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Regular paper

Comparative Evaluation of Novel Configurations under Shading Conditions

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The main aim of this paper is to make a comparative analysis of Total Cross Tied (TCT), Bridge Link (BL), Honey Comb (HC) and Magic Square (MS) topologies. Due to shading, number of power peaks is obtained in power vs voltage curve which leads in enhancing power losses. For weakening this effect of shading on PV array, reconfiguration technique is adopted named as MS with same electrical connections as of TCT. This relocation of rows and column elements assist in extracting uniform difference in current. Different shading scenarios are considered and applied on each configuration to extract power output. In addition to power output, Fill Factor (FF), losses due to mismatch and efficiency parameters are also calculated for effective analysis. For testing the validity of new technique, four shading patterns are used and performance is evaluated. The results are verified by simulation via MATLAB/SIMULINK software. By the results, it is clear that MS is far better among all configurations.

Keywords: Bridge Link, Honey Comb, Magic Square, Partial Shading, Total Cross Tied.

1. Introduction

The energy crises keep on increasing globally which leads to the development of sustainable energy sources. Due to easy accessibility and available in abundance, solar energy is on priority for generation of electrical energy in contrast to fossil fuels. Photovoltaic (PV) cells are used to convert sun radiation into electricity. The performance of PV cells is limited by certain factors such as change in weather conditions, rising temperature, shading patterns and solar insolation. The authors of [1] investigated a new method enhancing total power and reducing shading effect on PV system. The experiment has been applied on 3x3 Total Cross Tied (TCT) connection under eight different shading patterns. The performance has been validated in phrase of Mismatch Losses (ML), Fill Factor (FF) and power loss in percent. It has been proved that suggested method allows 14% increase in obtained power in contrast with an existing technique. The paper [2] proposed a thermal and mathematical model which can be used for determining the PV panel temperature. The model is analysed via two cases: using system of cooling by air and not using any cooling system. The impact of shading on solar panels are discussed in [3] in terms of current vs voltage graphs. Two assumptions are decided in the paper – first one is that maximum total maxima will be equal to the total panels in a string, second one is that total maxima will be equal to the value of open circuit voltage. The software results proved both the assumptions. The aim of paper [4] is to simulate six different configurations of 7x7 array- series, series parallel (SP), total cross tied, bridge to link (BL), honey comb (HC) and triple tied. All the configurations performance are examined under six distinct shading scheme and it is observed by the author that triple tied topology is best among all

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configurations. The aim of the paper [5] is to examine the effect of shading conditions along with various topologies on on-grid PV array. It consists of mainly two stages – first stage includes converter which boost up the input power and second stage contains voltage source converter which acts as an inverter to provide supply to the grid. An algorithm is proposed in [6] based on true power as well as reactive power for controlling the efficiency which leads to better results in grid tied solar PV system. Various methods of tracking the solar radiations have been studied in [7] based on their classifications, costing as well as design considerations. These methods are deeply studied and compared in terms of number of factors such as controlling, complexity, energy gain, accuracy etc. The paper [8] presents standalone solar power system for improving the performance of power conditioner. The solar system is considered grid connected and results are verified by hardware as well as software processes. Reliability has been estimated in [9] for an induction generator along with wind energy. The voltage and frequency have been regulated by calculating suitable value of capacitor. The experimental and simulated results are compared for verification. The paper [10] provides probability approach for determining the reliability of residual magnetism in an induction motor. The experimental and software-based testing is done along with renewable energy operations.

The paper [11] discusses five conventional topologies and three hybrid topologies under static and dynamic shading conditions. Qing et al. [12] provide a model which depends upon sub module to improve the characteristics of Series Parallel configuration under different shading patterns, changing irradiance and temperature variation. A sample of submodules in addition with bypass diode are taken in the paper to evaluate Mismatch Losses in Series Parallel configuration PV array. The global maximum power point behavior has been studied and analysed in [13]. Also, the analysis has been done on the variation between global maximum power point voltage and rate of change of nominal voltage. The analyzation procedure is carried out under different transitions due to movement of clouds. The paper [14] provides effect of multiple shading and bypass diode on various conventional configurations. Three different array size is considered to improving reliability of results. Among all configurations, TCT comes out with better performance. The authors of [15] analyses all conventional configurations for ten operating conditions. PSIM software is used for simulating various configurations. Among all topologies, TCT achieves maximum power in all cases. The series connected system is presented in [16] for grid connected solar PV array. The analyzation is made on all working modes via simulation as well as hardware based. The paper [17] uses 5x5 PV array under distinct shading situations and analyzed effect of shading on four conventional configurations in MATLAB/SIMULINK environment. The production of energy can be enhanced by reconfiguration technique discussed in [18]. This paper also explained the economic advantages while implementing the reconfiguration method on PV system in various countries. The paper [19] deeply analyze auto reconfiguration method on 3x3 solar PV array. It is considered that the shading is progressively enhancing, thus three increasing order shading patterns are taken. Experimental procedure consists of three parts: first part includes four relays implementation on an array, second part includes controlling method for operation of relay and third part includes operating system. Further, simulation is done for comparing results with practical data and making output more accurate. The authors of [20] used three conventional configurations – SP, BL and TCT at ideal switch case and non-ideal switch case. The total switch gets minimized for enhancing output power and reducing power losses.

The reconfiguration techniques are investigated in [21] under different shading scenarios. These techniques are discussed under both static and dynamic cases on hardware. From the observed results, it is seen that costly dynamic method is superior to static method in terms of performance. The paper [22] presents comparison between conventional configurations and SuDoKu method. It is shown that SuDoKu topology performs better with respect to other topologies. The paper [23] gives review comprehensively of all topologies for solar PV array. This paper also includes merits and demerits of each technique described in the paper. Manjunath et al. [24] presents increase in solar PV array performance at shading conditions. The novel hybrid interconnection method is presented to enhance the power. Odd/Even and SuDoKu methods are taken for comparative analysis with proposed technique. The authors of [25] put forward magic square (MS) view configuration to enhance power under shading conditions. TCT and SuDoKu evaluation also carried out in comparison with magic square view topology. The paper [26] highlighted the performance of various configurations at different shading scenarios. 5x5 PV array is considered for evaluation and obtaining results. The reconfigured technique proves to be better than other topologies. The results are validated on the basis of software. Anurag Singh Yadav et al [27] presents Simulink evaluation of hybrid and reconfigured configurations along with magic square using power vs voltage characteristics. Six shading scenarios has been used on 4x4 matrix for various configurations. The paper [28] proposed series and parallel configurations and power output of these are enhanced via maximum power point tracking method. To verify the results, simulated and hardware-based methods are processed. The authors of [29] analyses perturb and observe technique along with fuzzy logic technique implemented on solar PV grid tied system. The paper [30] investigated different maximum power point tracking such as perturb and observe, incremental conductance, ripple correlation, etc. on basis of various parameters. The MATLAB/SIMULINK software is used for obtaining results and these results are compared with experimental data for validation. The double boost converter is presented in [31] and implemented on PV array. The fuzzy logic technique is also used for tracking maximum power. The paper [32] studies and compared different maximum power point tracking techniques in which intelligent techniques overcomes remaining techniques. The author also compared different configurations in which SuDoKu comes out with better results as compared to other techniques.

2. PV system description

The number of PV cells are tied in series to produce a single PV panel. The PV module of 200 W has been considered and different parameters description is specified in table 1.

Table 1: PV Panel Description

Voc	30 V
Vmp	24.6 V
Isc	8.56 A
Imp	8.13 A
Pmax	200 W
To	-40ºC to +85ºC
Dimensions	1320x992x35mm
Weight	14.5 kg

This paper has considered total 49 panels for forming 7x7 PV array. Each panel has Pmax of 200 W and total capacity of an array under standard test condition (STC) is 9.8 kW. The anti-parallel bypass diode is joined with every module which provides an extra track to the current so that the shaded path will be bypassed and there will be less effect of shading on an PV array. The behavior of PV panel is shown by figure 1 at different irradiation level.

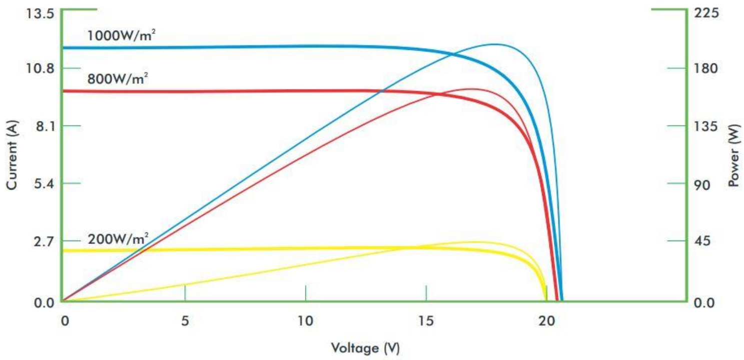


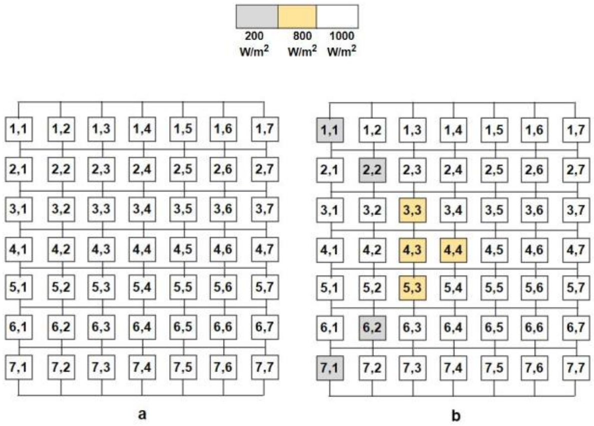
Fig. 1. Electrical Characteristics of PV module

3. Shading scenarios implemented on various topologies

The shade on PV array negatively affects the performance of overall PV system. Different shades are applied on topologies at three irradiations of 200W/m^2, 800W/m^2 and 1000 W/m^2 for analysing their outputs. The shading occurs because of multiple factors like tall trees, movement of clouds and aero planes, high rise buildings etc.

3.1. Total Cross Tied (TCT)

This configuration is extracted from Series Parallel scheme via joining ties across every row and column. The voltage around every row is same and current around every column is same in TCT connection. This configuration is superior to Series Parallel scheme in terms of resultant power but it has a drawback of large number of ties which leads in enhancing losses in cable. The TCT connection along with different shading scenario is shown by figure 2.



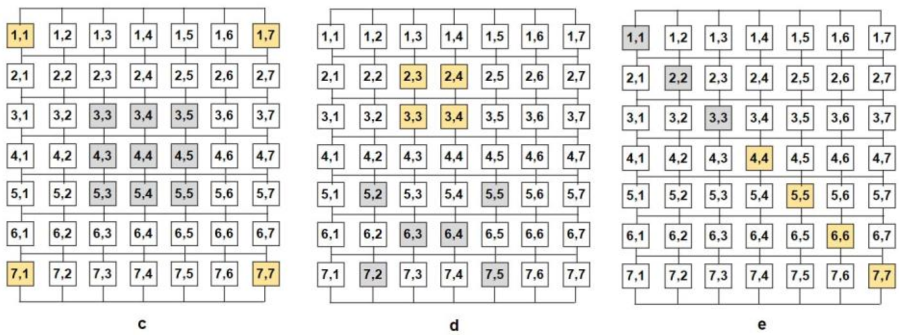


Fig. 2. (a) TCT Configuration (b) TCT Shading Pattern 1 (c) TCT Shading Pattern 2 (d) TCT Shading Pattern 3 (e) TCT Shading Pattern 4

3.2. Bridge Link (BL)

This connection is derived basically from TCT topology. It has an advantage of reduction in ties, reduced losses in cable and reduction in time of installation. The pattern of ties which connects all panels under different shading scenarios is shown by figure 3.

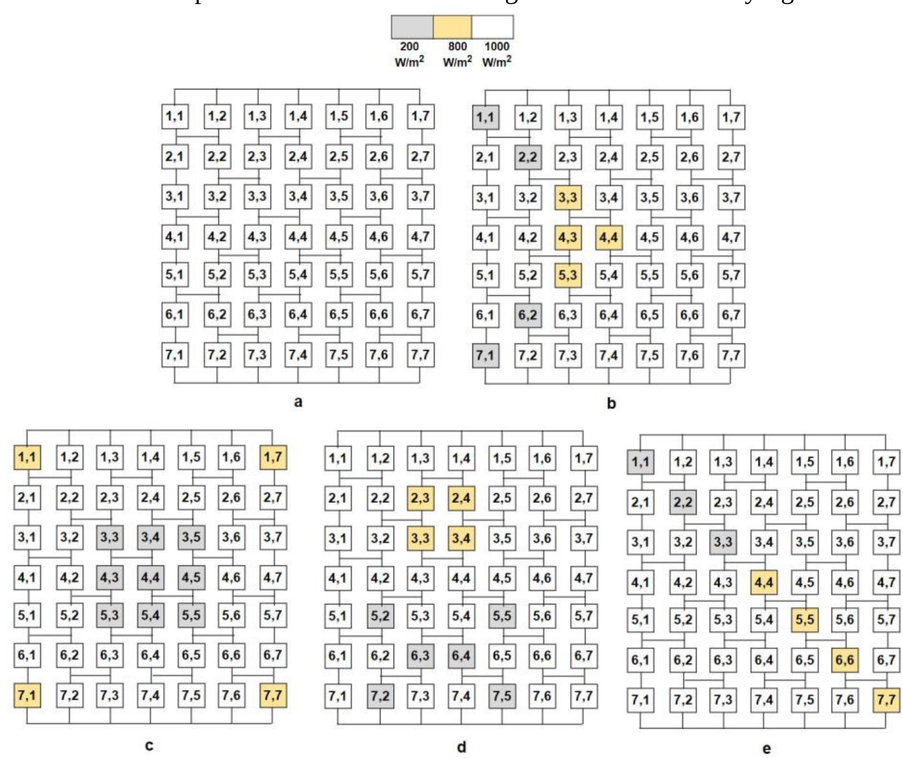


Fig. 3. (a) BL Configuration (b) BL Shading Pattern 1 (c) BL Shading Pattern 2 (d) BL Shading Pattern 3 (e) BL Shading Pattern 4

3.3. Honey Comb (HC)

It is also extracted from TCT following honey comb structure. This configuration has cross ties pattern different from bridge link structure. It is also similar to BL in terms of lesser number of crossly ties connection. The figure 4 shows connection pattern of honey comb structure.

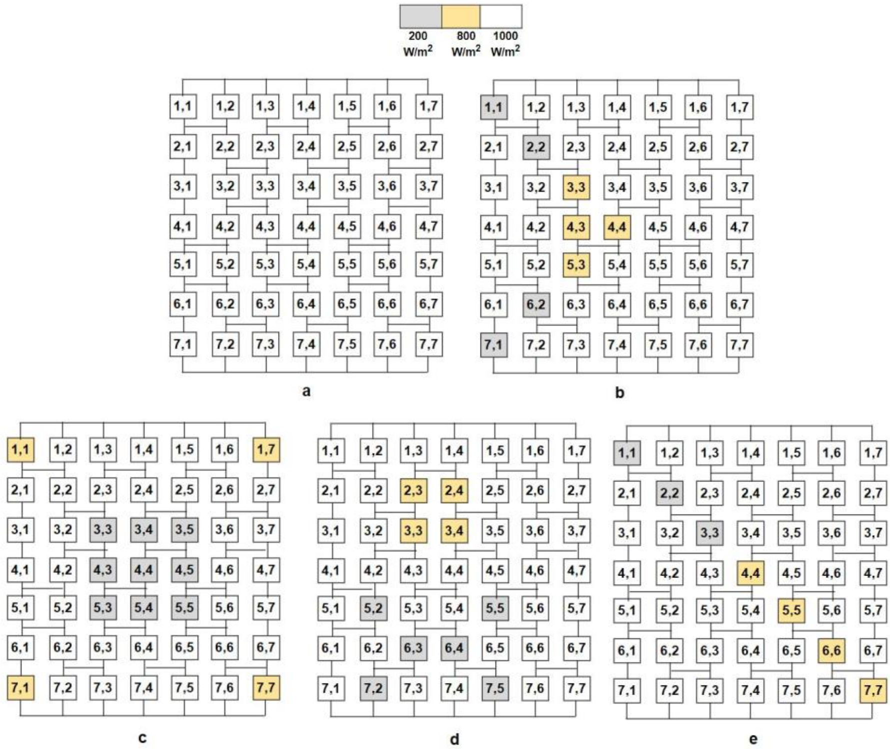


Fig. 4. (a) HC Configuration (b) HC Shading Pattern 1 (c) HC Shading Pattern 2 (d) HC Shading Pattern 3 (e) HC Shading Pattern 4

3.4. Magic Square (MS)

This configuration is obtained by solving a n-by-n puzzle in a way that summation of each row, each column and both diagonal elements provide exactly same number which is known as magic sum. In this paper, magic number is 175. The middle number is 25 in this MS pattern and sum of opposite position digits will give a number which is 50. The This configuration overcomes the limitation of previously described topologies without altering electrical connections. The steps which are followed for the formation of MS pattern are:

(a) The position of first number is at (i,j) where i=n/2. The alphabet i represent row, j represents column and n represents total number of rows.

(b) The position of next digit will be: i=i-1, j=j+1.

(c) If i>n or j>n, then

- Move the number at the top to the bottom.
- Move the number at the right to the far left.
- Move the number at top right corner to the bottom left corner.

(d) If the position is pre filled, then i=i+1, j remains same.

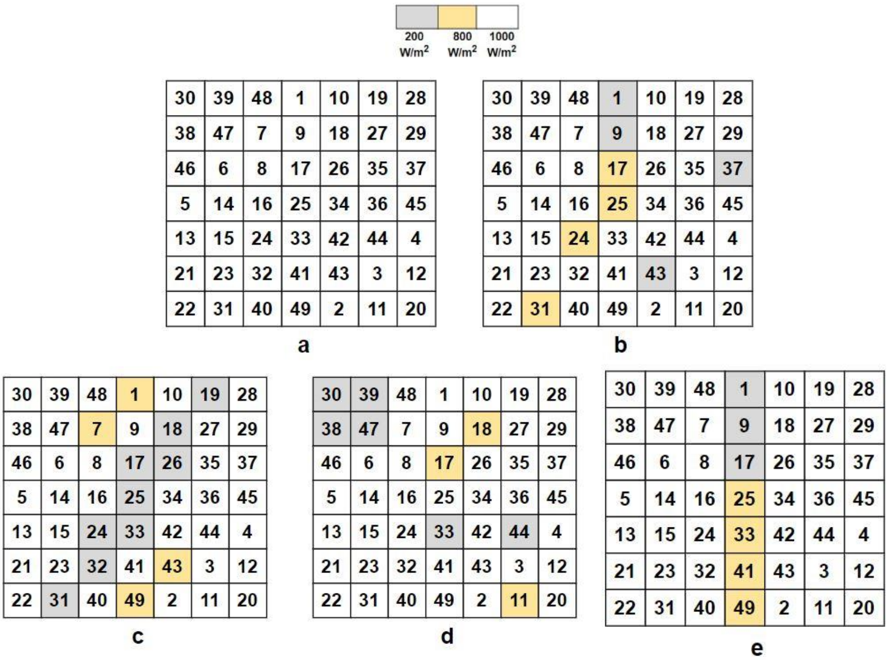


Fig. 5. (a) MS Configuration (b) MS Shading Pattern 1 (c) MS Shading Pattern 2 (d) MS Shading Pattern 3 (e) MS Shading Pattern 4

4. Simulation Results and Discussion

The 7x7 solar PV array is used in this paper for identification of performance of various topologies under different scenarios via simulation. The solar irradiance of 200 W/m^2 and 800 W/m^2 for shaded area and 1000 W/m^2 for unshaded area is applied on considered topologies. Four shading patterns- SP1, SP2, SP3 and SP4 are implemented on configurations to identify the shading effects. The table 2 to table 5 represents the information regarding configurations used in this paper.

Table 2: Power, power losses, FF and efficiency of all Configurations under SP1

Configurations	Power (W)	Power Losses (W)	FF	Efficiency (%)
TCT	6450	829	0.512	11.0
BL	6353	926	0.505	10.9
HC	6279	1000	0.499	10.7
MS	6571	708	0.522	11.2

Table 3: Power, power losses, FF and efficiency of all Configurations under SP2

Configurations	Power (W)	Power Losses (W)	FF	Efficiency (%)
TCT	6102	1177	0.485	10.9
BL	6056	1223	0.480	10.6
HC	6044	1235	0.482	10.5
MS	6226	1053	0.495	11.0

Table 4: Power, power losses, FF and efficiency of all Configurations under SP3

Configurations	Power (W)	Power Losses (W)	FF	Efficiency (%)
TCT	6226	1053	0.495	11.0
BL	6196	1083	0.492	10.7
HC	6128	1151	0.487	10.6
MS	6395	884	0.508	11.1

Table 5: Power, power losses, FF and efficiency of all Configurations under SP4

Configurations	Power (W)	Power Losses (W)	FF	Efficiency (%)
TCT	6473	806	0.514	11.4
BL	6309	970	0.501	11.2
HC	6336	943	0.504	11.3
MS	6625	654	0.526	11.6

The figure 6 to figure 9 provides behavior of power vs voltage characteristic of each topology. In every case of shading, MS achieve highest output power with reference to other configurations. The power of HC topology is lowest among all topologies except under SP4 shading pattern. In SP4 pattern, BL obtained lowest output of 6309W.

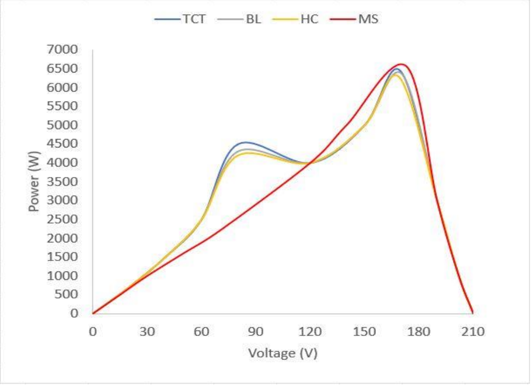


Fig. 6: Power vs voltage curve of various topologies under SP1

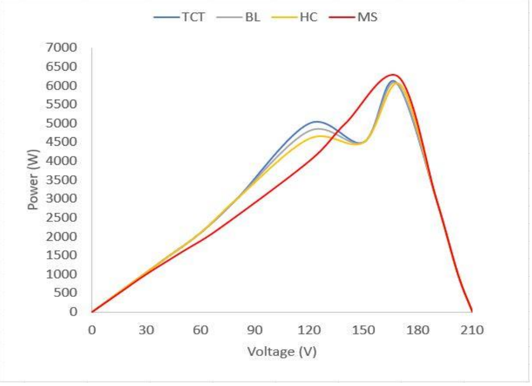


Fig. 7: Power vs voltage curve of various topologies under SP2

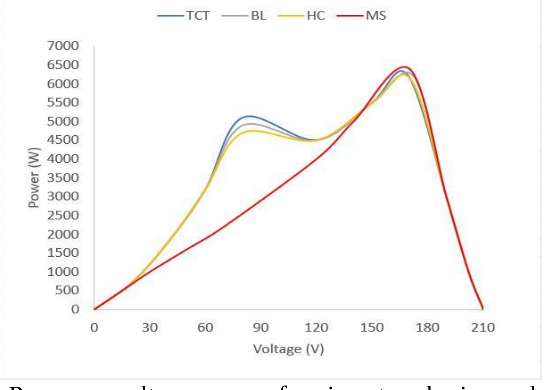


Fig. 8: Power vs voltage curve of various topologies under SP3

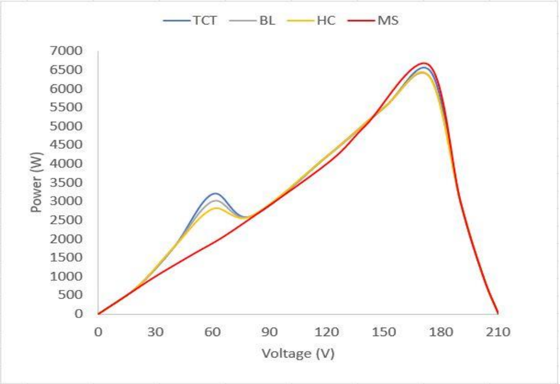


Fig. 9: Power vs voltage curve of various topologies under SP4

The fill factor is defined as the ratio of highest power under shading condition to the rated power of an array. The efficiency of an array is the ratio of highest power to the product of solar irradiation and total area of PV array. Figure 10-13 shows the variation in all considered parameters which are power, losses, fill factor and efficiency.

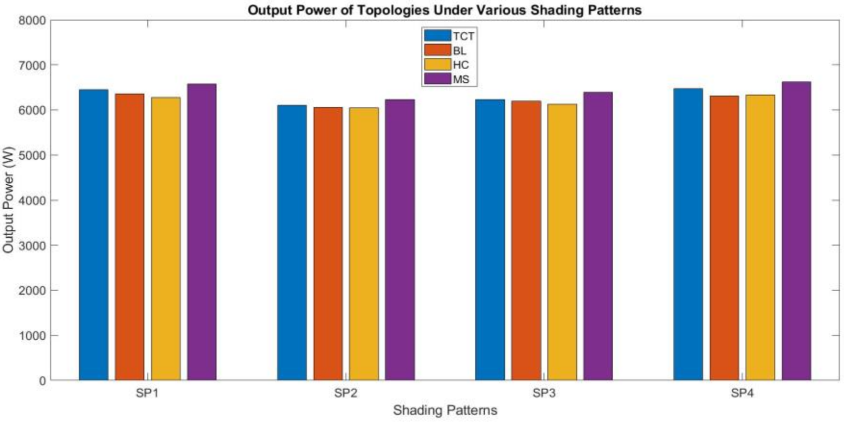


Fig. 10: Output Power of Topologies Under various Shading Patterns

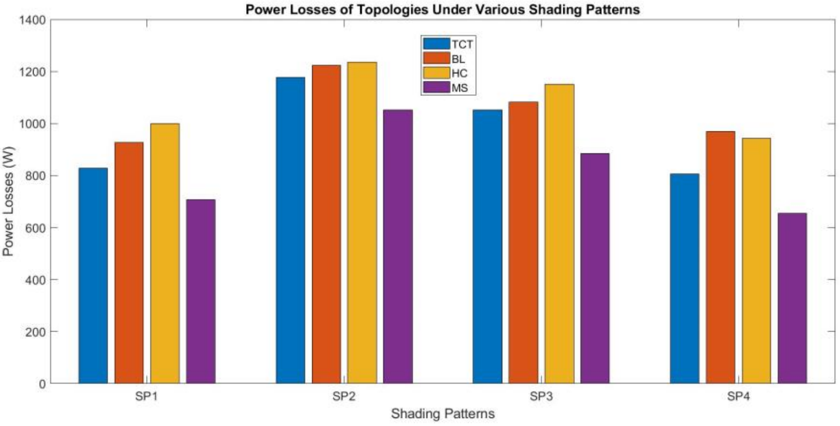


Fig. 11: Power Losses of Topologies Under various Shading Patterns

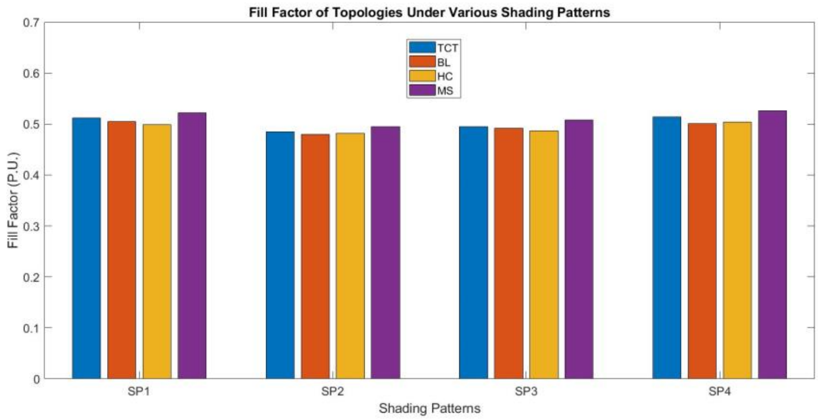


Fig. 12: Fill Factor of Topologies Under various Shading Patterns

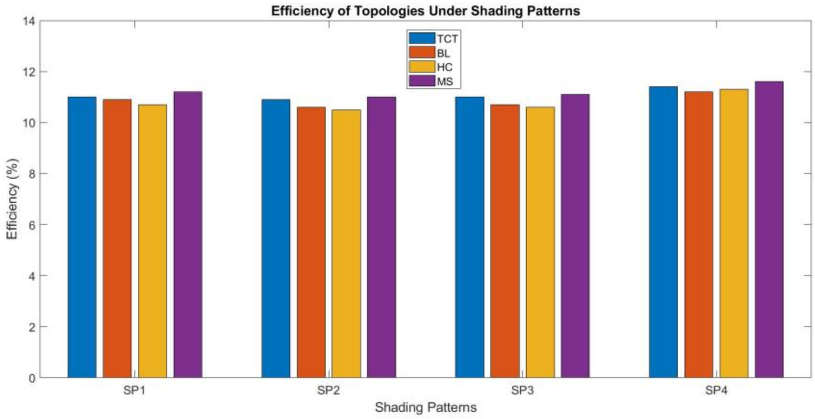


Fig. 13: Efficiency of Topologies Under various Shading Patterns

5. Conclusion

This paper presents comprehensive analysis of various configurations at four different shading conditions. The simulation is done for analyzing and obtaining resultant power, losses, fill factor and efficiency. Different interconnections topologies such as TCT, BL, HC and MS have been investigated and compared for verifying their performances. As seen from results extracted, MS is superior in all configurations. MS achieved highest efficiency of 11.6% among all configurations in all shading patterns as shown in table 5. From table 3, it is seen that HC has lowest efficiency of 10.5% under SP2 among all configurations at all shading scenarios. It is seen from table 2-4 that BL topology performs better than HC under all shading scenarios except under SP4. The power vs voltage characteristic indicates that MS obtained highest power as output under all shading conditions. MS performs better with respect to BL, HC and TCT topologies considering all shading conditions and four factors namely power output, fill factor, power losses and efficiency.

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