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Impact of Partial Shading on Various PV Array Configurations and Different Modeling Approaches: A Comprehensive Review

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ABSTRACT Since the last decade, partial shading conditions (PSCs) and its adverse influences on photovoltaic (PV) system performance have received due attention. It motivates researchers to explore methods to diminish/disperse the shading effects and/or novel PV array configurations to sustain under PSCs. To diminish the effects of PSCs, this article presents a comprehensive review of various PV array configuration models for PV systems and metaheuristic approaches for shade dispersion effectively. Different PV array modeling approaches are identified, emphasizing their benefits, inadequacies and categorized according to vital features such as shade dispersion and improved performance in terms of efficiency; fill factor (FF), and maxima power, minimized power losses (PL) primarily. Besides these various PV array configurations such as hybrid, reconfigured, mathematical/game puzzle based advanced configurations are uniquely discussed with the existing configurations. In the current scenario, the metaheuristic algorithms are explored and widely accepted by researchers due to the less wire length requirement for PV array reconfiguration. This article discusses and deliberates recent developments in methods of solar PV performance enhancement that deserves further study. Overall, the present study is helpful for academicians and researchers in the committed solar power installation area.

INDEX TERMS Photovoltaic system, partial shading condition (PSC), game puzzle, total cross-tied (TCT), honey comb, bridge link, metaheuristic algorithm.

I. INTRODUCTION

In recent years, solar PV technology is very commanding and fast-growing at a global level from a small rooftop to multi-MW power plants. Solar energy is considered as a promising option of renewable energy [1]–[3]. However, because of the low conversion efficiency of the PV cell, it is necessary to extract maximum energy as much as possible in a practical PV system [4]–[6]. This leads to the design of different PV arrays with various cells/modules arrangement in series and parallel conventionally to achieve the required load power.

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All kinds of PV system installation sites, from off-grid (rural) to residential areas inside the metro cities, often forward to operation at non-uniform irradiation levels due to surrounding obstacles conditions, whereas, it is forced to reduce the size of installation land [7]–[9]. The shading effect has major non-linear impacts on the PV system performance. More than one power maxima point's such as local maximum power point (LMPP) and global maximum power point (GMPP) are available on the power-voltage (P-V) characteristics due to non-uniform solar irradiation levels [10], [11].

The major causes behind the occurrence of PSCs are the non-uniform solar irradiation due to static shading patterns

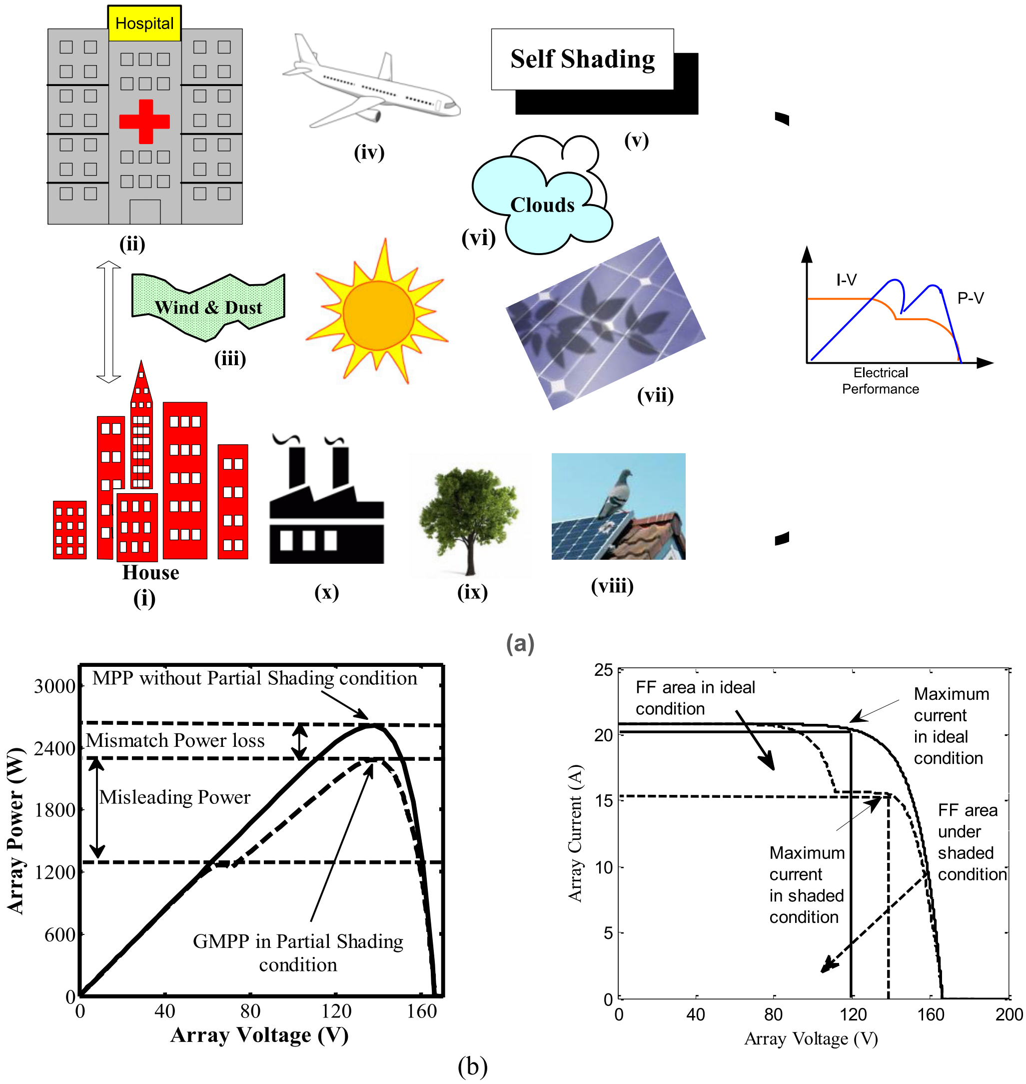

FIGURE 1. (a). Schematic diagram of PSCs on PV array (b) Effect of partial shading on P-V and I-V characteristics.

such as nearby trees, pole (especially telecom tower), high rise buildings, bird dropping, passing clouds (dynamic shading), etc. The shading conditions have predominant effects on PV module performance connected in an array. To enhance the PV system performance, an analysis is carried out on the interconnections of modules of the PV array system in some pre-defined configurations. Moreover, it is motivating research activity to gain performance in terms of reducing the shading effect on PV systems. The present research aspect follows extensively for the comprehensive review analysis to investigate the influences of PSCs on PV array performance. The causes and shading influences on PV array are shown in terms of distorted current, voltage, and power characteristics as depicted in Figure 1(a)-(b). The non-linear behavior of P-V characteristics is helpful for performance assessment.

A. NOVELTY OF WORK

The contribution of the present research manuscript is as follows,

- A comprehensive literature review is carried out on the conventional and game puzzle PV array configurations for the extensive comparison in terms of topology, array size, grid connectivity, etc. and uniquely classified according to array configurations.
- A critical review on puzzle/game based advance configurations of the solar module is comprehensively proposed.
- The present study also includes the metaheuristic approaches for showing higher shade dispersion capability and reducing the wire length for PV array reconfigurations.

B. LITEATURE REVIEW

In this article, various types of PV array configuration models are reviewed and investigated in terms of their performance parameters such as accuracy, reliability, GMPP location, FF, minimum power loss, power enhancement (PE), and hardware implementation scope. A wide-range analysis is shown

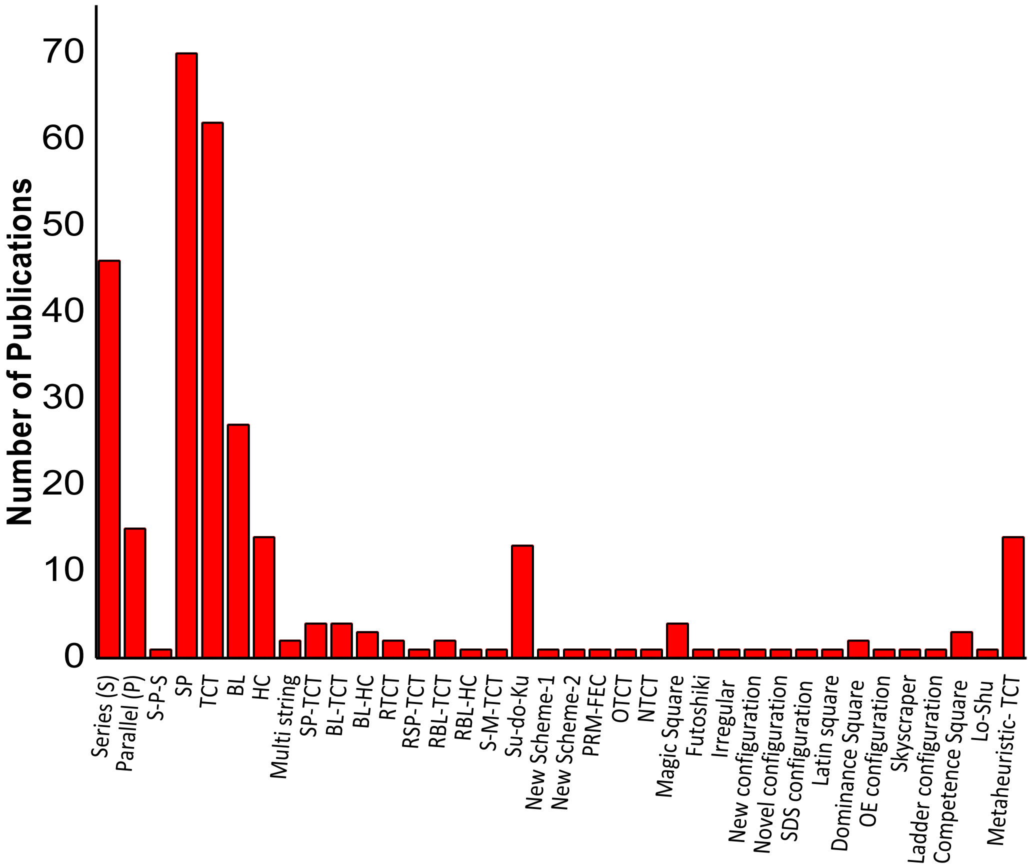

FIGURE 2. Number of publications on distinct configurations in the time span of year 2002-2020.

related to the accuracy, robustness, ease of execution, efficiency, simplicity, and applications, pointing out the strength and weaknesses of each scheme. Based on the available literature, the research topics explore further investigation are identified and deliberated.

A sufficient number of research papers [12]–[147] are considered for extensive literature review to cover all the present and future research aspects of PV module interconnections along with shade dispersion schemes on PV array for performance improvement under the PSCs.

The significance of the categorized study is depicted in Table 1 based on research publications as available literature as per the author's best knowledge. The number of publications on distinct configurations in the period of the year 2002- 2020 is illustrated in Figure 2 as,

In this present comprehensive study, the performance parameters are considered such as PV array topology, the occurrence of partial shading, irradiation levels for investigation, capacity, and grid integration or standalone mode of power generation. The taxonomy of the PV systems under PSCs is depicted in Table 2 as,

II. PV ARRAY CONFIGURATIONS

It is a very challenging task for researchers to explore more sustainable and reliable solutions to achieve the best performance of the PV system. The best available methods are to reconfigure the locations of PV modules to form a novel structure of the PV array. Moreover, a state of art study is carried out for various existing configurations of PV array and categorized in Figure 3 as,

A. CONVENTIONAL PV ARRAY CONFIGURATIONS

1) SERIES CONFIGURATION

The authors investigated the partial shading effect on the current-voltage (I-V) characteristic of a series connected PV cell in a module. It is observed that an area of shaded PV cell directly affects the I-V characteristic behavior [16]. Furthermore, the maximum current of 0.8A and 3.3 A is obtained for irradiation level of 200W/m^2 and 1000W/m^2 respectively.

The effect of shading on series-connected 108 PV cells in different four strings 6 × 18, 4 × 27, 3 × 36, and 2 × 54 under different irradiation levels of 250-1000 W/m^2 is analyzed in [17]. The authors in [21] have investigated the 2-5 PV modules which are connected in the series configuration for analyzing the performance under PSCs at the irradiation level of 200W/m^2. The observed values for GMPP are found to be 32.65W (in the case of two series-connected PV modules), 3 series-connected PV modules have 50.12W, 4 series-connected PV modules have 67.61W, and 5 series-connected PV modules have 85.21W.

TABLE 1. Types of configurations with the number of publications in the time span of 2002- 2020.

Types of Configuration		No. of Publications	References
Conventional configurations	Series (S)	46	[12,16,17,21,24-30,32,35,38,39,45,47-51,55,63,64,66,68-75,77,84-87,90,93,97,101,105,109,119,125]
	Parallel (P)	15	[25,26,30,43,45,47,49,51,70,73,84,85,87,93,101]
	Series-parallel-series (S-P-S)	1	[12]
	Series-parallel (SP)	70	[12,14,15,18-20,22,23,25,27,28,32-34,36,37,40-44,46,51-54,56,57,60-62,65,70,76,78,80-83,87,88,91,93,96-98,101,104-109,113,116,117,120-125,128, 131, 132, 133, 136, 137, 141, 142, 146]
	Total cross-tied (TCT)	62	[14,15,18,20,33,36,44,51,53,59,65,67, 78,79,81,83,87-89,91-95,99,100,102,104,106,107,110-116,118,120,121,123,124,126-128, 129, 130, 131-136, 138-141, 143- 147]
	Bridge link (BL)	27	[14,15,20,33,51,53,76,78,79,81,87,91, 93,99,104,107,113,116,120,124,128, 132, 133, 135-137, 140]
	Honey comb (HC)	14	[51,53,81,87,93,107,116,120,128, 132, 135-137, 140]
	Multi string	2	[31,43]
Hybrid Configurations	Series-parallel-Total cross Tied (SP-TCT)	4	[116, 126, 136, 146]
	Bridge link- Total cross Tied (BL-TCT)	4	[116, 126, 136, 137]
	Bridge link- Honey comb (BL-HC)	3	[118, 126, 136]
Reconfigured/ Modified configurations	RTCT	2	[100, 118]
	RSP-TCT	1	[118]
	RBL-TCT	2	[118, 137]
	RBL-HC	1	[118]
	S-M-TCT	1	[121]
Puzzle based Advanced configurations	Su-do-Ku	13	[67, 89, 94, 95, 99, 102, 122, 132, 134, 138, 139, 144, 145]
	New Scheme-1	1	[116]
	New Scheme-2	1	[116]
	PRM-FEC	1	[111]
	OTCT	1	[115]
	NTCT	1	[115]
	Magic Square (MS)	4	[110, 118, 127,113]
	Futoshiki	1	[112]
	Irregular configuration	1	[91]
	New configuration	1	[93]
	Novel configuration	1	[120]
	SDS configuration	1	[120]
	Latin square (LS)	1	[129]
	Dominance Square (DS)	2	[130, 139]
	OE configuration	1	[133]
	Skyscraper	1	[134]
	Ladder configuration	1	[136]
	Competence Square (CS)	3	[139, 143, 147]
	Lo-Shu	1	[139]
Metaheuristic- TCT based PV array configurations	GA	5	[142-145, 147]
	PSO (ASM based configuration)	3	[141, 145, 147]
	FRA	1	[143]
	SMO	1	[143]
	RAO	1	[143]
	GOA	1	[144]
	BOA	1	[146]
	MMHO	1	[147]

TABLE 2. Taxonomy of the PV system under PSCs.

Authors, [Ref]	Methodology /array configuration-ns	Best PV Array configuration	Conditions to Detect occurrence of PS	Array Size	Power Output/ GMPP (W)	Irradiation Levels (W/m^2)	Grid connected/ Off-grid
Bishop [12]	S, SP, S-P-S	S-P-S	Artificial	Small	Lab based	Hot spot heating	Off-grid
Blas et al. [13]	Single PV module	Single PV module	Artificial	Small	75 W	649-918	Off-grid
Gautam and Kaushik [14]	SP, TCT, BL	TCT	Artificial	720×20	13869 W	20- 1000	Off-grid
Kaushik and Gautam [15]	SP, TCT, BL	TCT	Artificial	9×4, 6×6	35.04 W	20- 1000	Off-grid
Kawamura et al. [16]	S	S	Artificial	Small	13.6- 69.3 W	200-1000	Off-grid
Alonso-Garcia and Herrmann [17]	S	S	Simulation based	108 PV cells arranged in 6×18, 4×27, 3×36, 2×54 strings	96.8 W	250-1000	Off-grid
Nguyen and Lehman [18]	SP, TCT	TCT	Passing clouds	Small	158 W	1000	Off-grid
Candela et al. [19]	SP	SP	Simulation based	Small	65 W	1000	Off-grid
Karatepe et al. [20]	SP, BL, TCT	TCT	Simulation based	2×6, 6×2, 4×3, 3×4	589.79 W	100-1000	Off-grid
Xiao et al. [21]	S	S	Simulation based	2-5 PV modules	85.21 W	200-1000	Laboratory based system
Patel and Agarwal [22]	SP	SP	Passing clouds	30×10	1.5 KW	500-1000	Grid connected
Patel and Agarwal [23]	SP	SP	Passing cloud	10×90	230 KW	500-1000	Grid connected
Silvestre and Chouder [24]	S	S	Simulation based	Small	35.31 W	300-1000	Off-grid
Dio et al. [25]	S, P, SP	SP	Serially partial shading	Small	28 W	500-800	Off-grid
Gao et al. [26]	S, P	P	Shading due to tree	20×4, 3×27	1.19 W	200-900	Off-grid
Velasco-Quesada[27]	S, SP	SP	Simulation based	72 series and 36 parallel PV cells	230 W	100-500	Off-grid
Silvestre et al. [28]	S, SP	SP	Simulation based	36 PV cells	208.07 W	500-1000	Laboratory based
Bellini et al. [29]	S	S	Simulation based	4 PV modules	1760 W	100-1000	Off-grid
Chowdhury et al. [30]	S, P	P	Simulation based	Small	195 W	500-1000	Off-grid
Piazza and Vitale [31]	Multi string	Multi string	Natural and artificial	Small	205 W	250- 750	Off-grid
Martinez-Moreno et al. [32]	S, SP	SP	Simulation based	8 PV modules	125 W	100-1000	Off-grid
Picault et al. [33]	SP, TCT, BL	TCT	Simulation based	Medium	1039 W	631-651	Off-grid
Tsai [34]	SP	SP	Simulation based	Small	60 W	500-980	Laboratory based
Wang and Hsu [35]	S	S	Simulation based	Small	80 W	160-960	Laboratory based
El-Dein et al. [36]	SP, TCT	TCT	Simulation based	6×4	1528W	250-1000	Off-grid
Ishaque et al. [37]	SP	SP	Simulation based	20×3	1200 W	200-1000	Off-grid
Maki et al. [38]	S	S	Simulation based	18×3	1.350 KW	175-1000	Off-grid
Moballegh and Jiang [39]	S	S	Simulation based	96 PV cells	171.5 W	130-992	Off-grid
Patnaik et al. [40]	SP	SP	Simulation based	3×3, 4×4	1.4 W,1.7W and 2.25W	250-1000	Laboratory based
Renaudineau, et al. [41]	SP	SP	Simulation based	3×2	550 W	500-1000	Laboratory based
Santos et al. [42]	SP	SP	Artificial	3×2	58 W	500-1000	Off-grid
Li et al. [43]	Multistring, SP, P	SP	Artificial	4- 8 PV modules	10kW	NA	Grid connected
Wang and Lin [44]	SP, TCT	TCT	Simulation based	36 PV modules	1256 W	500-1000	Off-grid
Kadri et al. [45]	S, P	NA	Artificial	3 PV modules	180W	400-1000	Off-grid

TABLE 2. *(Continued.)* **Taxonomy of the PV system under PSCs.**

Alahmad *et al.* [46]	SP	SP	Simulation based and artificial	3×3	3.7W	NA	Laboratory based
Ding *et al.* [47]	S, P	P	Simulation based and artificial	3×2	93.6W	220 -890	Laboratory based
Diaz-Dorado, [48]	S	S	Simulation based	36 PV cells	1164 W	NA	Off-grid
Maki and Valkealahti, [49]	S, P	P	Simulation based	18 PV modules	2350 W	132- 729	Off-grid
Moschitta *et al.* [50]	S	S	Simulation based	20 PV modules	4.9 KW	NA	Off-grid
Ramaprabha and Mathur [51]	S, P, SP, TCT, BL, HC	TCT	Simulation based	2×4, 4×2, 2×6, 6×2, 3×4, 4×3, 3×3, 4×4, 6×4, 4×6	676.8W	325-1000	Off-grid
Salam and Ramli [52]	SP	SP	Simulation based	4 PV modules	135.54 W	400-1000	Off-grid
Villa *et al.* [53]	SP, BL, HC, TCT	TCT	Simulation	3×3, 5×3	1000W	200-1000	Off-grid
Zhang *et al.* [54]	SP	SP	Simulation	6×3	1000 W	100-1000	Off-grid
Ziar *et al.* [55]	S	S	NA	2 PV modules	70 mW	150-300	Laboratory based
Alajm *et al.* [56]	SP	SP	Simulation	3×3	150 W	300-1000	Off-grid
Bastidas *et al.* [57]	SP	SP	Manually	2×2	689 W	500-1000	Off-grid
Reinoso *et al.* [58]	Conf 1, Conf. 2 and Conf. 3	Conf. 1	Simulation	9 PV module	1.1 kW	75-525	Off-grid
El-Dein *et al.* [59]	TCT, HRPVA, FRPVA	FRPVA	Simulation	6×4	1834W, 1630W, 1786W	500-1000	Off-grid
Huynh *et al.* [60]	SP	SP	Simulation	4×3	150 W	100-1000	Off-grid
Jung *et al.* [61]	SP	SP	Simulation based and artificial	6×5	144 W	500-1000	Off-grid
Kouchaki *et al.* [62]	SP	SP	Simulation based and artificial	6×6	1355 W	535-1000	Off-grid
Lu *et al.* [63]	S	S	Simulation	72 PV modules	300 W	0-1000	Off-grid
Nezhad *et al.* [64]	S	S	Simulation	4 PV modules	800 W	250-1000	Off-grid
Romos-Paja *et al.* [65]	SP, TCT	TCT	Simulation and artificial	2×2 PV modules	140 W	322-560	Off-grid
Pareek *et al.* [66]	S	S	Simulation	2 PV modules	375 W	200-1000	Off-grid
Rani *et al.* [67]	TCT, Su-Do-Ku	Su-Do-Ku	Simulation	9×9	4532 W	200-900	Off-grid
Rodrigo *et al.* [68]	S	S	Simulation	24 PV modules	1.1 kW	771-1000	Off-grid
Seyedmahmoudian *et al.* [69]	S	S	Simulation	25 PV modules	350 W	400-1000	Off-grid
Tian *et al.* [70]	S, P, SP	SP	Simulation	4 PV modules	954.88 W	750-1160	Off-grid
Batzelis *et al.* [71]	S	S	Simulation	46 PV module	1000 W	200-1000	Laboratory based
Bauwens *et al.* [72]	S	S	Simulation and artificial	45 PV cells	43.16 W	NA	Laboratory based
Dorado *et al.* [73]	S, P	P	Outdoor shading	6×9	2.3 kW	100-1000	Off-grid
Fialho *et al.* [74]	S	S	Simulation	2 PV module	150 W	700-1000	Off-grid
Parlak [75]	S	S	Simulation	3 PV modules	165W	300-1000	Off-grid
Lun *et al.* [76]	SP, BL	BL	Artificial	2×6	173.9445W	100-1000	Off-grid
Ma *et al.* [77]	S	S	Natural shading	4 PV module	130.72 W	235-870	Off-grid
Moballegh *et al.* [78]	SP, TCT, BL	TCT	Artificial shading	2×4	678.40W	279-992	Off-grid
Pareek and Dahiya [79]	SP, TCT, BL	TCT	Simulation	4×4	2.86 kW	200-1000	Off-grid
Qi *et al.* [80]	SP	SP	Artificial	3×3	40 W	100-1000	Off-grid
Ramaprabha [81]	SP, TCT, BL, HC	TCT	Simulation	2×4, 4×2, 2×6, 6×2, 3×4, 4×3, 3×3, 4×4, 4×6, 6×4	234.57W	200-1000	Off-grid
Shirzadi *et al.* [82]	SP	SP	Simulation	3×6, 4×10, 5×13, 5×18	3.767 kW	253-512	Off-grid
Storey *et al.* [83]	SP, TCT	TCT	Simulation	2×6, 3×3	1.34 kW	100-1100	Off-grid
Vijayalekshmy *et al.* [84]	S, P	P	Simulation	10×3	290.5W	0-1000	Off-grid
Wang *et al.* [85]	S, P	P	Simulation and artificial	4×4	16.28W	500-1000	Laboratory based
Bai *et al.* [86]	S	S	Simulation	60 PV cells	90 W	733.1-751.1	Off-grid
Belhachat and Larbes [87]	S, P, SP, TCT, BL, HC	TCT	Simulation	24 PV modules	1446 W	300-1000	Off-grid

TABLE 2. *(Continued.)* **Taxonomy of the PV system under PSCs.**

Celik *et al.* [88]	SP, TCT	TCT	Simulation	2×2, 6×8, 8×3	2724 W	100-1000	Off-grid
Deshkar *et al.* [89]	TCT, Su-Do-Ku, GA	GA	Simulation	9×9	4802 W	200-900	Off-grid
Fathy [90]	S	S	Simulation	3 PV module	480 W	200-1000	Off-grid
Grisales *et al.* [91]	SP, TCT, BL, Irregular	Irregular	Simulation	3×3	353W	NA	Off-grid
Malathy and Ramaprabha [92]	TCT, novel configuration	Novel configurat ion	Simulation	3×3, 6×4	708. 57 W	200-1000	Off-grid
Malathy and Ramaprabha [93]	S, P, SP, TCT, BL, HC, New Configuration	New configurat ion	Simulation	2×18, 3×12, 4×9, 6×6, 9×4, 12×3, 18×2	981.3W	300-1000	Off-grid
Potnuru *et al.* [94]	TCT, Su-do-Ku	Su-do-Ku	Simulation	9×9	5554W	100-1000	Off-grid
Rao *et al.* [95]	TCT, Su-Do-Ku and Improved Su-Do-Ku	Improved Su-Do-Ku	Simulation	9×9	5168W	200-900	Off-grid
Sankar and Mukherjee [96]	SP	SP	Simulation	10×100	40.5KW	500-1000	Off-grid
Sundareswaram *et al.* [97]	S, SP	SP	Natural and simulation	2×3	38.06W	100-1000	Laboratory based
Vicente *et al.* [98]	SP	SP	Artificial	2×2, 2×3	40 W	100-1000	Laboratory based
Vijaylekshmy *et al.* [99]	Su-Do-Ku arranged HC, BL, TCT	Su-Do-Ku arranged TCT	Artificial	6×6	1250W	200-1000	Off-grid
Vijayalekshmy *et al.* [100]	TCT, RTCT	RTCT	Simulation	6×6	1160 W	200-1000	Off-grid
Xueye and Tianlong [101]	S, P, SP	SP	Simulation	30 PV modules	5000W	400-1000	Off-grid
Yadav *et al.* [102]	SP-TCT, Su-Do-Ku, TCT	Su-Do-Ku	Simulation	4×4	2278W	350-1000	Off-grid
Boukenoui [103]	S, SP	SP	Simulation	2×4	225 W	100-980	Off-grid
Braun *et al.* [104]	SP, BL, TCT, BR	TCT	Simulation	12×4	180W	100-1000	Off-grid
Forcan *et al.* [105]	S, SP	SP	Simulation	3 PV modules	375W	800-1200	Off-grid
Amit Kumar *et al.* [106]	SP, TCT	TCT	Artificial	4×4 PV cells	8 W	360- 500	Laboratory based
Mohammadnejad *et al.* [107]	SP, BL, TCT, HC	TCT	Simulation	4×4, 6×4	1123W	200-1000	Off-grid
Pankaj Kumar *et al.* [108]	SP	SP	Artificial	4×4 PV cells	8 W	360- 500	Laboratory based
Ram and Rajasekar [109]	S, SP	SP	Artificial	2×4	119.7W	100-1000	Off-grid
Rakesh and Madhavaram [110]	TCT, MS	MS	Artificial	4×4	960W	200- 900	Off-grid
Sahu and Nayak [111]	TCT, PRM-FEC	PRM-FEC	Natural	7×5	73.55W	195-940	Off-grid
Sahu and Nayak [112]	TCT, Futoshiki	Futoshiki	Artificial	4×4, 5×5	64.87 W	220-950	Laboratory based
Samikannu *et al.* [113]	SP, TCT, BL, MS	MS	Artificial	3×3, 3×5, 4×8, 6×6	2.8849W	200,- 900	Off-grid
Pareek and Dahiya [114]	TCT, HRPVA, FRPVA	FRPVA	Simulation	6×4	4354. 3W	500-1000	Off-grid
Vijaylekshmy *et al.* [115]	TCT, OTCT, NTCT	NTCT	Simulation	4×3	567W	500-1000	Off-grid
Yadav, Pachauri and Chauhan [116]	SP, TCT, BL, HC, BL-TCT, SP-TCT, NS-1, NS-2	NS-1, NS-2	Simulation	5×4, 9×4	2733W	350 - 1000	Off-grid
Ahmad *et al.* [117]	SP	SP	Simulation	4×4, 5×5	300W	100-1000	Off-grid
Yadav *et al.* [118]	TCT, RTCT, RSP-TCT, SP-TCT, RBL-HC, RBL-TCT, BL-HC, MS	MS	Simulation	4×4	2733W	350 - 1000	Off-grid
Tabish and Asharaf [119]	S	S	Artificial	Single PV module	28 W	500-950	Laboratory based
Bana and Saini [120]	SP, TCT, BL, HC, Novel	Novel	Experimental	4×5	1290W	100-980	Off-grid
Belhaouas *et al.* [121]	SP, TCT, S-M-TCT	S-M-TCT	Artificial	3×3, 2×2	540W	200-900	Off-grid
Bosco and Mabel [122]	SP, SPSDK (SP Su-do-Ku), SPCDV (SP Cross Diagonal	SPCDV, TCTCDV	Artificial	9×9	7083W	200-1000	Off-grid

TABLE 2. *(Continued.)* Taxonomy of the PV system under PSCs.

	View), TCT, TCTSDK (TCT Su-do-Ku), TCTCDV (TCT Cross Diagonal View)						
Pareek, Chaturvedi and Dahiya [123]	SP, TCT, proposed	Proposed	Simulation	2×2, 2×3	4419 W	200-1000	Off-grid
Satpathy *et al.* [124]	SP, BL, TCT, SDS	SDS	Experimental	3×3, 7×7	1746W	400-1000	Off-grid
Vengatesh and Rajan [125]	S, SP	SP	Simulation	3 PV modules	581W	800-1000	Off-grid
Mishra *et al.* [126]	TCT, BL-TCT, BL-HC, SP-TCT, NS	NS	Simulation	6×4	3419W	350-1000	Off-grid
Malathy and Ramaprabha [127]	TCT, MS	MS	Experimental	5×5	300 W	500-1000	Off-grid
Rodriguez *et al.* [128]	SP, TCT, HC, BL	TCT	Experimental	3×3	400W	70- 960	Off-grid
Pachauri *et al.* [129]	TCT, LS-TCT	LS-TCT	Simulation	4×4	2609 W	350, 1000	Off-grid
Pillai *et al.* [130]	TCT, DS	DS	Simulation	9×9	8 kW	200-900	Off-grid
Pachauri *et al.* [131]	SP, TCT	TCT	Experimental	3×3	30W	380-710	Off-grid
Krishna and Moger [132]	TCT, Su-Do-Ku and improved Su-Do-Ku, SP, BL, HC	Improved Su-Do-Ku	Simulation	9×9	2280W	100-1000	Off-grid
Nasiruddin *et al.* [133]	SP, TCT, BL, OE	OE	Simulation and Experimental	4×4	2512W	300, 600, 1000	Laboratory based
Nihanth *et al.* [134]	TCT, BS, So-Du-Ku, Skycraper	Skycraper	Simulation and Experimental	9×9, 5×5	5658W	200-800	Off-grid
Haq *et al.* [135]	SP, BL, HC, TCT, RM	RM	Simulation	6×6	9kW	400-1000	Off-grid
Premkumar *et al.* [136]	SP, TCT, HC, BL, Ladder, BL-HC, BL-TCT, SP-TCT	Ladder	Simulation	4×4	3200W	300-1000	Off-grid
Sagar *et al.* [137]	SP, HC, BL, BL-TCT, SRBL-TCT	SRBL-TCT	Simulation and Experimental	6×6	8118W	200-1000	Off-grid
Srinivasan *et al.* [138]	TCT, Su-Do-Ku	Su-Do-Ku	Experimental	4×4	140W	200-950	Off-grid
Venkatiswari and Rajasekar [139]	TCT, Su-Do-Ku, DS, CS, Lo-Shu	Lo-Shu	Simulation	9×9	5601W	300-900	Off-grid
Gul *et al.* [140]	SP, HC, TCT	TCT	Simulation	6×6	5.5 kW	400, 500, 1000	Off-grid
Chao and Liao [141]	SP, TCT	TCT	Simulation	4×3	260W	700, 1000	Off-grid
Juan *et al.* [142]	SP, GA	GA	Simulation	3×3	230W	400, 700, 1000	Off-grid
Babu *et al.* [143]	TCT, CS, GA, RAO, SMO, FRA	FRA	Simulation	9×9	2731.10W	200-900	Off-grid
Fathy [144]	TCT, Su-Du-Ko, GA, GOA	GOA	Simulation	9×9	5042W	200-900	Off-grid
Babu *et al.* [145]	TCT, Su-Du-Ko, GA, PSO	PSO	Simulation	9×9	5530W	200-900	Off-grid
Fathy [146]	SP, TCT, BOA, SP-TCT, NS, GWO	BOA	Simulation	6×6	3766W	350-1000	Off-grid
Yousri *et al.* [147]	TCT, CS, PSO, GA, MHHO	MHHO	Simulation	9×9	3045W	300-900	Off-grid

The observation results clearly show that there is a sharp increment in the power loss from 8% to 50% as the irradiation levels increase from 300W/m^2-800W/m^2. Authors have analyzed the impact of PSCs on PV module performance for the off-grid application in [26] and the experimental results illustrate that the reduction of PV module power. They have compared two configurations (S, P) under translucent and opaque shading patterns. In the case of translucent shading for the parallel connection, GMPP sharply increased from 5% to 50% at 97.8% and 72.4% irradiation respectively. While for the series connection GMPP is found 5% at 86.8% irradiation and 50% at 41.9% irradiation. In [29], the authors found GMPP as 1760W and 1610W for ideal and shading condition respectively and there is an increment in power loss of 8.5%. Experimental work is performed by the authors in [30], where series-connected PV modules at different irradiation levels: 500W/m^2, 750W/m^2, 1000W/m^2, and temperature levels: 35°C, 40°C, and 45°C, are analyzed. It was found that power loss is 22% for all the non-uniform irradiation conditions. In [32], a simple mathematical model is implemented to show the robustness of the proposed model and experimental MPP values are 120W and 226.8W at irradiation levels increase from 100-1000 W/m^2. In [35], laboratory work is performed by the researchers in which PV cells are kept at two different irradiation levels of 160W/m^2 and 960W/m^2, found maximum current as 0.5A and 2.8A respectively. An analysis of the performance of PV panels for distinct types of shading patterns are described in [38]. Where 18 PV modules are connected in series and, the value of GMPP is found as 1375W at 50% shading at 70% shading conditions. In [39], authors have

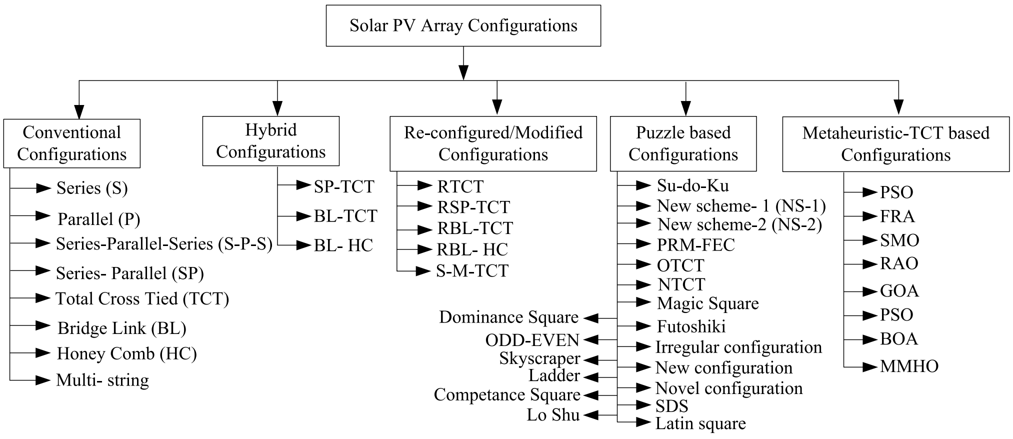

FIGURE 3. Classifications of PV array configurations.

considered eight types of shading cases with irradiation levels varying from 130 to 992W/m^2. The value of GMPP is found to be 171.5 W and 58W at the irradiation level of 992W/m^2 and 279W/m^2 respectively. In [45], an experimental study on three PV modules at different irradiation levels: 400W/m^2, 700W/m^2, 1000W/m^2 is performed and found the best value of GMPP as 180W. An experimental and simulation study is carried out in [47] by considering two strings with three PV modules connected in series at different irradiation levels 220-890W/m^2. Furthermore, boost topology is employed to reduce the GMPP error of up to 0.56%. In [48], authors have considered thirty PV modules in the series configuration for different shading cases. The placement of the bypass diode is used to examine the performance of the PV array. It is depicted by the experimental results that the losses produced by shadow depend on the bypass diode configuration for the PV module. In another research study [50], authors have considered series configuration with experimental validation of 56, 96, and 36 number of PV modules to assess the performance and the best value of GMPP is found to be 4900W. In [55], two PV modules are connected in series and are kept at two different irradiation levels of 150W/m^2 and 300W/m^2. The experimental results depicted that the GMPP is having the best value of 70mW. SP configuration of seventy-two PV cells is investigated by the authors in [63]. The simulation results show that SP configuration is having minimum power losses and generates a maximum output power of 300W at non-uniform irradiation level.

In [64], authors have investigated the series configuration of four PV modules under PSCs. The MPP at 1000W/m^2 is found as 800W while at 250W/m^2, it is 230W. A research investigation is performed in [66] where two PV modules are connected in a series configuration to study the effect of insolation, temperature, series resistance, and parallel resistance on the I-V and P-V characteristics. Furthermore, a similar study is also carried out in [68] on twenty-four PV modules connected in series with a power generation capacity of 1.1kW at a minimum irradiation level of 771 W/m^2. An experimental analysis is carried out for the performance analysis in [69] by implementing the twenty-five PV modules connected in series under PSCs, where GMPP is found to be 350W at the minimum irradiation level of 400W/m^2.

Although in another study [71], a comparative study is given by considering the hardware and simulation platform with or without bypass diode PV modules connected in series. While in [72], authors have implemented only the bypass diode to reduce the effect of shading on PV panels. In [74], two PV modules connected in series, generating maximum power of 150W in ideal condition, whereas 110W at an irradiation level of 700 W/m^2. In [75] authors have implemented three PV panels connected in the series and pointed out the values of GMPP as 165W and 130W at 100% and 30% of irradiance respectively. Authors in [77] employed an experimental setup in real-time, where four PV modules are connected in a series configuration and compared with the simulation results. There is only 0.8% of error as reported between experimental and simulation results. A similar experimental and simulation study is performed by the authors in [86], [90] where sixty PV cells are kept at under different shading conditions: 25%, 50%, and 75%. Moreover, these obtained results are verified with the practical results for all the PSCs. The series configuration of the PV array is illustrated in Figure 4.

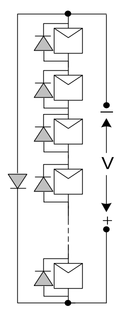

FIGURE 4. Series configuration [12], [68].

2) PARALLEL CONFIGURATION

The authors have implemented a MATLAB/Simulink model to study a parallel configuration of PV arrays for analyzing the performance in [26], [30]. In this work, 20 × 4 and 3 × 27 PV array sizes are examined under different PSCs at irradiation levels of 200W/m^2, 500W/m^2, and 900W/m^2 in terms of maximum voltage, current and GMPP. The shading effect is observed extensively under the real environmental conditions to validate the obtained results. In another investigation [34], authors have implemented a laboratory based real-time setup of PV cells in a controlled environmental having an irradiation level of 500-980W/m^2 along with temperature variation of 31°C - 34°C. Each PV module having a capacity of 60W, is connected in series and the parallel arrangement is made to investigate the electrical performance under different shading patterns. In [43], [45], a MATLAB based Simulink model is implemented where the PV modules are arranged in three, four, and eight numbers to form the configuration of SP, parallel, and multi-string for examining the effect of shading pattern on system performance. The best value of GMPP is observed in the case of the SP configuration. In another simulation study [47], [49], the effect of shading patterns is examined by taking the 3 × 2 PV array size arranged in series and parallel configurations. Where the best value of GMPP (2350W) is observed for the case of the parallel configuration at varying irradiation levels (132-729 W/m^2). The authors in [70] implemented an experimental setup, where 4 PV modules are arranged in three configurations: series, parallel, and SP configuration to investigate the electrical performance under different shading patterns. The best value of GMPP is found to be 954.88W for parallel configuration at irradiation level varying from 750 W/m^2 to 1160W/m^2. A hardware implementation of 6 × 9 PV array size is investigated in [73] to analyze the shading effect for two configurations: series and parallel at irradiation level varying from 100W/m^2 to 1000W/m^2. The experimental results clearly illustrate that PV modules arranged in the parallel configuration are having the best value of GMPP. In [84], the authors affirm the best electrical performance in terms of GMPP and FF for the case of PV modules arranged in a parallel configuration. They have employed a Simulink model in MATLAB for simulating the 10×3 PV array size for both series and parallel configurations and validated the results through hardware implementation. Three shading patterns: A, B, and C are considered for the performance evaluation where the best value of GMPP for three patterns is 290.5W, 214.3W, and 114.3W respectively. Similar work is pointed out by the researchers in [85], where, both simulation and hardware implementation are employed for 4×4 PV array size in series and parallel configurations. The best value of GMPP (16.28W) is observed for the parallel configuration at the irradiation level in the range of 500-1000 W/m^2. The generalized schematic diagram of the parallel interconnection of PV modules is depicted in Figure 5 as,

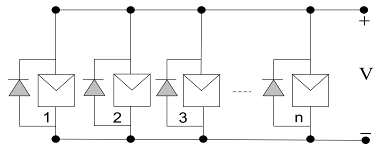

FIGURE 5. Parallel configuration.

3) SERIES-PARALLEL-SERIES CONFIGURATION

In [12], the author proposed a modification in the existing PV array configurations for more efficient performance under the PSCs. The series-parallel-series (S-P-S) configuration has a series arrangement of parallel configured PV array and performance comparison shows the best results for S-P-S configuration. The generalized schematic diagram of S-P-S interconnections of PV modules is shown in Figure 6 as,

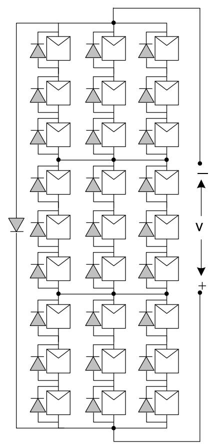

FIGURE 6. Series-parallel-series configuration [12].

4) SERIES-PARALLEL, TOTAL CROSS-TIED, BRIDGE-LINK AND HONEY-COMB CONFIGURATIONS

In [14], [15] the authors have implemented three types of configurations: SP, TCT, and BL for the two array size 9 × 4 and 6 × 6 of PV panels where the performance for both array size is measured in terms of GMPP and FF. Out of which, for TCT configuration, GMPP is found as 13863.40W and FF as 0.72 at different irradiation levels varying from 20W/m^2 to 1000W/m^2. In addition to this, the author has proposed a simulation model based on the Simulink where PV modules having a capacity of 158W, 65W, and 28W are considered for the performance analysis in terms of maximum power, output voltage and current. The simulation results depict the best performance of TCT configuration with GMPP of 158W [18], [19], [25]. A mathematical model is employed for performance investigation of 12 PV modules arranged in 2 × 6, 6 × 2, 4 × 3, 3 × 4 array sizes. In this work, the TCT configuration illustrates the maximum value of GMPP as 589.79W under the distinct irradiation levels varying from

$100W/m^2$ to $1000W/m^2$ [20]. In another study [27], two configurations; S and S-P are implemented for the performance analysis of PV panels having an array size of 9 × 9, out of which the best value of GMPP is obtained as 230W for SP configuration at irradiation level from 100-500 W/m^2. In [28], researchers have analyzed the two types of configurations: S and SP for the size of 36 PV cells at irradiation level varying from $500W/m^2$ to $1000W/m^2$. Experimental results state the better performance of SP configuration where the values of maximum current and voltage are 7.25A and 28.7 V respectively. In [31], the authors have developed a new configuration known as multi-string configuration, where the best value of GMPP is found to be 205W at irradiation levels of $250\text{-}750W/m^2$. More recent experimental results based on hardware and simulation model, given in [32], [40], which indicate that for the array size of 4 × 4 and 3 × 3 PV modules in SP configuration the finest value of GMPP is 125W. A simulation and hardware model is employed in [41], [42] for the SP configuration of 3 × 2 PV array size at irradiation level $500\text{-}1000W/m^2$ and the finest value of GMPP is found to be 550W for SP configuration. In subsequent investigation [33], three configurations: SP, TCT, and BL are considered for PV modules under different PSCs, where the performance parameters are found better for the TCT configuration in terms of improved FF, minimum power losses, and maximum voltage.

In [36], SP, and TCT configurations having 6 × 4 size of PV array, the best performance of TCT configuration at GMPP of 1528W is found at irradiation level $250\text{-}1000W/m^2$. In [37], a MATLAB/Simulink modeling of 20 × 3 array of PV size for SP, TCT configurations are considered for the performance evaluation under the non-uniform irradiation. The best value of GMPP (1200W) is found at the irradiation level varying in the range of 200-1000 W/m^2 for TCT configuration. The authors in [44] developed a 9 × 4 PV array size of SP and TCT configurations under the variable solar irradiance as $500W/m^2$ to $1000W/m^2$. Reduced power loss and maximum power and voltage at GMPP (1256W) are observed from the P-V characteristic for TCT configuration.

The modeling of series (24 PV modules), parallel (12 PV modules), SP, TCT, BL, and HC configurations of 4 × 2, 2 × 4, 6 × 2, 2 × 6, 4 × 3, 3 × 4, 3 × 3, 4 × 4, 6 × 4, 4 × 6 sizes PV array is done for all considered configurations respectively. TCT configuration is found superior in terms of maximum values of power and voltage at GMPP under the artificial shading effect conditions [51]. In [52], the SP configuration is employed for 4 PV modules, irradiation level $400\text{-}1000W/m^2$ at variable temperature 25°C, 28°C, 33°C, and 35°C respectively, GMPP is 135.54W. In [53], four configurations: SP, BL, HC, and TCT are employed for a PV array size of 3 × 3. The best value of GMPP (950W) is found for the PV array arranged in TCT configuration while SP configuration has maximum power losses as compared with TCT configuration. In [54], only SP configuration for PV array size 6 × 3 is employed for three different PSCs. For case-1, case-2, and case-3 the best values of GMPP are 900W, 545 W, and 730W respectively, at irradiation level of $100W/m^2$ to $1000W/m^2$. In [56], SP configuration for 3 × 3 PV array size is employed for five shading cases, whereas for case-5 and case-3 the best value of GMPP is found as 105W and 65W respectively. In [57], SP configuration is employed for the PV array size of 2 × 2 and the best value of GMPP is found as 689W at two levels of irradiation 500 and 1000 W/m^2. In [59], [114], the MATLAB/Simulink model of three configurations: TCT, half reconfigured PV array (HRPVA) and full reconfigured PV array (FRPVA) is presented by the authors for four different shading patterns: single row shading, double row, quarter and oblique array. The best value of GMPP is obtained for FRPVA configuration under all four shading patterns at two different irradiation levels $500W/m^2$ and $1000W/m^2$. Moreover, the performance investigation in terms of maximum power and voltage at GMPP with improved FF, and minimize power losses under the PSCs, is also reported by the authors. In [131], the authors have taken a 3 × 3 size PV system for performance evaluation under the obscured irradiance such as $380\text{-}710W/m^2$. An electromechanical relay system is used and remotely controlled using an embedded based designed system to switch from SP to TCT configuration for achieving higher power and voltage at GMPP, power loss, and FF. Comprehensive analysis of PV system deficiencies due to non-uniform irradiance conditions of $400\text{-}1000W/m^2$ on configured PV systems SP, HC, BL, and TCT, reconfigured method (RM). A special case of multiple PV array defects with a uniform irradiance is also examined its cumulative effect on the various PV connections. Various shading scenarios are considered for detailed quantification of the impact of the PV faults studied on the power grid [135], [140].

In [60]–[62], the mathematical modeling of a PV module including shaded solar cells in SP configuration of 4 × 3, 6 × 5, 6 × 6 sizes are proposed for MPP tracking under uniform insolation conditions. Moreover, an experimental investigation has also been performed to confirm the validity of simulation results. In [65], the authors simulated the SP and TCT configurations of a 2 × 2 size PV array system. The performance is tested under the shading effect and observed that the TCT configuration has maximum power and voltage, 140W GMPP at irradiation level as $332.63\text{-}560.60W/m^2$. In [78], an experimental setup of PV array configurations: BL, TCT of 2 × 4 size are implemented under ten different shading patterns for validation of result. The experimental results clearly show that TCT configuration has maximum power as 678.40W for variation of irradiation level in the range of $289\text{-}992W/m^2$. Similar system configurations are developed of 4 × 4 size in the Simulink environment for the investigation during the shadow effect. In both types of study, the TCT configuration outperformed the other configurations [79] for eight different shading cases. Where, for shading cases IV and VIII, GMPP is the same for all configurations while in other shading cases, TCT has developed maximum GMPP. In [80], array of 3 × 3 PV modules connected in SP arrangement, GMPP is 40W at irradiation level range of $100\text{-}1000W/m^2$. In [81], [83], the authors investigated the performance of

PV array configurations such as 4×2, 2×4, 6×2, 2×6, 4×3, 3×4, 3×3, 4×4, 4×6, 6×4 sizes under the non-uniform irradiance as 100-1000W/m^2. The TCT has maximum voltage and current at most of the shading environment as compared to other PV array configurations. In [87], a comprehensive study on shaded S, P, SP, TCT, BL, and HC configured 24 PV modules (6 × 4) under the artificially indoor PSCs is carried out for performance assessment in terms of obtained maximum power, voltage, and improved FF, where the best value of GMPP (1446W) is found for TCT configuration at irradiation level 300-1000 W/m^2. A MATLAB/Simulink modeling of PV array configurations such as S, P, SP, TCT, BL, and HC of 2×2, 6×8, 8×3 sizes is presented in [88]. Performance comparison is carried out among the configurations under the predefined shading scenarios in terms of maximum power generation and the maximum GMPP is found for TCT configuration as 2724W at variable irradiation levels ranging from 100-1000 W/m^2. In [93], the performance evaluation of configurations: S, P, SP, TCT, BL, HC is carried out, and also proposed a new PV array configuration for array size of 2 × 18, 3 × 12, 4 × 9, 6 × 6, 9 × 4, 12 × 3, 18 × 2 (total 38 PV modules) under shading cases as 300-1000W/m^2. The best value of GMPP is found at 981.3W, at irradiation level of 200W/m^2. Moreover, the TCT and new configurations have more efficient results in terms of improved FF, minimum power losses. In [96], a simulation study is carried out for SP configuration, where the finest value of GMPP is found to be 40.5kW for the 10 × 100 PV array size. Similarly, in [97], laboratory-based experimental and simulation work is presented for two configurations: S and SP. Where, SP configuration is having better performance with a GMPP of 38.06 at irradiation levels of 100-1000 W/m^2. In a subsequent study presented by authors in [98], SP configuration is implemented for 2 × 2 and 2 × 3 PV array size. The experimental results are obtained for a laboratory-based system and illustrate the best value of GMPP as 40W for varying irradiation levels in the range of 100-1000W/m^2. In [101], three configurations: S, P, and SP are implemented at irradiation levels as 400-600-1000W/m^2, where thirty PV modules are bifurcated in distinct sizes and configurations. An experimental and simulation work is presented for two configurations: S and SP at irradiation level 100-980 W/m^2, 2 × 4 PV array size is considered. SP configuration shows the best performance with the best value of GMPP as 225W [103]. In [104], four configurations: SP, BL, TCT, bypass, and reconfigured (BR) topology are implemented for GMPP, where TCT is having the best performance with GMPP of 180W in all five-shading patterns. In [105], simulation work is presented for S and P configurations where parallel configuration performed well with GMPP of 375W at irradiation levels of 800-1200W/m^2. In [106], [108], experimental work is presented for one PV module with a total of sixteen PV cells are arranged in 4 × 4 array size for, three configurations: S, P, and TCT. Experimental results show that TCT has minimum current loss with maximum FF in all shading patterns (progressive shading increment from left to right and diagonally). Another simulation study is presented in [107] for four configurations: SP, BL, TCT, and HC for 4 × 4 PV array size with two shading patterns: first shading pattern (5 cases) and a second pattern (4 cases), where, TCT configuration performed well in first and second shading pattern as compared with SP and BL configurations, at irradiation level 200-1000 W/m^2. In [109], an experimental analysis for S and SP configurations is performed for 2 × 4 PV array size, where SP configuration is reported as the best performance with the finest value of GMPP as 119.7W at irradiation level 100-2000W/m^2. In [128], simulation and experimental work are presented for SP, TCT, HC, and BL. The best performance is found for TCT configuration, 3 × 3 PV array size, with GMPP of 400W. In all the shading conditions, TCT has improved performance as compared with other configurations. The schematic diagrams of SP, TCT, BL, HC configurations are clearly depicted in Figure 7-10.

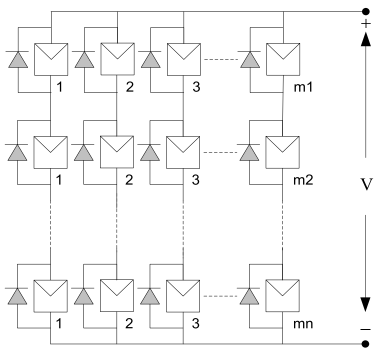

FIGURE 7. PV modules connected in SP configuration [18]–[20].

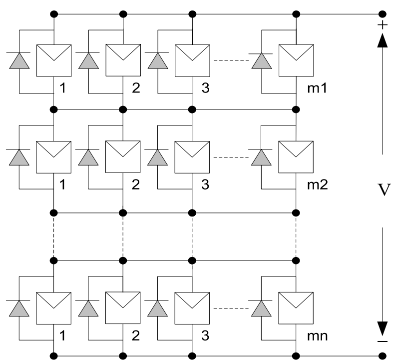

FIGURE 8. PV modules connected in TCT configuration [33], [51].

5) MULTI-STRING CONFIGURATION

An experimental analysis is carried out for performance enhancement under uniform and non-uniform irradiation levels. For the performance assessment in terms of maximum voltage and power at GMPP are observed from the performance I-V and P-V characteristics of multi-string PV array configuration, where the best value of GMPP is found to be 205W at irradiation levels in the range of 250-750W/m^2 [31]. In [43], the authors have implemented a multi-string SP and P

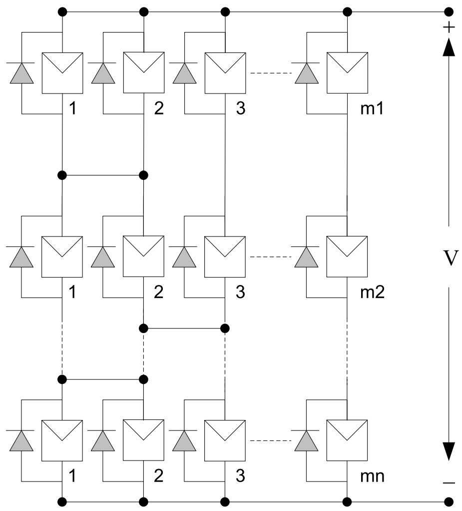

FIGURE 9. PV modules connected in BL configuration [53], [59].

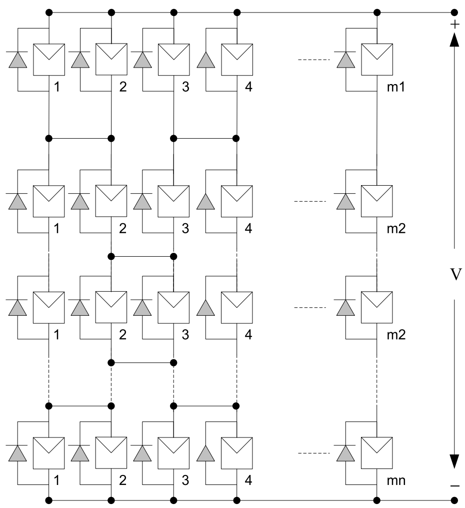

FIGURE 10. PV modules connected in HC configuration [51], [53].

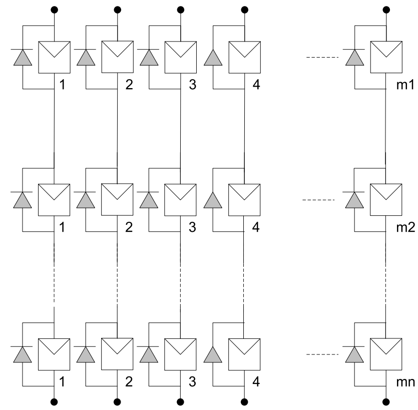

FIGURE 11. PV modules connected in multi-string configuration [43].

configurations for a 4 × 8 PV array module to investigate the performance of the PV system under PSCs. The experimental results illustrate the best performance of the SP configuration with total power enhancement (PE) of 10W. The schematic diagram of the multi-string arrangement of PV modules is shown in figure 11.

B. HYBRID PV ARRAY CONFIGURATIONS

SP-TCT, BL-TCT and BL-HC PV Array Configurations: For the performance analysis and improvement, hybrid configurations such as SP-TCT, BL-TCT, and BL-HC configuration (a combination of conventional SP, BL, HC, and TCT configurations) for 4 × 4, 5 × 4, and 6 × 4 PV array sizes are proposed by various researchers. The progressive shading patterns (i) from left to the right side (ii) from bottom to the top side (iii) diagonally shading movement etc. are considered for the performance evaluation. Simulation analysis for three types of configurations including hybrid configurations: SP, SP-TCT, and Su-Do-Ku is implemented by the authors for 4 × 4 PV array size at irradiation level in the range of 350-1000W/m^2, where the performance of Su-Do-Ku configuration is found superior with the finest value of GMPP as 2278W [102].

Moreover, in a subsequent research investigation [116], MATLAB based Simulink model is developed to simulate SP, TCT, BL, HC, BL-TCT, SP-TCT, and novel structure (NS-1, NS-2) configurations. Results show the best performance of NS-1 configuration for the PV module array sizes of 5 × 4 and 9 × 4 with GMPP as 2733W at 350-1000 W/m^2 irradiation level. In [118], authors have designed a MATLAB based Simulink model for TCT, reconfigured total cross-tied (RTCT), reconfigured hybrid series-parallel total cross-tied (RSP-TCT), S-P-TCT, reconfigured bridge-link total cross-tied (RBL-TCT), BL-HC, and magic square (MS) for performance analysis of 4 × 4 PV array size module, whereas the best performance is found for MS configuration with the finest value of GMPP as 2733W at irradiation level in the varying range of 350-1000W/m^2. In another subsequent study [126], a simulation model is proposed for a 6 × 4 PV array size to implement the TCT, BL-TCT, BL-HC, SP-TCT, and novel structure (NS) configurations at four different irradiation levels: 350W/m^2, 500W/m^2, 800W/m^2 and 1000W/m^2. By experimental analysis, it is observed that the numbers of ties are lower as compared to the TCT configuration for modeling of the same size PV array configuration. The schematic diagrams of hybrid SP-TCT, BL-TCT, and BL-HC configurations are depicted in Figure 12- 14.

C. MODIFIED PV ARRAY CONFIGURATIONS

1) RTCT, RSP-TCT, RBL-TCT, RBL-HC AND S-M-TCT CONFIGURATIONS

Hardware-based, 6×6 PV array size module is designed [100] for TCT and RTCT (Su-Do-Ku puzzle-based rearrangement of TCT) configuration to analyze the electrical performance in terms of output power and current. The best performance

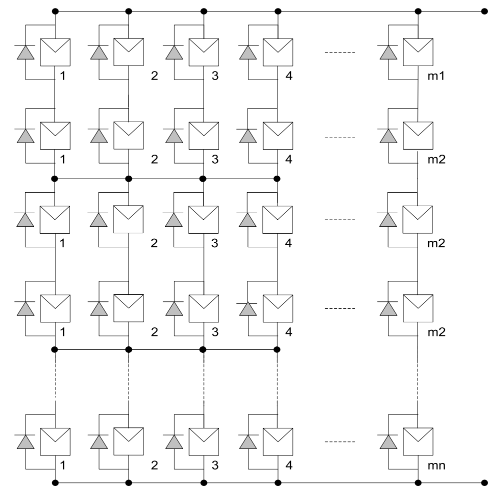

FIGURE 12. PV modules connected in SP-TCT configuration [116].

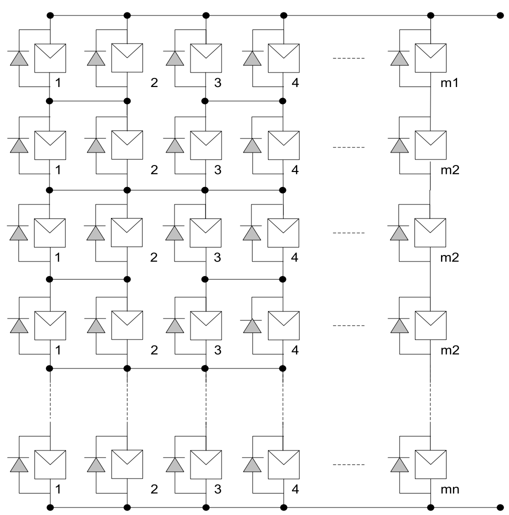

FIGURE 13. PV modules connected in BL-TCT configuration [116], [118].

parameters are observed for RTCT configuration with GMPP of 1160W at irradiation level 200-1000W/m^2. In [118], the authors have implemented the reconfigured PV array configurations: RTCT, RSP-TCT, RBL-TCT, and RBL-HC for 4 × 4 PV array size to investigate the electrical performance. Moreover, these hybrid configurations are reconfigured based on the Su-Do-Ku puzzle pattern. In most of the shading cases, RSP-TCT configuration outperformed as compared with other configurations. The authors in [121] have implemented a hardware-based model for 3 × 3 and 2 × 2 PV array size modules to analyze and compare the performance of TCT and S-M-TCT (reconfigured TCT configuration: altering the electrical connections of PV modules but the physical position is to remain fixed) configuration, where the experimental results show that S-M-TCT has maximum FF and minimum power losses as compared to the existing TCT configuration with the finest value of GMPP as 540W at interval of irradiation level varying in the range of 200-900W/m^2. The schematic diagrams of RTCT, RSP-TCT,

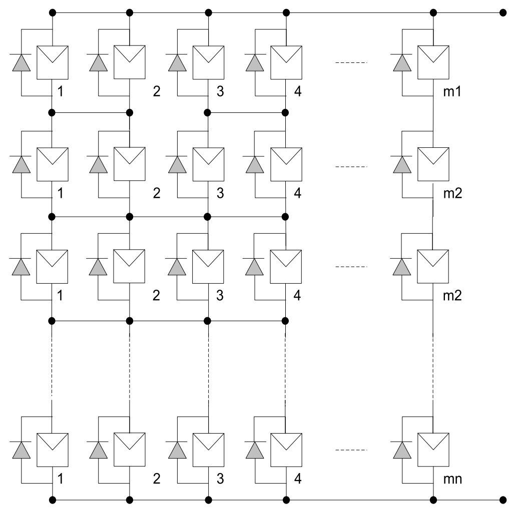

FIGURE 14. PV modules connected in BL-HC configuration [118].

RBL-TCT, RBL-HC, S-M-TCT configurations with their PV module interconnections are shown in Figure 15- 19 as,

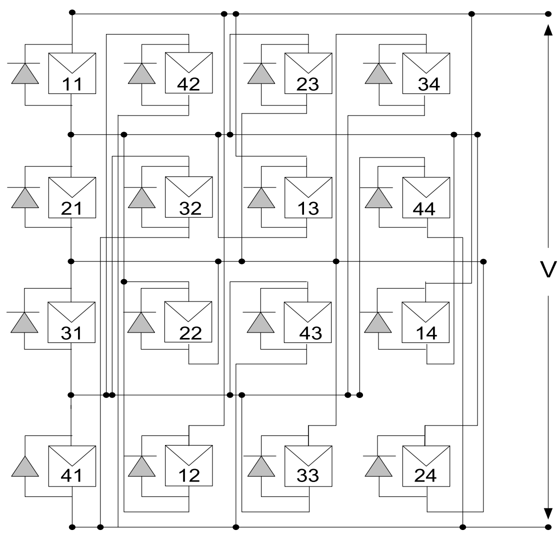

FIGURE 15. PV modules connected in RTCT configuration [100], [118].

D. PUZZLE BASED ADVANCED PV ARRAY CONFIGURATIONS

1) SU-DO-KU CONFIGURATION

Simulation-based modeling of 9 × 9 PV array size module is implemented in [67] for TCT and Su-Do-Ku configurations at irradiation level varying from 200W/m^2 to 900W/m^2. Four different shading cases: short wide (SW), long wide (LW), short narrow (SN), and long narrow (LN) are considered for the performance investigation in terms of PE, maximum power, and voltage. Experimental results illustrate the best performance for the Su-Do-Ku configuration with the best value of GMPP as 4532W. Recently, authors in [89], [95] have employed hardware-based experimental analysis for 9 × 9 and 6 × 6 array size PV module to analyze the reduction of line and mismatch losses (ML) in PV array

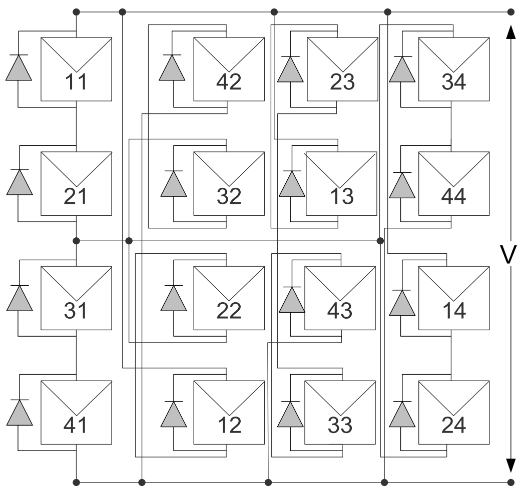

FIGURE 16. PV modules connected in RSP-TCT configuration [118].

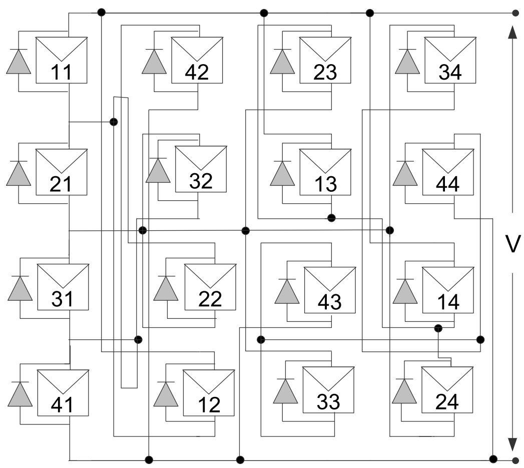

FIGURE 17. PV modules connected in RBL-TCT configuration [118].

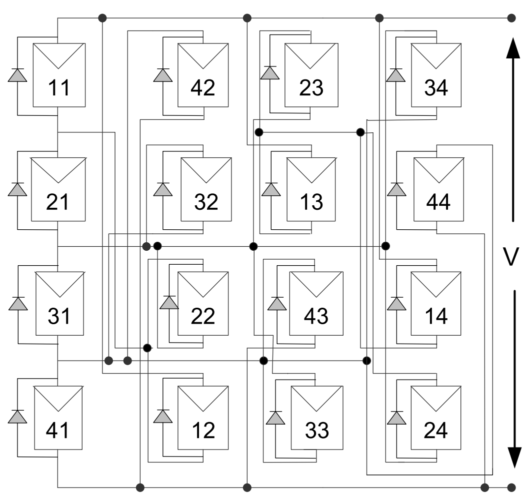

FIGURE 18. PV modules connected in RBL-HC configuration [118].

modules under distinct PSCs, where TCT and Su-Do-Ku configurations are compared by using GA for maximum power extraction. The electrical performance for both the

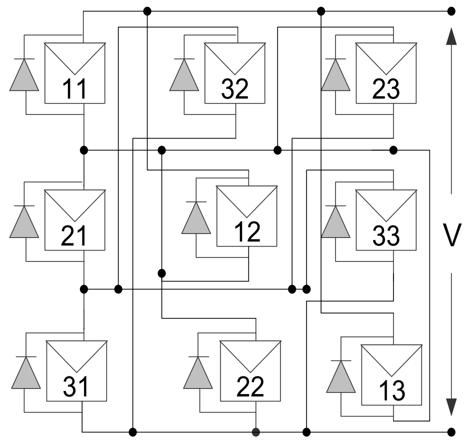

FIGURE 19. PV modules connected in S-M-TCT configuration [121].

configurations is evaluated under the variable shading cases: Long, narrow, short and wide at irradiation level varying from 200W/m^{2}to 900W/m^2 with the finest value of GMPP as 4802W.

In subsequent study [95], an improved version of Su-Do-Ku configuration is implemented to reduce the mismatch and line losses in PV array modules and compared with both normal TCT and Su-Do-Ku configuration. Where the best value of GMPP is found to be 5168W in the case of improved Su-Do-Ku configuration at regular interval of irradiation level: 200W/m^2, 400W/m^2, 600W/m^2, and 900 W/m^2. In [99], authors have investigated the hardware-based 6 × 6 PV array size module for power loss under different PSCs. Experimental results clearly illustrate the best value of GMPP as 1250W in the case of Su-Do-Ku configuration. The schematic diagram of the 6 × 6 PV array size module in the Su-Do-Ko puzzle configuration is shown in Figure 20.

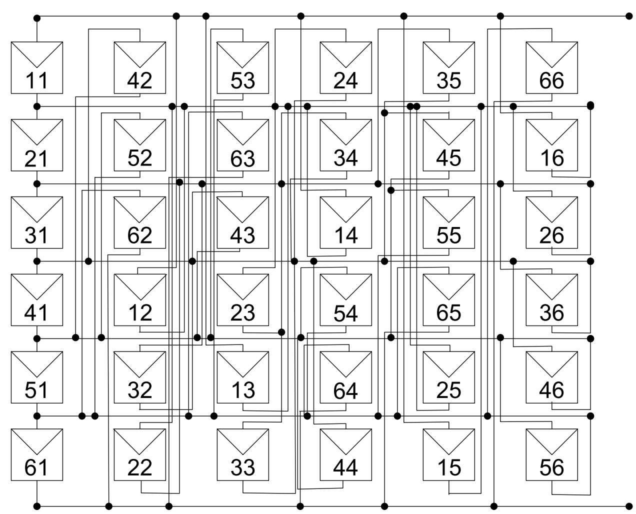

FIGURE 20. PV modules connected in Su-do-Ku configuration [95], [100], [121].

2) NEW SCHEME-1 (NS-1), NEW SCHEME-2 (NS-2) AND NOVEL STRUCTURE (NS) CONFIGURATIONS

In [116], [126], the authors have implemented three types of configurations: NS-1, NS-2, and NS for 5 × 4 and 6 × 4 PV array size module, where the electrical performance is evaluated in terms of GMPP, maximum FF, and reduced power losses under the progressive shading cases. Moreover, NS-1, NS-2, and NS configurations are found to be better in most of the shading cases as compared to conventional configurations. The schematic diagrams of NS-1, NS-2, and NS configurations are shown in Figure 21- 23.

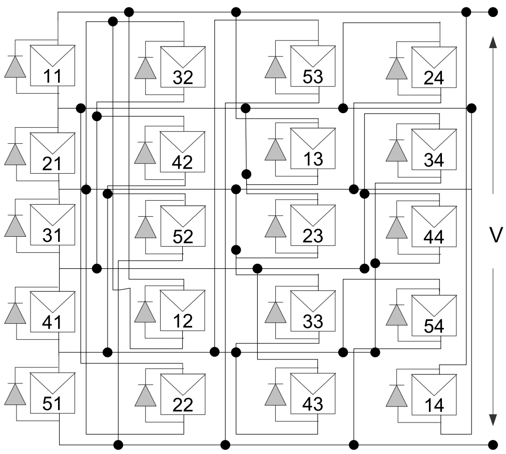

FIGURE 21. PV modules connected in NS-1 configuration [116].

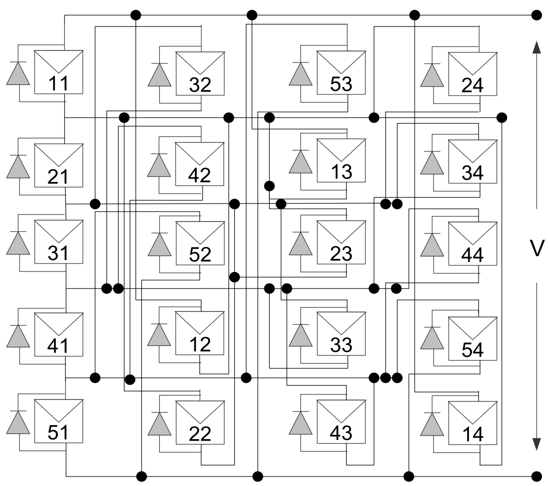

FIGURE 22. PV modules connected in NS-2 configuration [116].

3) PHYSICAL REALLOCATION OF MODULE-FIXED ELECTRICAL CONNECTIONS (PRM-FEC) CONFIGURATION

The authors in [111] have employed a ubiquitous method for the physical relocation of the 7 × 5 PV array size module with a fixed electrical connection in the case of TCT configuration. The experimental results are analyzed based on the MATLAB/Simulink model having the best value of GMPP as 73.55W at irradiation level 195-940W/m^2. The 7 × 5 PV array size modules connected in PRM-FEC configuration is depicted in Figure 24 as,

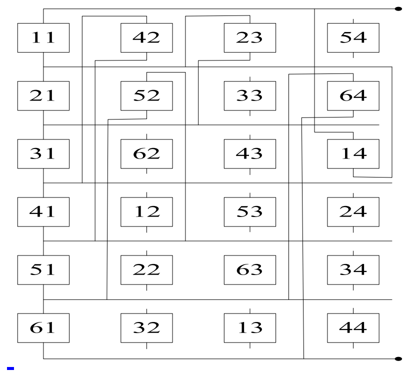

FIGURE 23. PV modules connected in NS configuration [126].

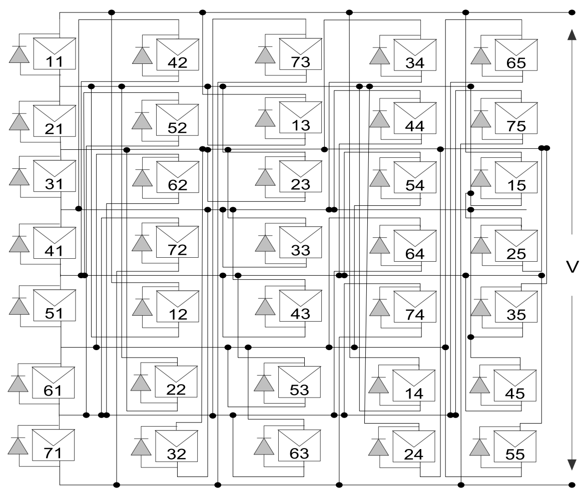

FIGURE 24. PV modules connected in PRM-FEC configuration [111].

4) OPTIMAL TOTAL-CROSS-TIED AND NOVEL CROSS-TIED CONFIGURATIONS

The mathematical modeling and comparison study are carried out for TCT and optimal total-cross tied (OTCT) configuration to obtain the optimal position of PV modules [115]. Where Zig-Zag pattern is adopted to reconfigure the TCT connections and a new configuration is designed known as NTCT configuration. The comparative study is done between TCT, OTCT, and NTCT configurations for the array size of 4 × 3 PV modules. The best value of GMPP is found in the case of NTCT configuration as 567W at irradiation level 500-1000W/m^2. Moreover, under the predefined shading conditions, NTCT configuration also shows better results in terms of voltage, power at GMPP, FF, PE, and performance ratio (PR) than other configurations. The schematic sketches of OTCT and NTCT configurations are shown in Figures 25 and 26 as,

5) MAGIC SQUARE CONFIGURATION

A comprehensive research investigation of 4 × 4 PV array size modules is carried out by the researchers in [110] for two configurations: TCT and MS. Where four shading

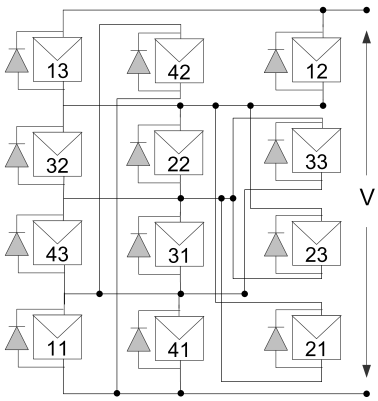

FIGURE 25. PV modules connected in OTCT configuration [115].

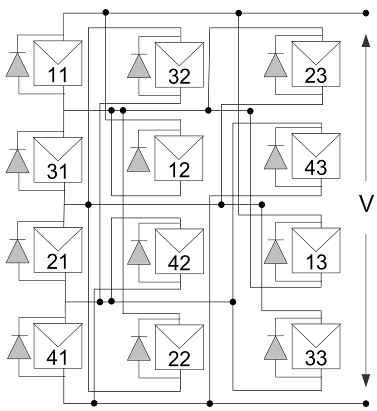

FIGURE 26. PV modules connected in NTCT configuration [115].

cases: SW, LW, SN, and LN are considered. The obtained results for the TCT and MS puzzle configuration are compared and it is observed that the MS puzzle configuration has maximum FF, power, and voltage at GMPP of 960W with reduced power losses. The authors in [113], implemented an experimental PV array system of 3 × 3 and 6 × 6 sizes for SP, BL, TCT, and MS puzzle configurations under the predefined partial shading patterns. Where the performance of MS puzzle configuration is found best and acquires the maximum voltage at GMPP of 2.88W with a varying range of irradiation level 200-900W/m^2.

Moreover, in a subsequent study [118], authors have found the best performance of 4 × 4 size MS puzzle-based PV array configuration related to TCT and hybrid SP-TCT, BL-TCT, BL-HC configurations in terms of voltage, power at GMPP, improved FF. In [127], both simulation and hardware study is performed by the authors to compare the performance of 6 × 6 PV array size module for the case of TCT and MS puzzle-based configurations, where the finest value of GMPP is found as 300W in the case of MS puzzle-based configuration at irradiation level 500-1000W/m^2. The schematic diagram of the MS puzzle-based PV array configuration is shown in Figure 27.

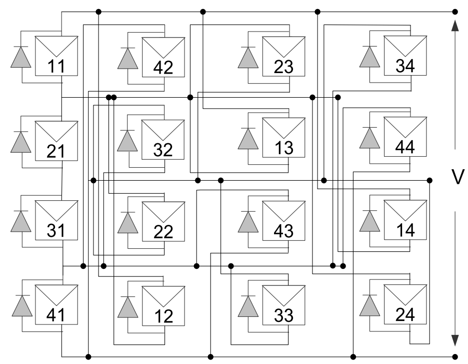

FIGURE 27. PV modules connected in MS configuration [118].

6) FUTOSHIKI CONFIGURATION

The performance of 5 × 5 and 4 × 4 PV array size modules is investigated for TCT and Futoshiki puzzle-based configuration under the distinguished PSCs [112]. Both PV array configurations are compared with each other and validated experimentally. Where, in terms of electric performance parameters, Futoshiki puzzle-based configuration is found best with a GMPP of 64.87W. The schematic diagram of the Futoshiki puzzle configuration is shown in Figure 28.

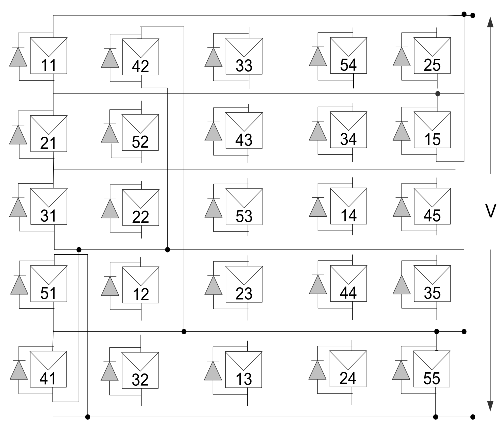

FIGURE 28. PV modules connected in Futoshiki configuration [112].

7) IRREGULAR CONFIGURATION

The interconnection of PV modules in the irregular order to form an 'n × n' PV array size configuration is known as 'Irregular configuration' [91]. A MATLAB/Simulink model is implemented to compare the irregular configuration with other existing configurations such as SP, TCT, and BL, where the best performance of irregular configuration is found with GMPP of 353W. The schematic diagram of the Irregular configuration of PV array is shown in Figure 29 as,

8) NEW CONFIGURATION

A simulation study, presenting the best performance of 'New' configuration, is proposed by the authors in [93] for a 6 × 6 PV array size module. Where the 'New' configuration is

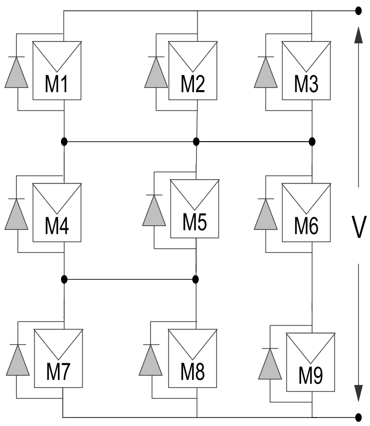

FIGURE 29. PV modules connected in Irregular configuration [91].

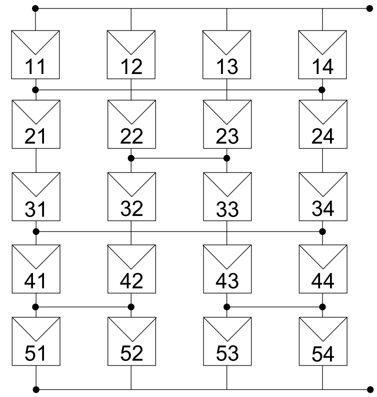

FIGURE 31. PV modules connected in novel configuration [120].

compared with the conventional PV array configurations: S, P, SP, TCT, BL, and HC. The performance is evaluated in terms of maximum power and voltage under distinct PSCs. The best value of GMPP is found to be 981.3W for 'New' configuration at regular interval of irradiation level 300-500-700-800-1000W/m^2. The schematic design of the 'New' configuration of the PV array is shown in Figure 30.

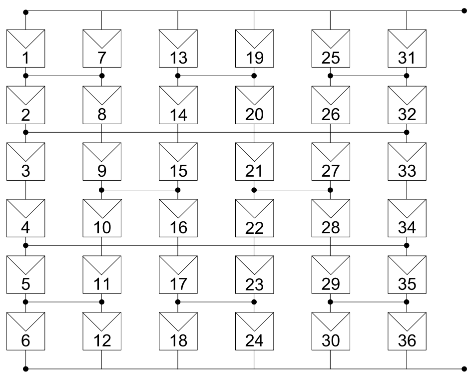

FIGURE 30. PV modules connected in new configuration [93].

9) NOVEL CONFIGURATION

In [120], the authors have modified the pre-existing conventional TCT configuration and designed a ubiquitous configuration know as a 'Novel' configuration for a 4 × 5 PV array size module. An experimental analysis is also carried out to compare the 'Novel' configuration with SP, TCT, BL, and HC configuration with the best value of GMPP as 1290W, at irradiation level in the range of 100-980W/m^2. The schematic design of the 'Novel' configuration of PV array is shown in Figure 31 as,

10) SHADOW DISPERSION SCHEME CONFIGURATION

In [124], authors anticipated a new configuration (based on the shade dispersion) known as shadow dispersion scheme (SDS) for 3 × 3 and 7 × 7 PV array size module at irradiation level of 400-1000W/m^2. Where, the authors have compared the SDS configuration with the pre-existed PV array configurations [124]. Three shading patterns: SW, LW, SN, and LN are considered for performance evaluation. The finest value of GMPP as 1746W is found for SDS configuration. The schematic design of the SDS configuration of PV array is shown in Figure 32 as,

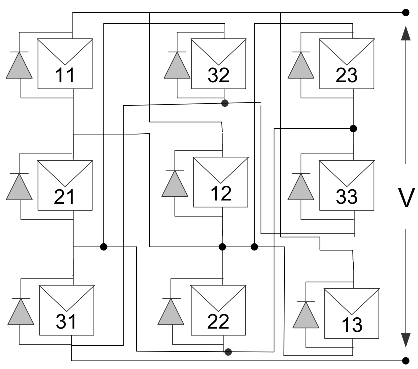

FIGURE 32. PV modules connected in SDS configuration [120].

11) LATIN SQUARE CONFIGURATION

In [129], the Latin square (LS) game puzzle is used to modify the TCT configuration entitled LS-TCT for performance evaluation under a realistic approach of progressive shading patterns (i.e. bottom to top, left to right, diagonal multi-story building pattern). Only three performance indexes such as FF, PL, and GMPP are assessed for LS-TCT configuration and found best values as 78.7%, 330W, and 2279W respectively as compared with TCT configuration. Some more important performance parameters can be analyzed such as PR and ML, which are helpful for new learners. The LS configuration is shown in Figure 33 as,

12) DOMINANCE SQUARE CONFIGURATION

During the reconfiguration, the challenge to minimize the wire length for PV module interconnections is solved by the

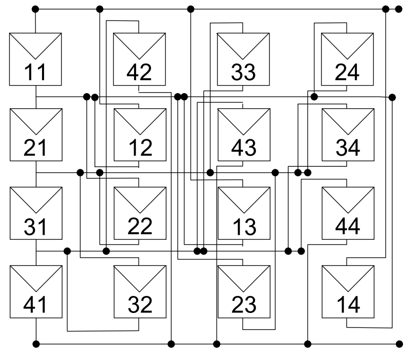

FIGURE 33. Latin square (LS-TCT) configuration [129].

authors in [130]. The 9 × 9 size of Dominance Square (DS) is reconfigured using column index method (CIM) and compared with SP and TCT configurations during SW, LW, SN, and LN shadow types in terms of GMPP location (4.647kW), ML (3.453kW), PL (0.43W) and FF (0.75). The irradiation levels are kept regular during the study as 200 W/m^2, 400W/m^2, 600W/m^2, and 900W/m^2. DS configuration is shown in Figure 34 as,

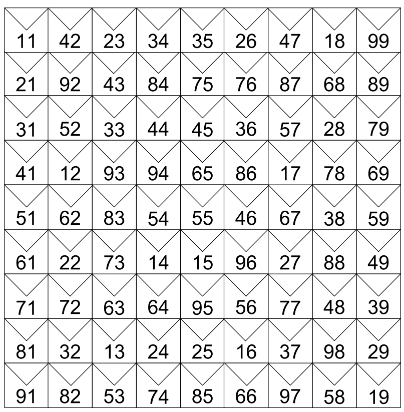

FIGURE 34. DS configuration [130].

13) ODD-EVEN CONFIGURATION

Efficiency assessment of solar PV configurations is the most required performance parameter along with GMPP, ML, and FF, which is evaluated for improved Su-Do-Ku puzzle-based TCT reconfigured PV array system. A comprehensive comparison is carried out during shadow test cases and observed that the improved Su-Do-Ku arrangement enhance the GMPP by 26.9%, 30.3%, 30.8%, 16.8%, 4.2%, and 6.3% as compared to existing SP, BL, HC, and TCT and Su-Do-Ku arrangement of PV array [132]. The scattering behavior of the shading pattern reduces the impact on PV array performance. For achieving high shade dispersion capability of shadow, ODD-EVEN (OE) PV number module methodology is used to reconfigure the existing TCT connection. A comprehensive comparative study is performed under four realistic shading

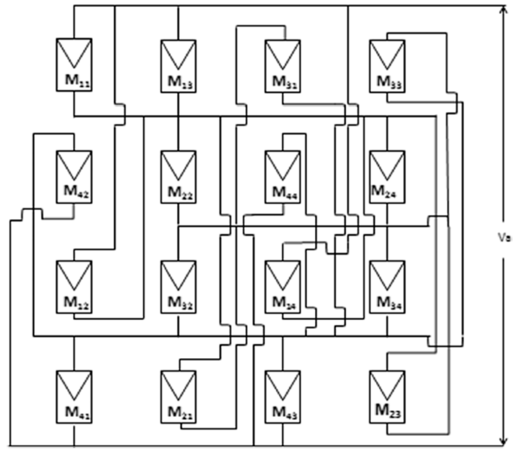

FIGURE 35. ODD- EVEN configuration [133].

cases: Dwarf broad, tall broad, dwarf narrow, and tall narrow shading patterns. Proposed OE configuration is observed highest values of FF as 30.88%, 14.31%, 8.47%, and 2.18% as compared SP, BL, and TCT conventional PV configuration [133].

14) SKYSCRAPER CONFIGURATION

In [134], authors have introduced new PV configurations i.e. Skyscraper puzzle-based, and found higher power at GMPP as 22.36%, 43.36%, and 39.31% compared with DS puzzle-based PV array configuration. The major performance indices are found best also for Skyscraper PV configuration than TCT, DS, and Su-Do-Ku configurations under LW, SN, and SW shadowing test cases. Simulation and real-time experimental studies are carried on 9 × 9 and 5 × 5 size PV arrays respectively. The skyscraper configuration is shown in Figure 36 as,

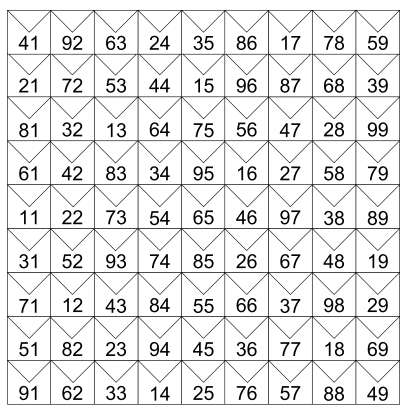

FIGURE 36. Skyscraper configuration [134].

15) LADDER CONFIGURATION

In [135]–[137], along with conventional PV configuration, the authors have introduced ladder (LD) configuration for performance evaluation under obscured irradiation levels from 300W/m^2-1000W/m^2. The efficient performance index output such as V_{oc}, I_{sc}, V_m, I_m, P_m, PL, ML, and FF are observed and found that the hybrid and LD based configurations are having superior performance under all climatic conditions. Ladder configuration is shown in Figure 37 as,

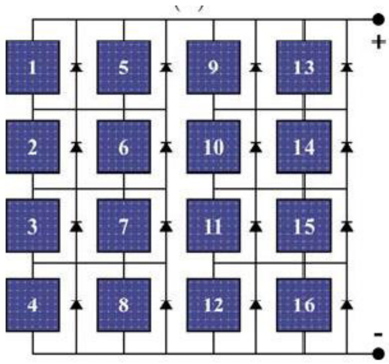

FIGURE 37. Ladder configuration [136].

The utilization of a smaller number of switches during electrical connections of the PV array system is a novel work reported in [138]. The proposed two-step reconfiguration scheme is investigated experimentally under distinguished realistic shading patterns (200W/m^2-950W/m^2). The proposed configuration is reconfigured and divided into small sub-matrices of 2×4 size using the Su-Do-Ku puzzle and achieved minimized ML values as 6.7%, 8%, 9.9%, 23.7%, and 5% as compared to others during experimentation.

16) CS AND LO SHU CONFIGURATIONS

A critical approach is adopted for extensive analysis of TCT, Su-Do-Ku, DS, Competence Square (CS), and Lo Shu puzzle-based configurations (9×9 size) is carried out in [139]. Novel performance indexes such as capacity factor (CF), execution ratio (ER), and capture loss (CL) are included along with conventional parameters for result analysis perspective under SW, LW, LN, and SN shading conditions (200W/m^2- 900 W/m^2). During the study, the performance of Lo Shu configuration is achieved as best in terms of reduced ML (2542W), reduced PL 3%, high CF as 0.69, and reduced CL as 135.08, highest 91% ER, and 100% value of PR parameters as compared to other considered PV array configurations. The schematic diagram of the Lo Shu configuration is shown in Figure 38 as,

FIGURE 38. Reconfigured Lo Shu configuration [139].

E. METAHUERISTIC-TCT BASED PV ARRAY CONFIGURATIONS

Although the game puzzle-based PV array reconfiguration has a wide acceptable solution to diminish the effect of PSCs, it is observed that this game puzzle theory requires relocation/reconfigure of PV modules in an array system. In addition to this, higher numbers of tie connections are required for shade dispersion purpose. To avoid such economic liability, researchers have explored metaheuristic algorithms to enhance shade dispersion capability on the entire PV array with minimum wire length requirement from conventional TCT configuration. Various metaheuristic approaches are used for performance enhancement as discussed.

1) PARTICLE SWARM OPTIMIZATION (PSO) BASED SWITCH MATRIX ALGORITHM

In [141], PSO algorithm based adaptive switch matrix (ASM) used to reduce the number of power maxima points along with wire length between PV modules. ASM is used to reconfigure SP during the shading and malfunction test cases. Enhanced power output is observed as 3.22%, 16.68%, and 5.62% under test cases as compared to SP.

2) FLOW REGIME ALGORITHM (FRA), SOCIAL MIMIC OPTIMIZATION (SMO), RAO OPTIMIZATION

In this sequence, a GA is devoted to reconfigure the PV array using a switch matrix operation. The results obtained as a higher power performance side as 17% and 22% as compared to conventional Brute force algorithm based 3×3 size SP configuration under non-uniform irradiation levels (400W/m^2, 700W/m^2, and 1000W/m^2) [142]. Moreover, high shade dispersion property is introduced by using FRA, SMO algorithm, and RAO algorithm which helped to enhance power 13%, 11%, and 9% respectively as compared to 9×9 size of TCT, CS, GA configurations. Performance parameters such as FF, ML, %PL and %PE are observed and found higher power, reduced MPP for FRA under three non-uniform shading levels with 200W/m^2, 400W/m^2, 500W/m^2, 600W/m^2 and 900W/m^2 [143].

TABLE 3. Purview of work.

Authors, [Ref]	Contribution	Performance parameters	Publication year
Bishop, [12]	○ Real time analysis of I-V curve	Current, voltage	1988
Blas *et al.* [13]	○ Experimental study under climatic changes	Voltage, Current	2002
Gautam and Kaushika [14]	○ Simulink analysis of SP, TCT, BL under PSCs	GMPP, Current, FF	2002
Kaushika and Gautam [15]	○ Simulink analysis of SP, TCT, BL under PSCs	GMPP, Current, FF	2003
Kawamura *et al.* [16]	○ I-V curve analysis of SP configuration	Voltage, Current,	2003
Alonso-Garcia and Herrmann [17]	○ Investigation of PV cells connected in series	Voltage, current	2006
Nguyen and Lehman [18]	○ Comparison of SP and TCT configurations under dynamic clouds	Power	2006
Candela *et al.* [19]	○ Optimization of layout of PV array system	Power, voltage	2007
Karatepe *et al.* [20]	○ Roll of bypass diode to reduce mismatch effects	GMPP, Current	2007
Xiao *et al.* [21]	○ Parallel of PV modules arrangements	GMPP, Current	2007
Patel and Agarwal [22]	○ Investigation on SP configuration	GMPP	2008
Patel and Agarwal [23]	○ Identify LMPP and GMPP during PSCs	GMPP	2008
Silvestre and Chouder [24]	○ Reported resistive losses under PSCs	V_m, I_m, FF	2008
Dio *et al.* [25]	○ Investigation on SP configuration	Power, voltage, current	2009
Gao *et al.* [26]	○ Power enhancement under PSCs	PL, GMPP	2009
Velasco-Quesada[27]	○ Adopt Switch matrix strategy for PV array reconfiguration	Power, voltage	2009
Silvestre *et al.* [28]	○ Test on S and SP configuration of PV cells under PSCs	Power voltage	2009
Bellini *et al.* [29]	○ Investigation on S configured PV system	Power, voltage, irradiation	2010
Chowdhury *et al.* [30]	○ PSO utilization to track MPP during PSCs	GMPP	2010
Piazza and Vitale [31]	○ Experimentation for I-V curve study	Power, voltage, current	2010
Martinez-Moreno *et al.* [32]	○ Experimental validation of PV array under PSCs	Power, voltage, current	2010
Picault *et al.* [33]	○ Introduced adaptable PV module interconnections	Power, voltage, current	2010
Tsai [34]	○ Analysis of I-V and P-V curves under shading conditions	Power, voltage, current	2010
Wang and Hsu [35]	○ Analytic study on PV array under PSCs	GMPP	2010
El-Dein *et al.* [36]	○ Performance comparsion of SP and TCT configurations	Power, ML, PE	2011
Ishaque *et al.* [37]	○ Double diode PV system investigation at low irradiance	GMPP	2011
Maki *et al.* [38]	○ I-V curves analysis on series connected PV modules	GMPP	2011
Moballegh and Jiang [39]	○ Experimental study on PV system under climatic changes	GMPP	2011
Patnaik *et al.* [40]	○ PV array (4x4 size) reconfiguration under PSCs	GMPP	2011
Renaudineau *et al.* [41]	○ Study on MPPT location	GMPP	2011
Santos *et al.* [42]	○ PV panel performance analysis during PSCs	Voltage and current	2011
Li *et al.* [43]	○ S and P configurations analysis under PSCs	PL, P_m, V_m	2011
Wang and Lin [44]	○ Analysis on SP and TCT configurations under different PSCs	FF, Efficiency	2011
Kadri *et al.* [45]	○ Investigation on S and P connections under PSCs	GMPP	2012
Alahmad *et al.* [46]	○ Study on adaptive flexible switch array matrix topology	PL, P_m, V_m, Efficiency	2012
Ding *et al.* [47]	○ Experiment study to obtain GMPP location	GMPP	2012
Diaz-Dorado *et al.* [48]	Investigation on single PV module under PSCs	Power	2012
Maki and Valkealahti, [49]	○ Arrangement of 18 PV modules in S and P configurations	GMPP	2012
Moschitta *et al.* [50]	○ Study on optimized reallocation of PV modules	GMPP	2012
Ramaprabha and Mathur [51]	○ Study on conventional PV array configurations during PSCs	P_m, V_m, I_m	2012
Salam and Ramli [52]	○ Study on bypass diode PV module	GMPP	2012
Villa *et al.* [53]	○ Experimental study on the existed PV module interconnections	GMPP, Shading factor, ML	2012
Zhang *et al.* [54]	○ Analysis on different PV array configurations under PSCs	GMPP	2012

TABLE 3. ***(Continued.)*** **Purview of work.**

Ziar *et al.* [55]	○	Experimental validation of two series connected solar cells	P_m, V_m	2012
Alajm *et al.* [56]	○	Study on GMPP tacking using FLC under PSCs	GMPP	2013
Basidas *et al.* [57]	○	Experimental study to identify GMPP under PSCs	GMPP	2013
Reinoso *et al.* [58]	○	Study on dynamic shading patterns	P_m, V_m, I_m, Efficiency	2013
El-Dein *et al.* [59]	○	Study on mathematical based optimal reconfiguration of PV array	PR, ML, PL	2013
Huynh *et al.* [60]	○	PSO algorithm study to track the GMPP under PSCs	Tracking efficiency	2013
Jung *et al.* [61]	○	Efficiency analysis of PV module under PSCs	Efficiency	2013
Kouchaki *et al.* [62]	○	Formulation of MPPT under non-uniform insolation	GMPP	2013
Lu *et al.* [63]	○	Simulation study on series arranged 72 PV modules	PL, GMPP	2013
Nezhad *et al.* [64]	○	Study on GMPP of solar PV module under PSCs	P_m, Efficiency	2013
Romos-Paja *et al.* [65]	○	Analysis on TCT configuration under PSCs	GMPP	2013
Pareek *et al.* [66]	○	MATLAB/Simulink study on PV array under PSCs	GMPP	2013
Rani *et al.* [67]	○	Study on Su-Do-Ku puzzle-based configuration under PSCs	P_m, PE	2013
Rodrigo *et al.* [68]	○	Analysis of current loss from I-V curves in PSCs	Tracking power	2013
Seyedmahmoudian *et al.* [69]	○	MATLAB/Simulink study to achieve GMPP	GMPP	2013
Tian *et al.* [70]	○	Study on I–V and P–V curves under three types of shading	PL, GMPP	2013
Batzelis *et al.* [71]	○	Study on GMPP existence under PSCs	MPP error, GMPP	2014
Bauwens *et al.* [72]	○	Study on bypass diode for PV arrays under PSCs	P_m, PL	2014
Dorado *et al.* [73]	○	Comparison of S and P configuration under PSCs	GMPP	2014
Fialho *et al.* [74]	○	Study on S connected monocrystalline PV system under PSCs	GMPP	2014
Parlak, [75]	○	MATLAB/Simulink study to find GMPP under PSCs	GMPP, Current	2014
Lun *et al.* [76]	○	Study on GMPP of SP and BL configurations under PSCs	GMPP, Current	2014
Ma *et al.* [77]	○	Study on grid-connected PV system under climatic conditions	GMPP, Current	2014
Moballegh *et al.* [78]	○	GMPP tracking of PV system under PSCs	GMPP, Current, PL	2014
Pareek and Dahiya [79]	○	Comparison of SP, TCT and BL configurations under PSCs	GMPP, Current	2014
Qi *et al.* [80]	○	Identify MPP location on P-V curve experimentally	GMPP, Current	2014
Ramaprabha [81]	○	Study on PSO algorithm to track the GMPP under PSCs	GMPP, Current	2014
Shirzadi *et al.* [82]	○	Study on GA to achieve high GMPP under PSCs	GMPP, Current	2014
Storey *et al.* [83]	○	Novel optimized-string reconfiguration is proposed	GMPP, Current	2014
Vijayalekshmy *et al.* [84]	○	Investigation on S and P configured PV modules	GMPP, Current, ML, FF	2014
Wang *et al.* [85]	○	S and P arrangement of PV modules for investigation under PSCs	GMPP, PL	2014
Bai *et al.* [86]	○	I-V and P-V curves observation for GMPP under PSCs	GMPP, Current	2015
Belhachat and Larbes [87]	○	Investigation of conventional PV array configurations	GMPP, FF, PL	2015
Celik *et al.* [88]	○	GMPP Investigation of different PV array electrical connections	GMPP	2015
Deshkar *et al.* [89]	○	GA based configuration scheme is proposed	GMPP, PL	2015
Fathy [90]	○	Study on new optimization approach for PV array configuration	GMPP, PL	2015
Grisales *et al.* [91]	○	Studied conventional PV array configurations under PSCs	Power, Voltage	2015
Malathy and Ramaprabha [92]	○	Shade dispersion analysis to enhance GMPP of PV array	GMPP, Utilization factor	2015

TABLE 3. ***(Continued.)*** **Purview of work.**

Malathy and Ramaprabha [93]	○ PV array reconfigured scheme to track GMPP in PV array	GMPP	2015
Potnuru *et al.* [94]	○ Su-do-Ku arrangement is adopted for the reconfiguration of PV array	Power	2015
Rao *et al.* [95]	○ Improved Su-Do-Ku method to reconfigure the PV array	GMPP	2015
Sankar and Mukherjee [96]	○ GA and hybrid PSO algorithms are adopted for GMPP under PSCs	Maximum power	2015
Sundareswaram *et al.* [97]	○ Study on PSO algorithm to track GMPP under PSCs	GMPP	2015
Vicente *et al.* [98]	○ Simulation study to reconfigure PV array	P_m, V, I_m	2015
Vijayalekshmy *et al.* [99]	○ Adopt Reconfigured-TCT configuration for PE	P_m, V_m, PE	2015
Vijayalekshmy *et al.* [100]	○ RTCT method for PV array under PSCs	GMPP, PE	2015
Xueye and Tianlong [101]	○ Study on S, P and SP configuration under PSCs	P_m, V_m, I_m	2015
Yadav *et al.* [102]	○ Analysis of TCT, SP-TCT and Su-Do-Ku configurations	Power, voltage at GMPP	2016
Boukenoui [103]	○ Ubiquitous method to track the GMPP under PSCs	Pm, Efficiency,	2016
Braun *et al.* [104]	○ Analyzed different configurations of PV array under PSCs	Power	2016
Forcan *et al.* [105]	○ Simulation study of innovative approach for PV array	Voltage, Current, Power, Efficiency	2016
Kumar *et al.* [106]	○ Experimental study of SP and TCT configurations under two PSCs	GMPP, PL, FF	2016
Mohammadnejad *et al.* [107]	○ Study on SP, HC, BL and TCT configurations under PSCs	GMPP, PL	2016
Kumar *et al.* [108]	○ PL study on SP configuration under PSCs	GMPP, PL	2016
Ram and Rajasekar [109]	○ Study on S and SP configuration under PSCs	GMPP	2016
Rakesh and Madhavaram [110]	○ Study on MS configuration for PE under PSCs	Maximum power, PE	2016
Sahu and Nayak [111]	○ PRM-FEC method for PV array reconfiguration	Maximum power, PE	2016
Sahu and Nayak [112]	○ Study on Futoshiki puzzle-based configuration	GMPP	2016
Samikannu *et al.* [113]	○ Study on MS-based puzzle configuration under PSCs	GMPP, ML	2016
Pareek and Dahiya [114]	○ Study on TCT configuration for GMPP tracking	GMPP, PR	2016
Vijaylekshmy *et al.* [115]	○ Study on OTCT and NTCT configurations under PSCs	GMPP, ML, PL FF, PR, PE	2016
Yadav, *et al.* [116]	○ SP–TCT, BL–TCT configurations for GMPP analysis	GMPP, PL, FF	2016
Ahmad *et al.* [117]	○ Analysis of the shading effect on SP configuration	GMPP	2017
Yadav *et al.* [118]	○ Performance evaluation of existing PV array configurations	GMPP, PL, FF	2017
Tabish and Asharaf [119]	○ Experimental validation of PV system under PSCs	GMPP	2017
Bana and Saini [120]	○ Experimental study on conventional configurations	Maximum power, voltage	2017
Belhaouas *et al.* [121]	○ New physical relocation of PV array configurations	Power at GMPP	2017
Bosco and Mabel [122]	○ Implemented TCT-SDK and TCT-CDV configuration under PSCs.	Power, voltage and current	2017
Pareek, Chaturvedi and Dahiya [123]	○ Study on SP and TCT configurations under four distinguish PSCs	GMPP, PL	2017
Satpathy *et al.* [124]	○ Study on Novel SDS PV array configuration for study	Maximum power, PL	2017
Vengatesh and Rajan [125]	○ Study on S, P, and SP configurations under PSCs	GMPP	2017

TABLE 3. ***(Continued.)*** **Purview of work.**

Mishra *et al.* [126]	○ Study on TCT, hybrid and NS configurations	GMPP, PL, FF, PR	2017
Malathy and Ramaprabha [127]	○ Study on proposed MS configuration under PSCs	GMPP,	2018
Rodriguez *et al.* [128]	○ Study on TCT configuration with experimental validation	GMPP	2018
Pachauri *et al.* [129]	○ Proposed LS-TCT configuration to achieve best results	FF, PL, GMPP	2018
Pillai *et al.* [130]	○ Study on CIM based DS configuration under PSCs	GMPP, ML, PL, FF	2018
Pachauri *et al.* [131]	○ Study on relay control to switch from SP to TCT configuration .	GMPP, FF	2019
Krishna and Moger [132]	○ Modified Su-Do-Ku configuration to achieve best shade dispersion	GMPP, ML, FF and efficiency	2019
Nasiruddin *et al.* [133]	○ Analyzed proposed Odd-Even PV array configuration under PSCs	GMPP, FF	2019
Nihanth *et al.* [134]	○ Sky-craper puzzle for PV array reconfiguration	GMPP, ML, FF, PL	2019
Haq *et al.* [135]	○ Adopt reconfigured method to alter PV modules connections	GMPP	2020
Premkumar *et al.* [136]	○ Investigation on Ladder PV array under PSCs	ML, GMPP, FF	2020
Sagar *et al.* [137]	○ Investigation on Su-Do-Ku puzzle based BL-TCT configuration	PL, FF, PR	2020
Srinivasan *et al.* [138]	○ Study on switch matrix approach for reconfiguration	GMPP, ML, FF	2020
Venkatiswari and Rajasekar [139]	○ CS and Lo Shu game puzzles PV array configurations study	ML, PL, FF, CF, PR, ER, CL	2020
Gul *et al.* [140]	○ Discussion on PV array faults to investigate GMPP	GMPP	2020
Chao and Liao [141]	○ PSO algorithm to reconfigure PV array for PE	GMPP	2012
Juan *et al.* [142]	○ Study on GA for shade dispersion to achieve higher GMPP	GMPP	2015
Babu *et al.* [143]	○ Comparsion of FRA, SMO and RAO algorithms	GMPP, ML, FF, PL, PE	2020
Fathy [144]	○ Comparisons of GOA with GA based PV array under PSCs	GMPP, FF, PL	2018
Babu *et al.* [145]	○ Su-Do-Ku PV array reconfigured using PSO algorithm	GMPP, Current	2018
Fathy [146]	○ Study on BOA with GWO based PV array under PSCs	FF, PL, PE, GMPP	2020
Yousri *et al.* [147]	○ Study on MHHO for reconfigure PV array configuration under PSCs	GMPP, V_m, FF, PL, PR	2020

* PE= POWER ENHANCEMENT, P_M= MAXIMUM POWER, V_M=MAXIMUM VOLTAGE, I_M= MAXIMUM CURRENT, CF= CAPACITY FACTOR, ER= EXECUTION RATIO, CL= CAPTURE LOSS

3) GRASSHOPPER OPTIMIZATION ALGORITHM (GOA)

In [144], presents a new methodology named the GOA in reconfiguring the partially shaded PV array to extract GMPP. Different shadow patterns SW, SN, LW, and LN are studied, and the obtained results are compared with TCT, Su-Do-Ku and GA connected PV array. The proposed GOA enhances the power output by 3.361%, 10.949%, 0.864%, and 6.748% under shading cases respectively.

4) PSO, BUTTERFLY OPTIMIZATION ALGORITHM (BOA) AND MODIFIED HARRIS HAWKS OPTIMIZATION (MHHO) ALGORITHMS

In [145], PSO is introduced to enhance shade dispersion and has the best results 5530W and 6150W as compared with TCT, Su-Do-Ku, and GA based configuration under mixed irradiation levels from 200W/m^2-900W/m^2. In [146], the BOA is investigated and found best output power 27.42% as compared to existed SP-TCT configurations under mixed irradiation levels from 350W/m^2-1000W/m^2. MHHO is investigated for the same environment and compared with TCT, CS, PSO, GA based on various performance indices i.e. FF, %PL, %PE and found higher power by 33.27%, 27.79%, 6.69%, and 7.17% [147].

III. CONTRIBUTION WORK AND PERFORMANCE PARAMETERS OF PV SYSTEM

The identified performance parameters of PV systems and year of publications of the available literature [12]–[147] are depicted in the Table 3 as,

IV. CONCLUSION

In this article, a novel state of the art on the development of various PV array configuration models for the PV system to counter the effect of partial shading has been introduced. Each configuration is reported and discussed from view points of benefits, inadequacies, and vital features. Following are the main concluding remarks as,

- An extensive literature survey on the existing PV configurations is carried out to compare them, based on topology, modeling, performance, scale, grid connectivity, etc.
- These PV array configurations are uniquely classified based on conventional, hybrid, reconfigured, and puzzle-based advanced configurations.
- In conventional configurations, the TCT scheme is found to have superior performance as compared to other configurations in this sub-category.
- In the hybrid configuration, various modeling approaches using conventional configurations are proposed and analyzed.
- In reconfigured/modified configuration, RTCT and S-M-TCT schemes possess relatively superior performance as compared to others in this sub-category.
- In the puzzle-based configuration, distinct types of mathematical/game puzzles are introduced, and performance is evaluated. The performance of these game puzzle-based configurations is found better as compared with conventional configurations.
- Due to lengthy wire requirements and higher number of tie between PV modules connections in an array system, the metaheuristic algorithms are studied and found the best performance as compared to game puzzle configurations. Moreover, metaheuristic approaches in the concern research area explored novel research directions because of higher shade dispersion capability.

Overall, the study will be useful for researchers, participating industries, and practicing engineering in this area, which will work as a benchmark for future study.

REFERENCES

[1] A. Woyte, J. Nijs, and R. Belmans, ''Partial shadowing of photovoltaic arrays with different system configurations: Literature review and field test results,'' *Sol. Energy*, vol. 74, no. 3, pp. 217–233, Mar. 2003.

[2] S. R. Ola, A. Sarswat, S. K. Goyal, S. K. Jhajharia, B. Khan, O. P. Mahela, H. H. Alhelou, and P. Siano, ''A protection scheme for a power system with solar energy penetration,'' *Appl. Sci.*, vol. 10, no. 4, pp. 1–22, 2020.

[3] D. La Manna, V. Li Vigni, E. R. Sanseverino, V. Di Dio, and P. Romano, ''Reconfigurable electrical interconnection strategies for photovoltaic arrays: A review,'' *Renew. Sustain. Energy Rev.*, vol. 33, pp. 412–426, May 2014.

[4] E. I. Batzelis, P. S. Georgilakis, and S. A. Papathanassiou, ''Energy models for photovoltaic systems under partial shading conditions: A comprehensive review,'' *IET Renew. Power Gener.*, vol. 9, no. 4, pp. 340–349, 2015.

[5] S. Daliento, F. Di Napoli, P. Guerriero, and V. d'Alessandro, ''A modified bypass circuit for improved hot spot reliability of solar panels subject to partial shading,'' *Sol. Energy*, vol. 134, pp. 211–218, Sep. 2016.

[6] J. Ahmed and Z. Salam, ''A critical evaluation on maximum power point tracking methods for partial shading in PV systems,'' *Renew. Sustain. Energy Rev.*, vol. 47, pp. 933–953, Jul. 2015.

[7] L. L. Jiang, D. R. Nayanasiri, D. L. Maskell, and D. M. Vilathgamuwa, ''A hybrid maximum power point tracking for partially shaded photovoltaic systems in the tropics,'' *Renew. Energy*, vol. 76, pp. 53–65, Apr. 2015.

[8] A. K. Tossa, Y. M. Soro, Y. Azoumah, and D. Yamegueu, ''A new approach to estimate the performance and energy productivity of photovoltaic modules in real operating conditions,'' *Sol. Energy*, vol. 110, pp. 543–560, Dec. 2014.

[9] H. Zheng, S. Li, R. Challoo, and J. Proano, ''Shading and bypass diode impacts to energy extraction of PV arrays under different converter configurations,'' *Renew. Energy*, vol. 68, pp. 58–66, Aug. 2014.

[10] D. G. Lorente, S. Pedrazzi, G. Zini, A. Dalla Rosa, and P. Tartarini, ''Mismatch losses in PV power plants,'' *Sol. Energy*, vol. 100, pp. 42–49, Feb. 2014.

[11] A. Mäki and S. Valkealahti, ''Differentiation of multiple maximum power points of partially shaded photovoltaic power generators,'' *Renew. Energy*, vol. 71, pp. 89–99, Nov. 2014.

[12] J. W. Bishop, ''Computer simulation of the effects of electrical mismatches in photovoltaic cell interconnection circuits,'' *Sol. Cells*, vol. 25, no. 1, pp. 73–89, Oct. 1988.

[13] M. A. de Blas, J. L. Torres, E. Prieto, and A. Garcıa, ''Selecting a suitable model for characterizing photovoltaic devices,'' *Renew. Energy*, vol. 25, no. 3, pp. 371–380, Mar. 2002.

[14] N. K. Gautam and N. D. Kaushika, ''An efficient algorithm to simulate the electrical performance of solar photovoltaic arrays,'' *Energy*, vol. 27, no. 4, pp. 347–361, Apr. 2002.

[15] N. D. Kaushika and N. K. Gautam, ''Energy yield simulations of interconnected solar PV arrays,'' *IEEE Trans. Energy Convers.*, vol. 18, no. 1, pp. 127–134, Mar. 2003.

[16] H. Kawamura, K. Naka, N. Yonekura, S. Yamanaka, H. Kawamura, H. Ohno, and K. Nait, ''Simulation of I-V characteristics of a PV module with shaded PV cells,'' *Sol. Energy Mater. Sol. Cells*, vol. 75, nos. 3–4, pp. 613–621, 2003.

[17] M. C. Alonso-García, J. M. Ruiz, and W. Herrmann, ''Computer simulation of shading effects in photovoltaic arrays,'' *Renew. Energy*, vol. 31, no. 12, pp. 1986–1993, Oct. 2006.

[18] D. D. Nguyen, B. Lehman, ''Modeling and simulation of solar PV arrays under changing illumination conditions,'' in *Proc. IEEE Conf. Comput. Power Electron.*, Jul. 2006, pp. 295–299.

[19] R. Candela, V. di Dio, E. R. Sanseverino, and P. Romano, ''Reconfiguration techniques of partial shaded PV systems for the maximization of electrical energy production,'' in *Proc. Int. Conf. Clean Electr. Power*, May 2007, pp. 716–719.

[20] E. Karatepe, M. Boztepe, and M. Çolak, ''Development of a suitable model for characterizing photovoltaic arrays with shaded solar cells,'' *Sol. Energy*, vol. 81, no. 8, pp. 977–992, Aug. 2007.

[21] W. Xiao, N. Ozog, W. G. Dunford, ''Topology study of photovoltaic interface for maximum power point tracking,'' *IEEE Trans. Ind. Electron.*, vol. 54, no. 3, pp. 1696–1704, Apr. 2007.

[22] H. Patel and V. Agarwal, ''MATLAB-based modeling to study the effects of partial shading on PV array characteristics,'' *IEEE Trans. Energy Convers.*, vol. 23, no. 1, pp. 302–310, Mar. 2008.

[23] H. Patel and V. Agarwal, ''Maximum power point tracking scheme for PV systems operating under partially shaded conditions,'' *IEEE Trans. Ind. Electron.*, vol. 55, no. 4, pp. 1689–1698, Apr. 2008.

[24] S. Silvestre and A. Chouder, ''Effects of shadowing on photovoltaic module performance,'' *Prog. Photovolt., Res. Appl.*, vol. 16, no. 2, pp. 141–149, Mar. 2008.

[25] V. Di Dio, D. La Cascia, R. Miceli, and C. Rando, ''A mathematical model to determine the electrical energy production in photovoltaic fields under mismatch effect,'' in *Proc. Int. Conf. Clean Electr. Power*, Jun. 2009, pp. 46–51.

[26] L. Gao, R. A. Dougal, S. Liu, and A. P. Iotova, ''Parallel-connected solar PV system to address partial and rapidly fluctuating shadow conditions,'' *IEEE Trans. Ind. Electron.*, vol. 56, no. 5, pp. 1548–1556, May 2009.

[27] G. Velasco-Quesada, F. Guinjoan-Gispert, R. Pique-Lopez, M. Roman-Lumbreras, and A. Conesa-Roca, ''Electrical PV array reconfiguration strategy for energy extraction improvement in grid-connected PV systems,'' *IEEE Trans. Ind. Electron.*, vol. 56, no. 11, pp. 4319–4331, Nov. 2009.

[28] S. Silvestre, A. Boronat, and A. Chouder, ''Study of bypass diodes configuration on PV modules,'' *Appl. Energy*, vol. 86, no. 9, pp. 1632–1640, 2009.

[29] A. Bellini, S. Bifaretti, and V. Iacovone, "MPPT algorithm for current balancing of partially shaded photovoltaic modules," in *Proc. IEEE Int. Symp. Ind. Electron.*, Jul. 2010, pp. 933–938.

[30] S. Roy Chowdhury and H. Saha, "Maximum power point tracking of partially shaded solar photovoltaic arrays," *Sol. Energy Mater. Sol. Cells*, vol. 94, no. 9, pp. 1441–1447, Sep. 2010.

[31] M. C. Di Piazza and G. Vitale, "Photovoltaic field emulation including dynamic and partial shadow conditions," *Appl. Energy*, vol. 87, no. 3, pp. 814–823, Mar. 2010.

[32] F. Martínez-Moreno, J. Muñoz, and E. Lorenzo, "Experimental model to estimate shading losses on PV arrays," *Sol. Energy Mater. Sol. Cells*, vol. 94, no. 12, pp. 2298–2303, Dec. 2010.

[33] D. Picault, B. Raison, S. Bacha, J. de la Casa, and J. Aguilera, "Forecasting photovoltaic array power production subject to mismatch losses," *Sol. Energy*, vol. 84, no. 7, pp. 1301–1309, Jul. 2010.

[34] H.-L. Tsai, "Insolation-oriented model of photovoltaic module using MATLAB/simulink," *Sol. Energy*, vol. 84, no. 7, pp. 1318–1326, Jul. 2010.

[35] Y. J. Wang and P. C. Hsu, "Analytical modelling of partial shading and different orientation of photovoltaic modules," *IET Renew. Power Gener.*, vol. 4, no. 3, pp. 272–282, 2010.

[36] M. Z. S. El-Dein, M. Kazerani, and M. M. A. Salama, "Novel configurations for photovoltaic farms to reduce partial shading losses," in *Proc. IEEE Power Energy Soc. Gen. Meeting*, Jul. 2011, pp. 1–5.

[37] K. Ishaque, Z. Salam, and Syafaruddin, "A comprehensive MATLAB simulink PV system simulator with partial shading capability based on two-diode model," *Sol. Energy*, vol. 85, no. 9, pp. 2217–2227, Sep. 2011. [Online]. Available: http://iranarze.ir/wp-content/uploads/2017/02/6117-English-IranArze.pdf

[38] A. Mäki, S. Valkealahti, and J. Leppäaho, "Operation of series-connected silicon-based photovoltaic modules under partial shading conditions," *Prog. Photovolt., Res. Appl.*, vol. 20, no. 3, pp. 298–309, May 2012.

[39] S. Moballegh and J. Jiang, "Partial shading modeling of photovoltaic system with experimental validations," in *Proc. IEEE Power Energy Soc. Gen. Meeting*, Jul. 2011, pp. 1–9.

[40] B. Patnaik, P. Sharma, E. Trimurthulu, S. P. Duttagupta, and V. Agarwal, "Reconfiguration strategy for optimization of solar photovoltaic array under non-uniform illumination conditions," in *Proc. 37th IEEE Photovolt. Spec. Conf.*, Jun. 2011, pp. 1859–1864.

[41] H. Renaudineau, A. Houari, J.-P. Martin, S. Pierfederici, F. Meibody-Tabar, and B. Gerardin, "A new approach in tracking maximum power under partially shaded conditions with consideration of converter losses," *Sol. Energy*, vol. 85, no. 11, pp. 2580–2588, Nov. 2011.

[42] P. dos Santos, E. M. Vicente, and E. R. Ribeiro, "Relationship between the shading position and the output power of a photovoltaic panel," in *Proc. 11th Brazilian Power Electron. Conf.*, Sep. 2011, pp. 676–681.

[43] S. Li, T. A. Haskew, D. Li, and F. Hu, "Integrating photovoltaic and power converter characteristics for energy extraction study of solar PV systems," *Renew. Energy*, vol. 36, no. 12, pp. 3238–3245, Dec. 2011.

[44] Y.-J. Wang and S.-S. Lin, "Analysis of a partially shaded PV array considering different module connection schemes and effects of bypass diodes," in *Proc. Int. Conf. Utility Exhib. Power Energy Syst., Issues Prospects Asia*, Sep. 2011, pp. 1–7.

[45] R. Kadri, H. Andrei, J.-P. Gaubert, T. Ivanovici, G. Champenois, and P. Andrei, "Modeling of the photovoltaic cell circuit parameters for optimum connection model and real-time emulator with partial shadow conditions," *Energy*, vol. 42, no. 1, pp. 57–67, Jun. 2012.

[46] M. Alahmad, M. A. Chaaban, S. K. Lau, J. Shi, and J. Neal, "An adaptive utility interactive photovoltaic system based on a flexible switch matrix to optimize performance in real-time," *Sol. Energy*, vol. 86, no. 3, pp. 951–963, Mar. 2012.

[47] K. Ding, X. Bian, H. Liu, and T. Peng, "A MATLAB-simulink-based PV module model and its application under conditions of nonuniform irradiance," *IEEE Trans. Energy Convers.*, vol. 27, no. 4, pp. 864–872, Dec. 2012.

[48] E. Diaz-Dorado, A. Suarez-Garcia, C. Carrillo, and J. Cidras, "Influence of the shadows in photovoltaic systems with different configurations of bypass diodes," in *Proc. IEEE Int. Symp. Power Electron., Electr. Drives, Autom. Motion*, Jun. 2010, pp. 134–139.

[49] A. Mäki and S. Valkealahti, "Power losses in long string and parallel-connected short strings of series-connected silicon-based photovoltaic modules due to partial shading conditions," *IEEE Trans. Energy Convers.*, vol. 27, no. 1, pp. 173–183, Mar. 2012.

[50] A. Moschitta, A. Damiani, and P. Carbone, "A simple and accurate model for predicting mismatch effects in photovoltaic arrays," in *Proc. IEEE Int. Energy Conf. Exhib.*, Sep. 2012, pp. 818–822.

[51] R. Ramaprabha and B. L. Mathur, "A comprehensive review and analysis of solar photovoltaic array configurations under partial shaded conditions," *Int. J. Photoenergy*, vol. 2012, pp. 1–16, Nov. 2012.

[52] Z. Salam and M. Z. Ramli, "A simple circuit to improve the power yield of PV array during partial shading," in *Proc. IEEE Energy Convers. Congr. Expo.*, Sep. 2012, pp. 1622–1626.

[53] L. F. L. Villa, D. Picault, B. Raison, S. Bacha, and A. Labonne, "Maximizing the power output of partially shaded photovoltaic plants through optimization of the interconnections among its modules," *IEEE J. Photovolt.*, vol. 2, no. 2, pp. 154–163, Apr. 2012.

[54] F. Zhang, J. Li, C. Feng, and Y. Wu, "In-depth investigation of effects of partial shading on PV array characteristics," in *Proc. Power Eng. Autom. Conf.*, Sep. 2012, pp. 1–4.

[55] H. Ziar, S. Mansourpour, E. Afjei, and M. Kazemi, "Bypass diode characteristic effect on the behavior of solar PV array at shadow condition," in *Proc. 3rd Power Electron. Drive Syst. Technol.*, Feb. 2012, pp. 229–233.

[56] B. N. Alajmi, K. H. Ahmed, S. J. Finney, and B. W. Williams, "A maximum power point tracking technique for partially shaded photovoltaic systems in micro grids," *IEEE Trans. Ind. Electron.*, vol. 60, no. 4, pp. 1596–1606, Sep. 2013.

[57] J. D. Bastidas, E. Franco, G. Petrone, C. A. Ramos-Paja, and G. Spagnuolo, "A model of photovoltaic fields in mismatching conditions featuring an improved calculation speed," *Electr. Power Syst. Res.*, vol. 96, pp. 81–90, Mar. 2013.

[58] C. R. Sánchez Reinoso, D. H. Milone, and R. H. Buitrago, "Simulation of photovoltaic centrals with dynamic shading," *Appl. Energy*, vol. 103, pp. 278–289, Mar. 2013.

[59] M. Z. Shams El-Dein, M. Kazerani, and M. M. A. Salama, "Optimal photovoltaic array reconfiguration to reduce partial shading losses," *IEEE Trans. Sustain. Energy*, vol. 4, no. 1, pp. 145–153, Jan. 2013.

[60] D. C. Huynh, T. M. Nguyen, M. W. Dunnigan, and M. A. Mueller, "Global MPPT of solar PV modules using a dynamic PSO algorithm under partial shading conditions," in *Proc. IEEE Conf. Clean Energy Technol.*, Nov. 2013, pp. 134–139.

[61] T. H. Jung, J. W. Ko, G. H. Kang, and H. K. Ahn, "Output characteristics of PV module considering partially reverse biased conditions," *Sol. Energy*, vol. 92, pp. 214–220, Jun. 2013.

[62] A. Kouchaki, H. Iman-Eini, and B. Asaei, "A new maximum power point tracking strategy for PV arrays under uniform and non-uniform insolation conditions," *Sol. Energy*, vol. 91, pp. 221–232, May 2013.

[63] F. Lu, S. Guo, T. M. Walsh, and A. G. Aberle, "Improved PV module performance under partial shading conditions," *Energy Procedia*, vol. 33, pp. 248–255, Jan. 2013.

[64] M. Etezadi Nezhad, B. Asaei, and S. Farhangi, "Modified analytical solution for tracking photovoltaic module maximum power point under partial shading condition," in *Proc. 13th Int. Conf. Environ. Electr. Eng.*, Nov. 2013, pp. 1–6.

[65] C. A. Ramoz-Paza, J. D. Bastidas, and A. J. Saavendra-Montes, "Experimental validation of a model for photovoltaic arrays in total cross-tied configuration," *Dyna*, vol. 80, pp. 191–199, Dec. 2013.

[66] S. Pareek, R. Runthala, and R. Dahiya, "Mismatch losses in SPV systems subjected to partial shading conditions," in *Proc. Int. Conf. Adv. Electron. Syst.*, Sep. 2013, pp. 343–345.

[67] B. Indu Rani, G. Saravana Ilango, and C. Nagamani, "Enhanced power generation from PV array under partial shading conditions by shade dispersion using Su Do Ku configuration," *IEEE Trans. Sustain. Energy*, vol. 4, no. 3, pp. 594–601, Jul. 2013.

[68] P. Rodrigo, E. F. Fernández, F. Almonacid, and P. J. Pérez-Higueras, "A simple accurate model for the calculation of shading power losses in photovoltaic generators," *Sol. Energy*, vol. 93, pp. 322–333, Jul. 2013.

[69] M. Seyedmahmoudian, S. Mekhilef, R. Rahmani, R. Yusof, and E. Renani, "Analytical modeling of partially shaded photovoltaic systems," *Energies*, vol. 6, no. 1, pp. 128–144, Jan. 2013.

[70] H. Tian, F. Mancilla–David, K. Ellis, E. Muljadi, and P. Jenkins, "Determination of the optimal configuration for a photovoltaic array depending on the shading condition," *Sol. Energy*, vol. 95, pp. 1–12, Sep. 2013.

[71] E. I. Batzelis, I. A. Routsolias, and S. A. Papathanassiou, "An explicit PV string model based on the Lambert *W* function and simplified MPP expressions for operation under partial shading," *IEEE Trans. Sustain. Energy*, vol. 5, no. 1, pp. 301–312, Jan. 2014.

[72] P. Bauwens and J. Doutreloigne, "Reducing partial shading power loss with an integrated smart bypass," *Sol. Energy*, vol. 103, pp. 134–142, May 2014.

[73] E. Díaz-Dorado, J. Cidrás, and C. Carrillo, "Discrete I–V model for partially shaded PV-arrays," *Sol. Energy*, vol. 103, pp. 96–107, May 2014.

[74] L. Fialho, R. Melicio, V. M. F. Mendes, J. Figueiredo, and M. Collares-Pereira, "Effect of shading on series solar modules: Simulation and experimental results," *Procedia Technol.*, vol. 17, pp. 295–302, Jan. 2014.

[75] K. S. Parlak, "FPGA based new MPPT (maximum power point tracking) method for PV (photovoltaic) array system operating partially shaded conditions," *Energy*, vol. 68, pp. 1–12, Apr. 2014.

[76] S.-X. Lun, S. Wang, T.-T. Guo, and C.-J. Du, "An I–V model based on time warp invariant echo state network for photovoltaic array with shaded solar cells," *Sol. Energy*, vol. 105, pp. 529–541, Jul. 2014.

[77] T. Ma, H. Yang, and L. Lu, "Development of a model to simulate the performance characteristics of crystalline silicon photovoltaic modules/strings/arrays," *Sol. Energy*, vol. 100, pp. 31–41, Feb. 2014.

[78] S. Moballegh and J. Jiang, "Modeling, prediction, and experimental validations of power peaks of PV arrays under partial shading conditions," *IEEE Trans. Sustain. Energy*, vol. 5, no. 1, pp. 293–300, Jan. 2014.

[79] S. Pareek and R. Dahiya, "Output power maximization of partially shaded 4 × 4 PV field by altering its topology," *Energy Procedia*, vol. 54, pp. 116–126, Jan. 2014.

[80] J. Qi, Y. Zhang, and Y. Chen, "Modeling and maximum power point tracking (MPPT) method for PV array under partial shade conditions," *Renew. Energy*, vol. 66, pp. 337–345, Jun. 2014.

[81] R. Ramaprabha, "Selection of an optimum configuration of solar PV array under partial shaded condition using particle swarm optimization," *Int. J. Electr., Comput., Energetic, Electron. Commun. Eng.*, vol. 8, no. 1, pp. 89–96, 2014.

[82] S. Shirzadi, H. Hizam, and N. I. A. Wahab, "Mismatch losses minimization in photovoltaic arrays by arranging modules applying a genetic algorithm," *Sol. Energy*, vol. 108, pp. 467–478, Oct. 2014.

[83] J. Storey, P. R. Wilson, and D. Bagnall, "The optimized-string dynamic photovoltaic array," *IEEE Trans. Power Electron.*, vol. 29, no. 4, pp. 1768–1776, Apr. 2014.

[84] S. Vijayalekshmy, S. Rama Iyer, and B. Beevi, "Comparative analysis on the performance of a short string of series-connected and parallel-connected photovoltaic array under partial shading," *J. Inst. Eng. India, B*, vol. 96, no. 3, pp. 217–226, Sep. 2015.

[85] Y. Wang, X. Lin, Y. Kim, N. Chang, and M. Pedram, "Architecture and control algorithms for combating partial shading in photovoltaic systems," *IEEE Trans. Comput. Aided Design Integr. Circuits Syst.*, vol. 33, no. 6, pp. 917–929, Jun. 2014.

[86] J. Bai, Y. Cao, Y. Hao, Z. Zhang, S. Liu, and F. Cao, "Characteristic output of PV systems under partial shading or mismatch conditions," *Sol. Energy*, vol. 112, pp. 41–54, Feb. 2015.

[87] F. Belhachat and C. Larbes, "Modeling, analysis and comparison of solar photovoltaic array configurations under partial shading conditions," *Sol. Energy*, vol. 120, pp. 399–418, Oct. 2015.

[88] B. Celik, E. Karatepe, S. Silvestre, N. Gokmen, and A. Chouder, "Analysis of spatial fixed PV arrays configurations to maximize energy harvesting in BIPV applications," *Renew. Energy*, vol. 75, pp. 534–540, Mar. 2015.

[89] S. N. Deshkar, S. B. Dhale, J. S. Mukherjee, T. S. Babu, and N. Rajasekar, "Solar PV array reconfiguration under partial shading conditions for maximum power extraction using genetic algorithm," *Renew. Sustain. Energy Rev.*, vol. 43, pp. 102–110, Mar. 2015.

[90] A. Fathy, "Reliable and efficient approach for mitigating the shading effect on photovoltaic module based on modified artificial bee colony algorithm," *Renew. Energy*, vol. 81, pp. 78–88, Sep. 2015.

[91] L. A. T. Grisales, C. A. R. Paja, and Y. A. J. S. Montes, "Equivalent circuits for simulating irregular PV arrays under partial shading conditions," *Technologicas*, vol. 18, no. 35, pp. 57–69, 2015.

[92] S. Malathy and R. Ramaprabha, "A static PV array architecture to enhance power generation under partial shaded conditions," in *Proc. IEEE 11th Int. Conf. Power Electron. Drive Syst.*, Jun. 2015, pp. 1–6.

[93] S. Malathy and R. Ramaprabha, "Comprehensive analysis on the role of array size and configuration on energy yield of photovoltaic systems under shaded conditions," *Renew. Sustain. Energy Rev.*, vol. 49, pp. 672–679, Sep. 2015.

[94] S. R. Potnuru, D. Pattabiraman, S. I. Ganesan, and N. Chilakapati, "Positioning of PV panels for reduction in line losses and mismatch losses in PV array," *Renew. Energy*, vol. 78, pp. 264–275, Jun. 2015.

[95] P. Srinivasa Rao, P. Dinesh, G. Saravana Ilango, and C. Nagamani, "Optimal Su-Do-Ku based interconnection scheme for increased power output from PV array under partial shading conditions," *Frontiers Energy*, vol. 9, no. 2, pp. 199–210, Jun. 2015.

[96] G. Shankar and V. Mukherjee, "MPP detection of a partially shaded PV array by continuous GA and hybrid PSO," *Ain Shams Eng. J.*, vol. 6, no. 2, pp. 471–479, Jun. 2015.

[97] K. Sundareswaran, V. Vignesh Kumar, and S. Palani, "Application of a combined particle swarm optimization and perturb and observe method for MPPT in PV systems under partial shading conditions," *Renew. Energy*, vol. 75, pp. 308–317, Mar. 2015.

[98] P. D. S. Vicente, T. C. Pimenta, and E. R. Ribeiro, "Photovoltaic array reconfiguration strategy for maximization of energy production," *Int. J. Photo Energy*, vol. 2015, pp. 2–11, Jan. 2015.

[99] S. Vijayalekshmy, G. R. Bindu, and S. Rama Iyer, "Analysis of various photovoltaic array configurations under shade dispersion by Su Do Ku arrangement during passing cloud conditions," *Indian J. Sci. Technol.*, vol. 8, no. 35, pp. 1–7, Dec. 2015.

[100] S. Vijayalekshmy, G. R. Bindu, and S. R. Iyer, "Performance improvement of partially shaded photovoltaic arrays under moving shadow conditions through shade dispersion," *J. Inst. Eng. India, B*, vol. 97, no. 4, pp. 569–575, 2016.

[101] Z. Junhong, W. Xueye, and Z. Tianlong, "Research on the output characteristics of photovoltaic array under the non-uniform light," *Int. J. Control Autom.*, vol. 8, no. 10, pp. 431–444, Oct. 2015.

[102] A. S. Yadav, R. K. Pachauri, and Y. K. Chauhan, "Comprehensive investigation of PV arrays under different shading patterns by shade dispersion using puzzled pattern based Su-Do-Ku puzzle configuration," in *Proc. 1st Int. Conf. Next Gener. Comput. Technol.*, Sep. 2015, pp. 824–830.

[103] R. Boukenoui, H. Salhi, R. Bradai, and A. Mellit, "A new intelligent MPPT method for stand-alone photovoltaic systems operating under fast transient variations of shading patterns," *Sol. Energy*, vol. 124, pp. 124–142, Feb. 2016.

[104] H. Braun, S. T. Buddha, V. Krishnan, C. Tepedelenlioglu, A. Spanias, M. Banavar, and D. Srinivasan, "Topology reconfiguration for optimization of photovoltaic array output," *Sustain. Energy, Grids Netw.*, vol. 6, pp. 58–69, Jun. 2016.

[105] M. Forcan, Ž. Đurišić, and J. Mikulović, "An algorithm for elimination of partial shading effect based on a theory of reference PV string," *Sol. Energy*, vol. 132, pp. 51–63, Jul. 2016.

[106] A. Kumar, R. K. Pachauri, and Y. K. Chauhan, "Experimental analysis of SP/TCT PV array configurations under partial shading conditions," in *Proc. IEEE 1st Int. Conf. Power Electron., Intell. Control Energy Syst.*, Jul. 2016, pp. 1–6.

[107] S. Mohammadnejad, A. Khalafi, and S. M. Ahmadi, "Mathematical analysis of total-cross-tied photovoltaic array under partial shading condition and its comparison with other configurations," *Sol. Energy*, vol. 133, pp. 501–511, Aug. 2016.

[108] P. Yadav, A. Kumar, A. Gupta, R. K. Pachauri, Y. K. Chauhan, and V. K. Yadav, "Investigations on the effects of partial shading and dust accumulation on PV module performance," in *Proc. Int. Conf. Intell. Commun., Control Devices, Adv. Intell. Syst. Comput.*, vol. 479, 2016, pp. 1005–1012.

[109] J. P. Ram and N. Rajasekar, "A new global maximum power point tracking technique for solar photovoltaic (PV) system under partial shading conditions (PSC)," *Energy*, vol. 118, pp. 1–14, Jan. 2016.

[110] N. Rakesh and T. V. Madhavaram, "Performance enhancement of partially shaded solar PV array using novel shade dispersion technique," *Frontiers Energy*, vol. 10, no. 2, pp. 227–239, Jun. 2016.

[111] H. S. Sahu and S. K. Nayak, "Extraction of maximum power from a PV array under non-uniform irradiation conditions," *IEEE Trans. Electron. Devices*, vol. 63, no. 12, pp. 4825–4831, Oct. 2016.

[112] H. S. Sahu, S. K. Nayak, and S. Mishra, "Maximizing the power generation of a partially shaded PV array," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 4, no. 2, pp. 626–637, Jun. 2016.

[113] S. M. Samikannu, R. Namani, S. K. Subramaniam, "Power enhancement of partially shaded PV arrays through shade dispersion using magic square configuration," *J. Renew. Sustain. Energy Rev.*, vol. 8, no. 6, pp. 1–20, 2016.

[114] S. Pareek and R. Dahiya, "Enhanced power generation of partial shaded photovoltaic fields by forecasting the interconnection of modules," *Energy*, vol. 95, pp. 561–572, Jan. 2016.

[115] S. Vijayalekshmy, G. R. Bindu, and S. Rama Iyer, "A novel Zig-Zag scheme for power enhancement of partially shaded solar arrays," *Sol. Energy*, vol. 135, pp. 92–102, Oct. 2016.

[116] A. S. Yadav, R. K. Pachauri, and Y. K. Chauhan, "Comprehensive investigation of PV arrays with puzzle shade dispersion for improved performance," *Sol. Energy*, vol. 129, pp. 256–285, May 2016.

[117] R. Ahmad, A. F. Murtaza, H. A. Sher, U. T. Shami, and S. Olalekan, "An analytical approach to study partial shading effects on PV array supported by literature," *Renew. Sustain. Energy Rev.*, vol. 74, pp. 721–732, Jul. 2017.

[118] A. S. Yadav, R. K. Pachauri, Y. K. Chauhan, S. Choudhury, and R. Singh, "Performance enhancement of partially shaded PV array using novel shade dispersion effect on magic-square puzzle configuration," *Sol. Energy*, vol. 144, pp. 780–797, Mar. 2017.

[119] S. Tabish and I. Ashraf, "Simulation of partial shading on solar photovoltaic modules with experimental verification," *Int. J. Ambient Energy*, vol. 38, no. 2, pp. 161–170, Feb. 2017.

[120] S. Bana and R. P. Saini, "Experimental investigation on power output of different photovoltaic array configurations under uniform and partial shading scenarios," *Energy*, vol. 127, pp. 438–453, May 2017.

[121] N. Belhaouas, M.-S.-A. Cheikh, P. Agathoklis, M.-R. Oularbi, B. Amrouche, K. Sedraoui, and N. Djilali, "PV array power output maximization under partial shading using new shifted PV array arrangements," *Appl. Energy*, vol. 187, pp. 326–337, Feb. 2017.

[122] M. John Bosco and M. Carolin Mabel, "A novel cross diagonal view configuration of a PV system under partial shading condition," *Sol. Energy*, vol. 158, pp. 760–773, Dec. 2017.

[123] S. Pareek, N. Chaturvedi, and R. Dahiya, "Optimal interconnections to address partial shading losses in solar photovoltaic arrays," *Sol. Energy*, vol. 155, pp. 537–551, Oct. 2017.

[124] P. R. Satpathy, R. Sharma, and S. Jena, "A shade dispersion interconnection scheme for partially shaded modules in a solar PV array network," *Energy*, vol. 139, pp. 350–365, Nov. 2017.

[125] R. P. Vengatesh and S. E. Rajan, "Analysis of PV module connected in different configurations under uniform and non-uniform solar radiations," *Int. J. Green Energy*, vol. 13, no. 14, pp. 1507–1516, Nov. 2016.

[126] N. Mishra, A. S. Yadav, R. Pachauri, Y. K. Chauhan, and V. K. Yadav, "Performance enhancement of PV system using proposed array topologies under various shadow patterns," *Sol. Energy*, vol. 157, pp. 641–656, Nov. 2017.

[127] S. Malathy and R. Ramaprabha, "Reconfiguration strategies to extract maximum power from photovoltaic array under partially shaded conditions," *Renew. Sustain. Energy Rev.*, vol. 81, pp. 2922–2934, Jan. 2018.

[128] J. D. Bastidas-Rodríguez, L. A. Trejos-Grisales, D. González-Montoya, C. A. Ramos-Paja, G. Petrone, and G. Spagnuolo, "General modeling procedure for photovoltaic arrays," *Electric Power Syst. Res.*, vol. 155, pp. 67–79, Feb. 2018.

[129] R. K. Pachauri, A. S. Yadav, Y. K. Chauhan, A. Sharma, and V. Kumar, "Shade dispersion based photovoltaic array configurations for performance enhancement under partial shading conditions," *Int. Trans. Electr. Energy Syst.*, vol. 28, no. 7, pp. 1–32, 2018.

[130] D. S. Pillai, J. Prasanth Ram, M. Siva Sai Nihanth, and N. Rajasekar, "A simple, sensorless and fixed reconfiguration scheme for maximum power enhancement in PV systems," *Energy Convers. Manage.*, vol. 172, pp. 402–417, Sep. 2018.

[131] R. Pachauri, R. Singh, A. Gehlot, R. Samakaria, and S. Choudhury, "Experimental analysis to extract maximum power from PV array reconfiguration under partial shading conditions," *Eng. Sci. Technol., Int. J.*, vol. 22, no. 1, pp. 109–130, 2019.

[132] G. S. Krishna and T. Moger, "Improved Su Do Ku reconfiguration technique for total-cross-tied PV array to enhance maximum power under partial shading conditions," *Renew. Sustain. Energy Rev.*, vol. 109, pp. 333–348, Jul. 2019.

[133] I. Nasiruddin, S. Khatoon, M. F. Jalil, and R. C. Bansal, "Shade diffusion of partial shaded PV array by using odd-even structure," *Solar Energy*, vol. 181, pp. 519–529, Mar. 2019.

[134] M. S. S. Nihanth, J. P. Ram, D. S. Pillai, A. M. Y. M. Ghias, A. Garg, and N. Rajasekar, "Enhanced power production in PV arrays using a new skyscraper puzzle based one-time reconfiguration procedure under partial shade conditions (PSCs)," *Sol. Energy*, vol. 194, pp. 209–224, Dec. 2019.

[135] A. Ul-Haq, R. Alammari, A. Iqbal, M. Jalal, and S. Gul, "Computation of power extraction from photovoltaic arrays under various fault conditions," *IEEE Access*, vol. 8, pp. 47619–47639, 2020.

[136] M. Premkumar, U. Subramaniam, T. S. Babu, R. M. Elavarasan, and L. M. Popa, "Evaluation of mathematical model to characterize the performance of conventional and hybrid PV array topologies under static and dynamic shading patterns," *Energies*, vol. 13, no. 12, pp. 1–37, 2020.

[137] G. Sagar, D. Pathak, P. Gaur, and V. Jain, "A Su Do Ku puzzle based shade dispersion for maximum power enhancement of partially shaded hybrid bridge-link-total-cross-tied PV array," *Sol. Energy*, vol. 204, pp. 161–180, Jul. 2020.

[138] A. Srinivasan, S. Devakirubakaran, and B. M. Sundaram, "Mitigation of mismatch losses in solar PV system–two-step reconfiguration approach," *Sol. Energy*, vol. 206, pp. 640–654, Aug. 2020.

[139] R. Venkateswari and N. Rajasekar, "Power enhancement of PV system via physical array reconfiguration based Lo Shu technique," *Energy Cnversion Manage.*, vol. 215, pp. 1–22, Jul. 2020.

[140] S. Gul, A. U. Haq, M. Jalal, A. Anjum, and I. U. Khalil, "A unified approach for analysis of faults in different configurations of PV arrays and its impact on power grid," *Energies*, vol. 13, no. 1, pp. 1–23, 2020.

[141] K.-H. Chao, P.-L. Lai, and B.-J. Liao, "The optimal configuration of photovoltaic module arrays based on adaptive switching controls," *Energy Convers. Manage.*, vol. 100, pp. 157–167, Aug. 2015.

[142] J. R. Camarillo-Peñaranda, F. A. Ramírez-Quiroz, D. González-Montoya, F. Bolaños-Martínez, and C. A. Ramos-Paja, "Reconfiguration of photovoltaic arrays based on genetic algorithm," *Revista Facultad de Ingeniería Universidad de Antioquia*, vol. 75, pp. 95–107, Apr. 2015.

[143] T. S. Babu, D. Yousri, and K. Balasubramanian, "Photovoltaic array reconfiguration system for maximizing the harvested power using population-based algorithms," *IEEE Access*, vol. 8, pp. 109608–109624, 2020.

[144] A. Fathy, "Recent meta-heuristic grasshopper optimization algorithm for optimal reconfiguration of partially shaded PV array," *Sol. Energy*, vol. 171, pp. 638–651, Sep. 2018.

[145] T. S. Babu, J. P. Ram, T. Dragicevic, M. Miyatake, F. Blaabjerg, and N. Rajasekar, "Particle swarm optimization based solar PV array reconfiguration of the maximum power extraction under partial shading conditions," *IEEE Trans. Sustain. Energy*, vol. 9, no. 1, pp. 74–85, Jan. 2018.

[146] A. Fathy, "Butterfly optimization algorithm based methodology for enhancing the shaded photovoltaic array extracted power via reconfiguration process," *Energy Convers. Manage.*, vol. 220, pp. 1–21, Sep. 2020.

[147] D. Yousri, D. Allam, and M. B. Eteiba, "Optimal photovoltaic array reconfiguration for alleviating the partial shading influence based on a modified Harris hawks optimizer," *Energy Convers. Manage.*, vol. 206, pp. 1–25, Feb. 2020.

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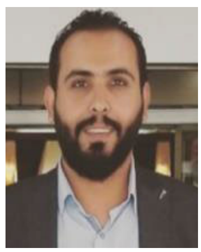

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