Comparative Analysis of Series–Parallel and Bridge Link Configurations Under Various Partial Shading Conditions

Ashwani Srivastav, Vinod Kumar Yadav, and M. Rizwan

Abstract Photovoltaic system is most popular renewable source of energy due to its widespread availability and comparatively easier conversion into electrical energy. Solar energy is also environmentally friendly in comparison with traditional energy sources. Solar energy is also expected to become viable source of energy in coming future. However, there are still some serious problems with photovoltaic systems that must be investigated and solutions sought. Partial shading conditions (PSCs) are one of the most serious issues with photovoltaic systems, as they can cause serious damage to the PV array by causing hotspots and reducing the PV array's ability to generate maximum power. In this paper, series–parallel and bridge link configuration of 3 × 3 PV array are modeled and simulated under different partial shading conditions, the resulting current voltage and power voltage characteristics are analyzed, and photovoltaic system's performance is compared. For the simulation, MATLAB/Simulink software is used.

Keywords Photovoltaic array configurations · Series–parallel · Bridge link · Bypass diode · Partial shading conditions (PSCs)

1 Introduction

Combination of multiple PV cells serially and parallelly makes one PV array which are then connected in different configuration to maximize the output generated. To enhance the terminal voltage photovoltaic cells are connected serially, similarly to enhance the output current photovoltaic cells are connected parallelly. The solar

A. Srivastav (✉) · V. K. Yadav · M. Rizwan
Department of Electrical Engineering, Delhi Technological University, New Delhi, India
e-mail: ashwanisrivastav_2k20pes06@dtu.ac.in

V. K. Yadav
e-mail: vinodkumar@dtu.ac.in

M. Rizwan
e-mail: rizwan@dce.ac.in

A. Rani et al. (eds.), *Signals, Machines and Automation*, Lecture Notes in Electrical Engineering 1023, https://doi.org/10.1007/978-981-99-0969-8_26

energy is the most popular form of renewable energy as it is available most abundantly, lower cost of generation, produce clean and green energy but along with all the advantages it possess, it also has certain serious issues associated with it like deposition of aerosol, partial shading condition (PSC) and generation of hotspot. Researches and study are being done to resolve these issues in order to produce a PV system with high efficiency, low cost and high reliability [1].

Reliability of the photovoltaic system is affected by the non-uniform illumination over the PV panel. Partial shading condition could be caused by various factors like snow, clouds, tree or building shadow, etc. [2]. Along with reliability, partial shading also effects maximum power generation, causes hotspot generation and electrical power mismatch [3]. Under partial shading condition, the shaded cell experiences the reverse biased voltage which causes generation of hotspot and lead to sudden rise in temperature which in turn can permanently damage the PV cell, can cause fire, joints may become fragile or shattering of protective glass [4, 5].

So the study of partial shading condition is necessary. To decrease the effects of the partial shading condition, bypass diode is use which is connected in antiparallel manner across a panel. Under full illumination, the bypass diode is reversed biased and the entire output current is passed through panel itself but under the condition of partial shading the bypass diode get forward biased due to the reversal of voltage across the shaded cell and bypass the entire PV panel across which it is connected [6–9].

The effects of the partial shading can also be reduced effectively with the proper selection of different configuration in which different panels are to be connected to form one array [10]. The most basic one is series configuration, but as per different study, it is already stated that the effect of partial shading condition is worse in it also the generated output is very low. So different configurations are suggested by the scholars, out of which the series–parallel and bridge link configuration are studied and analyzed in this work.

2 Mathematical Modeling

A PV panel contains number of photovoltaic cell which are interconnected serially or parallelly as per the output voltage and output current requirements. Figure 1 shows the circuit diagram of a photovoltaic cell. In Fig. 1, I_{p} is photocurrent, I_{d} is photodiode current, R_{sh} is shunt resistance depicting leakage current and R_{se} is series resistance depicting internal resistance of the cell, I is cell current and V is voltage produce by one cell [11] (Fig. 2).

Current and voltage equations of a photovoltaic cell are as follows [10]:

$$I = I_{\mathrm{p}} - I_{\mathrm{d}} - I_{\mathrm{sh}} \tag{1}$$

$$I_d = I_o\left[e^{\frac{V+IR_{\mathrm{se}}}{V\propto}} - 1\right] \tag{2}$$

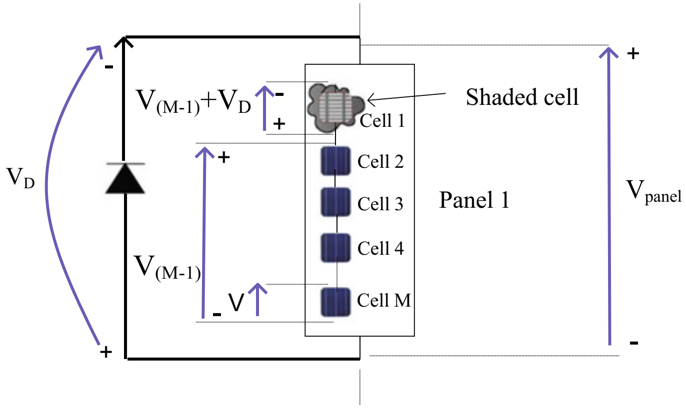

Fig. 1 Distribution of voltage in closed loop circuit of a sub-panel with M number of cell and a bypass diode

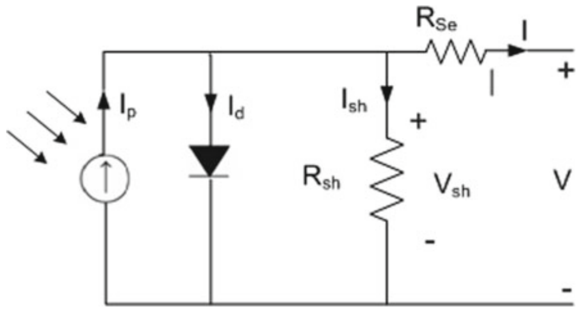

Fig. 2 Circuit diagram of PV cell

$$I = \frac{V + I R_{se}}{R_{sh}} \tag{3}$$

From Eqs. 1, 2 and 3, we get:

$$I = I_p - I_o\left[e^{\frac{V + I R_{se}}{V_t}} - 1\right] + \frac{V + I R_{se}}{R_{sh}} \tag{4}$$

where I_o is saturation current of the photodiode, $V_t = \frac{AkT}{q}$ in which A is ideality factor, k is Boltzmann constant, T is temperature of the cell (Kelvin) and q is elementary charge [12, 13]. From above equations, it can be inferred that photocurrent is dependent upon the temperature of the cell. Generated photocurrent rise slightly with rise in temperature but the saturation current reduces exponentially with rise in temperature hence decreasing cell voltage hence the efficiency and reliability of PV system decrease [14].

If N_S numbers of cells are connected serially and N_P numbers of cells are connected parallelly in the photovoltaic array than array current I_A is:

$$I_A = N_p I_p - N_p I_O \left[e^{\frac{V+IR_{se}}{V_t}} - 1 \right] - \frac{N_P V + I N_S R_{se}}{N_S R_{sh}} \quad (5)$$

3 Simulation Modeling and Results

Simulation of a 3 × 3 PV system is modeled for series–parallel and bridge link. As the name suggests in series–parallel configuration, some panels are connected serially to form one string and then different strings are reconnected parallelly. Bridge link configuration modifies version of series–parallel configuration in which alternate panels are connected together like a bridge. Connections of both configurations are shown in Fig. 3.

For the study, following different cases of partial shading are taken [15, 16].

Non-shaded Condition (NS): In this case, all the panels are fully and uniformly illuminated.

Row Shading Condition (RS): In this case, first panel of each string which are connected parallelly are shaded, i.e., one row is shaded.

Column Shading Condition (CS): In this case, one entire string, i.e., serially connected panels are shaded.

Diagonal Shading Condition (DS): In this case, diagonal panels of PV array matrix are shaded.

Random Shading Condition (RAS): In this case, panels are shaded randomly, i.e., they do not form any specific pattern.

Non-Uniform shading (NUS): In this case, a PV panel of the array receives irregular irradiance. This case may arise due to passing clouds etc.

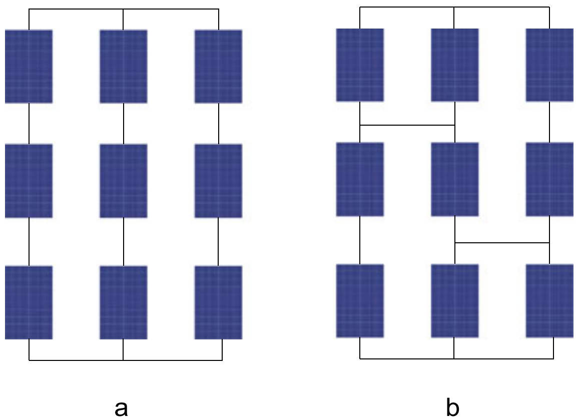

Fig. 3 **a** Series–parallel configuration and **b** bridge link configuration of a 3 × 3 PV array

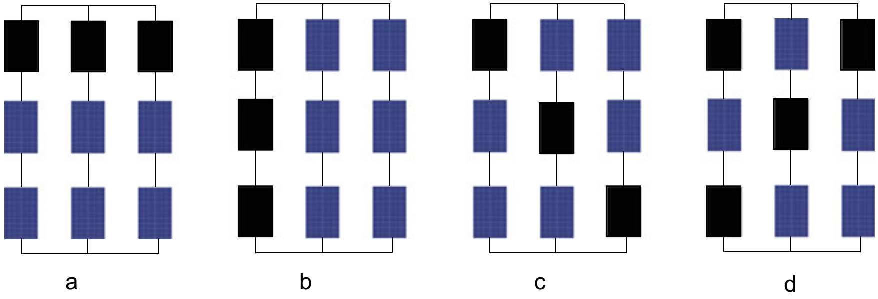

Fig. 4 Different shading patterns considered: **a** row shading, **b** column shading, **c** diagonal shading and **d** random shading

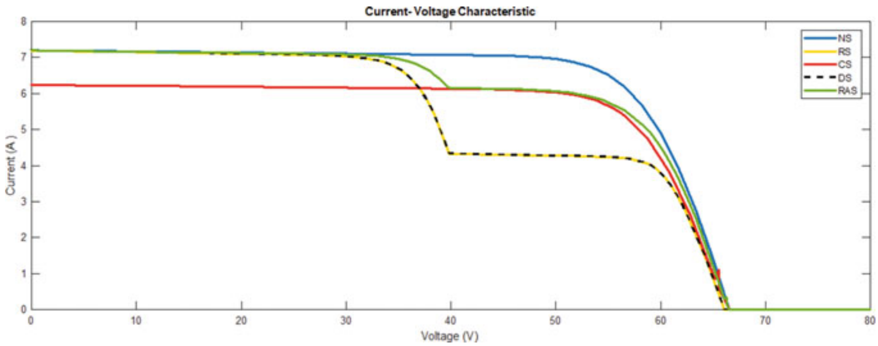

Fig. 5 I-V plot for series–parallel configuration under different PSC for 1000 W/m^2

All the cases of shading are taken for the analysis of PV system. For fully illuminated condition, irradiance is taken 1000 W/m^2. For the shading condition, the 600 W/m^2 irradiance is taken. For all the test condition, 25 °C temperature is taken (Fig. 4).

Simulation results for series–parallel and bridge link configuration for different partial shading condition stated above are shown in Figs. 5, 6, 7 and 8. Results include current voltage and power voltage characteristics of both configuration.

From Table 1, it can be observed that there are different power points, also we get global maximum and local maximum power points which cause problem for conventional power tracing algorithms.

4 Conclusion

The power generated depends upon the partial shading condition, as no. of modules under shading increases power generated decreases. Also it is observed from the

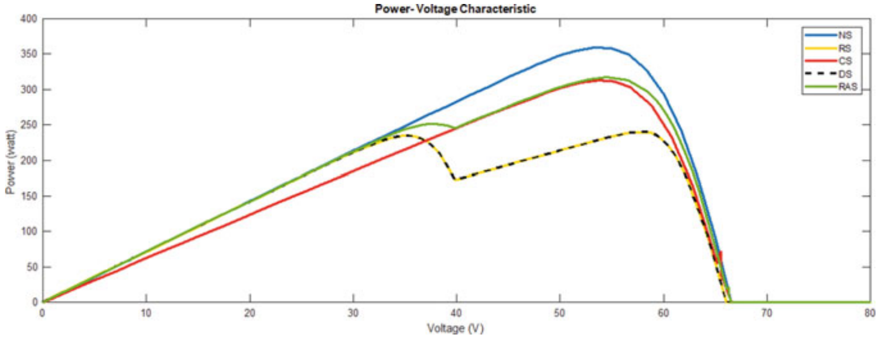

Fig.6 P–V plot for series–parallel configuration under different PSC for 1000 W/m^2

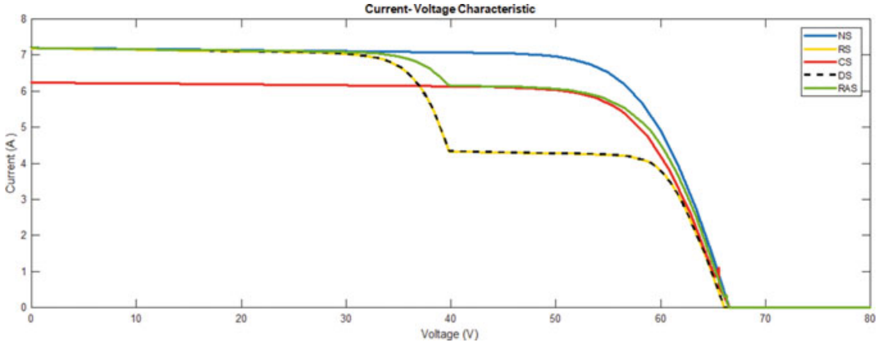

Fig.7 I-V plot for bridge link configuration under different PSC for 1000 W/m^2

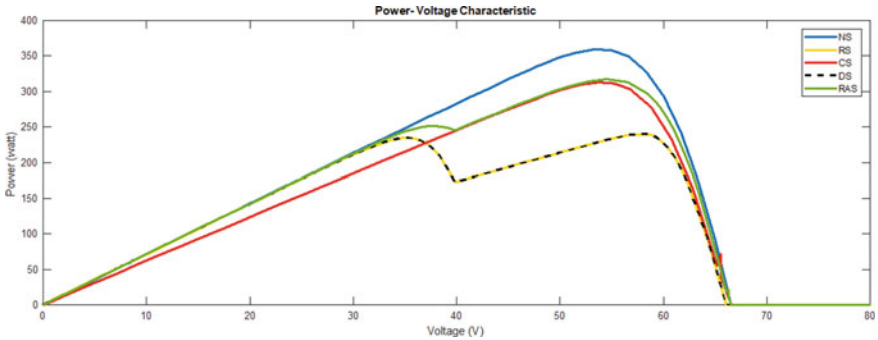

Fig. 8 P–V plot for bridge link configuration under different PSC for 1000 W/m^2

Table 1 GMPP and LMPP during various partial shading conditions

Topology	PSCs	GMPP			LMPP		
		Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)
Series–parallel	NS	53.44	6.732	359.7	–	–	–
	RS	58	4.152	235.8	34.86	6.707	231.3
	CS	54.17	5.770	305.5	–	–	–
	DS	54.17	5.770	305.5	–	–	–
	RAS	54.17	5.997	325.9	34.86	6.707	231.4
Bridge link	NS	53.42	6.727	359.7	–	–	–
	RS	58	4.159	242.8	34.86	6.707	236.3
	CS	53.79	5.808	312.5	–	–	–
	DS	53.79	5.808	312.5	–	–	–
	RAS	56	5.854	332.1	34.86	6.707	236.4

characteristics that for diagonal and row shading, we get similar results. From the above results, it can be analyzed that generated power and output voltage is more for bridge link configuration, as in bridge link comparatively more panels are interconnected which provides an extra path for the current to flow preventing decrease in current. So it can be concluded that bridge link is better than series–parallel in terms of power generation, impact of partial shading and hence efficiency.

References

1. Joshi AS, Dincer I, Reddy BV (2009) Performance analysis of photovoltaic systems: a review. Renew Sustain Energy Rev 13(8):1884–1897
2. Ghosh S, Yadav VK, Mukherjee V (2019) Impact of environmental factors on photovoltaic performance and their mitigation strategies—a holistic review. Renew Energy Focus, 153–172
3. Hamdi S, Saigaa D, Drif M (2014) Modeling and simulation of photovoltaic array with different interconnection configurations under partial shading conditions for fill factor evaluation. In: Proceedings of the 2014 international renewable and sustainable energy conference (IRSEC 2014), pp 25–31
4. Barreiro C, Jansson PM, Thompson A, Schmalzel JL (2011) PV by-pass diode performance in landscape and portrait modalities. In: 37th IEEE photovoltaic specialists conference, Seattle, WA, USA, pp 003097–003102, June 2011
5. Hu Y, Zhang J, Li P, Yu D, Jiang L (2017) Non-uniform aged modules reconfiguration for large-scale PV array. IEEE Trans Device Mater Reliab 17(3):560–569
6. Guerriero P, Daliento S (2019) Toward a hot spot free PV module. IEEE J Photovoltaics 9(3):796–802
7. Guerriero P, Di Napoli F, Coppola M, Daliento S (2016) A new bypass circuit for hot spot mitigation. In: 2016 international symposium on power electronics, electrical drives, automation and motion (SPEEDAM), pp 1067–1072
8. Hui L, Yunmei C, Xiangwei L (2019) Study of bypass diodes configuration on PV modules with partial shaded. In: Chinese control and decision conference (CCDC), pp 511–515

9. Ghosh S, Yadav VK, Mukherjee V (2020) A novel hot spot mitigation circuit for improved reliability of PV module. IEEE Trans Device Mater Reliab, 191–198
10. Ghosh S, Yadav VK, Mukherjee V (2019) Improvement of partial shading resilience of PV array though modified bypass arrangement. Renew Energy 143:079–1093
11. Bingöl O, Özkaya B (2018) Analysis and comparison of different PV array configurations under partial shading conditions. Sol Energy 160:336–343
12. Zhao Z, Cheng R, Yan B, Zhang J, Zhang Z, Zhang M, Lai LL (2020) A dynamic particles MPPT method for photovoltaic systems under partial shading conditions. Energy Convers Manag 220:113070. https://doi.org/10.1016/j.enconman.2020.113070
13. Walker G (2001) Evaluating MPPT converter topologies using a matlab PV model. J Electr Electron Eng Aust 21:49–55
14. Touati FA, Al-Hitmi MA, Bouchech HJ (2013) Study of the effects of dust, relative humidity, and temperature on solar PV performance in Doha: comparison between monocrystalline and amorphous. PVS, Int J Green Energy 10:680–689
15. Palawat KP, Yadav VK, Meena RL, Ghosh S (2021) Comparative performance of different PV array topologies under partial shading condition. In: Innovations in electrical and electronic engineering. Springer, Singapore, pp 367–380
16. Palawat KP, Yadav VK, Meena RL, Ghosh S (2021) Experimental investigation of performance of PV array topologies under simulated PSCs. In: Applied soft computing and embedded system applications in solar energy. CRC Press, pp 47–64