IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Experimental Study On Solar PV Array Configurations Under Non-Uniform Irradiation Conditions

Sandeep Rawat[1], Prateek Haldia[2], and Jasbir Singh[3]

[1]Department of Electrical Engineering, JB Institute of Technology, Dehradun, India 248007

[2]Department of Electrical Engineering, JB Institute of Technology, Dehradun, India 248007
[3]Department of Electrical Engineering, JB Institute of Technology, Dehradun, India 248007

Abstract. Effect of shading conditions on photovoltaic (PV) systems reduce the power output and produces the mismatch losses. In this paper, an experimental approach carries to configure various electrical connections of PV array (4×4 size) such as Series-Parallel (SP) configuration, Honey-Comb (HC) configuration, Bridge-Link (BL) configuration, and Total-cross-tied (TCT). For extensive comparative analysis of experimental, the present study shows the effective behavior of considered solar PV configurations under three shading cases. During the study, the performance parameters such as global maximum power point (Called GMPP), local maximum power point (LMPP), power loss (PL) and fill factor (FF) are analyzed to show the best PV array configuration. From the obtained results, it is observed that TCT configuration has best values in terms of maximum power (49.59 W , 54.33W, 48.28W) respectively in comparison to SP (46.25W, 53.01W, 40.63W), BL(47.7W, 51.9W, 39.76W), HC (48.9W, 50.68W, 44.83W) configurations under three partial shading conditions (PSCs).

Keywords— Partial shading condition, honey-comb, bridge-link, total-cross-tied, fill factor, power loss

1 Introduction

In current scenario, the energy consumption rate is increasing exponentially. Due to high cost and scarcity of fossil fuels, human being are showing interest towards the use of renewable energy (RE) sources. Solar PV system based RE sources is gaining more popularity rapidly as compared to other sources. Without any doubt, PV systems play a significant role towards accomplishing, enduring, feasible conditions, benevolent asset to satisfy the energy demands for human being. The PV system experienced low efficiency; along these lines, pulling out of energy is an open region of exploration, and accordingly, the PV array reconfiguration technique is gaining high attention to address this issue. For developing PV array systems, distinguish various PV modules are arranged in different configurations to attain the required power during the PSCs. Distinguished conventional methods such as SP, HC, BL, and TCT configurations are adopted to develop PV array systems. These days, various researchers are exploring the solution to enhance the PV system performance during the PSCs by satisfactory methods such as bypass diode integration with the modules and altering the PV module position with the fixed electrical connections in PV array system. Normally, the PV modules are connected in Series and SP configurations to supply the load power requirement. The power produced from the PV array reduces considerably if one or more panels are shaded.

El-Dein and et al., have proposed a scientific formulation for PV array reconfiguration to reduce the PSCs losses. Huynh and et al. have proposed particle swarm optimization (PSO) algorithm to operate the PV array at its GMPP to yield the maximum power from PV array. Kouchaki and Imran-Eini have developed a new MPPT method based on I-V characteristics not only to find out the GMPP more efficiently and rapidly under PSC's but also new MPP quickly under sudden changes that occur in insulation level. Guoa and Walsha used SPICE software micro-cap to investigate module configuration and simulated that SP hybrid interconnections of cells has importance improvement of the output power under PSCs. The authors have proposed an analytical method by Nezhad and et al., for tracking GMPP under iPSCs with high tracking accuracy and perfect steady state characteristics in MATLAB/Simulink environment. The authors studied the methods for improving the I-V curve of PV module under various PSCs by Lun and et al. Pareek and et al. used Su-Do-Ku puzzle configuration as a one-time arrangement for the PV modules and demonstrate the improvement of power generation under PSCs by distributing the shading condition over the whole array rather than the single row. Rani and et al., have arranged a NDMOS technology based solar bypass switch in place of bypass diode and compared the performance of the smart bypass with the traditional diode and an ideal bypass diode. Bauwens and Doutreloigne have developed the five parameters to design solar cell equivalent circuit to acquire I-V and P-V curve with the estimation of Heuristic method. Once the parameters simulation results are compared with the experimental results. Fialho and et al., compared in MATLAB/ Simulink considering three panels of PV module in series and parallel separately in PSCs and showed that there is considerable power loss in series than in parallel string under PSC's. Vijayalekshmy and et al., have presented the cost effective and dynamic programming algorithm to adaptively produce near – optimal reconfiguration to maximize the PV system output under PSC's. Wang and et al. used equivalent and explicit five parameters method to study the I-V and P-V characteristics of PV module of different properties under PSCs or mismatch conditions. Bai and et al. used genetic algorithm as an optimization technique for TCT connection in PV array to obtain uniform dispersion of shadow throughout the panels. Deshkar and et al. used TCT, SP-TCT and Su-Do-Ku puzzle pattern under 3 different PSCs to study GMPP and LMPP locations on P-V characteristics. Yadav and et al. used mono-crystalline solar cells of SP connections to study under PSCs and dust accumulation in terms of I-V and P-V characteristics, PV power output, weight of dust. Ali and et al. studied the PV array in terms of I-V characteristics under PSCs and co-related local maxima with the series-connection and shaded panel biasing of PV system. Pareek and et al. used optimize inter-connection technique in SP and TCT configuration to reduce power losses due to PSCs. Pachauri, et al. have studied that TCT and LS-TCT configuration of PV panel under PSCs in terms of GMPP, Power loss and FF. Nihanth et al., used skyscraper puzzle as a new physical relocation technique for uniform dispersion of shading effect over PV panels to improve the output [19]. Haq and et al. investigated faulty condition in PV system and used CIGS technology to compare with Polycrystalline techniques for three different configurations in MATLAB/simulation.

The organization of paper is follows. Section I introduces the paper. The salient points of study introduce in Section II. Section III briefs the novelty of work done in paper. In section IV, results and discussion are summarized. Moreover, section V concludes the paper.

1.1 Novelty of work

In this paper, an experimental investigation is performed to estimate I–V and P–V curves of a 4×4 size PV system for showing the effect of PSCs. The important points of the present studies are given as,

- To analyze the experimental comparison of SP, HC, BL, TCT configurations under shading cases
- The experimental consequence is useful to analyze the PV system performance under PSCs

2 Hardware set-up

The hardware setup is comprised two sections *i. e.* Solar PV array and performance measurement system. In first section, solar PV array consists of 2×2 PV configured in SP, HC, BL, and TCT forms. In the second section, performance-measuring system covers up two multi-meters with the resistive load for measuring the real time voltage and current. Performance indicator of the experimental system is sensed to show the impact on voltage and current by the analysis behavior of I-V and P-V curves. The specifications and suitable use of all the required components to design hardware are shown in Table-1. Moreover, developed system is shown in Figure 1 as,

Figure 1. Experimental set-up

Table 1. Specifications and role of supportive items used in developed hardware system

Section	Components	Specifications	Role/Function
Solar PV array(4x4)	PV array system	• Power: 20 W • O. C. voltage: 21.997 V • S. C. current: 1.2586 A • I_{mpp}: 1.12A, Vmpp: 18V • No. of PV module: 16 (4x4 array) • Cell technology: Poly-Si • Dimension (mm): 356×490×25 • Manf.: USHA SHRIRAM Technologies (Model NO: US 20/12V)	4×4 size PV array arranged in SP, HC, BL., and TCT connections
	Artificial solar lamp	• Total number of lamps- 16(4x4) • Light intensity 50- 650W/m^2	• Solar lamp array (4x4) system used for uniform light intensity
Performance measurement system	Multi-meter used as ammeter	• Number of ammeter: 1 • Measurement range: 0.01 to 10A DC • Mastech Technology	• Voltage measurement of voltage SP, HC, BL, and TCT connections.
	Multi-meter used as voltmeter	• No. of voltmeter: 1 • Measurement range: 0.1 to 250V DC • Mastech Technology	• Current measurement of current SP, HC, BL, and TCT connections.
	Decade resistive load	• Number of resistive load:2 • Range: 0.1 to 250Ω	• Variable load is used to characterize the solar PV system

3 PV system technology

3.1 Mathematical modeling

The electrical equivalent circuit is shown in Figure 2 as,

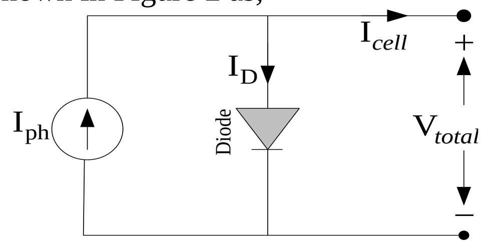


Figure 2. Schematic diagram of PV system

Deliberated solar cell (I_{cell}) current can be represented as,

$$I_{cell} = I_{ph} - I_D \quad (1)$$

$$I_{cell} = I_{ph} - I_o \left(exp^{\left(\frac{qV_c}{AkT_c}\right)} - 1\right) \quad (2)$$

Where I_{ph} :photocurrent of solar cell (A), I_D: diode current (A), I_o: Saturation current (A), q: charge (Coulomb), $V_c =$ voltage of PV cell (V), K: Boltzmann's constant (J/K), A: ideality factor and $T_c =$ temperature of cell (^{o}C).

3.2 Power loss and FF

The amount of current received from 4×4 PV array system is based on the sun irradiance and is calculated as

$$I=\left(\frac{s_x}{s_{STC}}\right)\times I_m \quad (3)$$

Where, I_m is the maximum current produced by the PV module under standard test condition irradiation (s_{STC}) of 1000W/m^2 and s_x is the actual irradiation on PV module surface . PV array voltage can be calculated as,

$$V = \sum_{n=1}^{2} V_{mn} \quad (4)$$

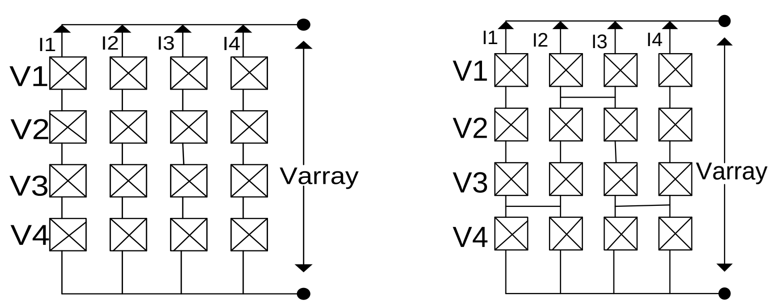
Where V_{mn} is the generated maximum voltage of nth row of the solar PV system and calculation of power loss (PL) of solar PV system is shown as,

PL=Maximum power at without shading–GMP under partial shadow
(5)

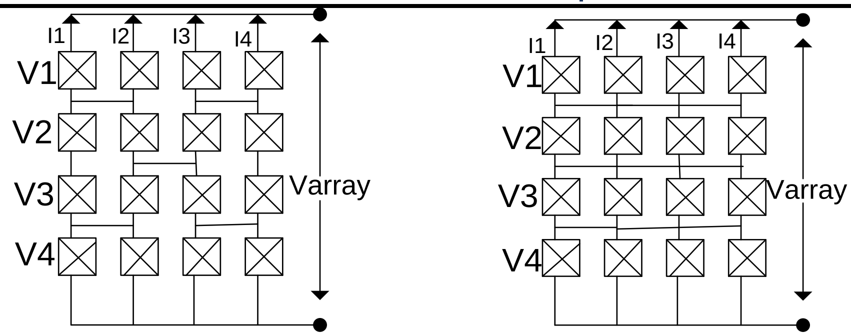
The change in FF is due to the power loss of PV array. FF is mainly dependent on V_{oc} and I_{sc} of PV array. The FF always affected with the variation in the location of shadow and is given as,

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \quad (6)$$

The electrical connectivity of PV module are considered as series and/or parallel in order to achieve higher range of current and voltage. The schematic diagram of SP, HC, BL, and TCT are depicted in Fig 3(a)-(c) as,



(a) SP (b) BL

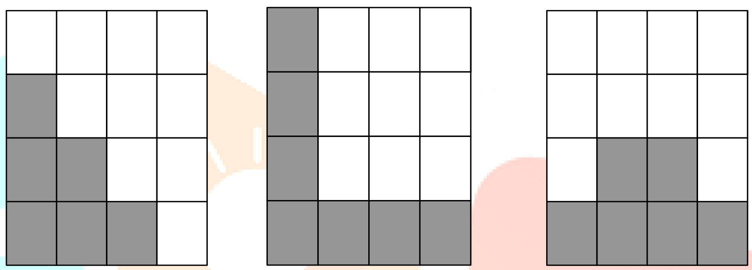


(c) HC (d) TCT

Figure 3. PV array configurations

4 Shadow test cases analysis

In this experimental study, three-shadow test cases-1, 2 and 3 are taken for performance index evaluation. The shadow test cases are in dynamic nature of sun. During this extensive study, solar PV performance is investigated in terms of PL, GMPP and improvised FF. In Figure 4, all the considered three shadow patterns are shown as,



(a) Case-1 (b) case-2 (c) case-3

Figure 4. Shadow test cases for performance evaluation

In the above cases of shadowing, the shaded PV modules receive the solar irradiation of $75W/m^2$ whereas the other unshaded PV modules receive the solar irradiation of $266W/m^2$. These cases are studied in different configurations to analyse the array performances on the basis of I-V and P-V characteristics.

The 4×4 size SP configured PV system generated the current for shadow cases-1,2,3 and is obtained as

(i) Current generated for shadow case-I

$$I_{R1} = \left(\frac{S}{S_{STC}}\right) I_m + \left(\frac{S}{S_{STC}}\right) I_m = \left(\frac{75}{1000}\right) I_m + \left(\frac{266}{1000}\right) I_m = 0.341 I_m \quad (7)$$

$$I_{R2} = \left(\frac{266}{1000}\right) I_m + \left(\frac{266}{1000}\right) I_m = 0.532 I_m \quad (8)$$

(ii) Current generated for shadow case-II

$$I_{R1} = \left(\frac{S}{S_{STC}}\right) I_m + \left(\frac{S}{S_{STC}}\right) I_m = \left(\frac{S}{1000}\right) I_m + \left(\frac{75}{1000}\right) I_m = 0.15 I_m \quad (9)$$

$$I_{R2} = \left(\frac{266}{1000}\right) I_m + \left(\frac{266}{1000}\right) I_m = 0.532 I_m \quad (10)$$

(iii) Current generated for shadow case-III

$$I_{R1} = \left(\frac{S}{S_{STC}}\right) I_m + \left(\frac{S}{S_{STC}}\right) I_m = \left(\frac{S}{1000}\right) I_m + \left(\frac{75}{1000}\right) I_m = 0.15 I_m \quad (11)$$

$$I_{R2} = \left(\frac{266}{1000}\right) I_m + \left(\frac{75}{1000}\right) I_m \quad (12)$$

Similarly, the theoretical value of SP, BL, HC and TCT configuration of PV array systems can be accessed easily.

5 Results and discussion

The comparison among the SP, HC, BL, and TCT connections are considered and analysis of P-V and I-V curves under normal and faulty scenarios. The outcomes of study are as follows.

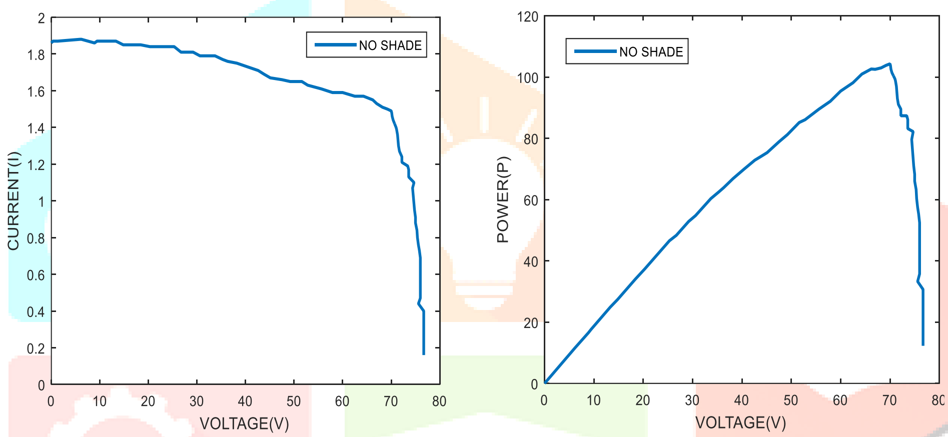
(a) I-V & P-V curves of PV modules at normal conditions.

(b) Effect of PSCs on PV systems

- Shading case-1 effect on PV array configurations
- Shading case-2 effect on PV array configurations
- shading case-3 effect on PV array configurations

5.1 P-V and I-V curves of PV system under uniform irradiation

The I-V and P-V curves of the PV array system at normal irradiation level 266W/m^2 are shown in Figure 5. Under normal irradiation level, the intensity of solar energy is uniform over the solar panel, which shows that under this condition the PV array shows the same response for all configurations. At zero load, the current (I_{sc})is maximum and voltage (V_{OC})is minimum but on increasing the load the I_{sc} decreases and V_{oc} increases, which is shown in figure 5 (I-V, P-V curves). The power increases with the increase of load up to the limit of P_m and after that it tends to decrease with the increase of load.



(a) I-V curve (b) P-V curve

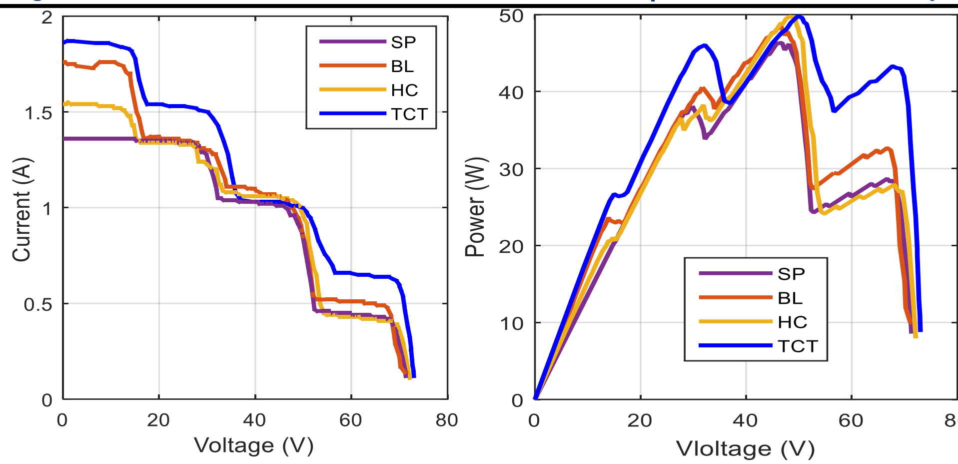
Figure 5. I-V and P-V curves of solar PV array under ideal scenarios

5.2 Partial shading effects on PV systems

Partial shading is the condition when one or more panel of the PV array do not receive the full irradiation of the solar light intensity due to the shadow of any objects. PSCs disturb the output efficiency and create hotspot in the PV panels, which can be seen graphically in I-V and P-V curves in the form of peaks. It may be due to the cloudy weather and may be due to the shadow of tree and buildings over the panel. In this study, we analyse the three shading pattern cases.

5.2.1 shading case-1 effect on PV array configurations

In first case of shading as shown in Fig.4(a) the panels under shaded condition receive 75W/m^2 of irradiation and rest of the panels receives normal irradiation of 266W/m^2. Hence panels under shaded condition decrease the output which can be seen in the forms of peaks in I-V and P-V curve. From the curve given below the maximum current (I_m) and GMPP for TCT is 49.59 W which is maximum in all configurations. On the other hand SP configuration generate minimum current and Least GMPP as shown in Fig. 6(a)-(b) as,

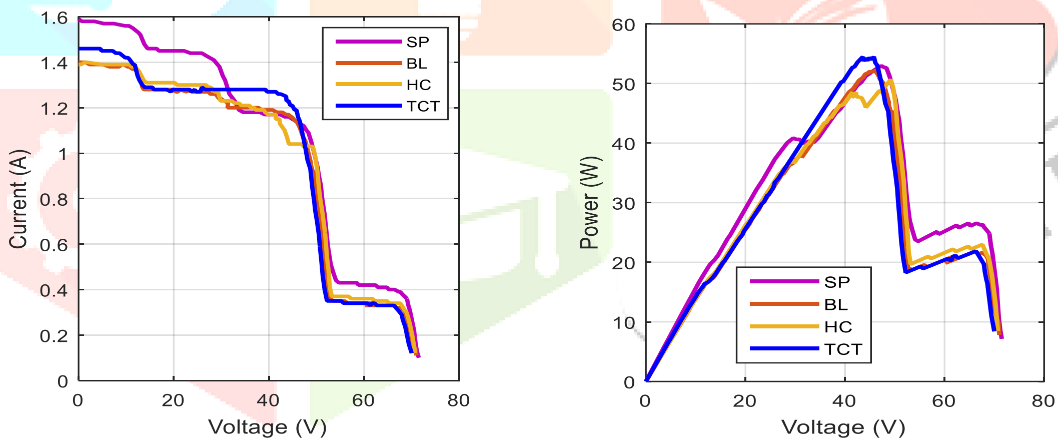


(a) (b)

Figure 6. Performance characteristics of PV array configurations under shading case-1

5.2.2 Shading case-2 effects on PV array configurations

In this case of shading, different shade condition is generating as shown in Figure 4(b). The output efficiency of these panels are low due to low solar irradiation over them whereas the rest of the panels receive full irradiation .Due to the effects of PSCs the graphical curve of I-V and P-V are regular and represent disturbance in the forms of peaks as shown in Figure 7(a)-(b). In this case of shading the TCT configuration has the maximum current (I_m) of 1.21A.In sense of global MPP the TCT has the maximum power that is 54.33 W as compared to the SP, HC, BL which has 53.01W, 50.68W, and 51.9W respectively.

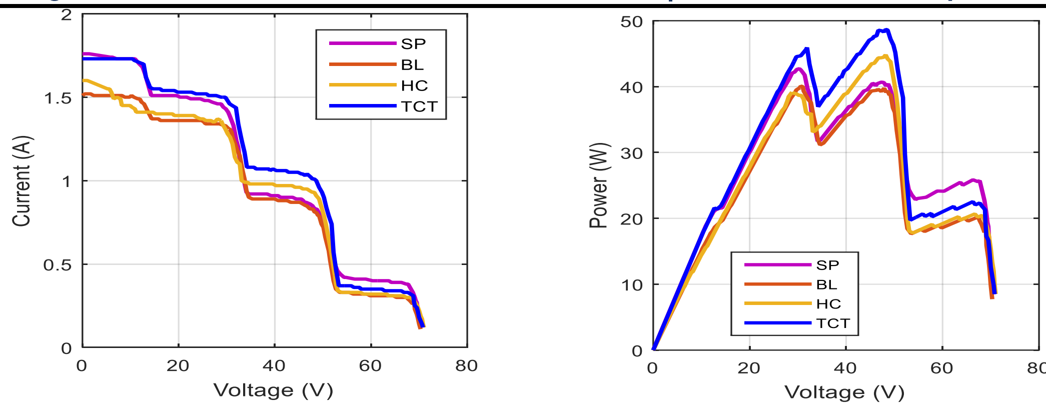


(a) (b)

Figure 7. Performance characteristics of PV array configurations under shading case-2

5.2.3 Shading case-3 effects on PV array configurations

Effect of shading case-3 on SP, HC, BL, and TCT configurations is shown in Figure 4(c). In this condition, the obtained I-V and P-V curve of SP, HC, BL, and TCT configuration is shown in the Figure 8(a)-(b). On comparing the performance of different configurations it is found that maximum current (I_m) is for TCT that is 1.01 A and SP has the minimum value of current of 0.85A. furthermore, the global MPP for TCT is 48.82W in comparison to SP,BL, HC which has 40.63W, 39.76W,44.8W respectively.



(a) (b)

Figure 7. Performance characteristics of PV configurations under shading case-2

During the experimental study, all the performance parameters are evaluated and depicted in table-2 as,

Table-2. Performance parameters of PV systems under shadow cases

Performance parameters	SP	BL	HC	TCT	Shading case
V_{oc} (V)	70.2	71.7	71.4	72.9	Case-1
$I_{sc}(A)$	1.36	1.76	1.54	1.87	
V_m (V)	44.9	46.7	48.3	50.6	
$I_m(A)$	1.03	1.02	1.01	0.98	
$P_m(W)$	46.25	47.7	48.9	49.59	
FF	0.48	0.37	0.44	0.36	
ML Power (W)	16.45	16	17	15.3	
PL (W)	58.05	56.6	55.4	54.71	
V_{oc} (V)	70.5	69.4	69.6	68.7	Case-II
$I_{sc}(A)$	1.58	1.39	1.39	1.46	
V_m (V)	46.5	45.8	48.8	44.9	
$I_m(A)$	1.14	1.13	1.03	1.21	
$P_m(W)$	53.01	51.9	50.68	54.33	
FF	0.47	0.53	0.51	0.54	
ML Power (W)	10.81	20.5	36.18	24.73	
PL (W)	51.29	52.4	53.62	49.97	
V_{oc} (V)	70.6	70.6	70.3	70.6	Case-III
$I_{sc}(A)$	1.76	1.52	1.60	1.73	
V_m (V)	47.3	48.3	48.2	47.8	
$I_m(A)$	0.85	0.82	0.93	1.01	
$P_m(W)$	40.63	39.76	44.83	48.28	
FF	0.32	0.36	0.39	0.39	
ML Power (W)	11.83	9.16	13.13	17.98	
PL (W)	63.67	64.54	59.47	56.02	

6 Conclusion

In this experimental study on the performance of solar PV array system, three shadow cases are considered for comparative analysis. The experiment was conducted to characterize the P-V and I-V curves of PV array system. Total sixteen PV modules (4×4 size) have arranged to form SP, BL, HC and TCT configurations. The electrical connections of all the four configuration are investigated and compared in term of GMPP. It is observed that TCT configuration (49.59W for case-1, 54.33W for case-II and 48.28W for case-III) shown best performance with lowest PL and improved FF vales compared to other PV array configurations.

References

Ali, R., Murtaza, A. F., Sher, H. A., Shami, U. T., Olalekan, S.: An Analytical Approach to Study Partial Shading Effects on PV Array Supported by Literature. Renewable and Sustainable Energy Review, vol. 74(2017) 721-732.

Bai, J., Cao, Y., Hao, Y., Zhang, Z., Liu, S., Cao, F.: Chracteristic Output of PV Syatem under Partial Shading or Mismatch Condition. Solar Energy, vol. 112(2015) 41-54.

Bauwens, P., Doutreloigne, J.: Reducing Partial Shading Power Loss with an Integrated Smart Bypass Diode. Solar Energy, vol. 103(2014) 134-142.

Deshkar, N., Dhale, S. B.: Solar PV Array Reconfiguration under Partial Shading Conditions for Maximum Power Extraction using Genetic Algorithm. Renewable and Sustainable Energy Review, vol. 43(2015) 102-110.

El-Dein, M. Z. S., Kazerani, M., Salama, M. M. A.,: Optimal Photovoltaic Array Reconfiguration to Reduce Partial Shading Losses. IEEE Transactions on sustainable Energy, vol. 4(2013) 145-153.

Fialho, L., Melicio, R., and et. al,: Effect of Shading on Series Solar Modules: Simulation and Experimental Results. Procedia Technology, vol. 17(2014) 295-302.

Guoa,S., Walsha, T. M.: Improved PV Module Performance under Partial Shading Condition. Energy Procedia. vol. 33(2013) 248-255.

Haq, A. U., Alammari, R., Iqbal, A., Jalal, M., Gul, S.: Computation of Power Extraction from Photovoltaic Array under Various Fault Conditions. IEEE Access, vol. 8(2020) 47619- 47639.

Huynh, D. C., Nguyen, T. M., et al,: Global MPPT of Solar PV Modules using a Dynamic PSO Algorithm under Partial Shading Conditions. In Proc. IEEE Conference on Clean Energy and Technology, at Malaysia on 18-20 Nov (2013) 1-6.

Kouchaki, A., Imran-Eini,H.: New Maximum Power Point Tracking Strategy for PV Array under Uniform and Non- uniform Insolation Condition. Solar Energy. vol. 91(2013) 221-232.

Lun, S. X., Wang, S., Guo, T. T., Du, C. J.: An I–V Model based on Time Warp Invariant Echo State Network for Photovoltaic Array with Shaded Solar Cells. Solar Energy. vol. 105(2014) 529-541.

Nezhad, M. E., Asaei, B., Farhangi, S.: Modified Analytical Solution for Tracking Photovoltaic Module Maximum Power Point under Partial Shading Condition. In Proc. IEEE Conference on Environment and Electrical Engineering, (2013) 182-187.

Nihantha, M. S. S., and et al.: Enhanced Power Production in PV Arrays using a New Skyscraper Puzzle based one-Time Condition (PSCs). Solar Energy, vol. 194(2019) 209-224.

Pachauri, R., Yadav, A. S., Chauhan, Y. K., Sharma, A., Kumar, V.: Shade Dispersion-based Photovoltaic Array Partial Shading Condition. International Transaction on Electrical Energy System, vol. 28(2018) 25-56.

Pareek, S., Chaturvedi, N.: Optimal Interconnection to Address Partial Shading Losses in Solar Photovoltaic Arrays. Solar Energy, vol. 155(2017) 537-551.

Pareek, S., Runthala, R., Dahiya, R.: Mismatch Losses in SPV Systems Subjected to Partial Shading Conditions. In Proc. IEEE Conference on Advanced Electronics System at Pilani, India on 21-23 Sept. (2013) 343-345.

Rani, B. I., Ilango, G. S., Nagamani, C.: Enhanced Power Generation From PV Array under Partial Shading Conditions by Shade Dispersion using Su-Do-Ku Configuration. IEEE Transactions on Sustainable Energy, vol. 4(2013) 554-601.

Vijayalekshmy, S.: Comparative Analysis on the Performance of a Short String of Series-Connected and Parallel-Connected Photovoltaic Array under Partial Shading. Journal of Inst. Eng. India, vol. 96(2015) 217-226.

Wang, Y., Lin, X., Kim, Y., Chang, N., Pedram, M.,: Architecture and Control Algorithms for Combating Partial Shading in Photovoltaic Systems. IEEE Transactions on Computer Aided Design of Circuits and Systems, vol. 33(2014) 917-930.

Yadav, A. S., Pachauri, R. K., Chauhan, Y. K.: Comprehensive Investigation of PV Arrays under Different Shading Patterns by Shade Dispersion Using Puzzled Pattern based Su-Do-Ku Puzzle Configuration. In Proc. IEEE Conference on Next Generation Computing Technology at UPES, Dehradun, (2015) 824-830.