A review of PV array reconfiguration techniques for maximum power extraction under partial shading conditions

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A R T I C L E I N F O

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A B S T R A C T

Partial shading is a significant obstacle to the effective use of photovoltaic (PV) systems because it reduces output power significantly. The output power reduction is not proportional to the shaded area but rather depends on the PV array configuration/reconfiguration and shadowing pattern. PV array reconfiguration is one of the most effective solutions for overcoming the adverse effects of partial shading in PV systems. The main objective of PV array reconfiguration strategies is to disperse shades consistently over the entire area of the PV array to reduce the adverse impact of partial shading situations. This paper provides an in-depth examination of the significant existing PV array reconfiguration methods used to address the problem of partial shading. The various methods are evaluated and compared based on their techniques, benefits, and drawbacks. This work is an interesting reference for researchers in the field and a simple guide for beginners on PV array reconfiguration.

Abbreviations: AAR, Adaptive Array Reconfiguration; ABC, Artificial Bee Colony algorithm; ACO, Ant Colony Optimization; AEO, Artificial Ecosystem-based Optimization; AI, Artificial Intelligence; AS, Arrow Sudoku; BBA, Branch and Bound algorithm; BL, Bridge Link; BOA, Butterfly Optimization Algorithm; BIPV, Building Integrated PV; BST, Bubble Sort Technique; BWSA, Best Worst Sorting Algorithm; CBMT, Chaotic Baker Map Technique; CIA, Column Index Algorithm; CI-DAR, Current Injection based Dynamic Array Reconfiguration; DES, Dynamic Electrical Scheme; DSA, Deterministic Research Algorithm; DST, Dominance Square Technique; DPA, Democratic Political Technique; EAR, Electrical Array Reconfiguration; EI, Equalization Index; FDRT, Fast Dynamical Reconfiguration Technique; FRA, Flow Regime Algorithm; FFANN, Feedforward Artificial Neural Network; FEC, Fixed Electric Configuration; FL, Fuzzy Logic; GA, Genetic Algorithm; GMPPT, Global Maximum Power Point Tracking; GOA, Grasshopper Optimization Algorithm; GSA, Gravitational Search Approach; GWO, Grey Wolf Optimization; HC, Honey-Comb; HCPV, Highly Concentrated Photovoltaic; IMI, Irradiance point Mismatch Index; KKST, Ken-Ken Square Technique; LMPP, Local Maximum Power Point; LST, Latin Square Technique; PSCs, Partial Shading Conditions; PSO, Particle Swarm Optimization; PV, Photovoltaic; MCR, Modified Circuit Reconfiguration; MHHO, Modified Harris Hawks Optimizer; MIQP, Mixed-Integer Quadratic Programming; MLA, Machine Learning Approach; MPA, Marine Predators Algorithm; MPPT, Maximum Power Point Tracking; MST, Magic Square Technique; OE, Odd-Even; OSBA, Optimum Sudoku-Based Arrangement; PCT, Power Comparison Technique; RSA, Random Search Algorithm; R-HCTCT, Reorganized outcross TCT; SD, Shadow Detection; SDBR, Shading Degree Based Reconfiguration; SDGA, Standard Deviation Genetic Algorithm; SDS, Shade Dispersion Scheme; SER, Settled Electrical Reconfiguration; SMO, Social Mimic Optimization; SP, Series Parallel; SRAP, Static Reconfiguration of Adjacent Panels; SS, Skyscraper Scheme; TCT, Total-Cross-Tied; TPAR, Two-phase Array Reconfiguration; TT, Tom; LCA, Liquid Cycle Algorithm.

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1. Introduction

Due to the continual reduction in fossil fuels and oil resources, sustainable energy asset is of immense appeal [1–3]. Solar energy is one of the most promising green energy sources and provides an improved restoration of conventional power. Researchers around the globe are interested in solar energy because of its developed scope and eco-friendly nature. Solar PV energy generation provides electrical energy from solar irradiance [2]. The PV module's irradiance mismatching/PSCs is one of the major hindrances in the successful implementation of the PV power system, and it causes substantial losses. The mismatching may also result in hotspots that eventually damage the PV panels. The bypass diodes are added in parallel with the PV module or with a string of series-connected PV modules to minimize the consequence of PSCs.

By connecting bypass diodes with a series of PV modules (PV array), some regional MPPs emerge on the characteristic curves of the PV array under PSCs. The presence of these various peaks is the cause of difficulties in the tracking of optimal operating points. The incorporation of a more proficient power control system is required. It is also used to distinguish between local and global maxima to get maximum output of the overall design. The literature presents several global maximum power point tracking (GMMPT) techniques that can be found to deal with PSCs [4].

Furthermore, various PV arrays' layouts, such as BL (Bridge-Linked), TCT (Total-Cross-Tied), and HC (Honey-Comb), are also used to reduce shading consequences in comparison with conventional SP (Series-Parallel) configuration [5–7]. Among which, TCT interconnection offers greater power conversion efficiency under prolonged shade conditions [6–8].

For most scenarios of PSCs, the TCT layout gives the most satisfying performance and improves the extracted output power, but it does not provide the highest attainable power [9]. Therefore, PV array reconfiguration strategies optimize power output in case of imperfect irradiance aspects. The foremost intention of PV array reconfiguration is to adjust the resulting currents through various electrical lines. On the other hand, it repositions the solar PV panels either electrically or physically associated with adjusting the irradiance [10]. Array reconfiguration techniques are of two types – (1) Static and (2) Dynamic.

In static reconfiguration methods, the physical combination of PV modules is revised under certain positions to circulate partial shading effects over the array. These do not adjust the module's location with dynamism. In other words, the module's physical position remains fixed for all shading circumstances. In dynamic reconfiguration techniques, electrical interconnections of the PV modules are changed, and the physical location of the modules remains unchanged.

Static reconfiguration techniques do not need numerous sensors and switches. However, the interconnection arrangement is fixed under varying irradiance conditions. Static methods need experienced people to execute physical adjustments in the PV module. Hence, the application of static reconfiguration techniques in small-scale PV array structures is limited.

The static reconfiguration techniques are one-time arrangements of PV panels in the array that at times employ puzzle-based shade dispersion techniques, circular shift-based techniques, rule-based mathematical techniques, and techniques based on engineering approaches [11–15].

Also, several dynamic reconfiguration techniques have been discussed earlier in the literature to alleviate the consequence of partial shading. The basic idea behind dynamic reconfiguration is that when partial shading occurs, changing the connections of the solar PV sub modules with a switching matrix can instantly minimize output power loss. A switching matrix allows the system to toggle between series and parallel connections [16]. However, the true dynamic reconfiguration has begun with the selection of an appropriate PV array interconnection, which can mitigate mismatch effects [17]. Some of them are optimization algorithms based on Adaptive array reconfiguration strategy [18], Equalization index (EI) [19], and adaptive reconfiguration arrangement [20]. A

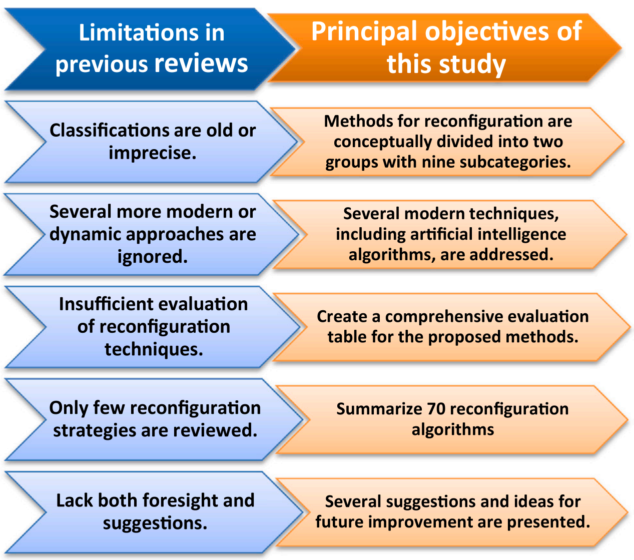


Fig. 1. Limitations of previous reviews and principal objectives of this study.

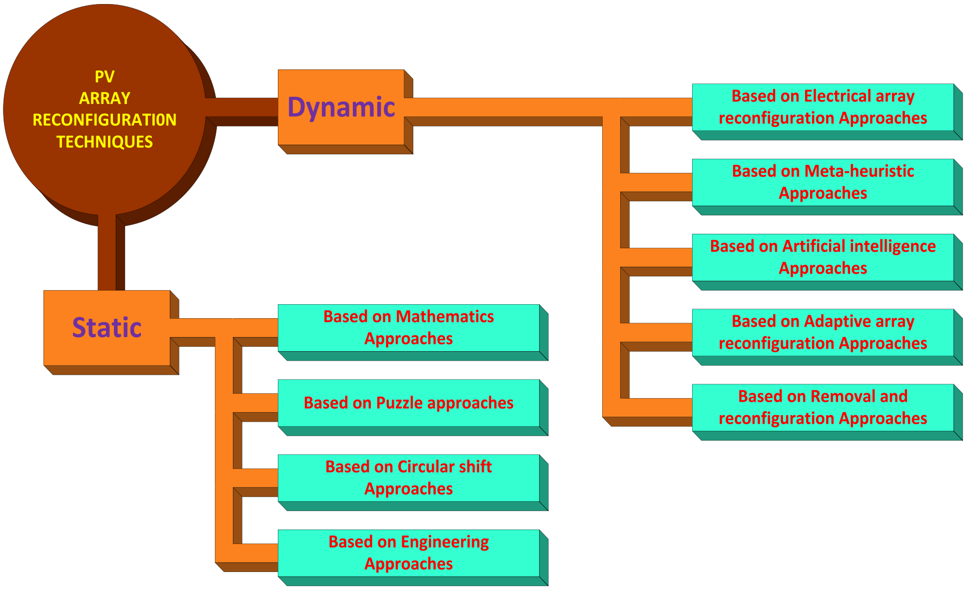


Fig. 2. Classification of Reconfiguration Strategies.

Dynamic Electrical Scheme (DES) allows for the connectivity of many different modules between the PV generator and the inverter. The method of mixed-Integer Quadratic Programming (MIQP) is resolved by the branch and bound technique[21]. The best configuration is identified using a hierarchical and iterative sorting approach based on the notion of irradiance equalization. Compared to a

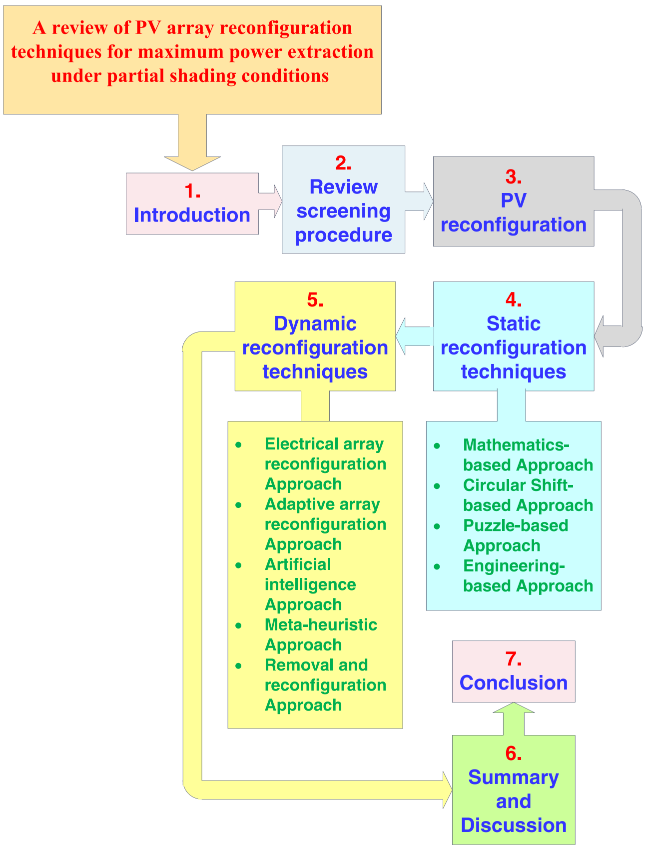
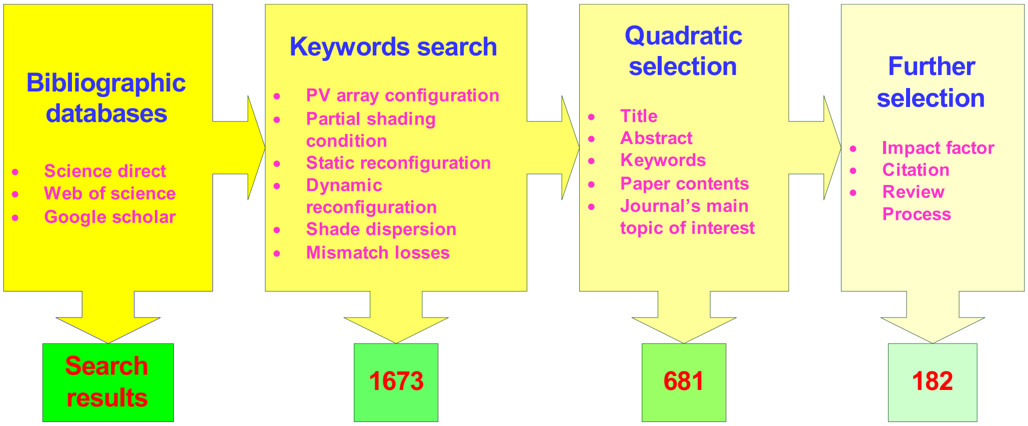
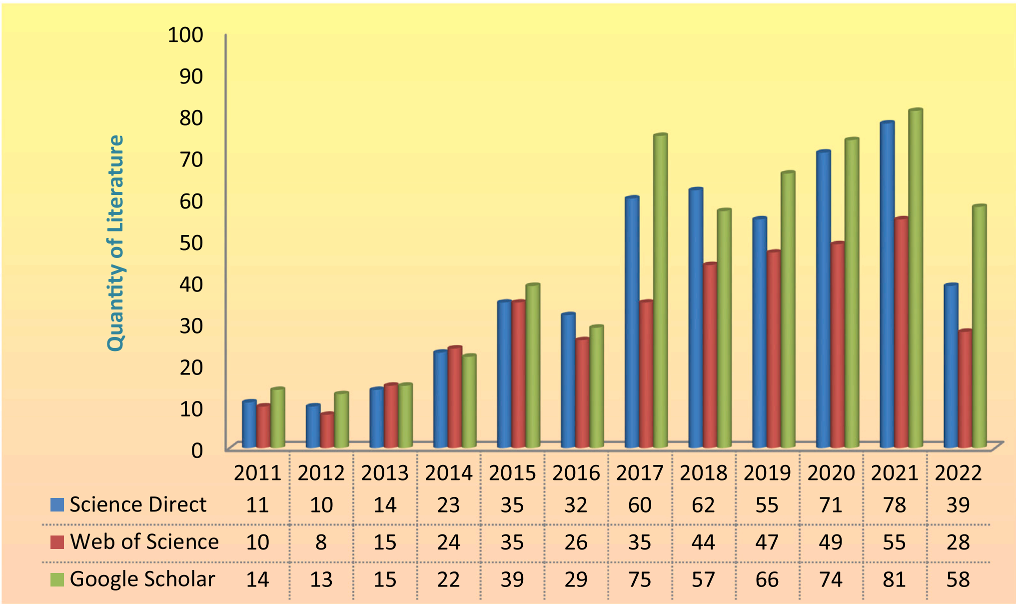


Fig. 3. The structure of this article.



(a)



(b)

Fig. 4. (a) shows the screening procedure and (b) shows the research data for a review of relevant literature over the last ten years.

static PV array, complex control algorithms and extra hardware are required [22]. In the Couple Matching Best Generation Algorithm, the complete photovoltaic array is divided into two halves, one male and one female. Each section has an equal number of rows and almost equal numbers of columns [23]. The Power comparison technique (PCT)was designed to optimize PV array power output in partially-shaded settings [24–26], and the irradiance equalization idea is used in almost all contemporary reconfiguration approaches. However, in Power Evaluation, the irradiance equalization principle enhances the output power by raising just the minimum row current without considering the influence of the voltage by the output characteristics of a solar array. As a result, under some partial shade situations, reconfiguration algorithms based on this concept cannot produce the global optimum configuration [25,27].

In DAR, many sensors, switches, and algorithms become the reason for expanding intricacy and boosting the system's cost. Hence, finding a suitable electrical switching arrangement is advised a challenging job [28]. Thus, the utilization of the optimization technique is the more convenient solution for these complications to determine satisfactory switching combinations in PV array reconfigurations [29,30].

As illustrated in Fig. 1, this study offers a more in-depth examination and assessment based on the demerits of previous evaluations. This paper discusses 70 different PV array reconfiguration methods and their transfigurations. This may be divided into nine subcategories, as shown in Fig. 2.

This paper carefully sets several realistic assessment standards to examine and evaluate these methods comprehensively and properly. These criteria primarily represent shadow dispersion, output power, PV array electrical parameters equalization extent, and other essential elements. Moreover, Fig. 3 illustrates the organization of this study. Based on a detailed review of existing research and the authors' own, numerous findings and viewpoints are suggested to give practical direction for future investigations.

2. Review screening procedure

This review is structured in accordance with content analysis. Searches for relevant material are conducted using three bibliographic databases (Google Scholar, Web of Science, and Science Direct), through several keywords like PV array configurations, Partial shading conditions, Static reconfiguration, Dynamic reconfiguration, Shade dispersion, Mismatch losses. Additionally, Fig. 4(a) shows the review screening flowchart. In addition, Fig. 4(b) depicts the data of important studies published in the recent span (from 2010 to 2022). The main components of review methodology up to this point have been the survey method, the empirical analysis technique, the experimental technique, the qualitative analysis technique, the quantitative analysis technique, and the observation technique. In order to evaluate and contrast various approaches of reconfiguring PV arrays, this work uses a literature research methodology.

3. PV Reconfigurations

For the reconfiguration of a Photovoltaic array, it is critical to study the electrical characteristics of the photovoltaic module. Several PV cell models have been presented in prior research works. These are the double-diode single-diode models, triple-diode, and [31–33]. The single-diode model is the most extensively utilized. Table 1 lists the designs and characteristics of these models [32]. The current-voltage curves of a vast space of industrial silicon PV cells are replicated using a triple-diodes model. The two-diodes representation accurately simulates the electrical characteristics of PV modules but adds complexity [34,35]. The one-diode representation is often used to exhibit PV module performance because of its reasonable accuracy and simplicity [36,37].

4. Static Reconfiguration Strategy

It is a method of physical relocation that changes the physical position of PV modules without disturbing the array's electrical contact. As a result of the lack of switches, this technology is often more convenient and less expensive to implement. Tables 2–5 present a comprehensive analysis of static reconfigurations.

Table 1
PV Model Parameters and Principles.

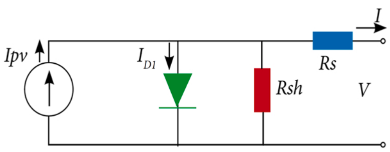
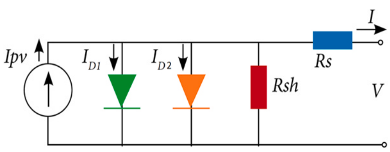
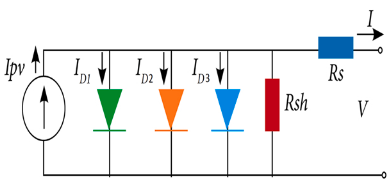
<table>
<tr><th colspan="2">One-Diode Model</th></tr>
<tr><td>Equivalent circuit:

</td><td>Output Current:
$I_{D1} = I_{01}(e^{V_{D1}/a_1 V_t} - 1) I = I_{pv} - (I_{D1} + \frac{V_{D1}}{R_{sh}})$</td></tr>
<tr><td>Two-Diode Model
Equivalent circuit:

</td><td>Output Current:
$I_{D2} = I_{02}(e^{V_{D2}/a_2 V_t} - 1) I = I_{pv} - (I_{D1} + I_{D2} + \frac{V_{D1}}{R_{sh}})$</td></tr>
<tr><td>Three-Diode Model
Equivalent circuit:

</td><td>Output Current:
$I_{D3} = I_{03}(e^{V_{D3}/a_3 V_t} - 1) I = I_{pv} - (I_{D1} + I_{D2} + I_{D3} + \frac{V_{D1}}{R_{sh}})$</td></tr>
<tr><td>Where,
α = ideality factor of the diode. T = temperature of cell in Kelvin. q= charge of an electron. N_S = number of cells in series. V_t = thermal voltage. I_0= leakage current of the diode.</td><td>Output Voltage:
$V = V_D - IR_S V_t = N_S$</td></tr>
</table>

Table 2
Comparison of various mathematics-based techniques.

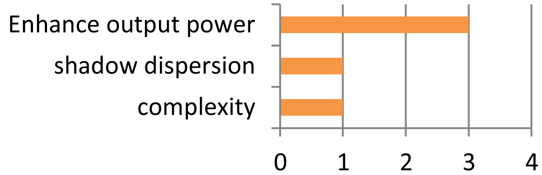
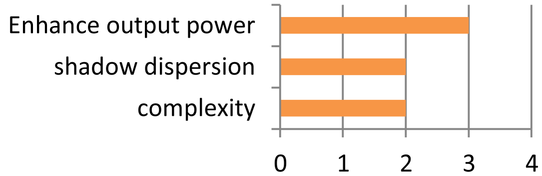
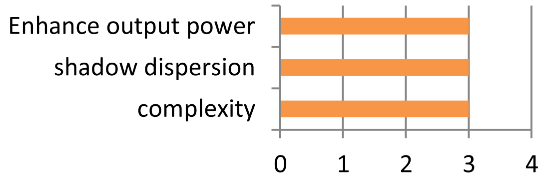
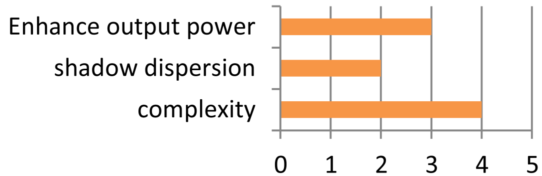
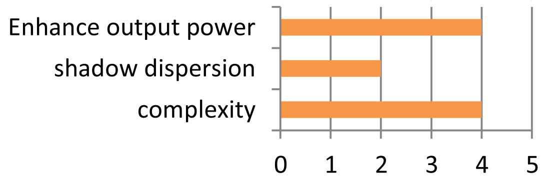
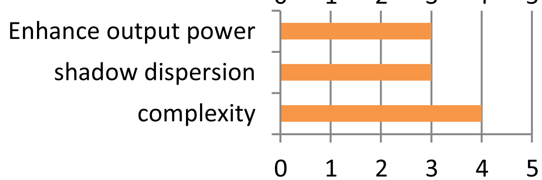
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
Sudoku	• Implementation is simple. • No sensor is required.	• Significant voltage drop and wire loss.	
Optimal Sudoku	• Extending the array to m×n elements. • Improved dispersion than Sudoku.	• Wire loss is high, and shade dispersal is poor than dynamic reconfigurations.	
Coyote Optimization Algorithm	• Enhancement of power is significant with moderate complications.	• Not suitable for Large PV systems.	
Zig-Zag	• It may be used in any dimension.	• Flexibility is limited.	
PRM-FEC	• Improve row current. • Implementation in real-time.	• Flexibility is limited.	
SDS	• Decrease mismatch losses by a significant amount.	• The modules in the first column will not change.	

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Table 2 (*continued*)

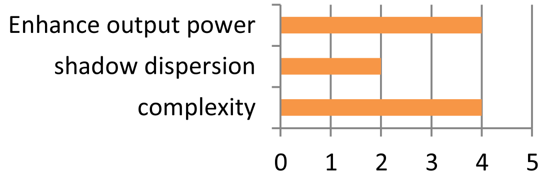
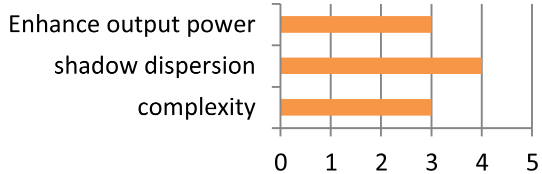
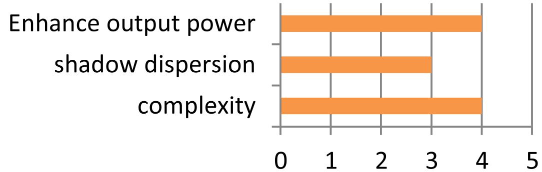
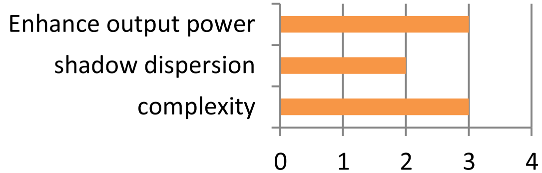
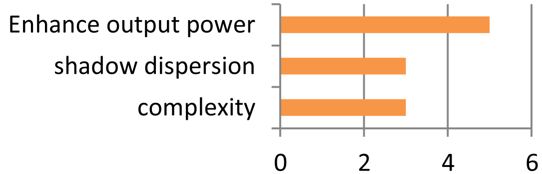
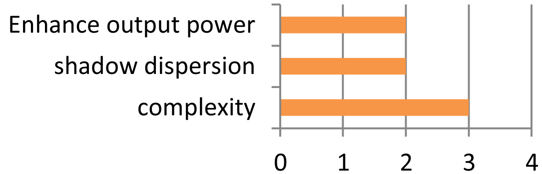
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
Prime-number Algorithm	• Improve row current. • Implementation in real-time.	• Flexibility is limited.	
CIA	• Wire loss is minimal.	• Flexibility is limited.	
OSBA	• Overcome the mutually obstructive shadow.	• Significant voltage drop and wire loss.	
Magic Sudoku	• The rightmost P-V curve contains GMPP. • Simple to implement.	• The dispersion factor is low.	
Arrow Sudoku	• Enhancements of instantaneous power.	• Significant voltage drop and wire loss.	
TomTom	• No sensors are required.	• The regulations are complicated.	

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Table 2 (*continued*)

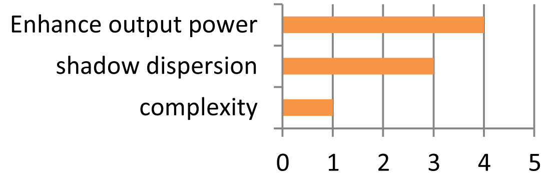
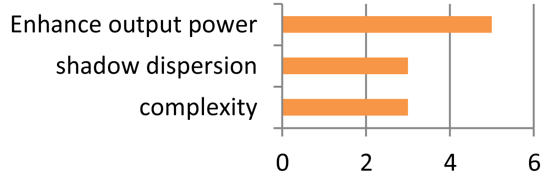
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
Odd-even	• LMPPs are to be avoided.	• Shade dispersion is insufficient shading situations.	
Alternate Panel Interchange	• Overcome the mutual shading • Simple in implementation	• Shade dispersion is insignificant in comparison to hybrid configurations	

Table 3
Comparison of various Puzzle-based techniques.

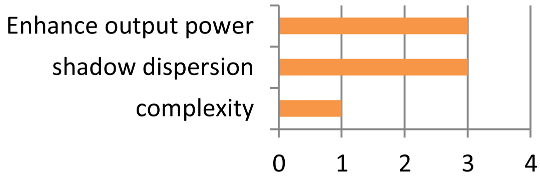
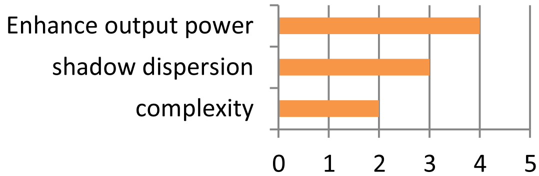
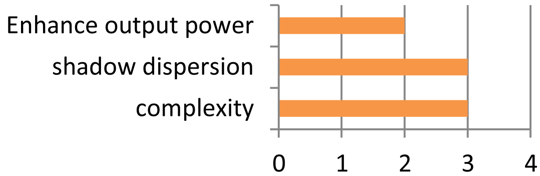
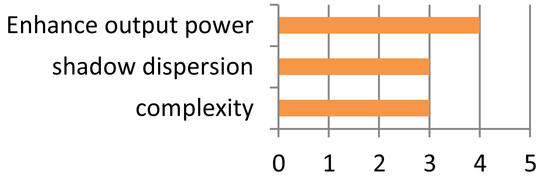
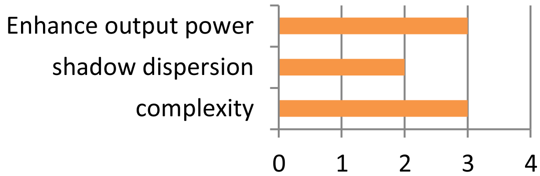
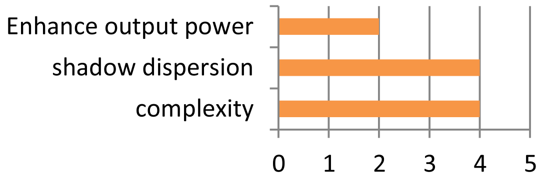
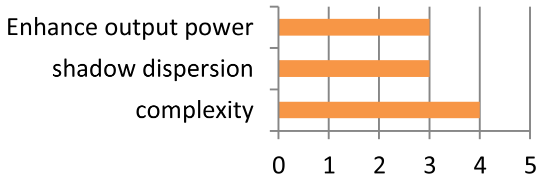
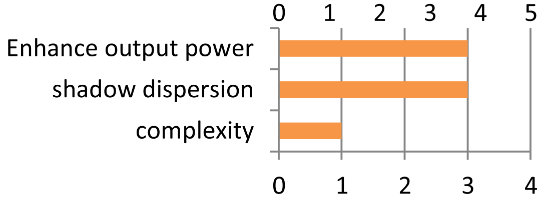
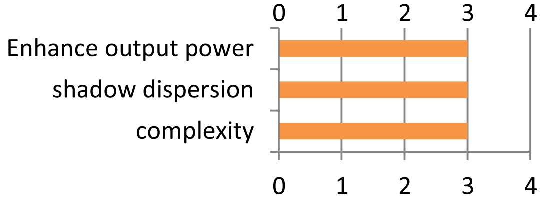
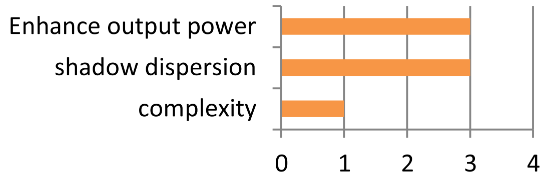
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
MS	• Power loss is minimal.	• Modules in the first column are unaffected.	
Futoshiki	• The solution to the puzzle is unique.	• The m×n array is not appropriate.	
R-HCTCT	• FF is high.	• Flexibility is limited.	
FS	• Enhancement of high power. • A straightforward procedure.	• Extensive calculations are required.	
SRAM	• Minimize MS's drawbacks.	• The regulations are complicated.	
Dominance square	• Current row differences are limited.	• Not suitable for Large PV systems.	
Competence square	• Simple in implementation.	• Wire loss is high.	
Latin square	• Enhancement of power is significant with lesser complications.	• Not suitable for Large PV systems.	
Ken-Ken square	• Enhancement of power is significant with moderate complications.	• Not suitable for Large PV systems.	

Table 3 (*continued*)

Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
Lo Shu scheme	• Fewer stages in the reconfiguration process.	• Flexibility is limited.	

4.1. *Mathematics-based Approach*

These strategies all have one thing in common: they all rearrange PV arrays according to a mathematical equation.

4.1.1. *Sudoku technique*

Every sub-matrix in the Sudoku design is filled with numbers ranging from 1 to 9, with no repetition. Sudoku reconfiguration may be used to disperse the darkened modules into alternative spots [38,39]. Optimal Sudoku, in particular, can overcome the drawbacks of standard Sudoku's poor dispersion in the cases of corner shading [40]. To fulfill the reconfigured PV array's dispersion factor condition, the first column's X lattices are shifted by the magic Sudoku approach as stated in the following calculation to create the nth column [41].

$$X = \left\lceil \frac{n-1}{3} \right\rceil + 3 \times ((n-1)\mathrm{mod}3) \tag{1}$$

The optimum Sudoku-based arrangement (OSBA) is recommended to cope with the mutual shade[12], which arises when a section of the back PV panels is shadowed by the front [42,43]. Furthermore, the authors in [44] propose an Arrow Sudoku (AS) approach to reduce row current discrepancy. In general, all these approaches and modifications are enhanced output power while increasing voltage drops and wire losses on extension wires.

4.1.2. *Zig-Zag technique*

The application of several static PV reconfiguration techniques is limited to symmetricalcal array size or small array order. However, the Zig-Zag approach may reconfigure PV arrays of alldimensions, including extensive PV facilities [45]. The model shows

Table 4
Comparison of various Circular shift-based techniques.

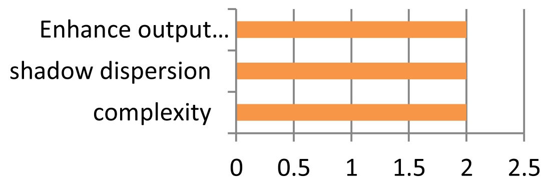
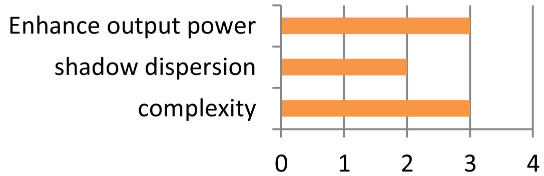
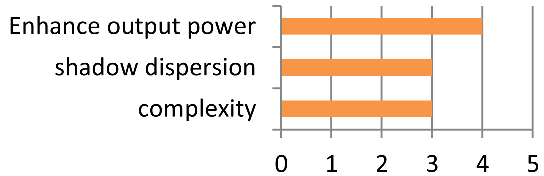
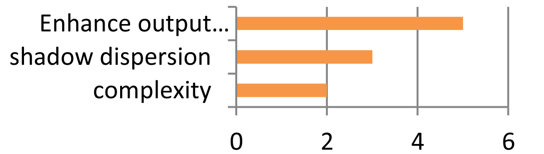
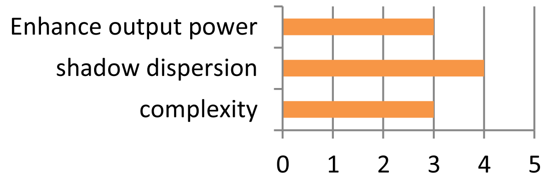
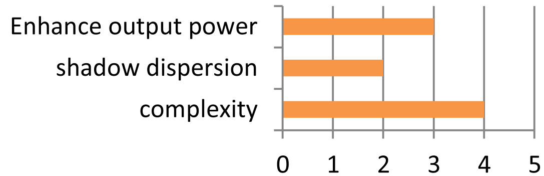
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
Non-symmetrical	• Implementation is simple.	• Dispersion of shadow is poor.	
Knight's Tour Algorithm	• FF is high.	• The regulations are complicated.	
TPAR	• Enhancement of high power. • A straightforward procedure.	• Extensive calculations are required.	
SER	• Simple guidelines for relocating. • FF is high.	• Dispersion of shadow is poor.	

Table 5
Comparison of various Engineering based techniques.

Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
Non-symmetrical	• Shade dispersion is significant.	• Relocation rules are complicated.	
TPAR	• In comparison to arrow sudoku, there is less wire loss.	• Dispersion of shadow is poor.	

that Zig-Zag reconfigures the array's current-voltage (I-V) and power-voltage (P-V) properties are leveled and have fewer deformationthanTCT configurations.

4.1.3. Fixed electrical configuration (FEC)

Fixed electrical configuration(FEC) presents a mathematical method for remodeling[46]. The process of using FEC is remodel a 10 × 10 photovoltaic array. Compared, FEC offers the advantage of reduced prices andeasy deployment caused byasmaller number of sensors and switches.

4.1.4. Column index algorithm (CIA)

The CIA is a one-time mechanical relocation mechanism based on a simple mathematical program [47]. As demonstrated in Fig. 3, each darkened panel in CIA is mainly shifted in the original column. The procedures in Fig. 3 show that the CIA can spread mismatches through all columns with a three-stage process. CIA also has the advantage of being simple to deploy and reducing wire loss.

4.1.5. TomTom (TT) puzzle technique

The TT puzzle is based on the principle that an array containing each column or row of N × N should include all numerals up to N from the start except duplication. Furthermore, these numerals must be completed in a specific order, as shown in Fig. 5, by combining these numerals with the assigned calculation procedure to obtain the necessary integer in the top left corner of each sub-grid. It has been proven that the TT problem has a remarkable capacity to increase the instantaneous power output of a Photovoltaic system [48].

4.1.6. Shade dispersion scheme (SDS)

The SDS is a basic reconfiguration system centered on numerical rules [49]. Each subsequent column lowers the lattices by a unique number of moves except for the first column. With SDS reconfiguration, intense shades are dispersed among distinct locations. SDS reduces PV array power losses under PSC [50].

4.1.7. Odd-Even (OE) scheme

An improved fixed structure technique based on the OE scheme is presented in [51]. There are two sections to the OE scheme. The initial section keeps the electrical connections between modules intact. The PV modules in the second section are replaced physically by the OE structure. Experiments with this design on a 4 × 4 array are studied under different shading situations. The results present a good gain in PV array power output in PSCs. This strategy minimizes the numeral of LMPP for varied shade designs, making it more MPPT-friendly [51,52]. The OE structure is further modified for better shade dispersion in a simple two-stepped procedure named the Alternate Panel Interchange technique (API) [53]. The performance of the API scheme is compared with hybrid array configurations. The results reveal output power enhancements ranging from 1.36% to 19.58%.

4.1.8. Prime-number technique

The accuracy of the data-driven prediction model largely relies on the obtained data's quality [54]. In this method prediction is based on prime numbers. It reconfigures the modules associated with the TCT PV array to obtain maximum output power by dispersing shaded modules based on the order of prime integers in separate rows [55]. Under varying shading cases, the reconfiguration of PV modules and the dispersion of shadows on 9 × 9 PV arrays are performed. Resiliency and practicability for execution in real time, and independent of the dimensions and size of the PV array are the most significant benefits of this method.

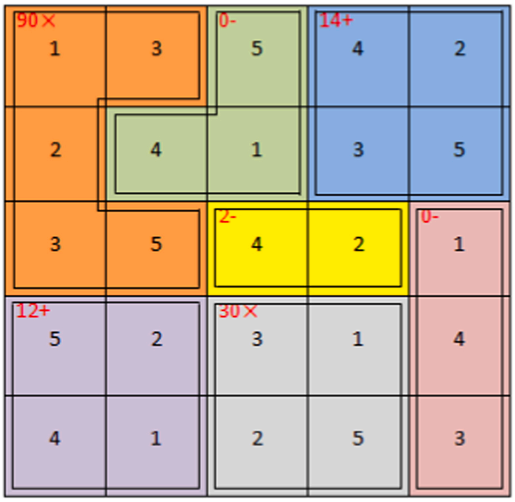


Fig. 5. The pattern of TomTom structure[48].

4.1.9. Puzzle-based coyote optimization algorithm

Its principle concept is derived from species of Canis latrans that inhabit primarily in North America. The algorithm is modified to take into account the social organisation of coyote-named agents that were previously served by a different algorithmic design. The primary benefit of this strategy is that it maintains a balance between the exploitation and exploration processes throughout the optimization procedure [56].

4.2. Puzzle-based approach

Various reconfiguration approaches are called puzzle-based methods since their fundamentals are supposed on a well before-introduced puzzle to reconfigure PV modules.

4.2.1. Dominance square technique (DST)

The DST is a puzzle solver reconfiguration approach which keeps the current of a row with a variation to a minimum in a small range [13]. DST can assist in the generation of a straight I-V graph with just a sole peak relying on this deductive technique. On the other hand, DST is not appropriate for substantial PV installations. The flowchart for DS reconfiguration is shown in Fig. 6.

4.2.2. Competence square technique (CST)

The CST is implemented using a particular logical order, which is another puzzle-based reconfiguration. The authors have compared CST with TCT and DST configurations. The CST approach improves mismatch power loss elimination, power enhancement, and fill factor (FF) [57]. The CST approach has the potential benefit of being easier to adopt in practice. The CST approach has difficulty with significant wire losses like the Sudoku strategy.

4.2.3. Magic square technique (MST)

The MST can be implemented for any N × N PV array order. The Sudoku technique is executed only on symmetrical array order [58]. MS matrix adheres to the mathematical principle that the sum of values in any column, row, or crosswise is equal, as seen in Fig. 7. Furthermore, as compared to bridge BL, SP, and TCT, the proposed MS has lower power losses and an improved FF [59,60]. Another remarkable outcome of the approach is that the MS method can provide a fairer P-V graph, making it further suitable for MPPT. Furthermore, a reorganized outcross TCT approach through MST (R-HCTCT) optimizes PV array output properties in mismatch environments [61].

4.2.4. Ken-Ken square technique (KKST) and latin square technique (LST)

The MST is reformed with specific computational instructions to form the LST and the KKST. The LST and KKST reconfiguration outperformed the Sudoku scheme and provided better wire loss reduction, instantaneous maximum power, shade dispersion, and FF in prominent PSCs. Except for Short-Narrow PSC, the LST overtakes Sudoku for the criteria mentioned in the remaining three PSCs [62].

4.2.5. Static reconfiguration of adjacent panels (SRAP)

The major disadvantage of the MST reconfiguration is that modules within the same row might still be dispersed in the next sub-array, as seen in Fig. 8. When such sub-arrays are darkened, the MS approach fails to disseminate the darkened panels throughout the complete array, resulting in higher mismatch losses. An SRAP is presented to solve this problem. SRAP seeks to remove modules from a row with the smallest distance possible. The comparative analysis of SRAM and TCT results proves the superiority of the proposed scheme in terms of FF [63].

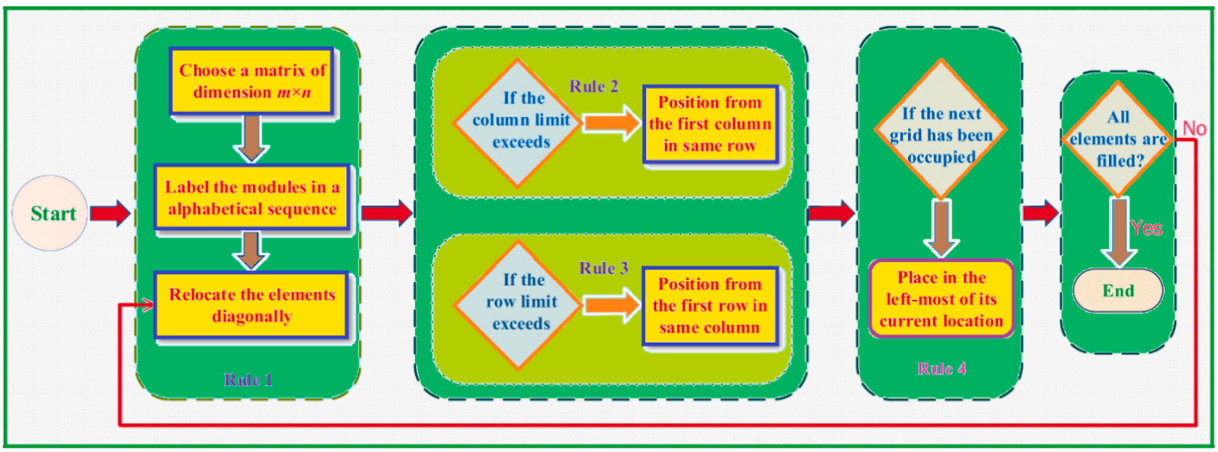


Fig. 6. DS Reconfiguration Flowchart [13].

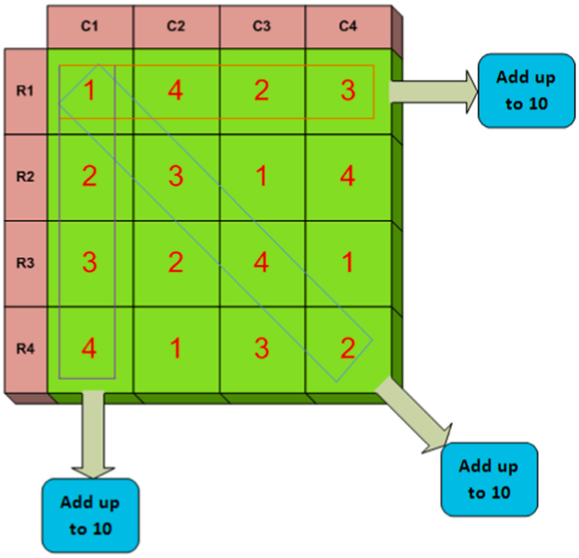


Fig. 7. MS's mathematical formula [61].

4.2.6. Lo Shu algorithm

Fig. 9(i) presents the Lo Shu approach. It is a different sort of puzzle-solver static reconfiguration based on the earliest and most enigmatic venation design known as 'Luo Shu' [65]. It can be seen in Fig. 9 (ii), Lo Shu reconfigures the first sub-array using the venation design and separates it into nine 3 × 3 sub-arrays from the 9 × 9 array 'Luo Shu.' Likewise, based on the initial subarray, the left sub-arrays are rearranged. Compared to CST, Sudoku, and DST, the key benefit of the Lo Shu approach is that it achieves significant shade distribution with lesser physical rearrangements.

4.2.7. Futoshiki puzzle technique

This is a single-time reconfiguration procedure where numbers from 1 to n are randomly put either in columns or rows. Meanwhile, the nearby numbers must be subjected to an unequal constraint that is carefully specified from the beginning. The technique employs a conventional programming method to generate an optimal result. The authors in [66] present the Futoshiki technique's hardware implementation and outcomes prove the output power is significantly enhanced for PV array with four different shade patterns.

4.2.8. Four square Sudoku technique

Four Square (FS) sudoku is an advanced sudoku configuration for a 9 × 9 total-cross-tied (TCT) shaded PV array. The suggested FS attempted to re-distribute the shade throughout the whole array by altering the physical placements of the shaded modules without altering their electrical connections in order to reduce the current discrepancies across rows [67]. Ten shade patterns were analyzed,

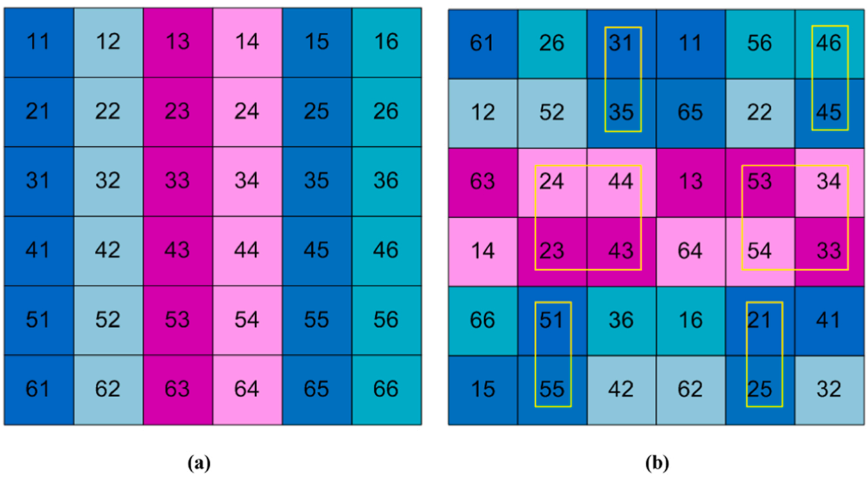


Fig. 8. Shade dispersion with MST: (a) initial configuration (b) MST configuration [64].

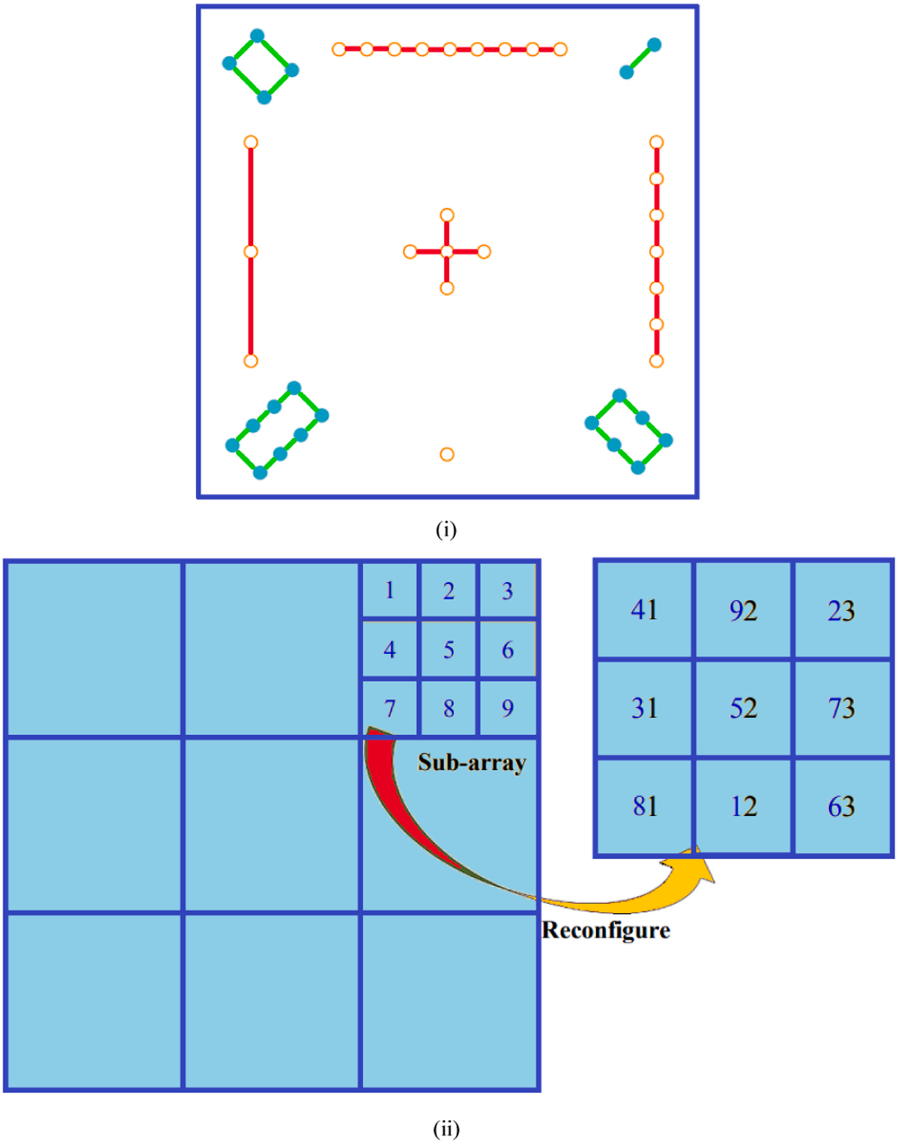


Fig. 9. Lo Shu Algorithm: (i) earliest stripe model 'Luo Shu' and (ii) Lo Shu array reconfiguration [65].

and the proposed FS approach was compared to other reported schemes, including basic sudoku (SDU), optimal sudoku (OSDU), chaos map (CMP), skyscraper (Sky-S), odd-even prime (OEP), and ancient Chinese magic square (ACMS) approaches.

4.3. Circular shift-based approach

These reconfiguration techniques use many grids to move each sub-array. The complete PV array is rearranged using this cyclic shift technique.

4.3.1. Settled electrical reconfiguration (SER) technique

Authors have presented a unique SER technique in [14] to optimize the maximum output power from PV arrays during PSCs. According to simulation outcomes of 4×3 and 6×6 PV arrays for all examined shading scenarios, the PV array implemented with the SER strategy has the optimal power output, excellent FF, and efficiency. The SER approach, in particular, benefits in the getting of evener P-V characteristics by the PV array [14,66].

4.3.2. Non-symmetrical reconfiguration technique

A non-symmetrical reconfiguration approach is proposed in the literature, where PV modules are relocated according to Eqs. (2) and (3) [68]. As compared to fundamental topologies, the non-symmetrical reconfiguration approach improves PV maximum power output while reducing power mismatch losses under PSCs.

$$\text{For non}-\text{symmetrical}-1, i' = \left\{ \begin{array}{c} i, \& j = 1 \\ i + (j-1) \times floor(\frac{i_{\max}}{2}), \& j > 1 \end{array} \right\} \tag{2}$$

$$\text{For non}-\text{symmetrical}-2, i' = \left\{ \begin{array}{c} i, \& j = 1 \\ i + (j-1) \times ceil(\frac{i_{\max}}{2}), \& j > 1 \end{array} \right\} \tag{3}$$

where i and j denote the number of row and number of column numbers of the PV module's initial location, correspondingly, and i′ and j′ denote the revised position.

4.3.3. Two-phase array reconfiguration (TPAR) technique

PV array shade dispersion structure is neither well-defined nor precise for most available static reconfiguration methods. The authors in [10] presented an innovative TPAR approach for maximizing PV power output. There are four significant steps in the TPAR. Initially, it splits the entire PV array into many sub-arrays. Next, each sub-array module is repositioned. Then it executes repositioning across the entire sub-arrays. Eventually, it swaps the columns to reposition them. The TPAR strategy is investigated for four prominent shading scenarios, and simulation results prove the enhanced power output for all the considered cases.

4.3.4. Knight's tour technique

The Knight's tour is a chess-based approach that reconfigures photovoltaic (PV) arrays depending on the Knight's moves on the chessboard so that shadows are dispersed evenly across all rows and maximum power is harvested. In this instance, the tour begins in the field that is immediately next to the beginning spot. It is categorized as an open tour due to the fact that the Knight is unable to return straight to their starting location [69].

4.4. Engineering-based approach

Engineering practice influenced the two static PV array reconfiguration methods in this section. They are modeled after architectural and computer engineering skills, respectively.

4.4.1. Skyscraper scheme (SS) technique

The building-integrated photovoltaic (BIPV) system is a PV plant put on the top or other unoccupied construction area. A new concept of PV array reconfiguration is proposed to present a new SS technique, resembling building blocks' architectural schemes with varying heights [15]. The power wastage induced with the drops in voltage from additional cable lines required to transfer PV panels is called wiring loss. Wiring loss increases with the length of the cable line. By measuring the cable lengths of both approaches, the wiring loss function Eq. (4) may demonstrate an SS technique advantage over Arrow-SuDoKu (AS) technique.

$$Wiringloss(\%) = \frac{L_{SS} - L_{AS}}{L_{AS}} \times 100\% \tag{4}$$

The cable lengths for the AS and SS configurations are L_{SA} and L_{SS}. In addition, this approach has additional advantages, such as resilience, extensibility, and the ability to be implemented in real-time [70].

4.4.2. Chaotic baker map technique (CBMT)

The CBMT is an image analysis method used in computer science to encrypt communication by randomly changing pixel locations. The physical placements of panels are represented as pixel locations in the CBMT, and they are shifted to different points across the array [71]. A K×K PV array is first partitioned into n rectangles. Scanning each rectangle creates a new array row. These rows merge the new array at the end. CBMT offers the benefit of having a naturally optimum algorithm key between large numbers of possible keys. Additionally, it may be used to build large-scale solar farms, and BIPV arrays with lower expenses as CBMT do not require electrical components like sensors and switches.

5. Dynamic reconfiguration strategy

The dynamic reconfiguration employs a switch sequence to change the electrical link among PV panels as per the shading situation is another essential form of PV reconfiguration methodology. Tables 6–10 present a comparative analysis of dynamic reconfigurations.

5.1. Electrical array reconfiguration (EAR) approach

The EAR method shifts PV panels by placing a switch combination among the PV array and the main inverter like a single ground for insolation level and row current [19]. The EAR approaches are confronted with a variety of challenges, including the need for a

Table 6
Comparison of various Electrical array reconfiguration-based techniques.

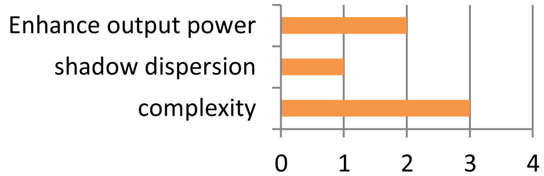
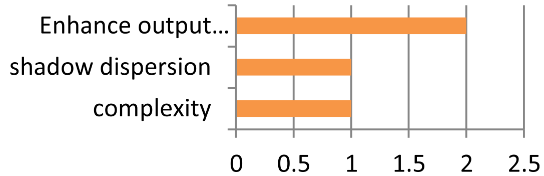
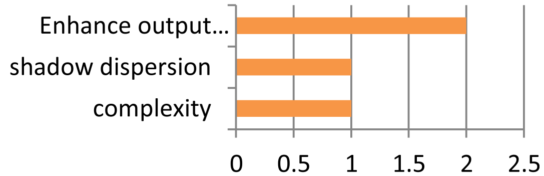
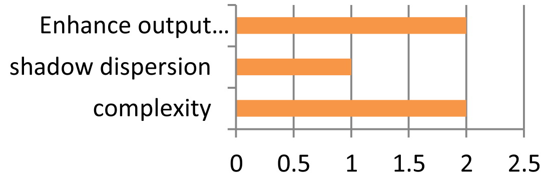
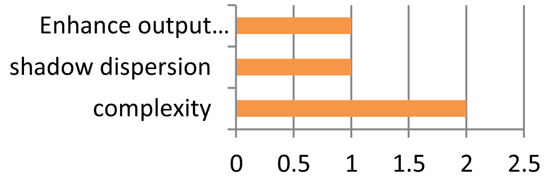
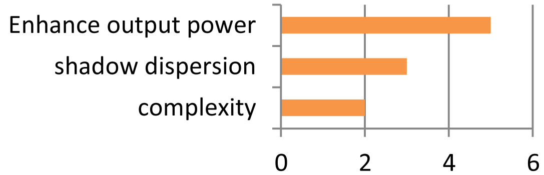
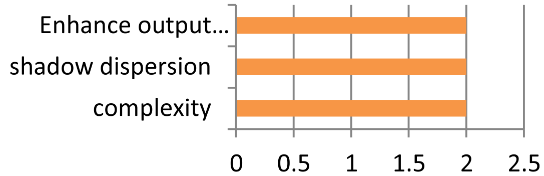
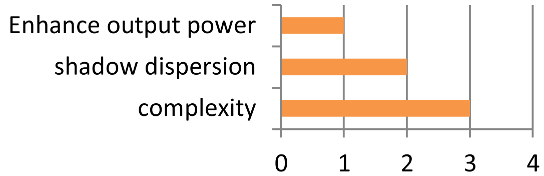
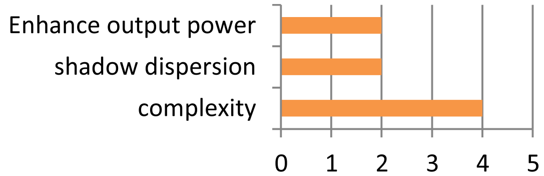
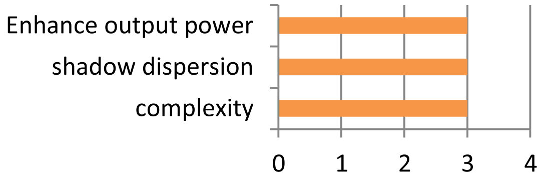
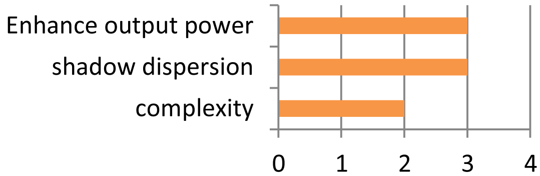
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
BBA	• Switches are fewer.	• Reconfiguration is only half complete.	
BWSA	• There are fewer iterations.	• Relocation rules are complicated.	
RSA	• The methodology is straightforward.	• Ignores the aging of relays.	
DSA	• Applicable in real-time.	• Ignores the aging of relays.	
FDRA	• By using the traversal strategy, able to find a virtually ideal configuration.	• A low rate of convergence.	
Munkres	• The methodology is straightforward. • lengthen the service life	• A low rate of convergence.	
RST	• Quick and effective control system.	• Shade dispersion is insufficient.	
Fault detection algorithm	• Shade dispersion is moderate.	• Relocation rules are complicated.	
Switched PV technique	• Fewer switches are required.	• Relocation rules are complicated.	

Table 6 (*continued*)

Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
MCR	• Low circuit loss and cost.	• Enhancement of less power.	
Two-step	• High shadow dispersion and little mismatch loss.	• Low rate of convergence.	

complete monitoring system that facilitates various tasks. For example, calculating the shade position and notifying the signals received between the switching matrix and the PV panels [72].

5.1.1. *Fast dynamic reconfiguration technique (FDRT)*

The FDRT comprises two segments: optimizing and grouping all components for optimal power output, through which FDRT estimates and evaluates all potential configurations. With PV array reconfiguration, the amount x of each panel j, as stated by Eq.(5), plays a significant role [73].

$$x = \sum_{k=1}^{N} |P_{b,k} - P_{j,k}| \tag{5}$$

$P_{b,k}$ signifies the kth sample of the panel's power, whereas denotes the kth sample of the jth panel's power. The complete sum of samples is symbolized through the letter N. The panels are sorted by x in increasing order. Finally, FDRT extracts the highest power output from the sorted arrangement by finding the optimal combination.

5.1.2. *Branch and bound technique (BBT)*

BBT separates the nonlinear mathematical problem into a pair of subtasks using the interior point approach. The reconfiguration task is altered as a mixed-integer quadrate programming difficulty using BBT. Eq.(6) can regulate the impact of power wastage during mismatch conditions depending on the DC yield power and permit evaluation across various extents' arrays in varied irradiation circumstances [21]. BBT obtains a higher PR and enhances the produced power based on extensive simulation findings.

$$PR = \frac{P_A}{IR_A} \times \frac{G}{P_{dc}} \tag{6}$$

$P_A$and P_{dc}denote the array's output power and maximum DC output power, correspondingly; G and IR_A denote the array's reference irradiance level and total irradiance level, respectively.

5.1.3. *Best worst sorting algorithm (BWSA)*

The BWSA operates on the insolation equalization (Ineq) principle, which is meant to balance the insolation of the entire PV array [22]. In addition, Ineq changes the electrical contact of a PV module to move it from a row with large irradiance to the next row with small irradiance [74]. BWSA has the advantage of providing a helpful arrangement through a lesser sum of iterations. On the other hand, this method may not necessarily result in the best reconfiguration.

5.1.4. *Deterministic research algorithm (DSA) and random search algorithm (RSA)*

To optimize the power output of PV systems during PSC. The DSA and the RSA are shaped, with both methods following the Ineq principle, although in an altered manner [75]. However, RSA is more accessible to build than DSA. The latter takes less time to provide the best response with the same conditions. On the other hand, both methods ignore the aging of the relays utilized in the reconfiguration [76]. At the same time, the best option with the same conditions is for both methods to ignore the aging of the relays utilized in the reconfiguration.

5.1.5. *Munkres technique*

A control system based on the well-known subgroup sum problem is proposed to achieve optimum PV array reconfiguration [76]. In addition, the control system uses the Munkres method to adjust the switch architecture in a post-processing section, which reduces switch action and increases switch durability. Furthermore, Fig. 10 depicts the Munkres method's reconfiguration impact, which equalizes the insolation of each row.

Table 7
Comparison of various Meta-heuristic-based techniques.

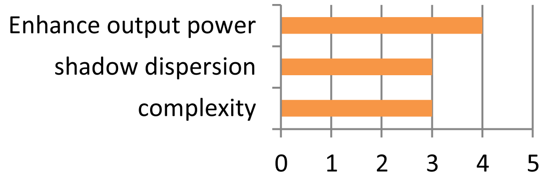
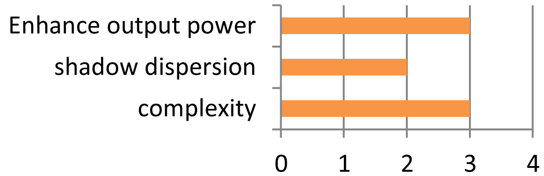
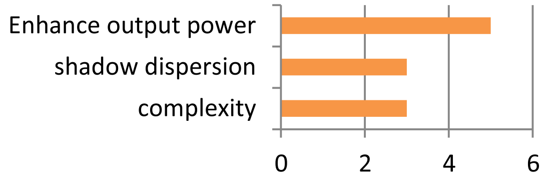
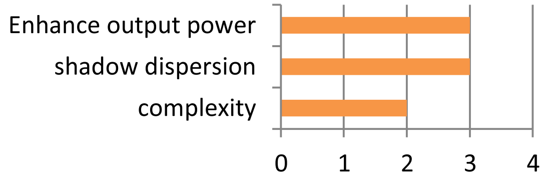
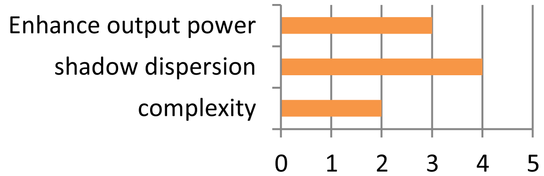
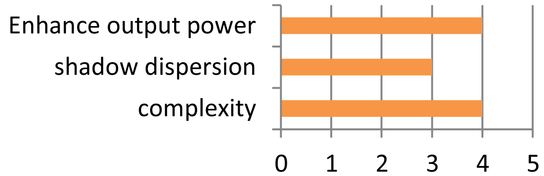
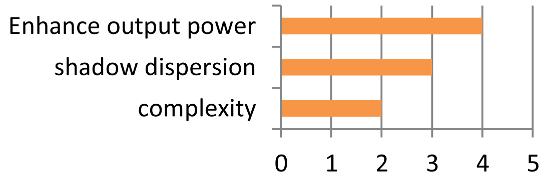
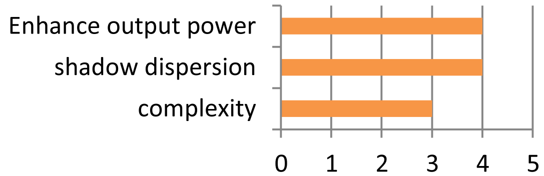
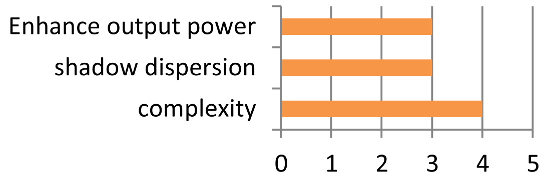
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
GA	• Significant Increase in power output.	• Relies too much on weight coefficient.	
GSA	• High-speed convergence.	• It is simple to get trapped in a local optimum.	
SDGA	• Standard deviation and GA are combined. • minimize the number of peaks	• It is simple to get trapped in a local optimum.	
MSSA	• Implement a unique object function.	• Mechanism of complicated search.	
PSO	• Shade dispersion is good. • Robust.	• It is simple to get trapped in a local optimum.	
GOA	• Efficient and reliable.	• A lot of computational data is required.	
LCA	• The time to execute is limited.	• They are not intended for real-time use.	
MHHO	• Significant Increase in power output.	• Mechanism of complicated search.	
FRA	• High-speed convergence.	• Mechanism of complicated search.	

Table 7 (*continued*)

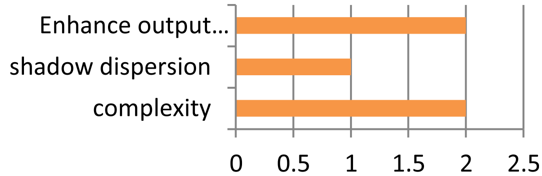
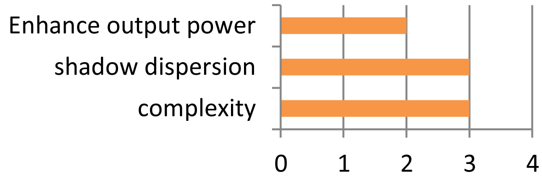
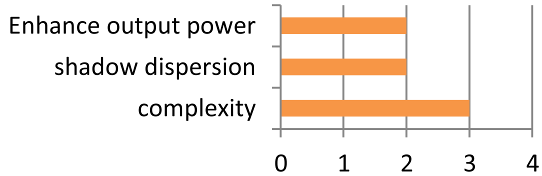
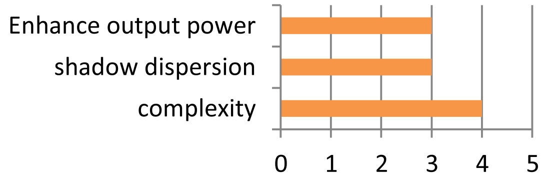
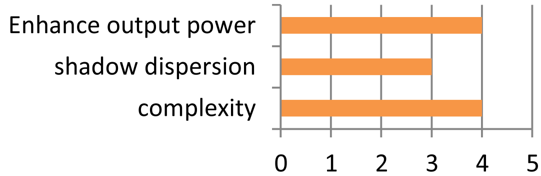
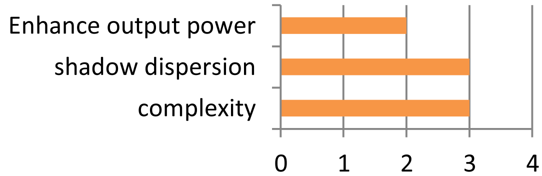
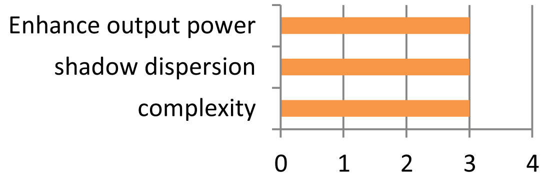
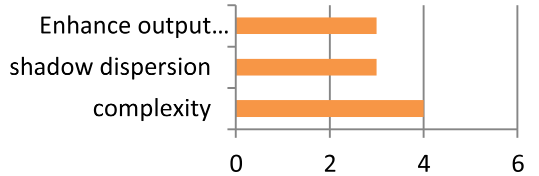
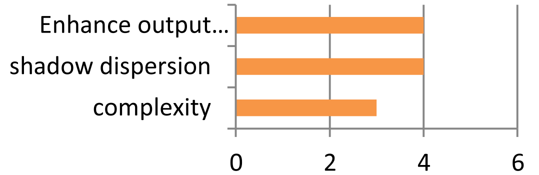
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
Dragonfly Algorithm	• Quick and effective control system.	• Shade dispersion is insufficient.	
SMO	• Decrease multiple peaks.	• Stability issues.	
Rao	• Reduce mismatch loss.	• Dispersion of shadow is poor.	
MPA	• High-speed convergence.	• Mechanism of complicated search.	
GWO	• Reduce mismatch loss.	• Mechanism of complicated search.	
MOGWO	• Decrease the divergence of row currents.	• Slow convergence rate.	
BOA	• There are fewer parameters to manipulate. • High-speed computation.	• Mechanism of complicated search.	
AEO	• Implement a unique object function.	• Mechanism of complicated search.	
DPA	• Enhancement of high power. • High level of stability.	• Mechanism of complicated search.	

Table 8
Comparison of various artificial intelligence-based techniques.

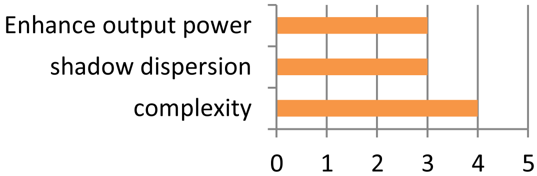
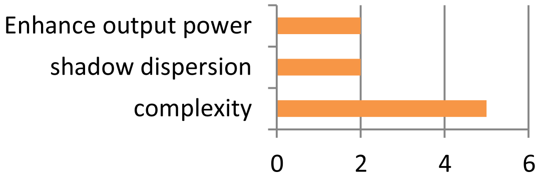
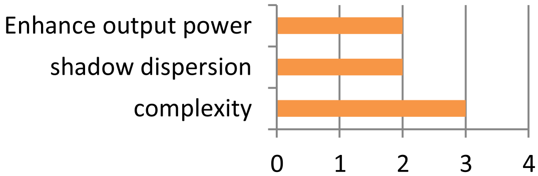
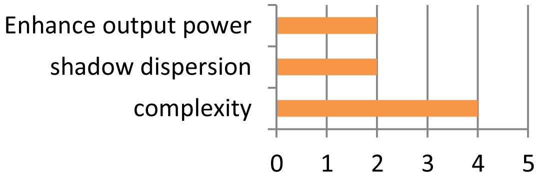
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
FFANN	• High versatility.	• A large amount of training data is required.	
Clonal selection	• The cost/power efficiency is taken into account.	• Mechanism of complicated search.	
FL	• Low price.	• Dispersion of shadow is poor.	
MLA	• It includes machine learning.	• Dispersion of shadow is poor. • Slow convergence.	

Table 9
Comparison of various Adaptive array reconfiguration-based techniques.

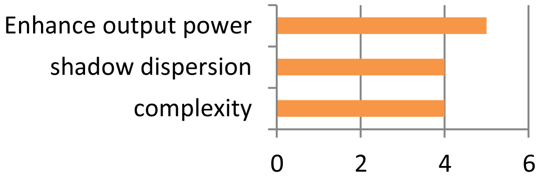
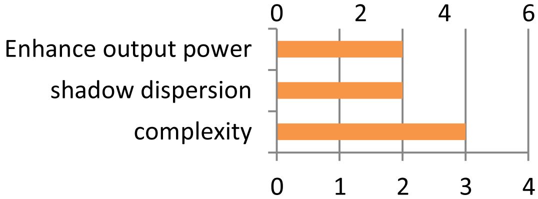
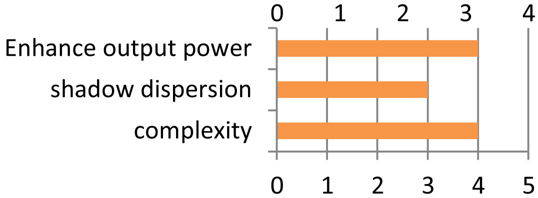
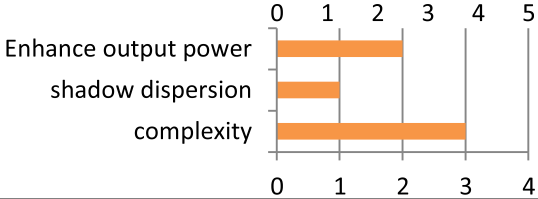
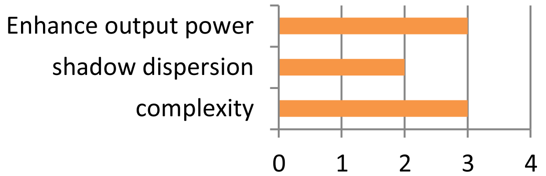
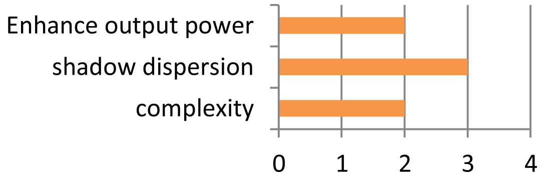
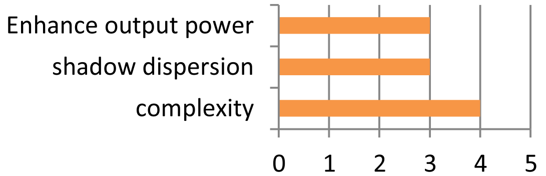
Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
BSA	• Excellent spreading of shadow.	• Many switches are required.	
SDMA	• Reduce the number of switches and sensors required.	• Dispersion of shadow is poor.	
CSA	• Only the adaptive part's short circuit current is required.	• Large-scale computations.	
SD	• included with fuzzy computation.	• Power augmentation and poor shadow dispersion.	

Table 10
Comparison of various Removal and reconfiguration-based techniques.

Technique	Advantages	Disadvantages	Rating Graph (Out of 5)
Reconfiguration based on selection	• Reduce the voltage variation from the voltage rating.	• Dispersion of shadow is poor.	
PCA	• The methodology is straightforward.	• Power boosting is ineffective.	
EMPP based algorithm	• Decrease current discrepancy.	• Not appropriate for real-time issues.	

5.1.6. *Fault detection scheme*

The Fault Detection Scheme uses the I_{MP} (current at maximum point), V_{MP} (voltage at maximum point), temperature, and aging information, a defect detection algorithm to detect problematic modules, including aged and shaded modules [77]. As per the extent of shade, diodes selectively skip damaged modules [78,79]. After that, the possible reconfiguration will be generated by analyzing power loss, MPP, and other factors. The schematic diagram in Fig. 11 is better designed to represent the suggested reconfiguration technique's procedure. The authors in [78] present a possible way to balance the complication of switch matrix operation with shade elimination efficacy using a fault diagnosis method.

5.1.7. *Rough set theory technique (RST)*

The RST is an innovative technique for working through inaccurate, inconsistent, and partial information. RST differs from the fuzzy logic concept because it does not demand previous knowledge other than processed information. In addition, the RST method has been used to reconfigure PV arrays. Hardware results and computer simulations have validated the efficiency of RST in minimizing shading effects [80].

5.1.8. *Modified circuit reconfiguration (MCR) technique*

The MCR approach reduces the switch combination and sophisticated control methods in PV array reconfiguration [81]. The MCR is distinguished for being the initial effort to reconfigure a highly concentrated photovoltaic (HCPV) scheme. MCR also offers the advantage of lower running expenses due to the lower circuit losses and lack of irradiation sensors. According to experimental results, MCR's efficiency increases, and the mean power amount is somewhat less than BWSA's [81].

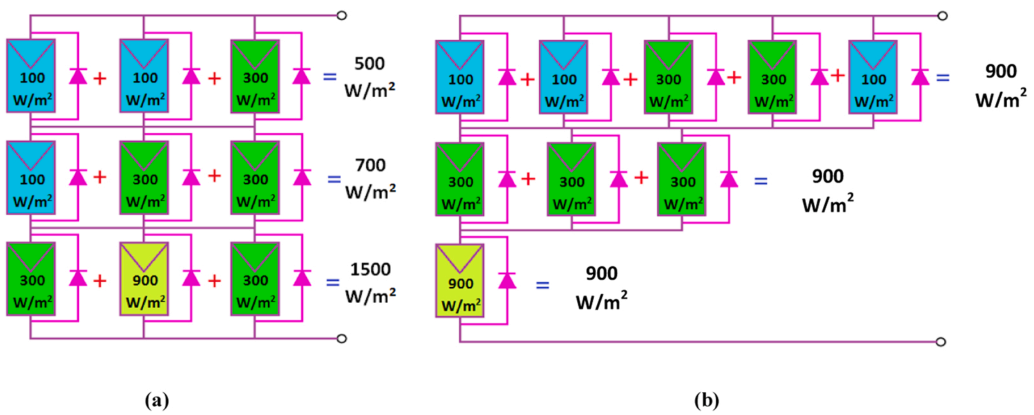


Fig. 10. Reconfiguration of the Munkres Technique: (a) initial network connection and (b) post reconfiguration [76].

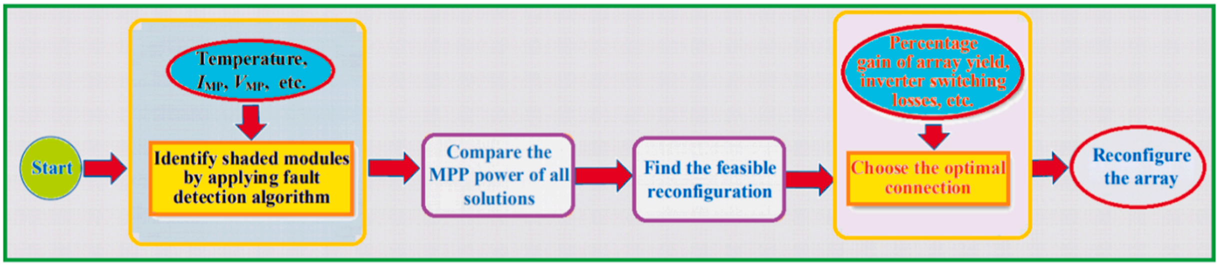


Fig. 11. Flowchart for the fault detection and reconfiguration technique [78].

5.1.9. *Two-stage technique*

The Two-Stage technique is a reconfiguration approach with a two-stepped cross method [82]. PV array of N × N order is split into portions of N/2 ×N and N/2 ×N arrays, as shown in Fig. 12 for the order of 4 × 4.

Second, it employs a switch combination to link the two portions together. With the help of the proposed reconfiguration strategy row, current equalization is achieved for the entire PV array. The proposed approach is validated by the results of the experiments in eight different shading scenarios revealing that the suggested method successfully reduces PSC's effects [82].

5.1.10. *Switched PV technique*

All switches are divided into primary and secondary switches. Each string is separated from its midsection by each primary switch. Secondary switches, sometimes known as left switches, are responsible for reconfiguring panels and coordinating the primary switches' actions. It improves power enhancement significantly in simulation and experimental analysis. However, it has a shortcoming of limited applications [83].

5.2. *Meta-heuristic approach*

When it comes to tackling difficult optimization issues, the meta-heuristic method is superior in terms of efficacy and dependability [84]. The meta-heuristic form has been recognized as among the most efficient ways of solving the PV array reconfiguration issues in PSCs.

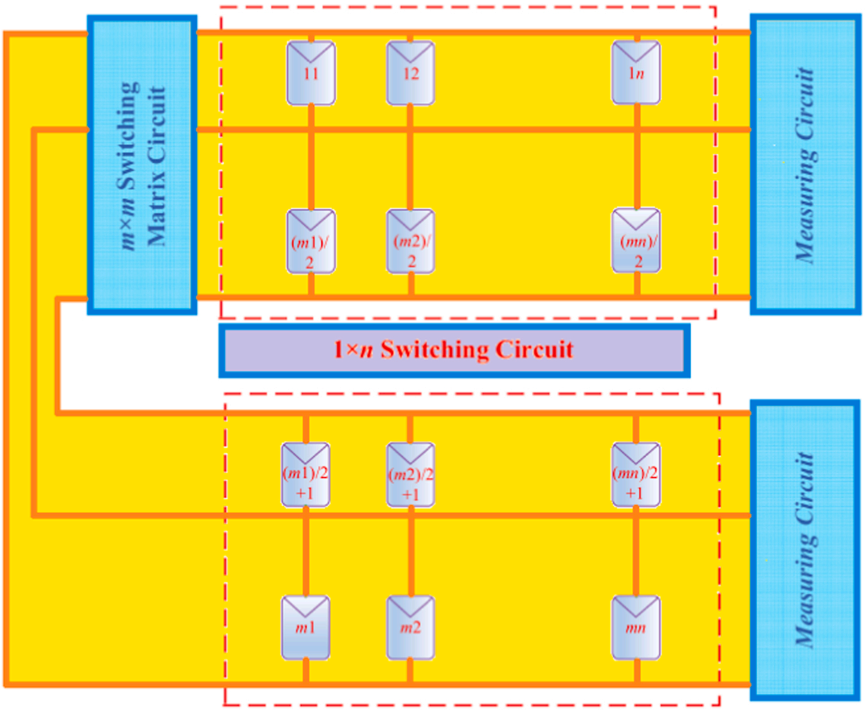


Fig. 12. PV array structure using a two-stage reconfiguration technique[82].

5.2.1. *Genetic algorithm (GA)*

The GA is a search-based optimization technique centered on genetics and natural selection principles. The objective function considered by the authors in [85] takes power production combined with weight current. In addition, the hit-and-miss approach is employed to determine suitable parameter extents. However, GA is usually stuck at local maxima solutions when incorrectly set parameters [86]. The modified GA based on the concept of standard deviation has been developed in the literature to solve problems in local maxima. The suggested standard deviation genetic algorithm (SDGA) has a specific objective function computed by Eqs.(7–9) [87] that tries to decrease the deviation of individual row currents:

$$\sigma_1 = \sqrt{\frac{1}{N}[\sum_{j=1}^{N} (I_j - I_m)^2]} \tag{7}$$

$$\max fitness(i) = \frac{1}{1+\sigma_1} \tag{8}$$

$$\text{bio}I_m = \frac{1}{N}\sum_{j=1}^{N} I_j \tag{9}$$

Where σ_1 indicates the standard deviation of each row's currents; fitness (i) represents the fitness amount of the i_{th} factor in the current population; It is the current of the j_{th} row, and N shows the number of rows. Both SDGA and GA are used in PV array reconfiguration, with SDGA having a faster confluence time [87],

5.2.2. *Gravitational search approach (GSA)*

The GSA is a meta-heuristic algorithm based on Newton's rule of motion and the concept of universal gravitation. PV array reconfiguration has been optimized using the insolation point mismatch intimation (IMI), measured as the sum of squares of the divergence involving the irradiance levels of the PV array's rows [88]. The optimum operational rate of GSA is substantially higher than BBA, according to a comparison of BBA and GSA reconfiguration.

5.2.3. *Liquid cycle algorithm (LCA)*

The performance of liquid traveling from rivers and streams to the sea-inspired the LCA. The LCA is used to reconfigure PV arrays; it efficiently minimizes IMI and power losses [89]. LSA has a relatively high execution time, making it unsuitable for the real-time implementation of advanced solar arrays.

5.2.4. *Particle swarm optimization technique*

Particle swarm optimization (PSO) is a technique that uses a simultaneous random searching approach to solve problems. It has a wide range of applications and is simple to implement [90]. As a result, it is used to reduce the effects of PSC in PV array reconfiguration. The mathematical formulation [20,91] is described as follows:

$$maximizeF(i) = Sum(P) + \left(\frac{W_e}{E_e}\right) + (W_p \times P_a) \tag{10}$$

Where Sum (P) is the PV array's output power generation, denotes the power generated by a single PV panel; is the error between the row current and the maximum current, and shows weight coefficients. The component in the current position fitness is $F(i)$.

PSO boosts output power and decreases local peaks while minimizing the row current difference, as per the comparative analysis with the TCT configuration [30]. On the other hand, PSO may cause misleading system behavior and early convergence and the limitations of sophisticated parameter variation.

5.2.5. *Grasshopper optimization algorithm(GOA)*

The GOA is applied to reduce the impact of PSC since it is simple and requires fewer control variables [92]. GOA updates the solution during iterations by considering each agent's current position and the global optimization method. This characteristic ensures the algorithm's optimization effectiveness, but it also raises the algorithm's computational weight. In conclusion, GOA decreases the effect of PSC while increasing the hardware processing speed requirements.

5.2.6. *Modified Harris Hawks optimizer technique*

A novel reconfiguration method built on the Modified Harris Hawks Optimizer (MHHO) has been presented [93] to tackle GOA's shortcoming. It simulates Harris hawks' predation behavior. Furthermore, the experiments comparing HHO, GA, PSO, CS, and MHHO show that MHHO provides the best reconfiguration with just 12.5% of GA's repetition numbers and produces more power than any other method [94].

5.2.7. *Flow regime algorithm (FRA)*

The FRA is based on fluid mechanics fundamentals. Eqs.(11) and (12) [95] correspondingly split the progression of optimizing the PV array arrangement into two phases: exploration and exploitation.

$$Z_{i_{(n_t+1)}} = Z_{i_{(n_t)}} + \beta L^{A}evy \times (g^{*}_{n_t} - Z_{i_{(n_t)}}) \times \frac{0.37}{\sqrt[5]{STF}} \tag{11}$$

$$Z_{i_{(n_t+1)}} = Z_{i_{(n_t)}} + \beta rand \times (g^{*}_{n_t} - Z_{i_{(n_t)}}) \times \frac{4.96}{\sqrt{STF}} \tag{12}$$

Where STF indicates the search type element; g^* it signifies the global optimum solution for repetition n_t; $Z_{i_{(n_t)}}$ indicates the solution component of the i^{th} agent for repetition n_t; FRA delivers four times the rate of convergence of GA while having a sophisticated search process [95].

5.2.8. *Rao optimization technique and social mimic optimization (SMO) technique*

Two alternative techniques to reduce the impact of PSC are proposed in the literature [95]. Rao and SMO optimization are the two techniques. Using real-time irradiance data, each of the three methods is tested. Rao and SMO are significantly less efficient than FRA, but they have a more accessible search technique. As a result, the Rao and SMO algorithms perform better in cost.

5.2.9. *Marine predators algorithm (MPA)*

The MPA simulates predator and prey behavior in the sea. MPA suggests a new objective function instead of the weighted objective function. To avoid early convergence due to erroneous weights, values is indicated in Eq.(13) [94] as follows:

$$Function(i) = \frac{P_{array}}{|I_{\max} - I_{\min}|} \tag{13}$$

Where $I_{\min}$ and $I_{\max}$ represent the minimum and maximum row currents, correspondingly, and Function(i) represents the estimated fitness amount for the i^{th} member in the current estimate. The new feature tries to increase output power while minimizing the disparity between row currents. In addition, when compared to other algorithms like PSO, MRFO, and HHO, MPA determines the best configuration in the shortest amount of time [94].

5.2.10. *Grey Wolf technique (GWO)*

GWO is a technique that aims to replicate the joint chasing habits of grey wolves, which are made up of tetrad different sorts of wolves: delta (δ), alpha (α), omega (ω), and beta (β). Grey wolves at the bottom of the food chain are frequently portrayed as scapegoats and followers [96–98].

Furthermore, the grey wolf optimization technique is modified with multi objectives to form an improved GWO. It maximizes power output by row current equalization, which is helpful for smoother characteristics. The abovementioned objectives of power and current [97–99] can be stated mathematically as:

$$Max(Obj_1) = sum(P_x) = \sum_{x=1}^{9} I_x \times V_x \tag{14}$$

$$Min(Obj_2) = |I_{\max} - I_{\min}| \tag{15}$$

Where $I_{\min}$ and $I_{\max}$ are the row current's minimum and maximum values, correspondingly, and *as well as Vx*, correspondingly the PV array's current and voltage in favor of the *Xth* row.

Simulation studies show improved GWO solves the multi peak issue and achieves power improvements of 9.4–18.8% over TCT [20, 99].

5.2.11. *Butterfly optimization algorithm (BOA)*

The BOA is a bio-inspired method that mimics butterflies' mating and foraging behavior [100]. Generally, the BOA provides better output power from a PV system with PSC for some shade patterns than GWO [101]. The approach starts by recording the PV panel's electrical properties and the PV array's size. Then, using BOA as a guide improves the solutions and finds the optimum matrix.

5.2.12. *Memetic salp swarm algorithm (MSSA)*

Salps are members of the family Salpidae, which have translucent barrel-shaped bodies. They move by contracting, therefore pushing water throughout their gelatinous bodies. Memetic salp swarm algorithm is a unique bio-inspired optimization technique (MSSA). This method was created by expanding the original salp swarm algorithm (SSA) with numerous independent salp chains. MSSA is used for effective and efficient maximum power point tracking (MPPT) of PV systems operating under PSC. In comparison to the traditional SSA, the suggested MSSA uses parallel salp chains for global exploration and local exploitation within the scope of memetic computing, while a virtual population is employed for global coordination with regroup operation [102]. MSSA may thus search for a better quality optimal with a quicker rate and more steady convergence.

5.2.13. *Artificial ecosystem-based optimization (AEO)*

AEO is a population-based optimizer inspired by an ecology's energy transfer. AEO imitates decomposition, production, and consumption tendencies. The authors in [103] use AEO to reduce PV system partial shading losses and employ a unique fitness function to address the weight factor problem that substantially impacts solution quality.

$$Max(F) = \frac{\max(P)}{STD(I)} \tag{16}$$

$$P = [P_1, P_2, \ldots P_9], I = [I_1, I_2, \ldots I_9] \tag{17}$$

Where STD(I) is the standard deviation of the vector, I row currents.

5.2.14. *Socio-inspired democratic political algorithm (DPA)*

The meta-heuristic approach is appropriate for reconfiguring a PV array. The significant advantage is that it does not require a precise model and is applicable for PV arrays of any size. The outcomes of the meta-heuristic method, on the other hand, are random. The authors in [103] improve randomness and develop a new heuristic technique. The researchers modified a recent socio inspired DPA based on the political optimizer. The optimization technique (DPA) is shown in Fig. 13. The outcomes are validated on real-time hardware-in-loop experimentation using the RTLAB technology. In addition to PSC, dust deposition's shadow is considered in the investigation. According to simulation studies, DPA may increase the power output of a PV array to 18.22%, considering the dust settling [104]. DPA has a minor standard deviation over ACO, TS, GWO, ABC, and GA, showing that DPA has a high level of stability [23].

5.2.15. *Dragonfly algorithm*

An optimization strategy known as the dragonfly algorithm (DA) has been presented. This strategy is usable for photovoltaic arrays of any size and tries to minimize the row current difference that occurs when partial shade is present. The success of DA in any optimization problem largely depends on two major factors: (i) Population generation, (ii) Fitness function design The primary benefit of this method is that convergence is independent of the choice of optimization parameters [105].

5.3. *Artificial intelligence (AI) Approach: The AI methods for PV array reconfiguration have recently received awareness*

5.3.1. *Feedforward artificial neural network (FFANN)*

The design of a PV array with an FFANN uses irradiance and current at the short circuit as basic training details to obtain the best possible reconfiguration [106]. Fig. 14 depicts the construction of a PV system with FFANN integration.

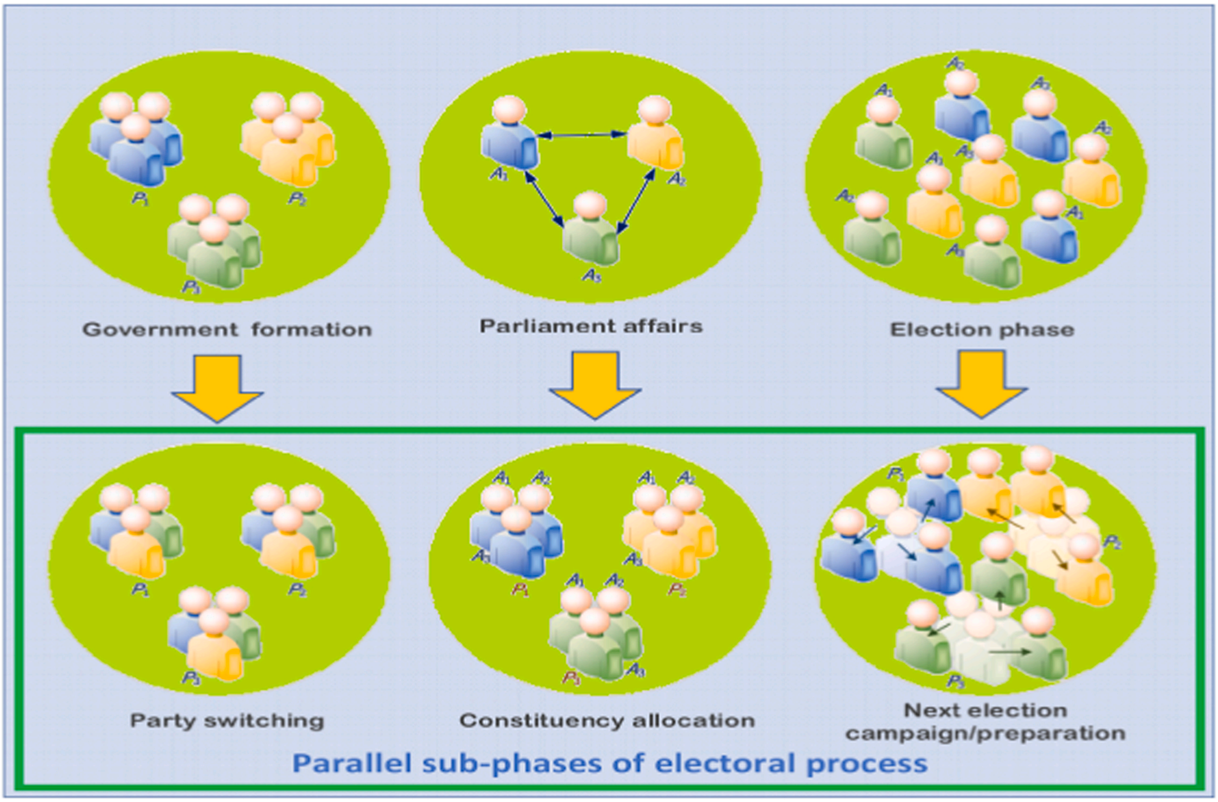


Fig. 13. Demonstration of the political optimizer in all stages [23].

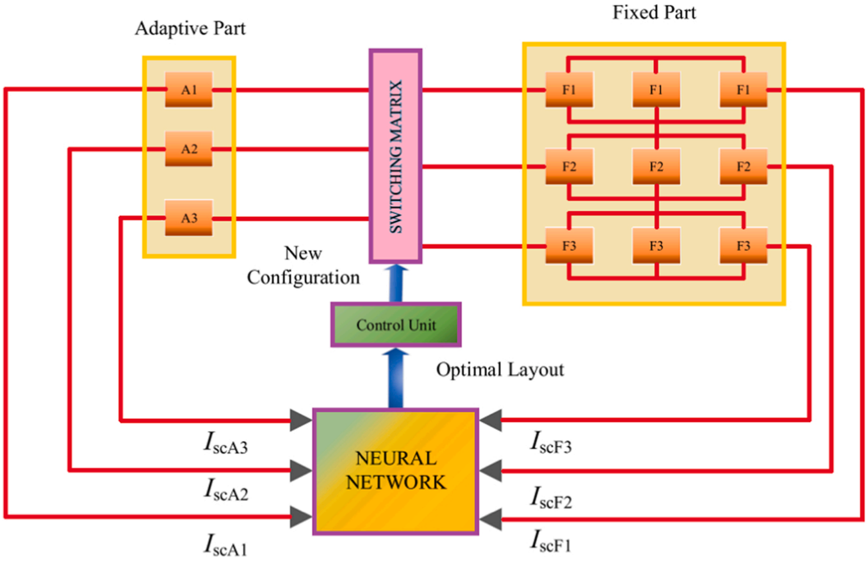


Fig. 14. PV system structure utilizing FFANN [106].

In this technique, a switch matrix connects PV modules on an adaptive part to similar rows of fixed parts. The findings of an unsymmetrical array experiment confirm FFANN's role in instantaneous adaptation along with scheme sturdiness [106].

5.3.2. *Fuzzy logic (FL) estimator technique*

FL replicates an individual's mind thinking to make fuzzy inclusive judgments and is used in an arrangement with an uncertain model [107]. The darkened panels may be recognized and located with the help of FL estimation. Furthermore, each darkened PV panel is considered detached or not based on the darkening level predicted using the FL estimator [108].

5.3.3. *Machine learning algorithm (MLA)*

MLA uses a cyber-physical system to achieve high signal processing capability [109]. A machine learning layout for reconfiguring the PV system is utilized to build a method for generating insolation profiles. In general, MLA achieves a 12% power progression over pre-reconfiguration.

5.3.4. *Clonal selection scheme*

The clonal selection approach works the same way as the organic immune system's learning and memory units, which process information [110]. The clonal selection method is responsible for determining the best configuration using the fitness function, which is derived as follows:

$$F_i = \frac{\sum_{j=1}^{n} (G_{avg})}{n}, (i = 1, 2, \dots, m) \tag{18}$$

$$\min(|F_{i+j} - F_i|) \tag{19}$$

Where Fi signifies optimal value; (G_{avg}) j represents the j^{th} row's average irradiance value; and n and m present column and row numbers, respectively. Second, the combined module assesses whether the clonal selection algorithm's optimum solution can be implemented. If this is not the case, it will execute using a less-than-ideal solution [111].

5.4. *Adaptive array reconfiguration (AAR) approach*

An additional form of dynamic reconfiguration technology is AAR. The AAR approach divides the Photovoltaic array into two sections linked by a switch combination: After installation, the electrical connectivity and physical location of a fixed sub-array cannot be changed. Under PSC, the dynamic sub-array will be dispersedly modified with the micro-control unit. To guarantee irradiance distribution, sensors collect current and voltage data from each panel, which is then transferred to the micro control device. The adaptable panels are adjusted in multiple rows according to shade distribution to compensate for darkened panels and balance the lighting of various rows.

5.4.1. Shading degree based reconfiguration (SDBR)

The extent of the current generated by incident light decreases in each row is described as the shading degree [112]. The SDBR reduces switches, optimization time, and sensors in Photovoltaic array reconfiguration. At the same time, the outcomes of a test with a large PV array show that SDBR can harvest higher power over a reconfigured TCT or SP array [112].

5.4.2. Shadow detection (SD) technique

SD approach compares the current at the short circuit of each panel to the reference current to transform it into a shading degree [113,114]. The control unit gives the actuator, i.e., switch matrix, the ideal PV panel configuration based on shading degree. The switch matrix then adjusts the adaptive part's electrical connection to balance the shading.

5.4.3. Configuration scanning technique (CST)

The CST examines every potential connection scheme and selects the optimal [115] for reconfiguring a PV array. CST tries to balance the current at the short circuit in each row. Furthermore, CST offers the advantage of being used in Photovoltaic systems of varying power ranges without requiring hardware or software alterations.

5.4.4. Bubble sort technique

The Bubble Sort technique (BST) iterates over the list of elements to be categorized, comparing two linked components in a sequence, and switching their locations for entries in improper order. BST selects each row as per the voltage to accommodate all adaptive Photovoltaic modules to the row of the fixed component. The usefulness of BST in enhancing power generation is validated in the experimental setup of a 3×3 PV array [18].

5.5. Removal and reconfiguration approach

This technique works on a two-stepped procedure. The first step includes both the elimination of active diodes and shaded modules. The reconfiguration of non-shaded modules is the next step. All modules are linked in series or parallel with any other module or deleted from the Photovoltaic array using the switch matrix. In addition, the removal procedure prevents any more power loss.

5.5.1. Reconfiguration technique based on selection

The selection-based reconfiguration adheres to evenly distributing modules and retaining more than 50% of each column's initial number of modules. Experiments show that with this reconfiguration strategy, the PV array's power output and operational voltage may significantly increase during PSC [116]. On the other hand, this approach is inadequate for a tiny shadow since it has minimal power enhancement in the slight shade.

5.5.2. Power comparison technique (PCT)

The PCT is used to rearrange the remaining Photovoltaic modules to get a smoother characteristic curve of the Photovoltaic array under PSC. PCT evaluates all MPPs (maximum power points) of each PV system to determine the maximum point. Specifically, the configuration that leads to the highest MPP is the best PV array arrangement. PCA also reduces power loss, according to simulated experiments [24].

5.5.3. The Operative MPP-based technique

Operative maximum power point (OMPP) represents the overall peak and specific local peaks with a higher current than the overall peak [117,118]. The current mismatch is reduced by increasing the total current of the minimal OMPP. Furthermore, balancing the number of effectual panels in several strings reduces voltage inequality. This PV array reconfiguration approach is incompatible with real-time execution clearly evident from simulation outcomes [118]. The current mismatch is diminished when the sum of the current of the minimal OMPP is increased. Furthermore, balancing the sum of active panels in various strings reduces voltage mismatches. Simulated outcomes reveals how this photovoltaic array reconfiguration approach is inadequate for actual-time use [118].

5.5.4. Optimal Mileage-based PV array Reconfiguration

Initially, the proposed OMAR integrates PV array reconfiguration and real-time generation scheduling, not only maximizes the power output of a power plant, but also decrease the additional capacity and mileage expenses brought on by the power fluctuation. OMAR's optimization difficulty can be reduced by separating it into an SRL-based upper-layer discrete optimization and an IPM-based lower-layer continuous optimization [119].

6. Summary and discussion

Tables 2-10 thoroughly analyze and summarize the 70 reconfiguration techniques for a structured and efficient comparison study. Various strategies to improve the power production in PSCs have been reported in the research, as detailed in the earlier sections. Sensors and switches are not required in static reconfiguration techniques, and the photovoltaic modules are positioned such that the shade is distributed across the array rather than concentrated. Static reconfiguration methods are easy (for limited areas), inexpensive, and provide a cost-effective option because the electrical connections are not changed. However, in some of the proposed configurations, the prospect of insufficient shade distribution is a disadvantage of this approach's scheme.

For changing the interconnections, the dynamic reconfiguration techniques use switches, sensors, and complex optimization control approaches, raising the number of control complications and reducing overall system efficiency.

For example, the fundamental drawback of the adaptive technique is that it requires a static adaptive bank of solar cells, which considerably raises the number of necessary switches, cells, and connections complications.

The approaches based here on the irradiance equalization concept have been developed to improve PV array layout and control methods to avoid problems with TCT setup, such as an algorithm based on actual shading patterns.

Other PV array topologies are employed to overcome the constraints of the methodologies mentioned above. Algorithms based on intelligent approaches, such as NN, PSO, GA, and Fuzzy logic, have decreased the number of switches.

Under partial shade conditions, the EAR method harvests greater power than dispersion schemes. On the other hand, Dispersion approaches are more manageable and less expensive to install than the EAR setup.

The optimization approach determines the best switching matrix configuration to reduce current row differences and maximize output power. Metaheuristic optimization algorithms strategies such as population-based Algorithms, GA, artificial ecosystem-based optimization, PSO (particle swarm optimization), GOA (grasshopper optimization algorithm), Modified Grey Wolf Optimizer, Butterfly Optimization Algorithm based methodology, COA (Coyote optimization algorithm), and Marine Predators Algorithm (FPA) are promoting practical ways to provide the most satisfactory optimum solution.

The dynamic reconfiguration techniques are shown to be beneficial in optimizing the power in shading situations after examining the different evaluated reconfiguration strategies. However, there are various obstacles to overcome when using dynamic reconfiguration approaches. Many static approaches have inefficient shadow dispersion or only enable column-by-column shade dispersion, reducing their dependability. As a result, it is necessary to consider addressing this problem.

Because the dynamic approach necessitates using a monitoring reconfiguration technique to determine a switching combination to link PV modules and the optimal configuration.

Researchers in the subject will be needed to design new, more appropriate optimization algorithms, improve current approaches, or use hybrid algorithms that generally outperform the optimization algorithm individually. Additional study on the switching combination's operation is needed.

Despite advancements in produced power and the range of works done in PV array reconfiguration, it is critical to strike a balance between system cost, complexity, and speed to maximize the power collected.

Any reconfiguration approach will be used depending on the application and size of the PV array.

7. Conclusion and suggestion

Solar PV systems are commonly partially shadowed in urban environments. Partial shading has a substantial influence on the electrical efficiency of conventional modules. In order to boost the yield of urban PV systems, shade-tolerant PV module topologies are necessary. This work attempts a comprehensive overview of 70 PV array reconfiguration approaches, including various distinctions. These have been inventively divided into nine sections. This study compares several PV reconfiguration strategies using more acceptable criteria to guarantee a fair and thorough assessment. Following is a summary of the major findings:

- The control approach for static methods is less complex than that of dynamic methods. However, it is challenging to put them into practice in field applications
- Despite the fact that dynamic approaches always have high costs. for using excessive amounts of sensors, switches, and integrated devices. Due to its quick reaction time and strong flexibility, it is still one of the most promising technologies for reconfiguring PV arrays.
- Meta-heuristic strategies provide more desired results in terms of shade distribution and power improvement when compared to basic static techniques. Consequently, they have received the greatest attention in recent publications.
- Recently, the use of AI techniques in this subject has attracted a lot of interest. While meta-heuristics and artificial intelligence (AI) are both difficult and need additional parameter alterations.
- The ability to successfully use simulation algorithms to a large-scale PV plant operation currently lacks executable procedures.
- It is urged to suggest significant innovation because many reconfiguration algorithms that have been developed in recent years have comparable effects.
- The complexity of parameter adjustments in the existing reconfiguration methods has to be reduced.
- Numerous engineering practices use hybrid algorithms, which combine the benefits of multiple single core algorithms and AI algorithms. Therefore, greater focus should be placed on optimising or combining a variety of strong individual algorithms for PV array reconfiguration. Further research is needed in order to optimise the appropriate "weighting" parameters of AI algorithms.
- The majority of studies are validated at ambient temperature, which has a significant impact on power generation. In order to provide more useful information for various field temperature situations, it is necessary to conduct additional research on PV array reconfiguration in irregular temperature.
- A key element of the search for the optimal solution is the algorithm's ability to perform global exploration. Utilizing self-adaptive procedures that can dynamically stable local exploitation and global investigation is therefore capable for efficiently locating the global finest configuration in mismatch PSCs scenarios.
- Instead of just increasing output power as was done in earlier studies, attention must be paid to the steadiness between improving output power and decreasing switch operation intervals. Until then, the return-on-investments catalogue should be used in further studies to successfully increase profits and decrease costs, which is of major significance for real-world engineering applications.

- To verify the practical performance of different algorithms, further hardware experiments should be carried out in addition to simulation and hardware-in-the-loop (HIL) testing.
- It will be carried out to develop more reliable heuristic algorithms. These algorithms will also be tested experimentally and applied to more complicated shadow circumstances, bigger PV arrays, and different configurations (TCT, BL, HC, etc.).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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