Mathematical Modelling of Engineering Problems
Vol. 10, No. 1, February, 2023, pp. 383-387
Journal homepage: http://iieta.org/journals/mmep

Performance Evaluation of Spider Web Tie (S-B-T) PV Panel Configuration to Reduce PV Mismatch Losses

Asadi Suresh Kumar[1,2*], Vyza Usha Reddy[1]

[1] Department of Electrical & Electronics Engineering, SVU College of Engineering, Tirupati 517507, India
[2] Department of Electrical & Electronics Engineering, G Pullaiah College of Engineering and Technology, Kurnool 518002, India

Corresponding Author Email: asureshkumareee@gpcet.ac.in

Special Issue: Hybrid Renewable Energy Systems and Integration

https://doi.org/10.18280/mmep.100145

Received: 13 September 2022
Accepted: 20 November 2022

Keywords:
BL, PV, PSC, S-B-T, S-P, T-C-T, T-T, Configurations, Photovoltaic

ABSTRACT

In non-uniform conditions, the power curve of a solar plant can vary significantly, which can affect the performance of the system. In such conditions, the configuration of the panels can help reduce the mismatch losses. Although dedicated electronics may be helpful in reducing a panel's mismatch, the panel configuration is a recent solution that can also reduce a panel's overall power consumption and mismatch losses. Hence in this paper Sider Web Tie (S-B-T) PV panel configuration is proposed. A test case of 5 X 5 200 W PV panel is considered. The proposed S-B-T PV configuration is implemented under real time PSC's in comparison with Series-Parallel (S-P), Total Cross-Tied (T-C-T), Triple-Tied (T-T), Bridge-Link (B-L) configurations. The factors such as PV mismatch losses, Max. current and voltage, OC Voltage, SC Current that influence the performance of the system are investigated. In all the cases proposed Spider Web Tie (S-B-T) PV configuration exhibits the superior performance.

1. INTRODUCTION

Due to its various advantages, solar panels have become an integral part of the energy landscape. They are more advantageous than traditional sources of energy. The feasibility of solar energy has become an attractive factor for the energy market. The global solar photovoltaics market continued to grow in 2021 with new capacity additions reaching 175 gigawatts. The global solar PV capacity grew by 36 gigawatts in 2021 to reach 942 gigawatts. Despite the various disruptions in the solar value chain, the market continued to grow. The increase in capacity was mainly due to the sharp rise in the prices of raw materials and shipping. In 2021, several countries had enough solar PV generation capacity to meet at least a 10% of their electricity demand. This is significantly higher than the two countries in 2020. At least 18 countries also have enough solar PV generation capacity to meet 5% of their electricity needs. Australia had the highest annual share of solar PV at 15.5%, followed by Greece, Spain, Honduras, Germany, and the Netherlands. In total, solar PV contributed about 5% of global electricity generation in 2021.

In 2021, the country's distributed rooftop installations reached an all-time high, and they are expected to contribute around 17% of the country's total solar market. The commercial and industrial sector is expected to be the biggest contributor to the country's solar growth, as it accounts for over 51% of the country's electricity generation. Despite the government's efforts to encourage the growth of the solar industry, the implementation of solar power projects has been hindered by various factors. In December 2020, the government announced that it would only allow PV installations with up to 10 kilowatts of power to be eligible for net metering. However, in April 2021, the government modified this policy to allow installations with up to 500 kilowatts.

The PV system was first introduced in 1954. The first PV cell is made with the impurities of silicon, which can convert the sunlight into electricity. The efficiency of this cell has been estimated to be around 4% to 24% [1-4]. Various factors such as partial shading, hotspots, and diode failure can affect the efficiency of solar PV system. This issue usually causes losses in the system and cannot be predicted. This partial shading mismatch causes losses in the power supply of the PV system. This issue can be solved through various means, such as by reducing the number of unshaded healthy cells in the system [5-8]. The maximum power point refers to the point at which the system can generate the maximum amount of power. It can be obtained from the characteristic curves of P-V.

The non-linear relationship between current and voltage of PV module is the main factor that influences its performance. Other factors such as temperature and solar insolation can also affect its efficiency and performance [9]. Partial shading conditions (PSCs) are the main factors that affect the generation of power from a PV module. These conditions happen due to the varying levels of insolation in an array. As a result, the mismatched current levels created by the insolation can lead to power loss in the shaded modules. This characteristic causes the multiple local maximum peak power (LMPPs), which are also known as the GMPP, to occur along with the observed PV array output current. This is a major disadvantage of the traditional MPPT methods. To get the maximum output from the PV array, it is necessary to minimize the mismatch power loss. The configuration of the system can help minimize the overall power loss and provide the best possible output. Pendem and Mikkili [10] presented comparison analysis of various PV configurations and concluded that Honey Comb HC configuration has superior performance. Ramaprabha and Mathur [11] presented HC and TCT are the best configuration under PSC's. Winston et al. [12] proposed modified TCT configuration for 4 X 4 PV configuration under PSC's. Nasiruddin et al. [13] proposed spiral array configuration to reduce mismatch losses. The results of this study reveal that the TCT configuration performs better than other configurations when compared to standard PV arrays. This paper presents the detailed simulations and modelling of various PV array configurations under various Performance Specific Conditions (PSCs) and proposed cost effective Spider Web Tie (S-B-T) PV configuration for Performance improvement. A test case of 5 X 5 200 W PV system is considered. The Proposed configuration is implemented under real time PSC's in comparison with S-P, T-C-T, T-T, B-L configurations. The factors such as PV mismatch losses, Max. current and voltage, OC Voltage, SC Current that influence the performance of the system are investigated, in all the cases and proposed Spider Web Tie (S-B-T) PV configuration exhibits the superior performance.

2. PROPOSED SPIDER WEB TIE (S-B-T) PV CONFIGURATION

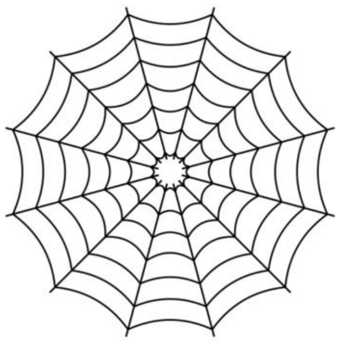

Figure 1. Typical spider web

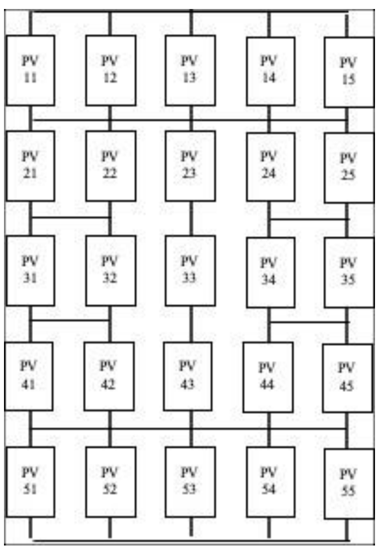

Figure 2. Proposed spider web PV configuration

In this paper S-B-T PV configuration is proposed as a cost effective model reduce the PV mismatch losses under various PSC's. Spider webs have been around for at least 100 million years. They are structures created by a spider that are made up of proteinaceous spider silk and are designed to catch their prey. Spider webs are usually referred to as unusable webs that have been left behind, the typical spider web is shown in Figure 1.

In the above spider web all are interconnected except the centre, the same pattern is inferred for the proposed S-B-T PV configuration i.e., all the PV panels are interconnected except the centre panel as shown in Figure 2.

3. PARTIAL SHADED CONDITIONS OF PV PANEL

The performance of PV arrays is mainly influenced by the type of shading patterns that are prevalent in today's world. This section discusses the various shading patterns as shown in Figure 3.

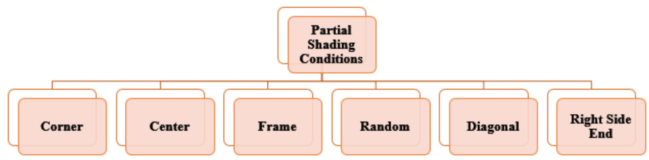

Figure 3. Partial Shading Conditions (PSC's)

A. Corner Shading Condition

In the corner shaded pattern solar irradiance of PV panels 11, 12, 21, 22 PV panels is considered as 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2 respectively, the rest of the PV panes are 1,000 W/m^2 and temperature as 250C.

B. Centre Shading Condition

In the centre shaded pattern solar irradiance of PV panels, 21, 22, 23 panels, is considered as 200 W/m^2, 400 W/m^2, 600 W/m^2 respectively, for PV panels 31, 32, 33 is considered as 200 W/m^2 400 W/m^2, 600 W/m^2 respectively, and for PV Panels 41, 42, 43 is considered as 200 W/m^2, 400 W/m^2, 600 W/m^2 respectively, other panels are kept at STC.

C. Frame Shading Condition

In the frame shading pattern solar irradiance of PV Panels 11, 12, 13, 14, 15 is considered as 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1,000 W/m^2 respectively, similarly for all corner frames, other panels are kept at STC.

D. Random Shading Condition

In the random shading pattern solar irradiance is considered as 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1000 W/m^2 for random panels, other panels are kept at STC.

E. Diagonal Shading Condition

In the diagonal shading pattern for all diagonal PV panels solar irradiance is considered as 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1000 W/m^2 respectively, other panels are kept at STC

F. Right Side End Shading Condition:

In the right side end shading pattern, solar irradiance for PV panels 51, 52, 53, 54, 55 panels solar irradiance is considered as 200 W/m^2, 400 W/m^2, 600 W/m^2, 800 W/m^2, 1,000 W/m^2 respectively, other panels are kept at STC.

4. TEST CASE

In this paper, a test case of a 200 W solar panel system is presented. The specification of the system is shown in Table 1. The proposed system is implemented under various PSC's and various configurations as shown in Figure 3 and Figure 4 respectively. Performance factors such Max. Voltage V_{mp} (V), Max. Power P_{mp} (W), OC Voltage V_{oc} (V), SC Current I_{sc} (A), Fill Factor FF (%), PV Missmatch Losses ΔP_{ml} (%), Efficiency η (%) as fill factor, maximum power, open circuit voltage, short circuit current and panel mismatch losses are analyzed in all the cases.

Table 1. PV system specifications

Name	Specification
P_{mp}	200.14 W
Size	5 X 5
V_{mp}	26.3 V
I_{mp}	7.6 A
V_{oc}	32.9 V
I_{sc}	8.2 A
Cells in Number	54

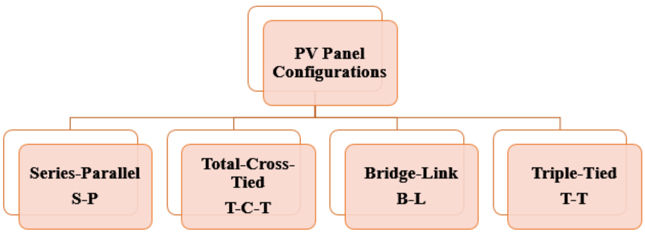

Figure 4. PV panel configurations

5. RESULTS AND DISCUSSIONS

In this paper the proposed S-B-T PV configuration is implemented under real time PSC's in comparison with S-P, T-C-T, T-T, B-L configurations.

5.1 Performance of uniform condition

The proposed S-B-T PV configuration is implemented under the uniform conditions i.e., for all the PV panels solar irradiance is considered as 1,000 W/m^2 and temperature is considered as 25°C. The performance S-B-T PV configuration is evaluated and tabulated in Table 2.

Table 2. Uniform condition

S. No	Performance Factor	Value
1	V_{mp}	131.505 V
2	I_{mp}	38.051 A
3	P_{mp}	5003.846 W
4	V_{oc}	164.49 V
5	I_{sc}	41.108 A
6	FF	74.002%
7	ΔP_{ml}	0
8	η	14.155%

In this case mismatch losses are zero and hence performance factors are same in all the PV configurations.

5.2 Performance of corner partial shaded condition

The proposed S-B-T PV configuration is implemented under the corner PSC's. The performance S-B-T PV configuration is evaluated and tabulated in Table 3.

Table 3. Corner partial shaded condition

S. No	Performance Factor	Value
1	V_{mp}	141.355 V
2	I_{mp}	30.218 A
3	P_{mp}	4271.465 W
4	V_{oc}	162.81 V
5	I_{sc}	41.083 A
6	FF	63.861%
7	ΔP_{ml}	17.146%
8	η	12.083%

The efficiency η (%) of the proposed PV configuration is 12.083%, and for TCT configuration efficiency η (%) is 12.255%.

5.3 Performance of center partial shaded condition

The proposed S-B-T PV configuration is implemented under the center PSC's. The performance S-B-T PV configuration is evaluated and tabulated in Table 4.

Table 4. Center partial shaded condition

S. No	Performance Factor	Value
1	V_{mp}	143.11 V
2	I_{mp}	30.212 A
3	P_{mp}	4323.639 W
4	V_{oc}	162.211 V
5	I_{sc}	41.051 A
6	FF	64.93%
7	ΔP_{ml}	15.732%
8	η	12.23%

The efficiency η (%) of the proposed PV configuration is 12.230%, and for TCT configuration efficiency η (%) is 12.389 %.

5.4 Performance of frame partial shaded condition

The proposed S-B-T PV configuration is implemented under the frame PSC's The performance S-B-T PV configuration is evaluated and tabulated in Table 5.

Table 5. Frame partial shaded condition

S. No	Performance Factor	Value
1	V_{mp}	143.674 V
2	I_{mp}	28.211 A
3	P_{mp}	4053.187 W
4	V_{oc}	158.989 V
5	I_{sc}	28.311 A
6	FF	90.048%
7	ΔP_{ml}	23.455%
8	η	11.465%

The efficiency η (%) of the proposed PV configuration is 11.465%, and for TCT configuration efficiency η (%) is 11.648%.

5.5 Performance of random partial shaded condition

The proposed S-B-T PV configuration is implemented under the random PSC's. The performance S-B-T PV configuration is evaluated and tabulated in Table 6.

Table 6. Random partial shaded condition

S. No	Performance Factor	Value
1	V_{mp}	143.344 V
2	I_{mp}	31.422 A
3	P_{mp}	4504.155 W
4	V_{oc}	162.316 V
5	I_{sc}	41.011 A
6	FF	67.663%
7	ΔP_{ml}	11.094%
8	η	12.741%

The efficiency η (%) of the proposed PV configuration is 12.741%, and for TCT configuration efficiency η (%) is 12.703%.

5.6 Performance of diagonal partial shaded condition

The proposed S-B-T PV configuration is implemented under the diagonal PSC's The performance S-B-T PV configuration is evaluated and tabulated in Table 7.

Table 7. Diagonal partial shaded condition

S. No	Performance Factor	Value
1	V_{mp}	145.511 V
2	I_{mp}	32.112 A
3	P_{mp}	4672.649 W
4	V_{oc}	162.441 V
5	I_{sc}	36.501 A
6	FF	78.807%
7	ΔP_{ml}	7.088%
8	η	13.218%

The efficiency η (%) of the proposed PV configuration is 13.218%, and for TCT configuration efficiency η (%) is 13.407%.

5.7 Performance of right side end partial shaded condition

The proposed S-B-T PV configuration is implemented under the right side end PSC's. The performance S-B-T PV configuration is evaluated and tabulated in Table 8.

Table 8. Right side end partial shaded condition

S. No	Performance Factor	Value
1	V_{mp}	140.011 V
2	I_{mp}	32.456 A
3	P_{mp}	4544.197 W
4	V_{oc}	161.411 V
5	I_{sc}	36.011 A
6	FF	78.179%
7	ΔP_{ml}	10.115%
8	V_{mp}	12.854%

The efficiency η (%) of the proposed PV configuration is 12.854%, and for TCT configuration efficiency η (%) is 13.098%.

6. COMPARISON OF PERFORMANCE FACTORS

Comparative analysis of performance factors such as V_{mp} (V), P_{mp} (W), V_{oc} (V), I_{sc} (A), FF (%), ΔP_{ml} (%), η (%) are compared with all the configurations as shown in Figure 5, Figure 6, Figure 7, Figure 8 respectively.

In all the cases the proposed S-B-T PV configuration exhibits the superior performance than S-P, T-T, B-L configurations and almost similar performance with T-C-T configuration. Since T-C-T configuration requires more cross ties than S-B-T configuration, the proposed configuration is cost effective configuration.

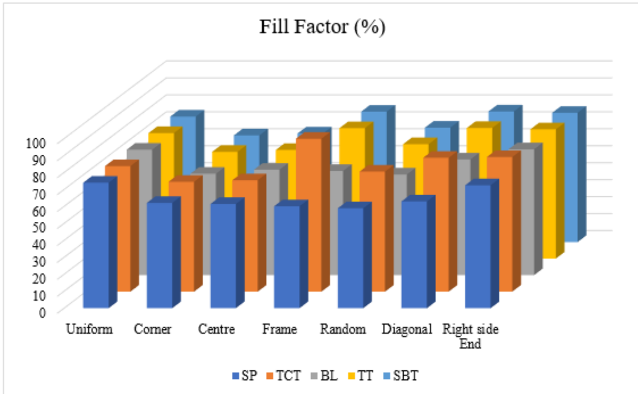

Figure 5. Fill factor comparison

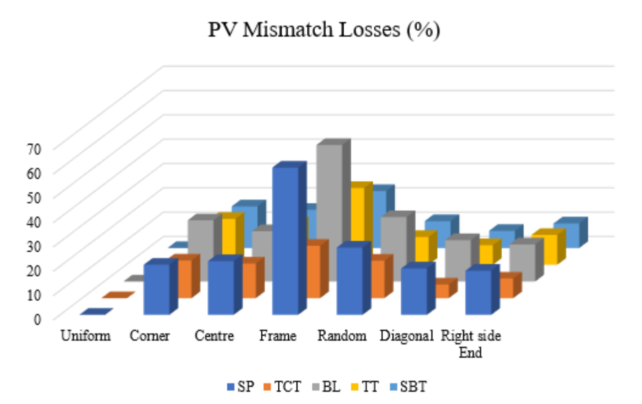

Figure 6. PV mismatch losses comparison

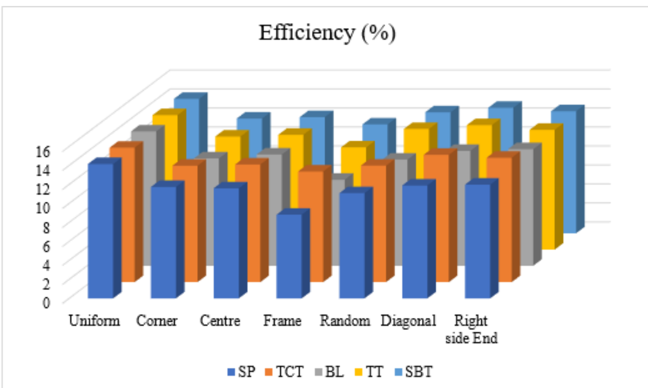

Figure 7. Efficiency comparison

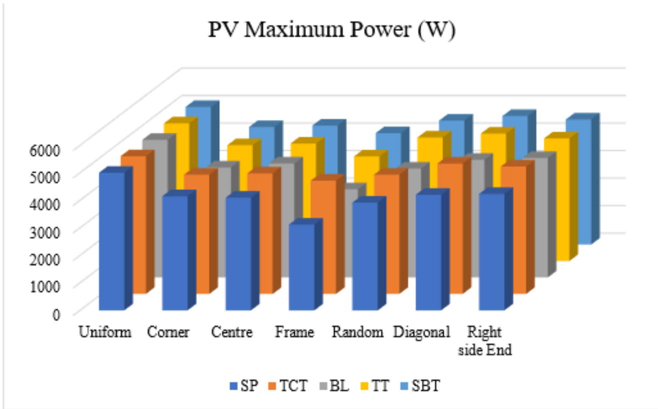

Figure 8. PV maximum power

7. CONCLUSIONS

In this paper the detailed simulations and modelling of various PV array configurations under various Performance Specific Conditions (PSCs) are presented and proposed cost effective Spider Web Tie (S-B-T) PV configuration for Performance improvement. A test case of 5 X 5 200 W PV system is considered. The Proposed configuration is implemented under real time PSC's with S-P, T-C-T, T-T, B-L configurations. The factors such as PV mismatch losses, Max. current and voltage, OC Voltage, SC Current that influence the performance of the system are investigated. In all the cases the proposed S-B-T PV configuration exhibits the superior performance than S-P, T-T, B-L configurations and almost similar performance with T-C-T configuration. Since TCT configuration requires more cross ties than S-B-T configuration, the proposed configuration is cost effective configuration.

REFERENCES

[1] Gosens, J., Hedenus, F., Sandén, B.A. (2017). Faster market growth of wind and PV in late adopters due to global experience build-up. Energy, 131: 267-278. https://doi.org/10.1016/j.energy.2017.05.046

[2] Gielen, D., Boshell, F., Saygin, D., Bazilian, M.D., Wagner, N., Gorini, R. (2019). The role of renewable energy in the global energy transformation. Energy Strategy Reviews, 24: 38-50. https://doi.org/10.1016/j.esr.2019.01.006

[3] Sinke, W.C. (2019). Development of photovoltaic technologies for global impact. Renewable Energy, 138: 911-914. https://doi.org/10.1016/j.renene.2019.02.030

[4] Parida, B., Iniyan, S., Goic, R. (2011). A review of solar photovoltaic technologies. Renewable and Sustainable Energy reviews, 15(3): 1625-1636. https://doi.org/10.1016/j.rser.2010.11.032

[5] Yousri, D., Thanikanti, S.B., Balasubramanian, K., Osama, A., Fathy, A. (2020). Multi-objective grey wolf optimizer for optimal design of switching matrix for shaded PV array dynamic reconfiguration. IEEE Access, 8: 159931-159946. https://doi.org/10.1109/ACCESS.2020.3018722

[6] Mamun, M.A.A., Hasanuzzaman, M., Selvaraj, J. (2017). Experimental investigation of the effect of partial shading on photovoltaic performance. IET Renewable Power Generation, 11(7): 912-921. https://doi.org/10.1049/iet-rpg.2016.0902

[7] Ahmad, R., Murtaza, A.F., Sher, H.A., Shami, U.T., Olalekan, S. (2017). An analytical approach to study partial shading effects on PV array supported by literature. Renewable and Sustainable Energy Reviews, 74: 721-732. https://doi.org/10.1016/j.rser.2017.02.078

[8] Lappalainen, K., Valkealahti, S. (2017). Effects of irradiance transition characteristics on the mismatch losses of different electrical PV array configurations. IET Renewable Power Generation, 11(2): 248-254. https://doi.org/10.1049/iet-rpg.2016.0590

[9] Cherukuri, S.K., Balachandran, P.K., Kaniganti, K.R., Buddi, M.K., Butti, D., Devakirubakaran, S., Babu, T.S., Alhelou, H.H. (2021). Power enhancement in partial shaded photovoltaic system using spiral pattern array configuration scheme. IEEE Access, 9: 123103-123116. https://doi.org/10.1109/ACCESS.2021.3109248

[10] Pendem, S.R., Mikkili, S. (2018). Modeling, simulation, and performance analysis of PV array configurations (Series, Series-Parallel, Bridge-Linked, and Honey-Comb) to harvest maximum power under various Partial Shading Conditions. International Journal of Green Energy, 15(13): 795-812. https://doi.org/10.1080/15435075.2018.1529577

[11] Ramaprabha, R., Mathur, B.L. (2012). A comprehensive review and analysis of solar photovoltaic array configurations under partial shaded conditions. International Journal of Photoenergy, 2012: 1-16. https://doi.org/10.1155/2012/120214

[12] Winston, D.P., Kumaravel, S., Kumar, B.P., Devakirubakaran, S. (2020). Performance improvement of solar PV array topologies during various partial shading conditions. Solar Energy, 196: 228-242. https://doi.org/10.1016/j.solener.2019.12.007

[13] Nasiruddin, I., Khatoon, S., Jalil, M.F., Bansal, R.C. (2019). Shade diffusion of partial shaded PV array by using odd-even structure. Solar Energy, 181: 519-529. https://doi.org/10.1016/j.solener.2019.01.076