Performance of PV System for Maximum Power Point Tracking

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Abstract-In this paper, performance of proposed Perturb & Observe (P&O) and Incremental Conductance (IncCond) algorithms to Maximum Power Point Tracking (MPPT) for photovoltaic (PV) systems have been analyzed critically. Based on above design methodologies, a PV module of maximum voltage 32.9V, maximum current 8.2A and maximum power 200W is simulated. The output of a solar panel depends on solar insolation and temperature. Also a power electronic converter is required to interface the solar panel output to the ac grid. A step up DC to DC converter circuit is modeled for simulation implementing algorithms Perturb & Observe and Incremental Conductance. Under different insolation conditions characteristics equations for the output current generated by a solar panel is studied and verified. From results the efficiency of the Incremental Conductance algorithm is slightly more than Perturb & Observe algorithm and it has reached to the maximum value in shorter time duration (0.02 second) while due to high tracking efficiency and simplicity Perturb & Observe algorithm is probably the most preferred maximum power point tracking technique. The work deals with the solar panel to operate at maximum power point and improve the efficiency of photovoltaic system applications.

Keywords-Solar photovoltaic generation module, Perturb & Observe (P&O) algorithm, Incremental Conductance (IncCond) algorithm and DC to Dc converter.

I. INTRODUCTION

In recent developments there is an increased demand of renewable energy in the consumption of electric power. The primary sources of electric power of fossil fuels cause environmental pollution. So, a transition from conventional energy system to more clean and secure energy is the need of the now. From this point of view the renewable energies attract for more and more attention. The most common renewable energy source in use is solar energy [1]. The energy from sunlight is converted in to DC from Photovoltaic cells. Photovoltaic has added advantages to other renewable energy sources that it gives no noise and no requires maintenance [2].

Power generation from solar source provides a realistic form has been carried out. Many studies on the use of renewable energy sources for power generation have been presented already. Due to its unpredictable nature the solar energy system is highly unreliable. To analyze the reduction in the fuel consumed the photovoltaic panel has been incorporated with a diesel electric system. The other energy source can compensate the difference when the sources are unavailable or insufficient in meeting the load demands [3].The renewable energy power sources are connected to the boost converter in the rectification of DC/DC converter by maximum power point tracking controller; due to the environmental factors the above systems have a problem.

In general, the environmental conditions highly depend on the energy generation in PV modules, despite their energy conversion efficiency, manufacturing technology, etc. The fluctuation mainly caused by passing clouds, adequately affects the module characteristics and changes the amount of electrical current generated by the module to the amount of received solar irradiance [3]. For the mentioned variations in the electrical power generated by photovoltaic (PV) module cause their efficiencies to be reduced and therefore larger systems are required to generate the desired amounts of electrical power. Taking the mentioned negative effects into consideration, application and development of appropriate methods to enhance the energy generation by the systems have obtained a significant importance for an efficient use of solar energy generation systems [3], [4]. Maximum power point tracking as one of the reveal methods has been subjected to numerous research and various techniques have been proposed by researchers [4]. Despite the differences in their performance and working principles, the aim of maximum power point tracking techniques is to extract the maximum power from photovoltaic modules under liable to change environmental conditions by operating them at their maximum power point. Perturb and Observe algorithm is the most widely preferred maximum power point tracking technique due to its efficacy and simplicity. The algorithm predominantly compares the photovoltaic power before and after the control parameter due to perturbation and decides on the next perturbation [5]. Therefore, the fixed step size perturbation in the conventional Perturb and Observe algorithm causes the algorithm to suffer from oscillations near maximum power point. Smaller perturbation steps decrease oscillations while larger perturbation steps increase the maximum power point tracking speed. Use of perturbation steps variable has been proposed by numerous researchers to reduce the problem of oscillation and hence enhance the maximum power point tracking efficiency [6].

This paper has implemented the two most common algorithms to evaluate the performance of Perturb and Observe and Incremental Conductance maximum power point tracking. Mathematical model of a solar cell has been simulated to analyze the characteristics of the Photovoltaic module. A boost DC to DC converter is utilized where the main criteria on the selection of this topology has been the appropriateness of this converter for applications of grid connected system. The parameters of photovoltaic (PV) module consider for comparison are input voltage, maximum power and efficiency.

II. MAXIMUM POWER POINT TRACKING (MPPT) ALGORITHM

For efficiency improvement and development methods have been considered by numerous researchers and number of maximum power point tracking techniques has been proposed [7]. By operating the photovoltaic system at its maximum power point (Pmax) the common principle of operation of these methods is that all of them

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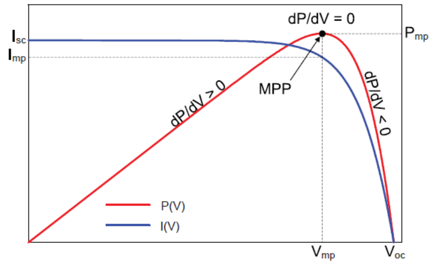

Fig. 1: Variation of $fracdPdV$ on the power and voltage characteristic of a PV module

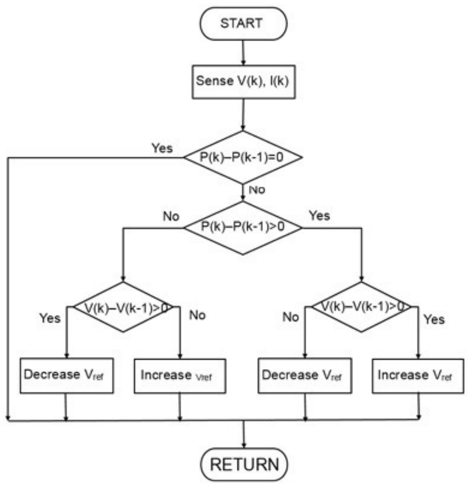

Fig. 2: Flowchart of the Perturb & Observe maximum power point tracking algorithm

enhance the system efficiency. Perturb & Observe and Incremental Conductance find the greatest application among the mentioned methods. The principle of operation of these two methods is briefly described in this section.

A. Perturb & Observe (P&O) Algorithm

Perturb & Observe algorithm is one of the Hill-Climbing maximum power point tracking techniques. Perturb & Observe algorithm tracks the maximum power point of the module with respect to the sign of $fracdPdV$. Fig. 1 shows the variation of $fracdPdV$ on the power and voltage characteristic of a photovoltaic module.

Above characteristics from the Fig. 1, $\frac{dP}{dV} < 0$ for the operating points on the right side of the maximum power point and $\frac{dP}{dV} > 0$ for operating points on the left side of the maximum power point. The variations in $\frac{dP}{dV}$ observes algorithm perturbs voltage by a constant value. If $\frac{dP}{dV} > 0$, it means the perturbation is in a forward direction and it reaches the maximum power point. If $\frac{dP}{dV} < 0$, it means that the operating point is getting far from the maximum power point, therefore, the next perturbation will be in the reverse direction. Above procedure continues the maximum power point until it reached, this means that the module operates at V_{mp} point. Due to high tracking efficiency and simplicity this method is probably the most preferred maximum power point tracking technique in the literature [7]. Low tracking efficiency under rapidly changing solar irradiation conditions and oscillations around the maximum power point are the disadvantages of this technique. In the literature efficiency of this technique has been reported over 90% [6]. Fig. 2 shows the flowchart of the Perturb and Observe maximum power point tracking algorithm.

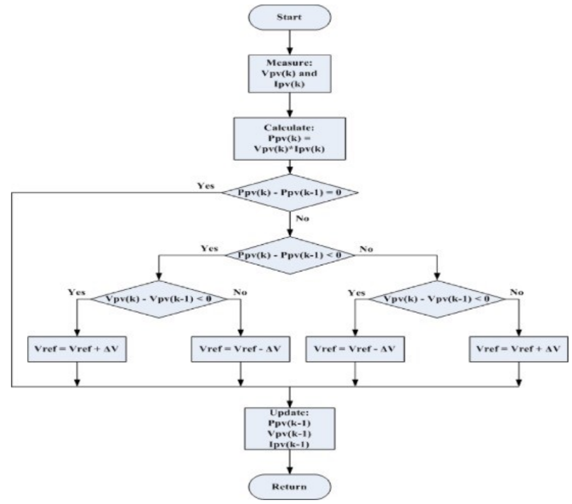

Fig. 3: Flowchart of the Incremental Conductance maximum power point tracking algorithm

B. Incremental Conductance (IncCond) Algorithm

An improvement in the Perturb & Observe algorithm introduced as another Hill-Climbing method is Incremental Conductance method. The maximum power point tracking by this algorithm is comparing the current-voltage characteristics of the module and its incremental conductance $\frac{dI}{dV}$ using by the following expression (1) and (2),

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \tag{1}$$

$$\left|\frac{dP}{dV}\right| I = I_m, V = V_m = 0; \left|\frac{dP}{dV}\right| I = I_m, V = V_m = -\frac{I_m}{V_m} \tag{2}$$

where, V_m -MPP voltage of the array, I_m -MPP current of the array.

The Incremental Conductance uses the photovoltaic array's incremental conductance $\frac{dI}{dV}$ to compute the sign of $\frac{dP}{dV}$ [6]. It does this using an expression derived from the condition that, at the maximum power point, $\frac{dP}{dV} = 0$. Beginning with this condition, it is possible to show that, at the maximum power point $\frac{dI}{dV} = -\frac{I}{V}$ [7].

The Incremental Conductance algorithm has the ability to determine the distance to the maximum power point, therefore stop the perturbation and tracking procedure after reaching the maximum power point [8]. Above mentioned property the oscillations around the maximum power point theoretically reduces by this algorithm. But practically it is observed that still oscillations exist around the maximum power point completely is not always achieved. Although higher accuracies are achieved with respect to the Perturb & Observe algorithm [9], under the fast changing environmental conditions this algorithm still has the low tracking efficiency [10]. Fig. 3 shows the flowchart of the Incremental Conductance maximum power point tracking algorithm.

III. Modeling Blocks of System Components

The main component of modeling system is shown in Fig. 4, for maximum power point tracking algorithm performance evaluation.

A. Mathematical Modelling of Solar Photovoltaic (SPV) cell

The mathematical model of single diode solar cell is used to simulate the photovoltaic module. Due to its simplicity and wide area of application, this model is preferred. The equivalent circuit of

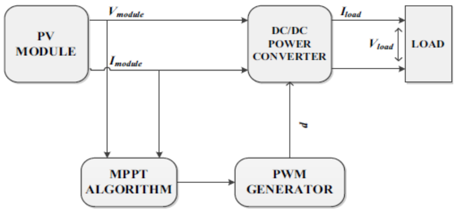

Fig. 4: Model of system components

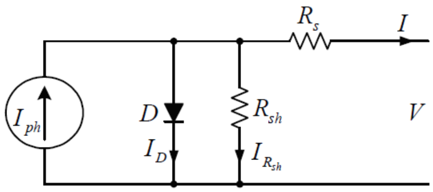

Fig. 5: Equivalent circuit of single diode solar cell

the single diode solar cell model is shown in Fig. 5.

The output current (I) is given by equation (3)

$$I = I_{ph} - I_0(e^{\frac{v+iRs}{NsV_t}} - 1)\frac{v + iRs}{R_{sh}N_s} \quad (3)$$

Thermal voltage:

$$V_t = \frac{AkT_{STC}}{q} \quad (4)$$

The simulated results of power- voltage (P-V) curve, current-voltage (I-V) curve and different insolation of power-voltage (P-V) curve presented in Fig. 6, Fig. 7 and Fig. 8 respectively.

The boost DC to DC converter is used in this paper for suitability of grid connection. The diagram of electrical circuit of a boost DC to DC converter is shown in Fig. 9. From Fig. 9it is clear that boost converter circuit consists of an inductor, a switch, a diode and a capacitor.

The boost DC to DC converter operates in two modes:

The 1^{st} mode operations switch is turned on i.e. t = T_{ON} and the rising input current flows through the inductor and the switch and the energy is stored in the inductor.

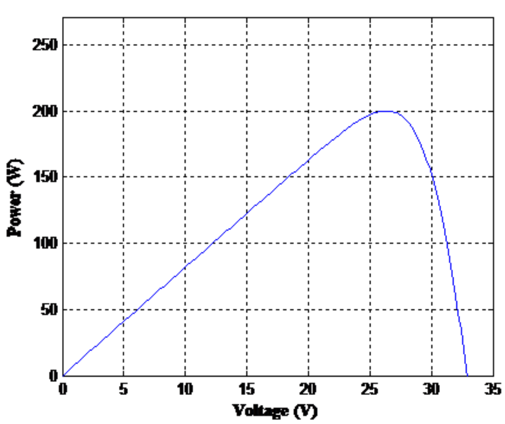

Fig. 6: Power-voltage (P-V) curve of Solar module

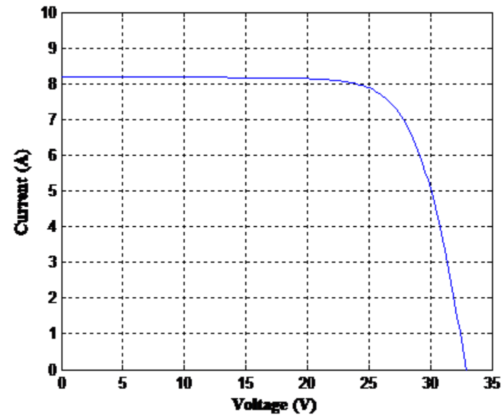

Fig. 7: Current-voltage (I-V) curve of Solar module

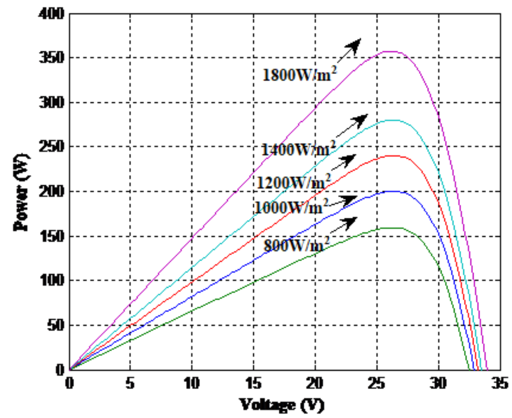

Fig. 8: Different insolation of power-voltage (P-V) curve of solar module

The 2^{nd} mode operations switch is turned off i.e. t = T_{OFF} and current flows through the inductor, diode, capacitor and the load. The inductor current falls until the beginning of the next cycle of operation and the energy is transferred to the load.

The output voltage can be described in terms of input voltage by the following equation (5),

$$V_O = \frac{V_{in}}{(1-\alpha)} \quad (5)$$

where, α = Duty cycle.

B. Modeling of Maximum Power Point Tracking Algorithm

The proposed models of the Perturb & Observe and Incremental Conductance maximum power point tracking algorithms are

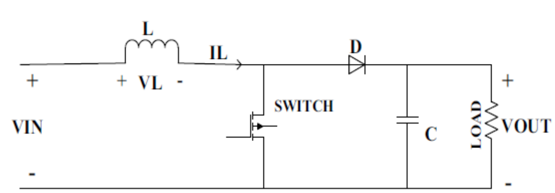

Fig. 9: Electrical circuit diagram of a boost DC to DC converter

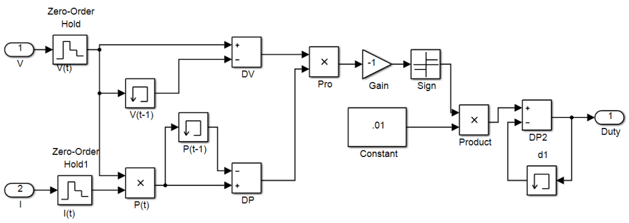

Fig. 10: Model of Perturb & Observe maximum power point tracking algorithm

constructed based on the flowcharts of the mentioned algorithms as explained in Fig. 2 and Fig. 3, respectively. The simulation models are shown in Fig. 10 and Fig. 11, respectively.

IV. Simulation Results

This research paper has carried out the simulation with both Perturb & Observe and Incremental Conductance maximum power point tracking algorithms. The Matlab/simulation model is run for 0.1 second under standard temperature condition (Ambient Temperature =250$^{\circ}C$ and $G = 1000W/m^2$,). Emphasize the value and improving effects of maximum power point tracking application results are compared with the results carried out from the simulation system.

A model of Boost DC to DC converter using Perturb & Observe maximum power point tracking algorithm and complete model is presented in Fig. 12.

Model of Boost DC to DC converter using Incremental Conductance maximum power point tracking algorithm is shown in Fig. 13.

From simulation results, both algorithms have same amount of power delivered to the load while the Incremental Conductance algorithm output power has been slightly higher than the Perturb & Observe algorithm.

The evaluation of efficiency and comparison is performed by given equation (6),

$$= \frac{Pout}{Preal} \qquad (6)$$

where, P_{real} = Under test condition available maximum power The simulation results of output power without and with maximum power point tracking algorithm and their efficiencies of the maximum power point tracking algorithms for both Perturb & Observe and Incremental Conductance are shown in Fig. 14 & Fig. 15 respectively.

Simulation result presented in Fig. 14 shows the operating point of the photovoltaic with Incremental Conductance algorithm represents at the right side of the maximum power point while the Perturb & Observe algorithm operates the photovoltaic at the left side of the maximum power point. It is also showed that the operating point without application of maximum power point trackers of open circuit. It is showing that maximum power point tracking algorithms have enhanced the overall efficiency greater than 72% of the system.

Simulation result presented in Fig. 15 shows the efficiency for both of the algorithms is more than 92%. It is also observed that the efficiency of the Incremental Conductance algorithm is slightly more than Perturb & Observe algorithm and it has reached to the maximum value in shorter time duration (0.02 second).

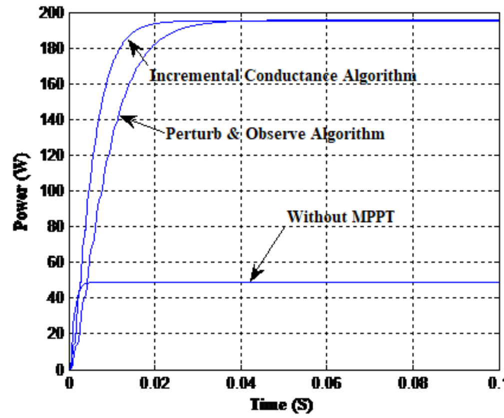

Fig. 14: Output power with and without MPPT Algorithm

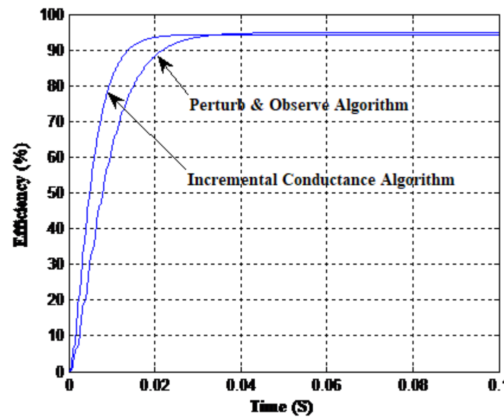

Fig. 15: Efficiency of MPPT Algorithm

TABLE I: Simulation Result (Numerical value)

Parameter	P&O Algorithm	IncCond Algorithm	Without MPPT
V_{in} (V)	32.9	32.9	47
P_{max} (W)	198.6	198.9	48.55
Efficiency (η%)	93.49	94.56	22.10

Tab. I shows the numerical data for simulation of Perturb & Observe and Incremental Conductance algorithms. In view of the simulation results together with the advantages and disadvantages of Perturb & Observe and Incremental Conductance algorithms, a tracking system which simultaneously tracks the maximum power point of the photovoltaic modules using both Perturb & Observe and Incremental Conductance algorithms may be indicated as a practical solution. Depending on the application requirement and environmental conditions maximum power point tracking system can control and compare the outputs of the mentioned methods and pick the appropriate maximum power point tracking method. Therefore, most reliable and efficient control can be given to take the merits of each individual maximum power point tracking method under application requirements and environmental conditions.

V. Conclusion

The Perturb & Observe method is the simplest maximum power point tracking method. The Incremental Conductance method is an improvement to the Perturb & Observe method and it has a quite complex structure. The results of simulation verified under identical insolation conditions both of the methods have nearly same efficiencies greater than 92%. The presented simulation results,

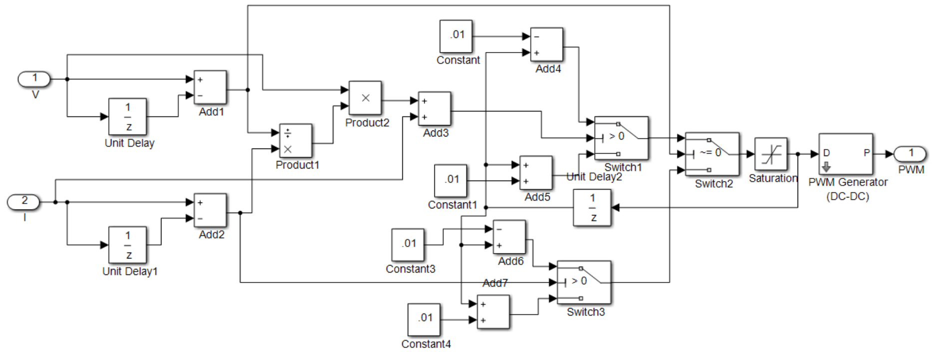

Fig. 11: Model of Incremental Conductance maximum power point tracking algorithm

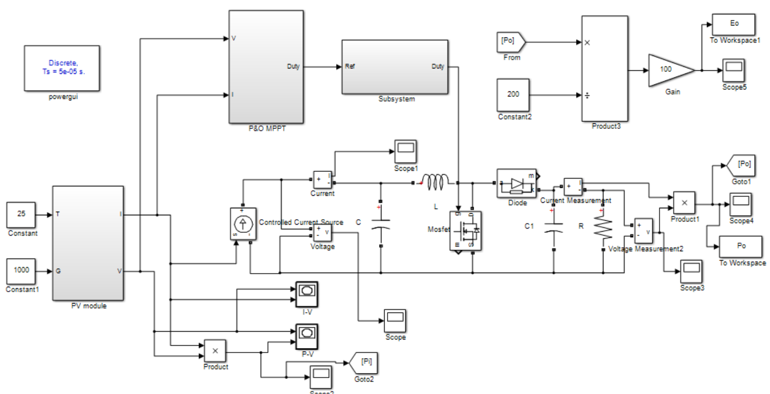

Fig. 12: Model of Boost DC/DC converter using P&O MPPT algorithm

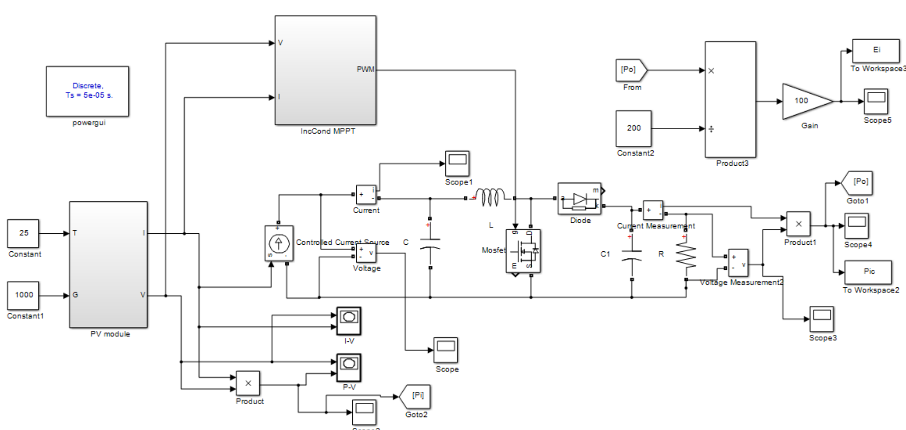

Fig. 13: Model of Boost DC to DC converter using Incremental Conductance maximum power point tracking algorithm

shown slightly better performance by Incremental Conductance method in tracking the maximum power point tracking of the solar photovoltaic (SPV) system. It is shown and observed that the output power of the Incremental Conductance method reaches to the maximum power point in a shorter time duration (0.02 second) as compared with the Perturb & Observe algorithm which takes more time duration (0.03 second). The high tracking and its simple structure efficiency makes the Perturb & Observe algorithm to be the most preferable one and can utilize maximum power point tracker for solar photovoltaic module. The maximum power point trackers application has increased the total output power by greater than 72%, where the simulation results clearly show the enhancing role of the maximum power point tracking in photovoltaic systems.

VI. Appendix

Parameters of Solar Photovoltaic (SPV) module
Open circuit voltage (V_{oc}) = 32.9V
Rated power (V_{mp}) = 200W
Current at maximum power (V_{mp}) = 7.58A
Short circuit current (I_{sc}) = 8.21A
Total number of cells in series (N_s) = 54
Total number of cells in parallel (N_p) = 1
Ideality factor of diode = 1.3
Charge of an electron (e) = 1.610-19C
Insolation = 1000W/M^2
Bandgap energy (E_{g_0}) = 1.1ev
Series resistance (R_s) = 0.221
Shunt resistance (R_{sh}) = 415
Nominal temperature (T_n) = 298K
Short circuit current of cell at 250° C and 1000W/m^2
Boltzmann constant k = 1.3810-23 J/k

References

[1] Shu-Hung et al, "A Novel Maximum Power Point Tracking Technique for Solar Panels Using a SEPIC or Cuk Converter," *IEEE Trans. Power Electronics,* vol. 18, no. 3, May, 2003.

[2] Wies et al., "Simulink Model for Economic Analysis and Environmental Impacts of a PV with Diesel-Battery System for Remote Villages," *IEEE Trans.Power Systems,* vol. 20, no. 2, May, 2005.

[3] Soeren Baekhoej Kjaer, "A Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules," *IEEE Trans. Industry Applications,* vol. 41, no. 5, Sep/Oct, 2005.

[4] A. K. Abdelsalam, A. M. Massoud, S. Ahmed, and P. N. Enjeti, "High-Performance Adaptive Perturb and Observe MPPT Technique for Photovoltaic-Based Microgrids," *IEEE Trans. Power Electronics,* vol. 26, no. 4, April, 2011.

[5] Q. Zhang, C. Hu, L. Chen, A. Amirahmadi, N. Kutkut, Z.J. Shen and I. Bataresh, "A Center Point Iteration MPPT Method with Application on Frequency-Modulated LLC Microinverter," *IEEE Trans. Power Electronics,* vol. 29, no. 3, March, 2014.

[6] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "Optimization of Perturb and Observe Maximum Power Point Tracking Method," *IEEE Trans. Power Electronics,* vol. 20, no. 4, July, 2005.

[7] B. N. Alajmi, K. H. Ahmed, S. J. Finney, and B. W. Williams, "Fuzzy-Logic-Control Approach of a Aodified Hill-Climbing Method for Maximum Power Point in Microgrid Standalone Photovoltaic System," *IEEE Trans. Power Electronics,* vol. 26, no. 4, April, 2011.

[8] R. F. Coelho, F. M. Concer and D. C. Martins, "Analytical and Experimental Analysis of DC-DC Converters in Photovoltaic Maximum Power Point Tracking Applications," *Proc. IECON 2010, IEEE Press,* Nov, 2010.

[9] Lin Chen, Ahmadreza Amirahmadi, Qian Zhang, Nasser Kutkut, and Issa Batarseh, "Design and Implementation of Three-Phase Two-Stage Grid-Connected Module Integrated Converter," *IEEE Trans. Power Electronics,* vol. 29, no. 8, Aug, 2014.

[10] Juan David Bastidas-Rodriguez, Edinson Franco, Giovanni Petrone, Carlos Andrs Ramos-Paja and Giovanni Spagnuolo, "Maximum Power Point Tracking Architectures for Photovoltaic Systems in Mismatching Conditions: A Review," *IET Power Electronics,* vol. 7, no. 6, pp. 13961413, 2014.

[11] G Bhuvaneswari and R Annamalai, "Development of a Solar Cell Model in MATLAB for PV Based Generation System," *Proceedings of Annual IEEE India Conference (INDICON),* pp. 1-5, 2011.

[12] Moein Jazayeri, Sener Uysal, Kian Jazayeri, "Evaluation of Maximum Power Point Tracking Technique in PV Systems using MATLAB/Simulink," *Sixth Annual IEEE Green Technologies Conference 2014,* pp. 54-60, 2014.

[13] Tekeshwar Prasad Sahu, T. V. Dixit, "Modelling and analysis of P & O and IncCond MPPT algorithm for PV array using Łuk converter," *IEEE Students' Conference on Electrical, Electronics and Computer Science 2014,* pp. 1 6, 2014.

[14] Kancherla Harini , Syama S., "Simulation and analysis of IncCond and P & O MPPT with DC-DC converter topology for PV array," *International Conference on Electrical, Computer and Communication Technologies (ICECCT) 2015,* pp. 15, 2015.

[15] M Praful Raj, Ann Mary Joshua, "Design, implementation and performance analysis of a LabVIEW based fuzzy logic MPPT controller for stand-alone PV systems," *IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI) 2017,* pp. 1012-1017, 2017.