maintaining electrical connections. Numerous studies have shown that PV array reconfiguration provides significant economic benefits, especially when taking into account the incentive programs offered in different countries. This underscores the importance of looking not only at technical improvements but also at regulatory and economic contexts when assessing the feasibility and profitability of such initiatives [20]. It is proposed to apply this technique practically, to study the future obstacles and difficulties that it may face, and to propose the integration of shadow scattering technology with maximum power point tracking (MPPT) algorithms. The facility's visual appearance may alter as a result of the application of shadow dispersion technology, which may not always be desirable, particularly if the facility has historical or artistic significance. In some contexts, the technology may encounter technical and engineering constraints, such as the requirement for enough room to install systems, or the required engineering adjustments.

References


