The Journal of CPRI,
Vol. 12, No.4, December 2016 pp. 797-805

Experimental implementation of 100 W Photovoltaic Panel with DC-DC Boost Converter for Maximum Power Point Tracking

Hareesh M*, Amarnath C** , Siva Kumar G*** and Sreenivasarao D****

The performance of a photovoltaic (PV) module is affected by irradiance and temperature. Often, it is also affected by partially or completely shaded conditions by passing clouds. This paper presents a MATLAB/Simulink^TM based model to study the I–V and P–V characteristics of a PV panel under partially shaded and non-shaded conditions. And also, Maximum Power Point Tracking (MPPT) of PV module by DC-DC boost converter is explained. The design of boost converter parameters and its affect on power tracking of the PV module are explained. The perturbation and observation (P&O) method is implemented for maximum power extracting from PV panel, because of its easy implementation. The P&O algorithm tune the dc-dc boost converter duty cycle to ensure that PV system operates at MPPT. A 100 W Photovoltaic (PV) panel with dc-dc boost converter is implemented practically for experimental validation. This work is extended for tracking of MPPT during shading conditions also. The P and O algorithm is implemented in DSpace, in which the output power of PV panel compared for every sampled time by varying the duty cycle in small steps.

Keywords: *Boost converter, Maximum Power Point Tracking (MPPT), Perturb and Observe (P&O), PV panel.*

1.0 INTRODUCTION

In recent years, enormous attention has been given to power generation from renewable sources, mainly due to the increased demand in power consumption, as well as the ecological and economic impacts caused by power generation from non-renewable energy sources, such as fossil fuels. For this reason, electrical power generation from renewable energy sources, such as hydro power, biomass, wind, sea, solar, and others, has increased considerably. Among different renewable energy sources, the photovoltaic (PV) source becomes the eye candy for power researchers due to its abundant availability, low running cost and pollution free. The power generated from PV system is not constant throughout the day, it is always varying with weather conditions, i.e., irradiation and temperature. Furthermore, the conversion efficiency of solar energy is very low which is only in the range of 9-17% [1], [2], especially under low irradiation states. When, a load is connected at the output of PV cell, it draws power but it is not maximum power because of non-linear characteristics of PV cell. The maximum power can be extracted at one particular voltage and current only, this point is called Maximum Power Point (MPP).

Different MPP tracking techniques are proposed for operating the PV module at maximum power

*Research Scholar, Dept. of Electrical Engg., NIT Warangal, TS - 506004, hari247.sol@gmail.com
** Execute trainee, Power Grid Corporation of India Ltd.(POWERGRID), Delhi., chinthaamarnath@gmail.com
*** Assistant Professor, Dept. of Electrical Engg., NIT Warangal, TS - 506004, gsivakumar@nitw.ac.in
**** Assistant Professor, Dept. of Electrical Engg., NIT Warangal, TS - 506004,srinudee@nitw.ac.in

[3]–[5]. These algorithms are differ from each other in terms of number of sensors used, complexity in algorithm and cost to implement the algorithm. Among different MPPT techniques available, the most popular techniques are Hill Climbing (HC) [6] and Perturb & Observe methods [7]. The HC method involves a perturbation in the duty ratio of the power converter. In case of a PV module connected to a power converter, perturbing the duty ratio of the power converter perturbs the PV module current and consequently perturbs PV module voltage.

The P&O method involves a perturbation in the operating voltage of the solar module. In P&O method, the voltage is being increased or decreased with a fixed step size in the direction of reaching the MPP. It is the most popular because of the simplicity of its control structure [8], [9]. The PV panel generated voltage is low in magnitude so it is connected to dc-dc boost converter. The boost converter act as voltage amplifier and also it is useful for integration with a high voltage dc grid. In this paper, a simulink based PV model is developed instead of mathematical model. The maximum power from the photovoltaic system is extracted with the help of MPPT technique. P&O algorithm is implemented for MPP tracking. The P&O algorithm operate the boost converter in such away to extract maximum power. A 100 W Photovoltaic (PV) panel with dc-dc boost converter is implemented practically for experimental validation. This work is extended for tracking of MPPT during shading conditions also.

2.0 PV MODULE MODELLING

The Photovoltaic (PV) is a p-n junction fabricated in the semiconductor. The P-V and I-V characteristics of PV module are nonlinear in nature and changing with solar irradiation and temperature. The P-V and I-V characteristics are explained with different mathematical equivalent circuit models in literature [10]. Here, the characteristics are explained with a photovoltaic simulation model.

2.1 Simulation model of PV Module

The basic available solar cell block in MATLAB™ simulation is shown in Figure 1. It has three terminals: positive, negative and irradiation. The inside parameters of the solar cell are short circuit current, open circuit voltage, rated irradiance, number of cells connected, series resistance and rated temperature. The solar cell parameters are chosen from the specification of standard 100 W Photovoltaic panels.

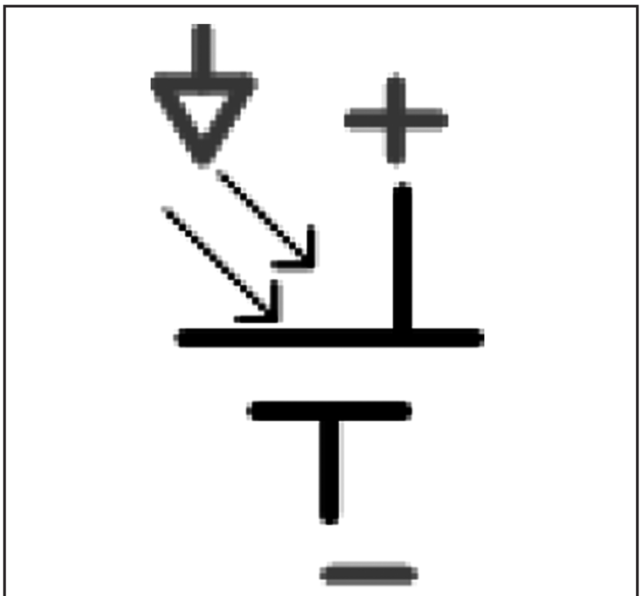

FIG.1. SOLAR CELL

The PV module characteristics are drawn using simulation model of PV system instead of a mathematical model of PV module. The simulation model of PV module is shown in Figure 2. The current sensor and voltage sensor are used for measurement of current generated and voltage across the PV module. The PS-Simulink Converter is used to change respective voltage and current quantity to a unitless quantity. A variable rheostat is connected as a load. The V-I and P-V characteristics are obtained by varying the rheostat value from zero to high value nothing but from short circuit to open circuit condition using ramp signal. A constant block gives the irradiation to the solar module. The PV characteristics at different irradiations can be obtained by varying constant block values. The I-V and P-V characteristics are drawn in XY Graph and XY graph1 respectively.

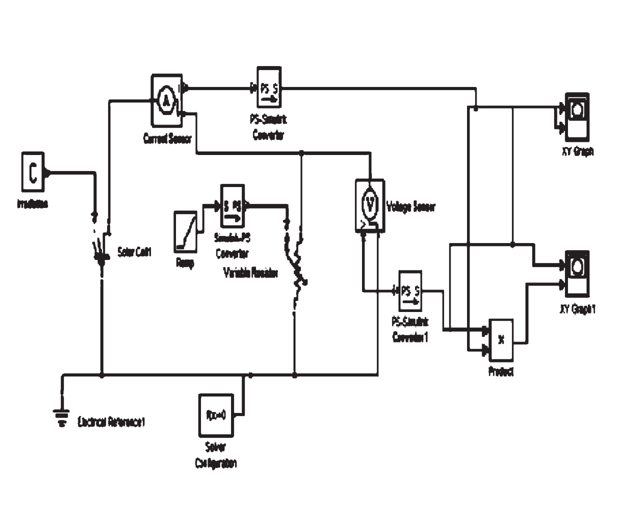

FIG. 2 SIMULATION MODEL OF PV MODULE.

2.2 PV Module Characteristics

The I-V and P-V characteristics curves obtained from simulation are shown in Figure 3 and Figure 4 respectively at irradiation 1000 W/m^2. The PV module

characteristics are non-linear in nature, so maximum power is extracted from the PV module only at one particular voltage and current, it is observed from Figure 3 and Figure 4. The voltage and current corresponding to maximum power (Pmax) are named as Vmax and Imax respectively. The ratio of Vmax and Imax gives resistance (RMPP) at maximum power. The maximum power from PV module is extracted when the load resistance equal to input resistance of PV module.

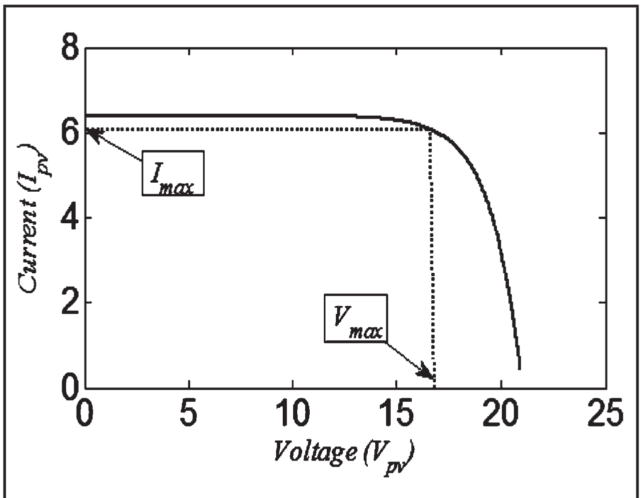

FIG. 3 I-V CURVE AT IRRADIATION (1000 W/M2)

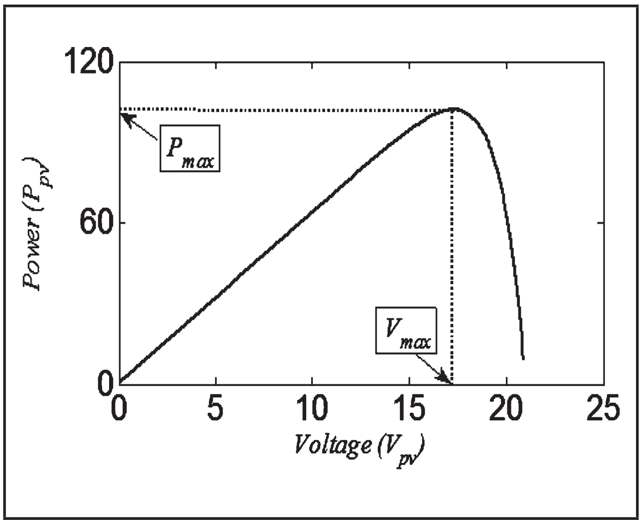

FIG. 4 P-V CURVE AT IRRADIATION (1000 W/M2)

3.0 PRACTICAL DESIGN OF BOOST CONVERTER PARAMETERS

The voltage obtained from PV module is low, so to interface with the grid, the voltage should be boosted to a higher value. Here, a dc-dc boost converter is developed to boost the PV module voltage. The dc-dc stage is also useful for extracting maximum power from PV module by varying duty cycle. The dc-dc boost converter integration with the solar module is shown in Figure 5.

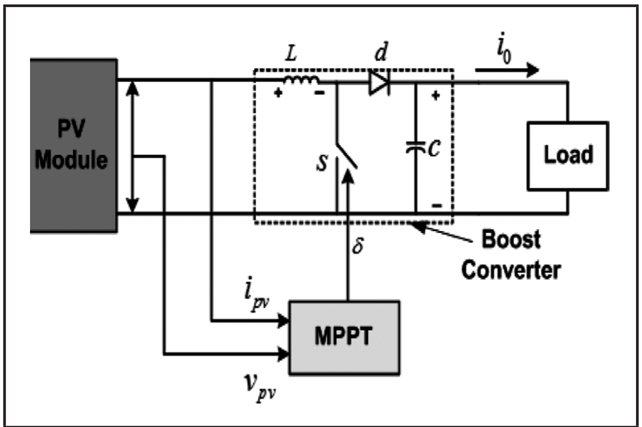

FIG. 5 BOOST CONVERTER FED BY PV MODULE

The components of boost converter are inductor (L), switch (s), diode (d) and filter capacitor (c). The gate signal for switch (s) is generated from MPPT algorithm. The switch and diode are chosen based on reverse blocking voltage capacity. In practical implementation IRF 640 switch and

MUR850 diode are taken because of their high reverse voltage capability. The capacitor value is choose based on ripple voltage, here electrolytic capacitor of rating 1000 micro Farads is taken. The inductor is designed based on following steps:

(a) First selected a suitable inductor core depending on required core area.

(b) The copper gauge wire wound on EE core is taken based on rated current flowing through the inductor at steady state condition. As the current is high, low gauge wire should be used which has a high diameter.

(c) The number of turns (N) required for the inductor value is calculated from,

$$N = \frac{LI_m}{A_c B_m}$$

Where L is inductor value, Im is maximum current flowing through the inductor, Ac is cross section area of inductor core, Bm is flux density of inductor core. Ferrite core is taken which has Bm = 0.2 T. The practically designed boost converter parameters are mentioned in Table. I.

TABLE 1

BOOST CONVERTER PRACTICAL PARAMETERS

Parameters	Values
Inductance	2 mH
Capacitance	1000 F
Load resistance	26 ohm
MOSFET	IRF 640N
Diode	MUR 860

4.0 MAXIMUM POWER POINT TRACKING ALGORITHM

The MPPT is achieved by varying the duty cycle of boost converter. The advantage of the boost converter is, it can change the input impedance by varying the duty cycle (D). The derivation of input impedance (Ri) of boost converter as follows,

$$V_0 = \frac{V_i}{\left(1-D\right)} \quad ...(1)$$

$$I_0 = I_i\left(1-D\right) \quad ...(2)$$

$$R_i = \frac{V_i}{I_i} \quad ...(3)$$

$$R_i = \frac{V_0}{I_0}\left(1-D\right)^2 \quad ...(4)$$

$$R_i = R_L\left(1-D\right)^2 \quad ...(5)$$

The effect of boost converter input impedance on the PV system is shown in Figure 6. From equation (5) as D is varied from 0 to 1, Ri varies from RL to 0. The range of Ri is [RL , 0] as D is [0 , 1]. As the input impedance is bounded, it has some limitations in getting of maximum power from PV module. To overcome this problem for any value of irradiation and temperature, the RMPP value lies in the range of 0 to RL. The I-V characteristic of PV module is shown in Figure 6, from which if the resistance (RL) is lies in the capturing zone i.e. RL > RMPP, in that condition only PV module gives maximum power. If RL lies in non-capturing zone i.e. RL < RMPP for any value of D, PV module does not reach maximum power. In detailed explanation, if the load resistance is RLA which is at point A on the curve. For any value of D, the resistance RLA does not reaches RMPP at point B. Similarly if the load resistance is RLC, which is at point C as D decreases it can slowly reaches point B where PV module gives maximum power.

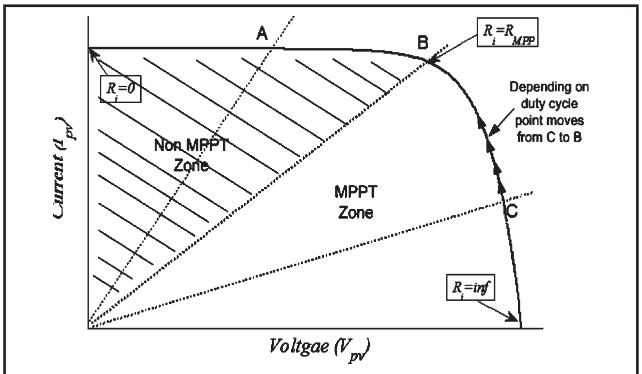

FIG. 6 EFFECT OF BOOST CONVERTER INPUT IMPEDANCE ON MPP TRACKING.

4.1 PERTURB AND OBSERVE METHOD

The objective of MPPT algorithm is to extract the maximum power (Pmax) corresponding to current

(IMax) and voltage (VMax) of PV module under a specified irradiance and temperature. In this paper, Perturb and Observe (P & O) method is developed for MPPT tracking. The flow chart of P&O method is shown in Figure 7. First, initialize the power and voltage values to zero and the duty cycle value other than zero because it decreases the time taken to reach the maximum power point. The increment is nothing but change in duty cycle if the increment value is low the oscillation around the maximum power is low. The voltage (Vk) and current (Ik) are measured by using LEM sensors. The Power is obtained from the product of voltage and current. The differential values dP and dV are the change in power and change in voltage between the present and previous values, respectively. Four possible conditions to be check by algorithm which is shown in flowchart. If dP > 0 and dV < 0 means the present instant power is on right side of MPP, so an increament is added to duty cycle to reach the MPP. If dP > 0 and dV > 0 means the present instant power on left side of MPP and it can reached by decreasing the duty cycle. Similarly for other two cases (dP < 0, dV < 0 and dP < 0, dV < 0) also the duty cycle is varied to reach the MPP. At the end of the cycle, the present values are exchanged with previous values, and the cycle continues. The duty cycle is used to control the boost converter, such that maximum power is extracted from PV module.

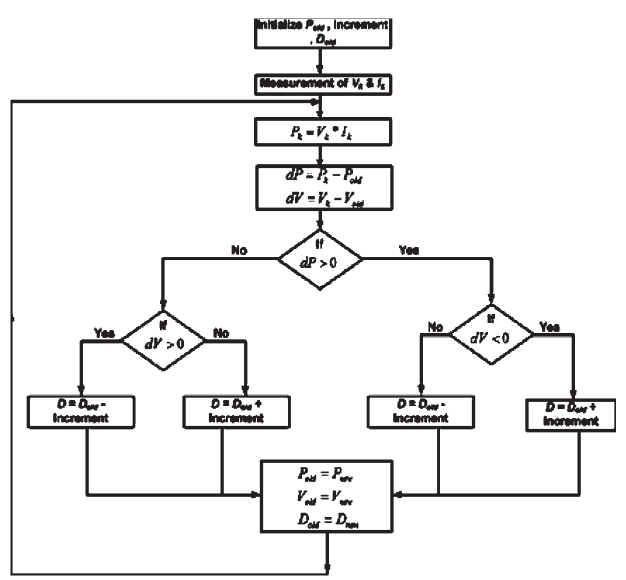

FIG. 7 FLOW CHART OF PERTURB AND OBSERVE ALGORITHM.

5.0 SIMULATION RESULTS

In simulation model, the MPPT algorithm is verified for both constant irradiation and partial shading conditions. The standard specifications of the 100 W PV module at Standard Temperature Pressure (STP) are given in Table. II.

TABLE 2

SPECIFICATIONS OF PV MODULE AT STP

Parameters	Symbol	Values
Irradiance	G_{reat}	1000 W/m^2
Temperature	T_{ref}	25 ^{O}C
Short Circuit Current	I_{SC}	6.4 A
Open Circuit Voltage	V_{OC}	21 V
Voltage at MPP	V_{MPP}	17 V
Current at MPP	I_{MPP}	6 A
Power at MPP	P_{MAX}	100 W

The designing of PV system is in such a way that, it will reach maximum power in worse condition of irradiation. The selection of output resistance of boost converter is mainly effected the maximum power tracking from the PV system. The output resistance of the boost converter is greater than RMPP in worse condition of irradiation as explained in section-4. The boost converter parameters are designed such that, for any value of duty cycle it will operate in a continuous mode of operation. Otherwise, it will affect the MPPT of PV module. The simulation model of PV system along with boost converter is shown in Figure 8. The sensed power and voltage of PV module are given to the P&O algorithm. Based on the P & O algorithm, it will generate duty cycle. This is compared with the triangular carrier signal to generate pulses. These pulses are applied as gating signal to the switch of the boost converter.

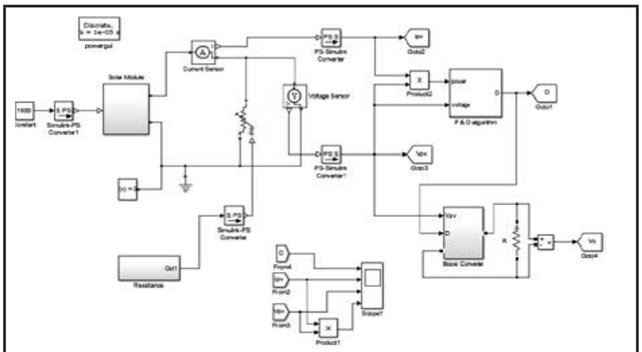

FIG. 8 SIMULATION MODEL OF MPPT WITH BOOST CONVERTER USING P & O ALGORITHM.

The tracking path of MPP for two different irradiances is shown in Figure 9. Initially, it is operating at 600 W/m^2 irradiation the voltage and power values are at B. Because of P&O algorithm, the duty cycle is increased when the change in power is positive, and change in voltage is negative until it reaches maximum power at point A. After reaching the maximum power, it oscillates around point A. In this simulation after t = 2 sec the irradiation is changed to 1000W/m^2, then the power is increased from point A to point C. It follows the same procedure until it reaches maximum power at point D.

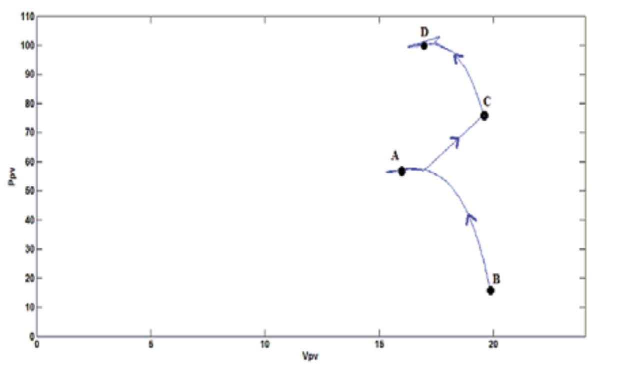

FIG. 9 MPP TRACKING PATHS DURING CHANGE OF IRRADIANCE

The MPPT tracking for different irradiations at 600 W/m^2 and 1000 W/m^2 with P&O algorithm are shown in Figure 10. Initially for irradiance 600 W/m^2, the tracking starts from open circuit voltage and slowly the voltage decreasing and current increasing by varying duty cycle up to maximum power reaches. As shown in Figure 10, after reaching maximum power it maintained constant up to further change in irradiance at t = 2 sec.

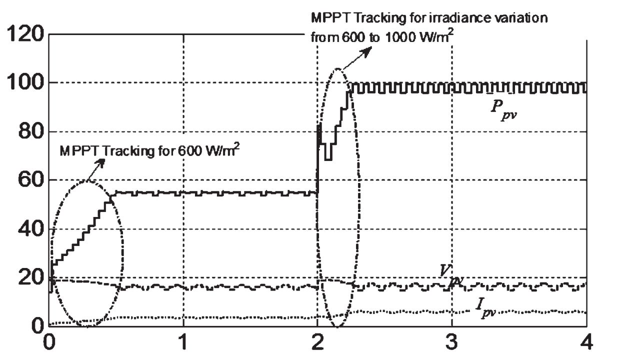

FIG. 10 PV MPP TRACKING AT DIFFERENT IRRADIANCE

The input and output powers of boost converter are shown in Figure 11 for different irradiance. Initially, the irradiance is chosen as 600 W/m^2 during which the input power to boost converter represented with thick line is greater than output power represented with dotted line because of losses in the converter. Similarly for irradiance 1000 W/m^2, the input is greater than output as shown in Figure 11.

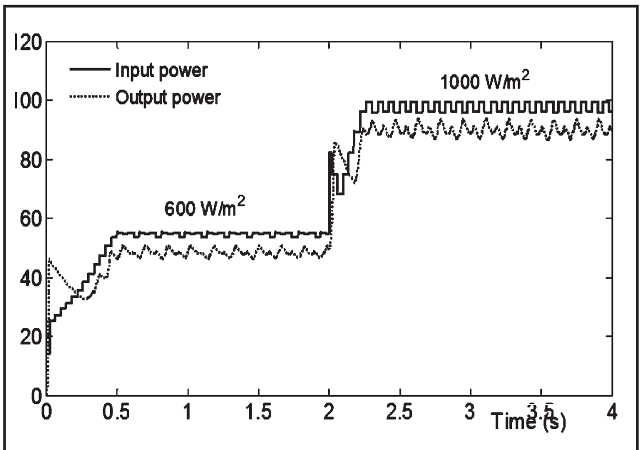

FIG. 11 INPUT AND OUTPUT POWER OF BOOST CONVERTER AT DIFFERENT IRRADIATION

The voltage applied to boost converter and output voltage are shown in Figure 12 for different irradiances. The output voltage is boosted according to duty cycle generated from P&O algorithm. The input and output currents are shown in Figure 13 for different irradiance. Even, the input current is having oscillations; these are suppressed by L-filter at the output side of boost converter.

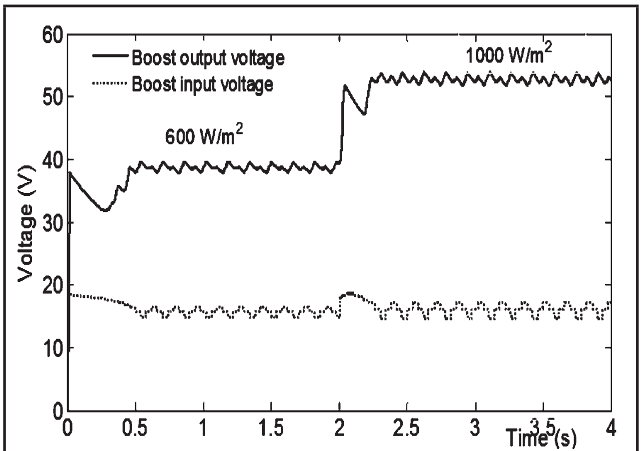

FIG. 12. INPUT AND OUTPUT VOLTAGES OF BOOST CONVERTER AT DIFFERENT IRRADIANCES

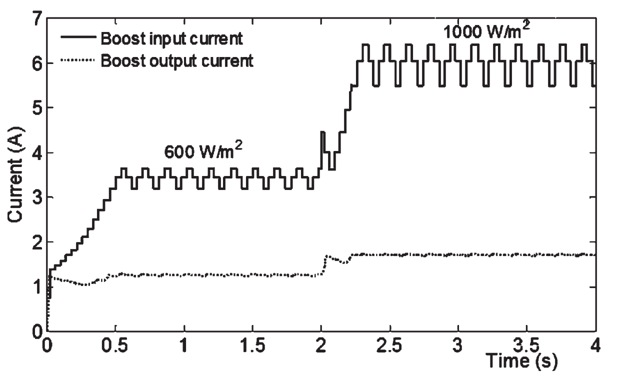

FIG. 13. INPUT AND OUTPUT CURRENTS OF BOOST CONVERTER AT DIFFERENT IRRADIANCES

6.0 EXPERIMENTAL RESULTS

6.1 PV Characteristics

A Photovoltaic panel of 100 W and its parameter specifications are shown in Figure 14. The solar irradiance is measured by using Pyranometer, which is shown in Figure 14. A rheostat of range 0 Ω to 26 Ω is connected to the panel to get practical I - V and P - V characteristics of PV panel. Initially, the resistance offer by rheostat is at high position, so voltage obtained from PV panel is very close to open circuit voltage. By changing the resistance of rheostat, the voltmeter and ammeter reading are noted. This process is continued up to short circuit position of PV panel. The Panel I - V and P - V characteristics are drawn for the above noted values, and these graphs are shown in Figure 15 and Figure 16 respectively. The maximum power of 38 W can be extracted corresponding to 11.6 V at irradiance of 500 W/m^2.

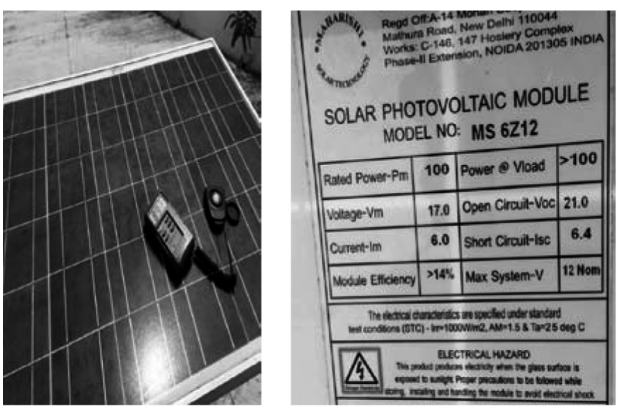

FIG. 14. A SOLAR PANEL OF 100 W AND ITS PARAMETERS

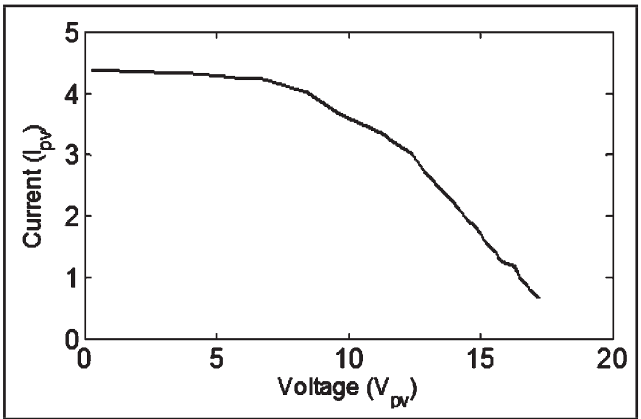

FIG. 15. I - V CHARACTERISTICS FROM PRACTICAL DATA

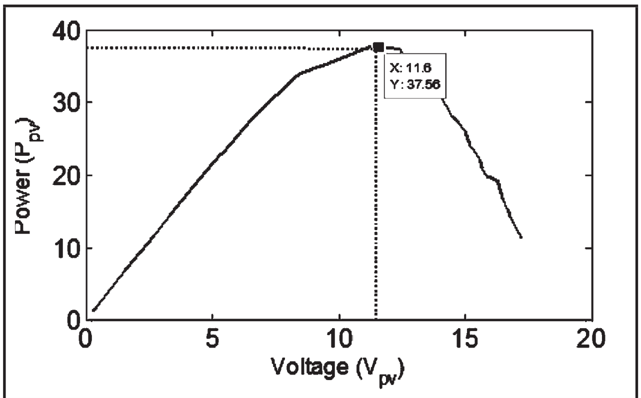

FIG. 16. P - V CHARACTERISTICS FROM PRACTICAL DATA

6.2 MPPT Tracking Setup

The total experimental setup along with dc-dc boost converter power circuit is shown in Figure 17. The circuit breaker isolates the power circuit from the solar panel and also protects the solar panel when the current more than rated current. Hall Effect sensors are utilized to sense the voltage and current of the solar panel. The reduced outputs of sensors are given to the dSPACE^{TM} through ADC ports. The power and voltage are given to the MPPT algorithm developed in DSpace. The P&O algorithm output is duty cycle, which varies at duty cycle perturbation of 0.02. The selection of duty cycle perturbation depends on the dynamics of boost converter [4]. A driver circuit is developed with IC 3120, which increases the power level of gate signal obtained from DSpace. The power level signal is applied as a gate signal to the switch of the boost converter.

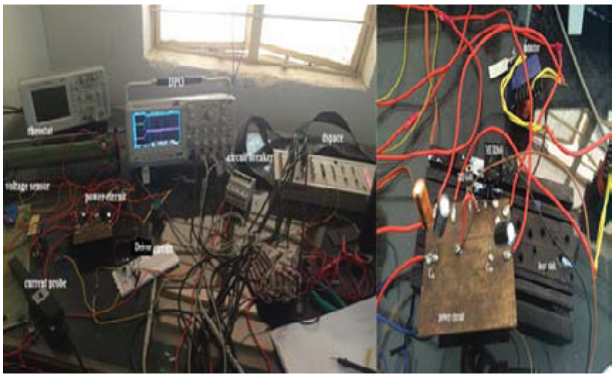

FIG. 17. EXPERIMENTAL SETUP AND BOOST CONVERTER POWER CIRCUIT

The solar panel current, voltage, input and output powers of the dc-dc converter are shown in Figure 18. Even the switch of boost converter is OFF position initially, there is path for input to output so solar panel is delivering power (not equal to maximum power) to the load. If the gating pulse obtained from control algorithm is applied to switch of the dc-dc boost converter, the maximum power is delivered to load by tracking MPPT as shown in Figure 18 after t = t1. The steady state values of PV panel current (Ipv), PV voltage (Vpv), PV power (Ppv) and boost output power (P0) are shown in Figure 19.

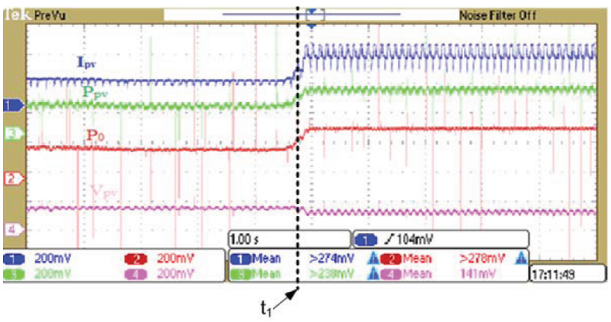

FIG. 18 MPPT TRACKING PERFORMANCE.

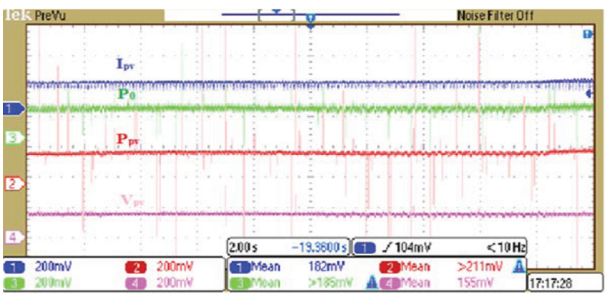

FIG. 19 STEADY STATE WAVEFORMS AFTER REACHING THE MPPT

In order to study the shading effect on MPP tracking, some part of the solar panel is shaded. The tracking performance of MPPT with shading and without shading conditions is shown in Figure 20. It consists of PV panel current (Ipv), PV voltage (Vpv), PV power (Ppv) and boost converter output power (P0). Initially, a gating pulse is not given to switch of the boost converter and also the panel is shaded, so MPPT is not tracked up to time t1. After gate pulse applied to switch, maximum power is extracted from PV panel, which is observed in between time t1 and t2. The shading is removed at time t2 so that the maximum power increases after time t2 at the same time the PV panel current (Ipv) is increases and voltage (Vpv) is deceases but the overall power (Ppv) increases. The output power (P0) of boost converter also increases. The extracted power from PV panel increases with the current increase and voltage decrease like in simulation, which shows that the P&O algorithm is working properly.

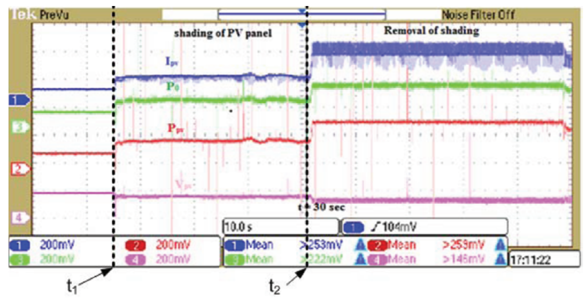

FIG. 20 MPPT TRACKING DURING SHADING AND NON-SHADING CONDITIONS.

The steady state values of PV panel current (Ipv), boost converter output power (P0), PV power (Ppv) and PV panel voltage (Vpv) are shown in Figure 21 for irradiation of G = 815 W/m2.

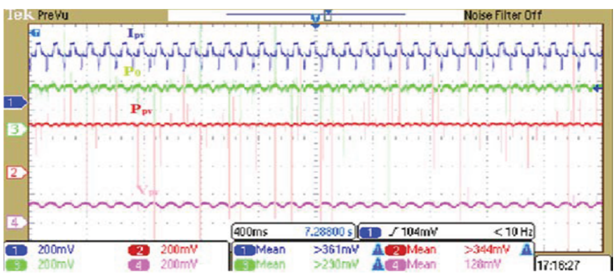

FIG. 21 PV PANEL CHARACTERISTICS UNDER G = 815 W/M2 AT T= 430OC.

7.0 CONCLUSIONS

MATLAB-Simulink model of solar system and experimental setup for Maximum Power Point Tracking (MPPT) of 100 W Photovoltaic (PV) panel with dc-dc boost converter is implemented. The practical design specifications of boost converter parameters are explained. The tracking of MPP for different radiation is discussed. The practical performance of photovoltaic panel during shading condition is analyzed.

REFERENCES

[1] M. A. Eltawil and Z. Zhao, “MPPT techniques for photovoltaic applications,” Renew. Sustain. Energy Rev., Vol. 25, pp. 793–813, 2013.

[2] J. M. Enrique, E. Duran, M. Sidrach-de-Cardona, and J. M. Andujar, “Theoretical assessment of the maximum power point tracking efficiency of photovoltaic facilities with different converter topologies,” Sol. Energy, Vol. 81, No. 1, pp. 31–38, 2007.

[3] T. Esram and P. L. Chapman, “Comparison of photovoltaic array maximum power point tracking techniques,” IEEE Trans. Energy Convers. EC, Vol. 22, No. 2, p. 439, 2007.

[4] R. Faranda and S. Leva, “Energy comparison of MPPT techniques for PV Systems,” WSEAS Trans. power Syst., Vol. 3, No. 6, pp. 446–455, 2008.

[5] E. Koutroulis, K. Kalaitzakis, and N. C. Voulgaris, “Development of a microcontroller-based, photovoltaic maximum power point tracking control system,” IEEE Trans. power Electron., Vol. 16, No. 1, pp. 46–54, 2001.

[6] T. J. Liang, Y. C. Kuo, and J. F. Chen, “Single-stage photovoltaic energy conversion system,” IEE Proceedings - Electric Power Applications, Vol. 148, No. 4. pp. 339–344, 2001.

[7] J. J. Nedumgatt, K. B. Jayakrishnan, S. Umashankar, D. Vijayakumar, and D. P. Kothari, “Perturb and observe MPPT algorithm for solar PV systems-modeling and simulation,” in 2011 Annual IEEE India Conference, pp. 1–6, 2011.

[8] H. Patel and V. Agarwal, “MATLAB-based modeling to study the effects of partial shading on PV array characteristics,” IEEE Trans. energy Convers., Vol. 23, no. 1, pp. 302–310, 2008.

[9] A. Reza Reisi, M. Hassan Moradi, and S. Jamasb, “Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review,” Renew. Sustain. Energy Rev., Vol. 19, pp. 433–443, Mar. 2013.

[10] B. Subudhi and R. Pradhan, “A comparative study on maximum power point tracking techniques for photovoltaic power systems,” IEEE Trans. Sustain. Energy, Vol. 4, No. 1, pp. 89–98, 2013.