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Shading Phenomenon Analysis for a Medium Size 3.8 kW Standalone PV System Connected in Series Parallel Configuration Using MATLAB Simulation

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Abstract

Photovoltaic array exhibits highly nonlinear electrical characteristics and the maximum power point tracking (MPPT) is always challenging. It becomes more complex during partial shading condition. The P-V array characteristics for shading condition have multiple maxima points and conventional MPPT technique fails to track global maximum power point. The operating point may settle at local points. In this paper, a medium size 3.8 kW PV system is simulated and shading effect on PV array is analyzed for different shading pattern. This PV array consisting of 64 (8×8) PV modules connected in series and parallel configuration of 60 W each. The dc-dc boost converter is used to control and operate above system at Global maximum power point (GMPP). The P-V and I-V characteristics are plotted using Matlab/ Simulink software platform and the simulation results are obtained to study shading effect.

Keywords: Photovoltaic (PV) module, Maximum Power Point Tracking (MPPT), partial shading, P&O (perturbation and observation)

INTRODUCTION

This The concerns of increasing demand for electrical energy and environment pollution the great attention is paid to a renewable energy source. Considering the environmental and technical constraints, the solar energy is becoming more popular. PV module is a device to generate electrical power. This PV generated system is formed by connecting number of PV modules in series and parallel to form an array. The electrical characteristics of PV array under different atmospheric conditions changes.

A PV generation system generally consists of solar array connected to load through a dc-dc converter that may be boost converter. The PV arrays with Boost dc-dc converter, which shall be employed in this paper, is shown in Figure1. In PV generation generally, a large number of PV modules are connected in series and parallel with bypass diode connected in parallel with each PV modules for protection. This PV array is subjected to shading phenomenon caused by earth's inclination with seasons, the presence of tall objects nearby PV modules.

In PV generation system, the insolation is not uniform throughout the day and moreover, some modules may be under shadow during the day time because of obstruction from long trees, tall buildings, cloudy conditions, poles, etc. present near the module layout. This shading causes a mismatch in the generation of modules output in each string and affects the overall efficiency of PV generation. The loss in generation due to shading can be found to be proportional to shaded area and location of PV module in a given array. A single PV module has low voltage and current rating. A 60 W PV module is considered for analysis. The modeling and parameter identification for PV systems is described by various researchers [1-2]

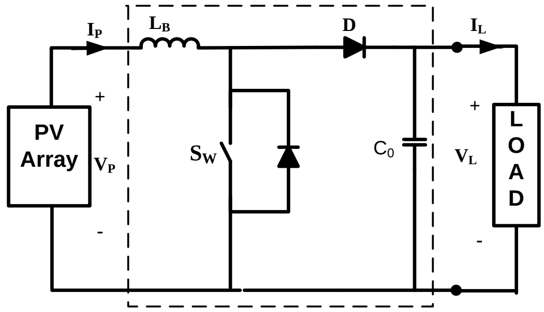


Figure 1: Circuit diagram of boost converter feed by PV system.

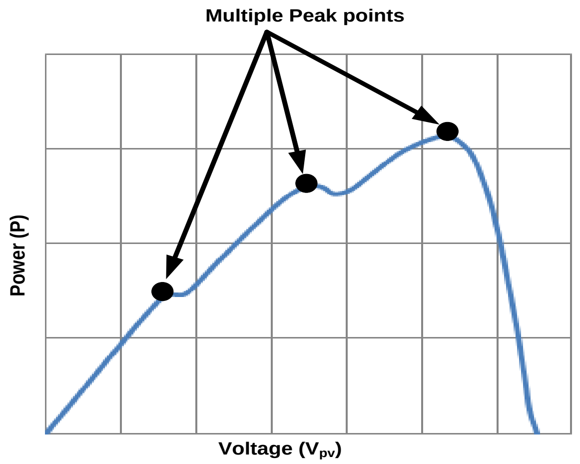


Figure 2: PV characteristics of array during partial shading conditions

Patel. H et.al. [4-5] has explained the different shading phenomenon for partial shading and also proposed a MATLAB based model to study the effects of partial shading on the characteristics of PV array. C. Manickam et.al [6-8] has implemented several evolutionary algorithms for GMPPT under partial shading conditions. Each algorithm has own advantage and limitation. A simulated annealing GMPPT approach [9] is also proposed for partial shading conditions. S. Mohanty et.al [10-11] has developed a Grey wolf optimization technique and compared results with P &O and Improved PSO MPPT methods.

Normally in experimental tests, all the modules in PV array are subjected to normal insolation and temperature and P-V characteristics have only one maximum point, but the PV array shows multiple peaks [12-17] in P-V characteristics under partial shading conditions as shown in Fig.2. The presence of multiple peak point makes it difficult to operate the system at Global Maximum Power Point (GMPP). The controller should be accurately designed otherwise the operating point may work stably on local maximum power point which is not a global maximum point and gives poor efficiency.

This paper investigates the shading effect in a small PV array comprising of sixty-four PV modules connected in the 8×8 array using boost converter. Section 2 describes the design of PV modules configurations using series and parallel configuration. The different groupings of PV array for different shading patterns are established for analysis. Section 3 explains the control strategy. Section 4 deals with the simulation PV system. Section 5 shows the simulation result and finally, conclusion is explained.

The detailed P-V and I-V characteristics and its analysis are presented. This will be highly beneficial for flexible controller development for partial shading conditions for GMPPT. Finally, this characteristic is obtained for four different shading patterns by dividing PV array into different groups for comparative study. Furthermore, group-wise characteristic for each shading pattern is also plotted for analysis. The block diagram for controlling the operating point of P-V characteristics is shown in Fig.3.

SYSTEM CONFIGURATION

A. Series and Parallel configuration of PV array A 8×8 PV array (3.84 KW) is formed by connecting PV panels in series and parallel arrangement for investigation, as shown in Fig 4. In this arrangement, eight modules are connected in series to form a string and these eight strings are connected parallel to form 8×8 PV array. Under normal operating condition, the P-V and I-V characteristics of 8×8 array shows only one peak point as shown in Fig.5. at 25 C and 100% insolation without shading effect.

B. Ratings of PV Array

A string is formed by connecting 8 PV panels in series. Hence overall open circuit voltage rating of PV array is given by

$$V_{pv} = 21.1 \text{ V}$$
$$V_{array} = 8 \times 21.1$$
$$= 168.8 \text{ V}$$

Now, these 8 stings are connected in parallel to form 8×8 PV array. Hence overall short circuit current rating of PV array is given by

$$I_{pv} = 3.8 \text{ A}$$
$$I_{array} = 8 \times 3.8$$
$$= 30.4 \text{ A}$$

The total power rating of PV array is calculated as

$$V_{pv} = 21.1 \text{ V}$$
$$P_{array} = 8 \times 8 \times 60$$
$$= 3.84 \text{ kW}$$

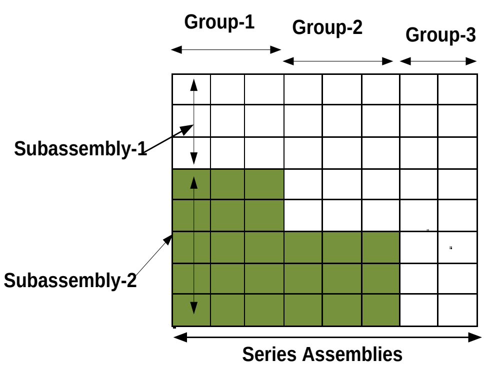


Figure 3: Grouping of PV array for partial shading analysis

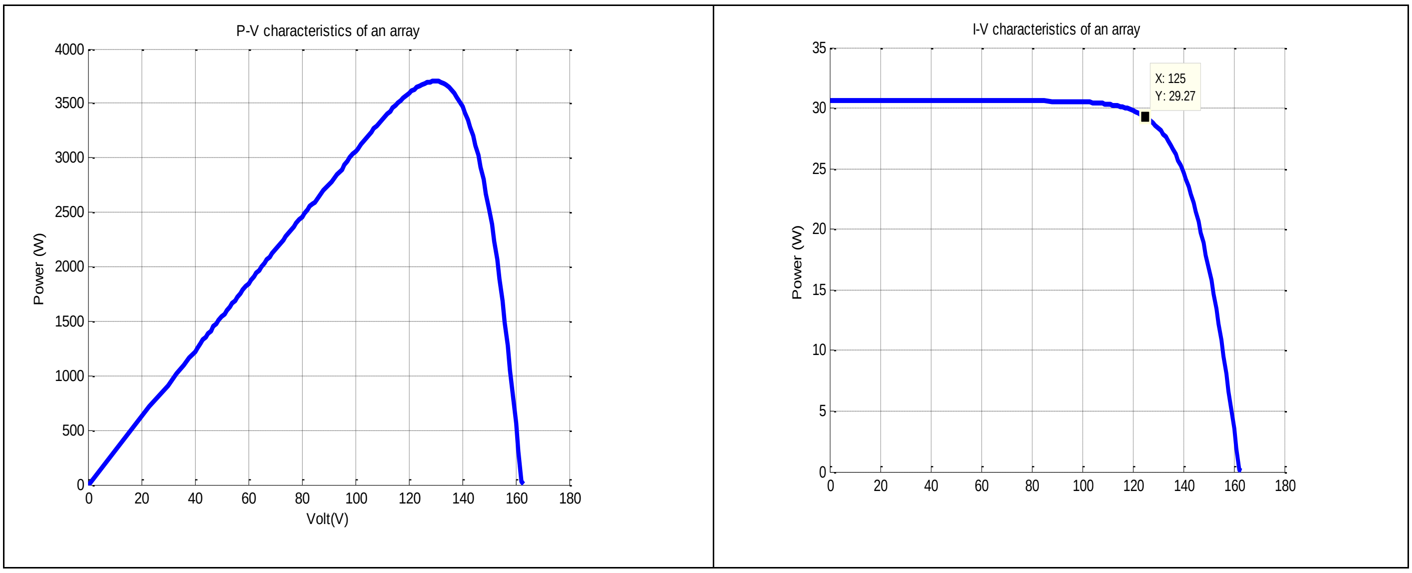


Figure 4: P-V and I-V characteristics of 8×8 PV array without shading and 100 % insolation condition

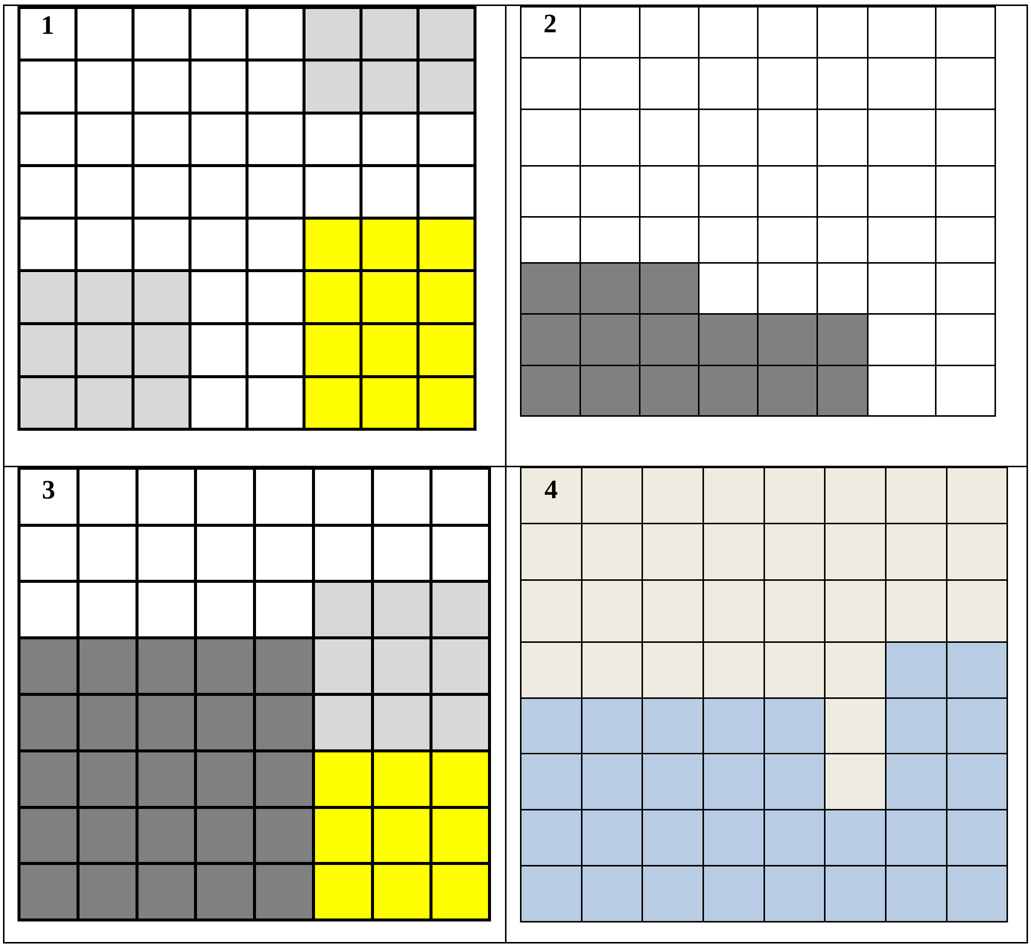


Figure 5: Different shading patterns observed for a 8×8 PV array

C. Grouping of PV Array

For partial shading effect analysis, grouping is done according to shading pattern. In this PV array, a series assembly is formed by connecting number of panels in series. Each series assembly is further divided into a number of subassemblies for a particular insolation and temperature level on the assembly. These numbers of series assemblies having the same pattern of shading, insolation and temperature are connected in parallel to form a group as shown in Fig 4.

The investigation for analysis of partial shading influence on PV system is carried out under non-uniform insolation and different shading pattern are shown in Fig.6. For analysis four shading pattern are considered at different insolation and temperatures levels. The detail grouping of an array for a particular shading pattern is shown in table III.

Table I. Single 60 W PV Module SPECIFICATIONS

S. No.	Electrical Characteristics of PV panel	Values
1	Maximum power point (Pmax)	60 W
2	Voltage at Pmax (Vmp)	17.1 V
3	Current at Pmax (Imp)	3.53 A
4	Short circuit current (Isc)	3.8 A
5	Open circuit voltage (Voc)	21.1 V

Table II. Different shading pattern with varying insolation and temperature

Shading Pattern	Group No.	Number of Subassembly	No. of panels in each subassembly	Temperature of an Assembly °C	Insolation (kW/m²)	Number of Assemblies in group
1	1	2	[5,3]	35,25	[1, 0.9]	3
	2	1	8	35	1	2
	3	3	[3,2,3]	[30,35,25]	[0.9, 1, 0.8]	3
2	1	2	[3,5]	[35,25]	[1,0.5]	3
	2	2	[6,2]	[35,25]	[1, 0.5]	3
	3	1	[8]	[35]	[1]	2
3	1	2	[3,5]	[35,25]	[1, 0.5]	5
	2	3	[2,3,3]	[35,30,30]	[1, 0.9, 0.8]	3
4	1	2	[4,4]	[40,30]	[0.9, 0.6]	5
	2	2	[6,2]	[40,30]	[0.9, 0.6]	1
	3	2	[3,5]	[40,30]	[0.9, 0.6]	2

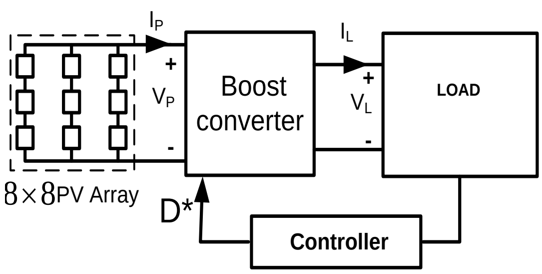


Figure 6: Block diagram showing PV array connected to load through boost converter and controller.

Control strategy of an PV Array

The block diagram of control scheme of PV system is shown in Fig.6. The boost converter acts as an intermediate platform to connect PV array and the load for control action. The effective electrical loading is controlled by varying the duty ratio (D*) of boost switch. The PI controller is used in feedback path for control action. The design specification of boost converter is shown in table II.

SIMULATION OF A PV ARRAY

Using MATLAB/Simulink software the 8×8 PV array system is simulated. The schematic diagram of complete system is shown Fig.7(a). The schematic diagram of subsystem for simulation of a single PV module is shown in Fig.7(b) Table III shows the parameters which are employed for simulation.

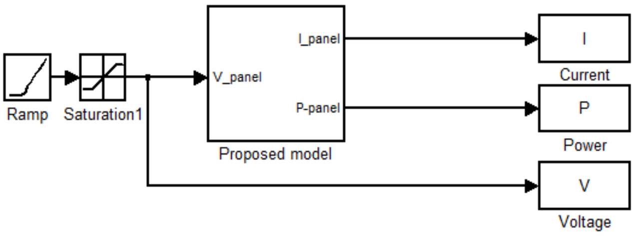


Figure 7(a): MATLAB Simulation model of PV Array for obtaining P-V and I-V characteristics.

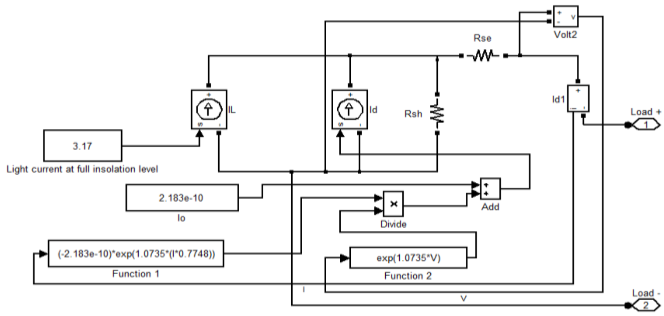


Figure 7(b): Simulation model of a PV panel under constant insolation

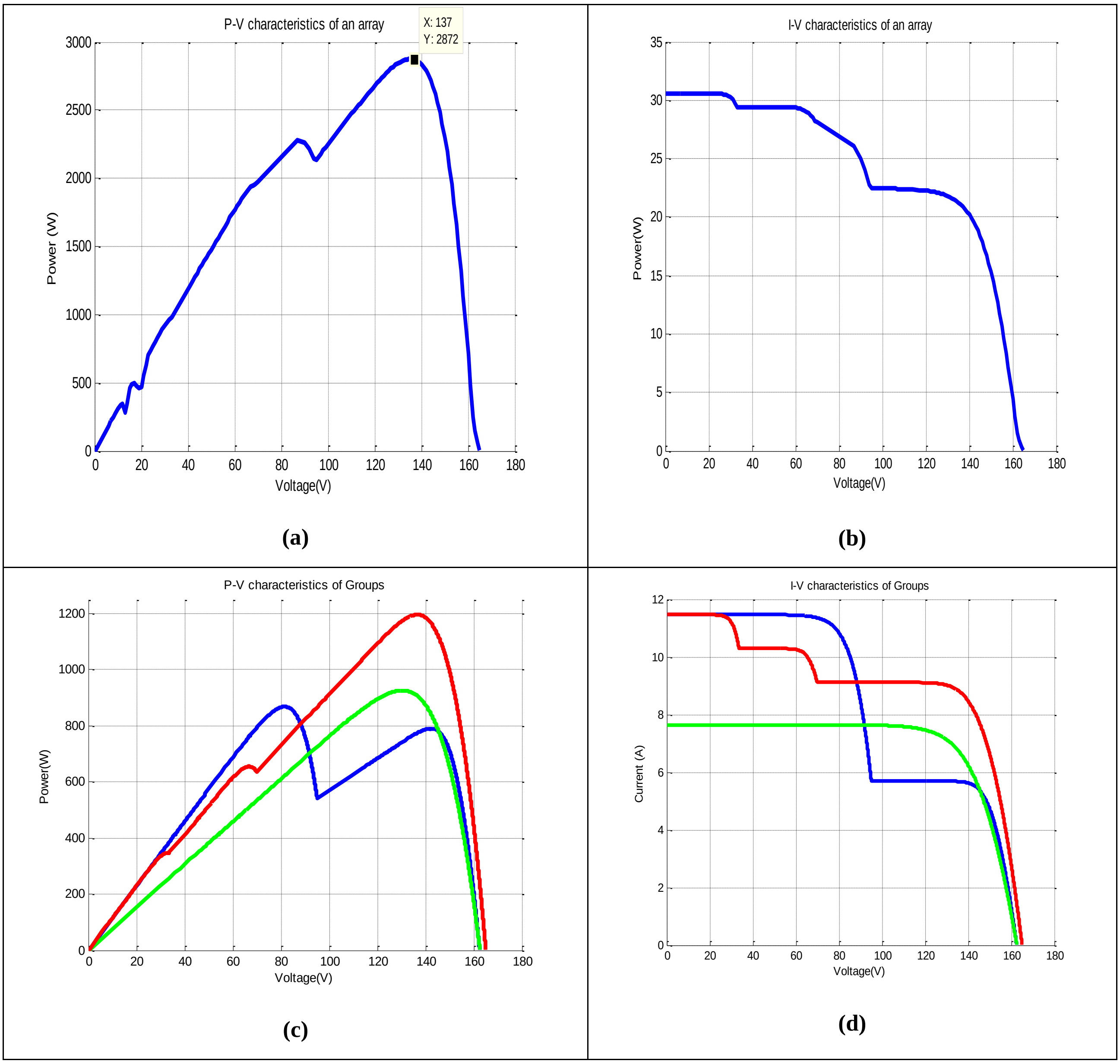


Figure 8 (a)-(b): P-V and I-V characteristics of the PV array under shading pattern-1

(c)-(d): P-V and I-V characteristics of individual groups of the PV array under shading pattern-1

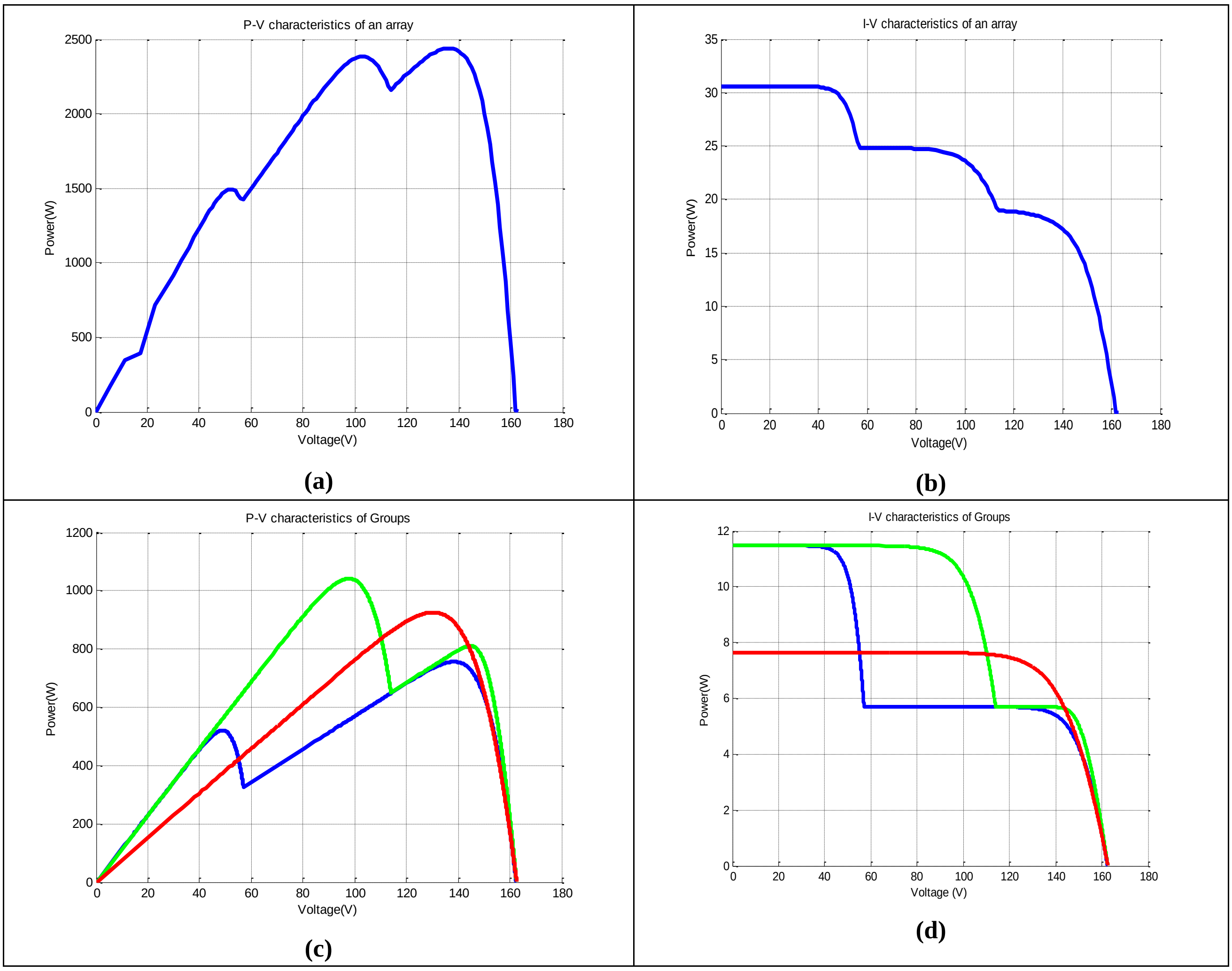


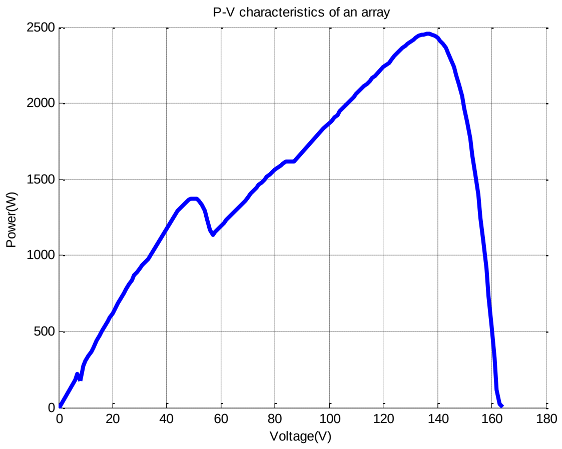
Figure 9 (a)-(b): P-V and I-V characteristics of the PV array under shading pattern-2
(c)-(d): P-V and I-V characteristics of individual groups of an array under shading pattern-2

RESULTS AND DISCUSSION

Fig.4 has shown the I-V and P-V characteristics of 3.84 kW PV array under standard test condition that all panels are subjected to 100 % insolation level with a constant temperature of 25° C. The four different shading patterns are studied. The electrical characteristics are highly non linear as given by Eqn. 1. Fig.3 shows the 8×8 PV module array connected in the series-parallel arrangement. This PV array is subjected to four different shading patterns which are graphically shown in Fig.5. and values are tabulated in Table 2. The effective load is changed by the varying duty ratio of boost switch and P-V curves are obtained. It shows that the multiple peak points are formed by different shading patterns and it becomes more complex to control the operating point.

CONCLUSIONS

This paper has analyzed the effect of shading on a 8×8 PV array for four different shading patterns. A MATLAB simulation model is developed to obtain the P–*V* and I–*V* characteristics of a PV array, having a large number of series-parallel connected modules, under partially shaded conditions. The PV curves show multiple peaks points under partially shaded conditions. Therefore utmost care must be taken for controller design to operate at the global peak point. Many times the controller operates stably at local peak points under partial shading conditions. The position of the global peak is dependent on the shading pattern formed along with commonly known factors, i.e., insolation level and temperature. A dc-dc boost converter is used to interface PV array to the load to vary the operating point by varying the duty ratio of boost switch and track the global peak point. Hence this control scheme is used for shading analysis and helps in predicting global peak point. This scheme can be implemented for large PV system for peak power tracking. These curves can be useful in designing the GMPPT algorithm for maximum power operation of large PV system.



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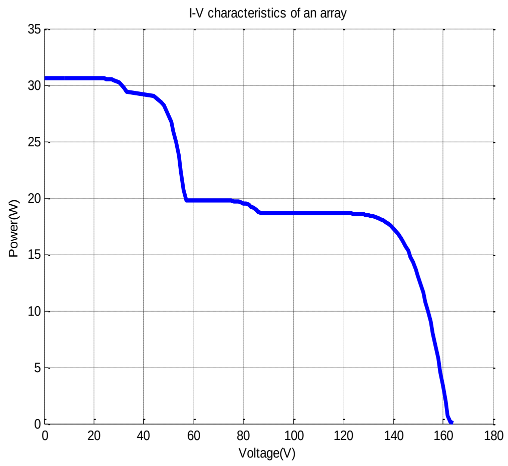

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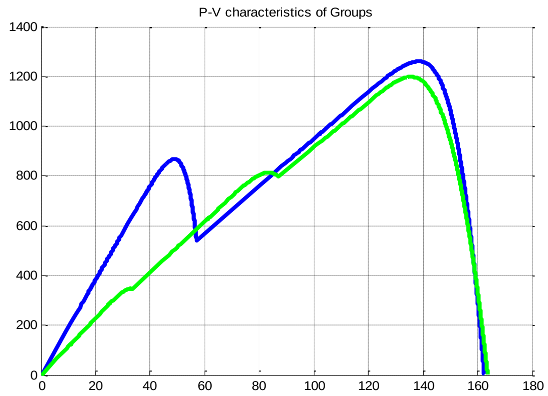
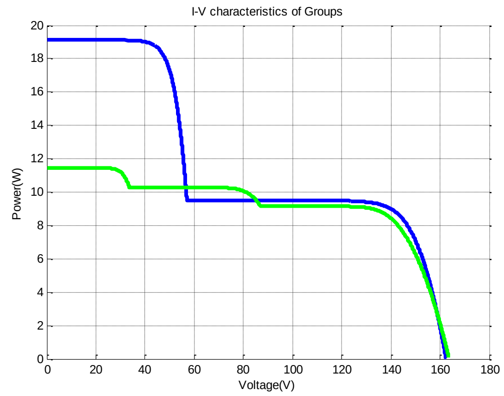
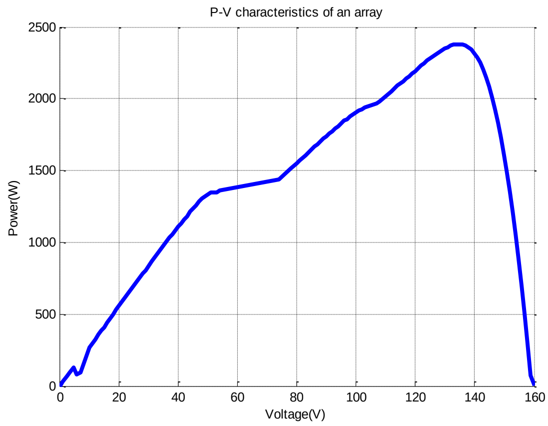


(c)

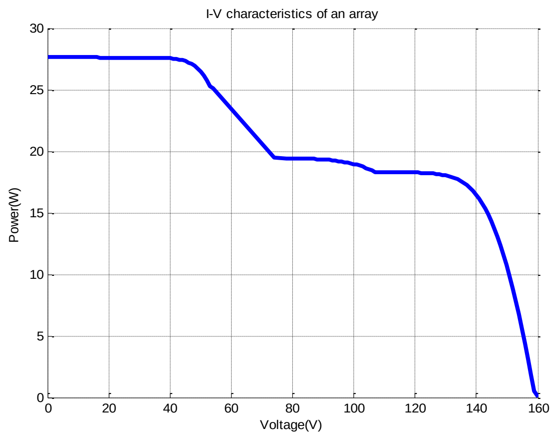


(d)

Figure 10 (a)-(b): P-V and I-V characteristics of the PV array under shading pattern-3
(c)-(d): P-V and I-V characteristics of individual groups of an array under shading pattern-3



(a)



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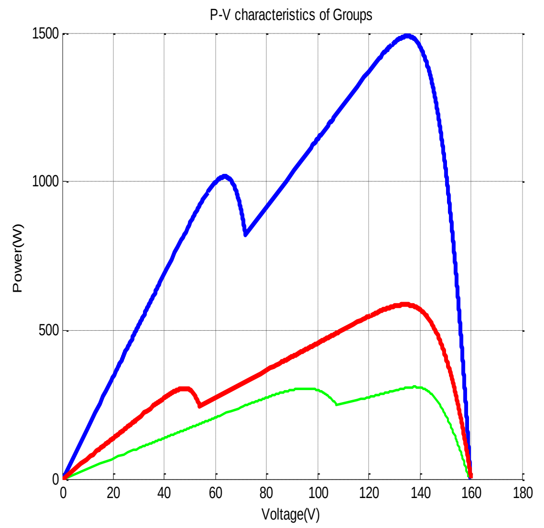
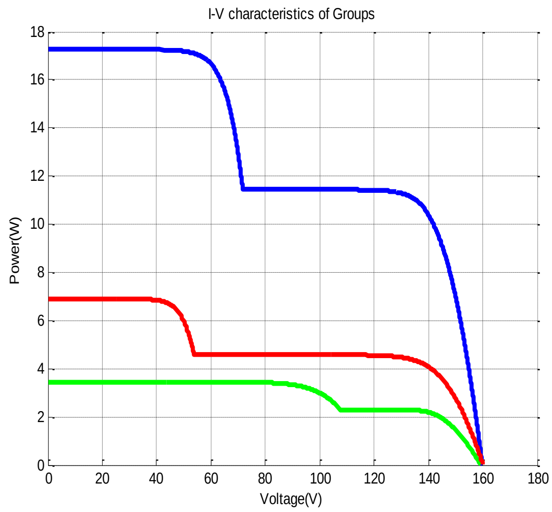


(c)



(d)

Figure 11 (a)-(b): P-V and I-V characteristics of the PV array under shading pattern-4
(c)-(d): P-V and I-V characteristics of individual groups of an array under shading pattern-4

Table III: Boost converter parameters

S. No.	Boost converter specification	Symbol	Values
1	Input voltage	V_i	140-170 V
2	Output voltage	V_o	200-240 [V]
3	Switching frequency	f_S	10 [kHz]
4	Main inductor	L_B	5 [m H]
5	Output capacitor	C_0	1000 [µ F]
6	Input capacitor	C_i	50 [µ F]
7	Power	P	3.84 KW

REFERENCES

[1] L. N. Rao and S. Gairola, "Modeling and Constant Power Operation of Photovoltaic (PV) Module Employing PSO," *International Conference on Electrical, Electronics, Signals, Communication and Optimization EESCO*, Jan. 24th & 25th 2015. Visakhapatnam, India

[2] D. Dondi, D Brunelli, L. Benini, P. Pavan and L. Larcher, " Photovoltaic cell modeling for solar energy powered sensor networks," *IWASI, International workshop on Advances on sensors and interface*. 2007. 26th -27th June, 2007, Bari, Italy.

[3] J.S. Ramos, H. M Ramos, " Solar powered pumps to supply water for rular or isolated zones: A case study," *Science direct Energy for sustainable Development* 13, pp. 151-158, 2009.

[4] Patel. H and Agarwal V. "MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics," *IEEE Transactions on Energy Conversion*, vol. 23, no.1, pp. 302-310, March 2008

[5] Patel. H and Agarwal. V. "Maximum Power Point Tracking Scheme for PV Systems Operating Under Partially Shaded Conditions,", *IEEE Transactions on Industrial Electronics*, vol. 55, no.4, pp.1689-1698, April 2008

[6] C. Manickam, G. P. Raman, G. R. Raman, S. I. Ganesan and N. Chilakapati, "Fireworks Enriched P&O Algorithm for GMPPT and Detection of Partial Shading in PV Systems," in IEEE Transactions on Power Electronics, vol. 32, no. 6, pp. 4432-4443, June 2017.

[7] C. Manickam, G. R. Raman, G. P. Raman, S. I. Ganesan and C. Nagamani, "A Hybrid Algorithm for Tracking of GMPP Based on P&O and PSO With Reduced Power Oscillation in String Inverters," in IEEE Transactions on Industrial Electronics, vol. 63, no. 10, pp. 6097-6106, Oct. 2016.

[8] C. Manickam, G. P. Raman, G. R. Raman, S. I. Ganesan and N. Chilakapati, "Efficient global maximum power point tracking technique for a partially shaded photovoltaic string," in IET Power Electronics, vol. 9, no. 14, pp. 2637-2644, 11 16 2016.

[9] S. Lyden and M. E. Haque, "A Simulated Annealing Global Maximum Power Point Tracking Approach for PV Modules Under Partial Shading Conditions," in IEEE Transactions on Power Electronics, vol. 31, no. 6,

pp. 4171-4181, June 2016.

[10] S. Mohanty, B. Subudhi and P. K. Ray, "A Grey Wolf-Assisted Perturb & Observe MPPT Algorithm for a PV System," in IEEE Transactions on Energy Conversion, vol. 32, no. 1, pp. 340-347, March 2017.

[11] S. Mohanty, B. Subudhi and P. K. Ray, "A New MPPT Design Using Grey Wolf Optimization Technique for Photovoltaic System Under Partial Shading Conditions," in IEEE Transactions on Sustainable Energy, vol. 7, no. 1, pp. 181-188, Jan. 2016.

[12] M. Kolhe, J.C. Joshi and D.P. Kothari, " Performance analysis of a directly coupled photovoltaic water pumping system," *IEEE Transactions on energy conversion* vol. 19, no.3, pp. 613-618, Sep 2004

[13] M. A. S. Masoum, H. Dehbonei, and E. F. Fuchs, "Theoretical and experimental analyses of photovoltaic systems with voltage and current-based maximum power-point tracking," *IEEE Trans. Energy Conversion.*, vol. 17, no. 4, pp. 514–522, Dec. 2002.

[14] 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. Industrial electronics.*, vol. 56, no. 5, pp. 1548–1556, May. 2009.

[15] W. Xiao, N. Ozog and W. G. Dunford "Topology study of Photovoltaic interface for maximum power point tracking" *IEEE Transactions on Industrial Electronics,* vol. 54, no. 3, pp. 1696–1703. Jun. 2007.

[16] M. Abdulkadir, A. H. M. Yatim, and S T. Yusuf, "An improved PSO-Based MPPT control strategy for photovoltaic systems," *International journal of photoenergy Hindawi Publishing Corporation*, vol. 2014. http://dx.doi.org/10.1155/2014/818232

[17] L Navinkumar Rao and S Gairola, "Analysis of Shading influence on Modeling of Standalone PV Array System for Optimal Power Output," IJEEE, vol. 7, Issue no.1, pp. 30-42, (Jan-Jun 2015). ISSN (Print): 2321-2055 (E)