International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-4, November 2019

Modeling and Simulation of Disturb and Detect Maximum Power Point Tracking Algorithm for Standalone Solar System

Amr Refky, Hamdy Abd El-Halim

Abstract**:** ***Modeling and simulation of photovoltaic (PV) module is presented in this work using Matlab/Simulink environment. The simulated PV array model will consider the temperature and irradiance as variable parameters inputs and I-V, P-V characteristics as outputs. Algorithms designed in this paper to achieve the maximum power point (MPP) at all time. DC-DC boost converter has been calculated and designed in this work. Analysis and study of the PV system and MPPT performance with variable parameters under transient conditions.***

Keywords **:** ***photovoltaic solar system, MPPT, Matlab Simulation, Perturb and algorithm, Boost Converter.***

I. INTRODUCTION

Nowadays there is a special global interest between researchers in renewable energy as it is clean energy resource. Among renewable energy sources, solar energy is wildly spread [1]. As Sun is a continuous source of energy it continues provide its energy to the world. The solar energy systems require less maintenance, noise free, and pollution free [2]. The PV solar systems are most suitable fitted for the home use and can be easily mounted on roof tops and are most feasible solution for distributed generation projects [3].

Solar cell is the basic segment of a PV systems, which delivers only a limited certain amount of electrical energy. A panel can be arranged from a group of connected cells. Several panels to be connected in series to form an array. Several arrays are connected in parallel to generate the required power [4]. Although there are about 30 different types of PV cells under development, there are only three main technologies in commercial production they are polycrystalline cells, mono crystalline cells and thin-film cells.

When the sunlight falls on photovoltaic array, photovoltaic system produces DC power. Small loads such as DC motors and lightning system can be energized be the generated power, which available at the terminal of a PV array [5]. Also power generated from PV cells may be used in a standalone system or grid-connected system [6]. The output power of the PV system can be stored in batteries in case of standalone systems. The battery systems have several disadvantages such as frequently maintenance required, high expensive, and bulky volume. Meanwhile, with grid-connected system, it is necessary to use inverter to produce AC power from the DC generated by PV system [7].

Controlling maximum power point tracker (MPPT)) is a major control strategy in PV system as the amount of power generated by PV array highly affected by change in environmental conditions such as shadow and temperature. Climate rapid changes such as sunless weather and ambient temperature rise lead to panels insulation changes which will reduce the PV array output power as well as the overall module conversion efficiency [5], [8].

MPPT can be achieved by mechanical control or electrical tracking. Mechanical tracking based on stepper motor drive which control the orientation of PV panel, while electric tracking is based on controlling output power via switching control of power electronic converter [9].

Solar radiation, ambient temperature, sunlight deviation and other parameters highly affect the efficiency of PV system [10]. For simulation simplicity of MPPT in PV system applications, linearization of nonlinear characteristics is carried out [11].

II. SOLAR CELL CHARACTERISTICS

The solar cell current-voltage (I-V) characteristic and power- voltage (P-V) characteristic are nonlinear and both of them vary with irradiation and temperature. Figure 1. shows the nonlinear (I-V), (P-V) characteristics of a solar cell.

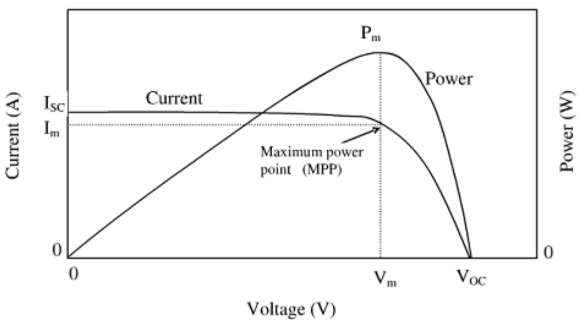

Fig. 1:The Nonlinear Characteristics of a Solar Cell.

The essential parameters of solar cell are short circuit current (ISC), open circuit voltage (VOC), MPP, efficiency and fill factor (FF).

Manuscript published on November 30, 2019.
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Open Circuit Voltage is the voltage across the cell terminals when are left open. In this case there is no current produced from the cell.

The open circuit voltage can be expressed as

$$V\left(at\ I=0\right)=V_{oc} \quad (1)$$

Short Circuit Current is the current that flows when the terminals are shorted together. It can be calculated when the voltage equals to zero. During short circuit condition, there is no current passing through the real diode since $V_d = 0$, The ideal current source provides current, which flows through the short circuit.

$$I_{V=0}=I_{sc} \qquad (2)$$

MPP is that operating point at which, the system will provide maximum load power [12].

$$P_m=V_m I_m \qquad (3)$$

Fill Factor (FF) is the maximum power Pm to the theoretical power Pt ratio. The fill factor is basically a solar cell quality measurement.

$$FF=\frac{P_m}{V_{oc}I_{sc}} \qquad (4)$$

Solar cell efficiency is the maximum power to the incident light power ratio.

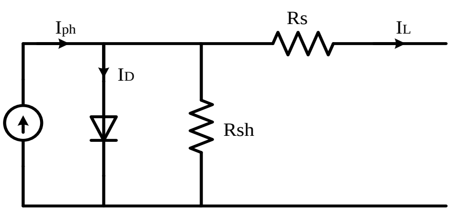
$$\eta=\frac{P_m}{P_{in}}\times 100 \qquad (5)$$

P_{in} is taken as the product of the solar irradiation of the incident light (G=λ/1000), measured in W/m^2, with the surface area (A) of the solar cell in m^2.

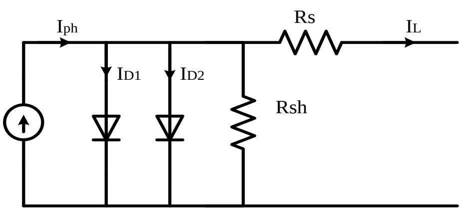
$$P_{in}=G\ A \qquad (6)$$

III. MATHEMATICAL MODELING OF PHOTOVOLTAIC ARRAY

A PV cell considered as a current source, which connected in parallel with one or two diodes and represented by an equivalent circuit as shown in Figure 2. In A single-diode model there are four components: photo-current source, diode parallel to the current source, series resistance R_s, and shunt resistance R_{sh}. The single diode model is more simple and quite accurate.



(a) Single-Diode Model,



(b) Two-Diodes Model.

Fig. 2: Equivalent-Circuit of PV Cell.

The mathematical model for the nonlinear I-V characteristics of the ideal cell can be represented by the following set of equations:

$$I_L=I_{ph}-I_d \qquad (7)$$

$$I_d=I_o\left(e^{\frac{qV}{KT}}-1\right) \qquad (8)$$

$$I_L=I_{ph}-I_o\left(e^{\frac{qV}{KT}}-1\right) \qquad (9)$$

$$I_L=I_{ph}-I_o\left[\exp\exp\left(\frac{q(V+IR_s)}{AK_BT}\right)-1\right]-\left(\frac{V+R_sI}{R_{sh}}\right) \quad (10)$$

Table I contains a clear comparison of the ideality factor for different PV technologies.

Both the solar irradiance and the temperature affect linearly the photocurrent Iph [14]. The photo current can be represented by:

$$I_{ph}=\frac{G}{G_n}\left[I_{phn}+K_i\left(T-T_n\right)\right] \qquad (11)$$

The ideality constant varies according to the PV technology [13].

Table I. Ideality Factor (A) for PV technology

PV Technology	Ideality Factor
Si-mono	1.2
Si-poly	1.3
a-Si-H triple	5.0
CdTe	1.5
CIS	1.5
AsGa	1.3
a-Si-H	1.8
a-Si-H tandem	3.3

IV. MAXIMUM POWER POINT TRACKING (MPPT)

The energy generated by PV array depends on the change in environmental condition such as insulation and temperature. In order to achieve highest generation of power to be supplied to the load continuously, MPPT technique should be used. [8].

Current-voltage and power-voltage characteristics are nonlinear in PV system, both of them depends on the solar irradiation and the temperature of PV cells [12]. MPP point is a unique point on I-V or P-V curve, at which PV system produces its maximum output power. The position of the MPP is not known, but can be detected, either through calculation models or search algorithms [15].

In order to calculate the MPP, DC-DC converter which connected to the photovoltaic system should be used. PV output voltage to be regulated by the duty cycle of the DC-DC converter, which affects the current of PV and consequently the PV power. The PV power is controlled in a direction of reaching the MPP [16].

The MPPT disturb and detect Algorithm is used because of simple hardware, less formula intense and simple to be implemented.

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DOI:10.35940/ijrte.D7529.118419
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It also is economic for small-scale PV plants. With disturb and detect technique, the operating voltage to be measured and the algorithm to control the operating voltage in the required direction. Measuring dp/dv, if it is positive, the algorithm will increase the voltage towards the MPP until dp/dv to be negative. These steps are continued while the algorithm finally achieves the MPP [8]. The whole process of disturb and detect algorithm is shown in Figure 4.

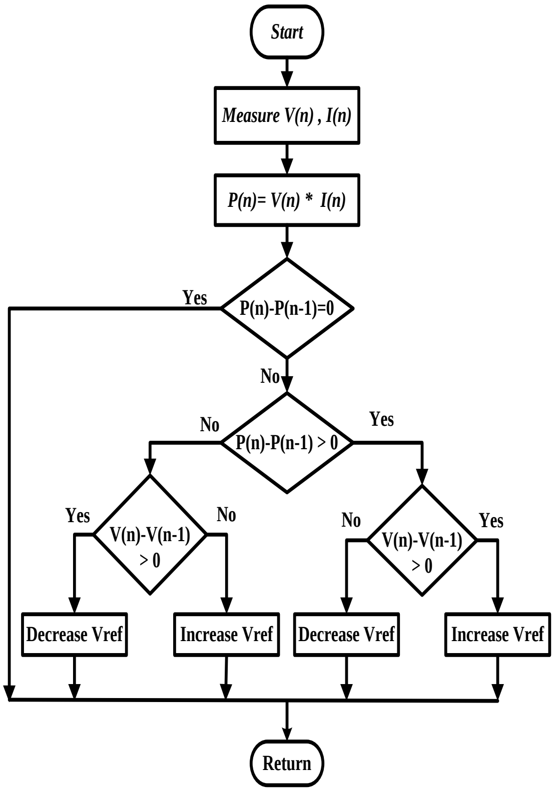

Fig.4: Flow Chart of P&O Control Technique.

V. DC-DC CONVERTER DESIGN

DC-DC converter to be used to connect PV system and the load, the point of operation of the module can be adapted by controlling the converter duty cycle. The simplest hardware to be used is the DC-DC boost converter in order to boost up the voltage of the PV and also to track the MPP of PV. The Boost converter design is carried out considering the operation in continuous conduction mode (CCM) [5]. The duty cycle (D) of the dc-dc boost converter can be expressed by:

$$\frac{V_O}{V_{pv}} = \frac{1}{(1-D)} \tag{15}$$

The inductor can be determined by:

$$L = \frac{V_{pv} D}{2\Delta i\ f} \tag{16}$$

The Input current in PV side ripple is taken as 5% of the input current. The capacitance value can be calculated by:

$$C = \frac{I_d D}{\Delta V\ f} \tag{17}$$

VI. PV SIMULATION WITH MPPT USING MATLAB/SIMULINK

The solar cell is modeled using the single diode mathematical model. Any number of solar cell group can be connected in series or parallel using the simulation model. The modifications will include only the solar cells parameters, which are available on the manufacturer's datasheet. Figure.5 shows the simulation model of the PV array and the DC-DC boost IGBT converter.

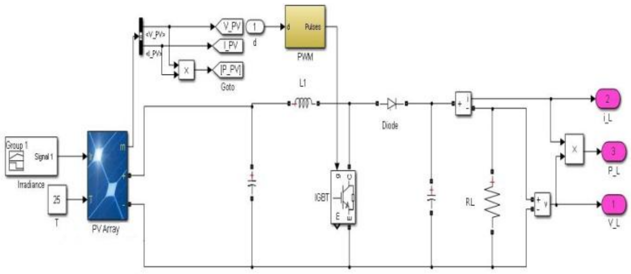

Fig.5: The Simulation of PV with Boost Converter.

VII. RESULTS AND DISCUSSION

The simulated PV array system with 415 W and open circuit voltage of 85.3 V. The PV characteristics are obtained by varying the factors one after the other.

A. Effect of solar irradiance

The efficiency of a PV system depends on the spectral distribution of the solar radiation. The effect of the solar radiation on the nonlinear I-V characteristic of the simulated PV array shown in figure 6.

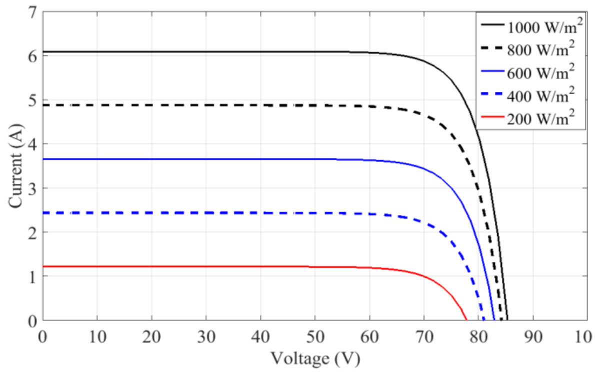

Fig.6: Voltage -current (I-V) characteristics at constant temperature (T=25oC) and different solar irradiations.

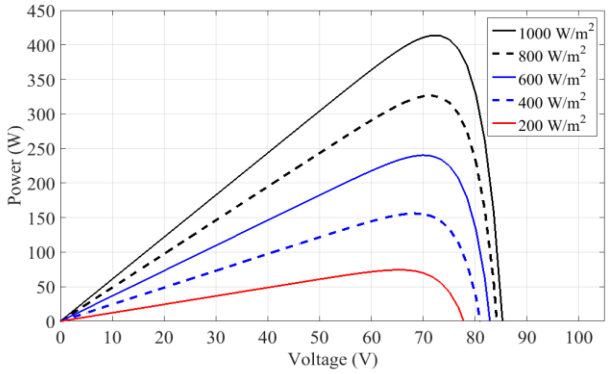

Fig.7: Power -Voltage (P-V) characteristics at constant temperature (T=25oC) and different solar irradiations.

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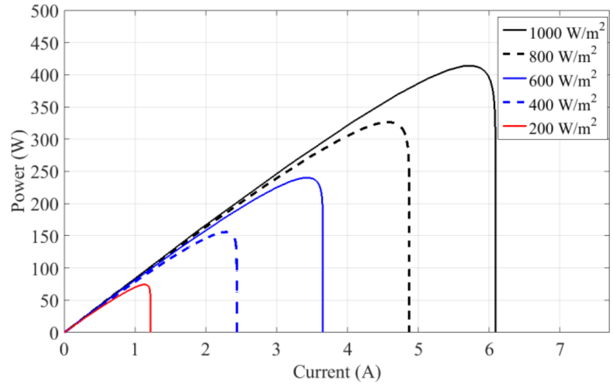


Fig.8: Power -Current (P-I) characteristics at constant Temperature (T=25oC) and different solar irradiations.

As shown in Figure 7 and Figure 8 the output power of the cell increases with increasing the solar irradiation.

B. Effect of temperature

Explaining the effect of temperature change on the PV characteristics, the solar irradiance will be considered constant and equal to 1000 W/m2. The nonlinear V-I characteristics at different temperatures shown in Figure.9. The V-I curve illustrates that the open-circuit voltage decreases and short circuit current rises slightly with increase in temperature. Figure.10 shows the characteristics of P-I curve which states that the maximum power increases with increasing the temperature. The P-V characteristics are presented in Figure.11. It is noticed that the open circuit voltage decreases very slightly with increasing the temperature, while the output power increases.

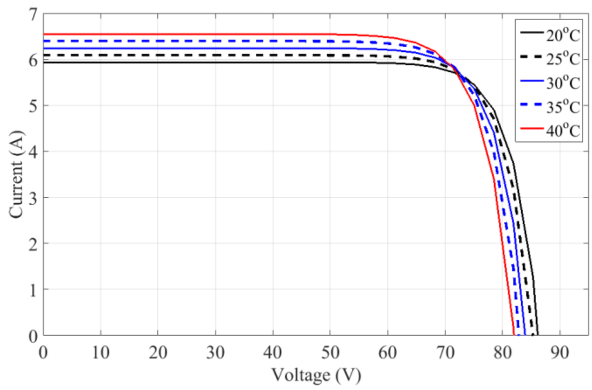


Fig. 9: Voltage-current characteristics at constant Irradiance (1000 W/m2) and different Temperatures.

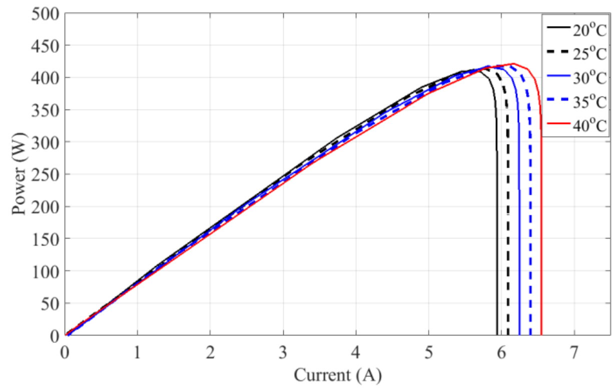


Fig.10: Power-Current (P-I) characteristics at constant Irradiance (1000 W/m2) and different Temperatures.

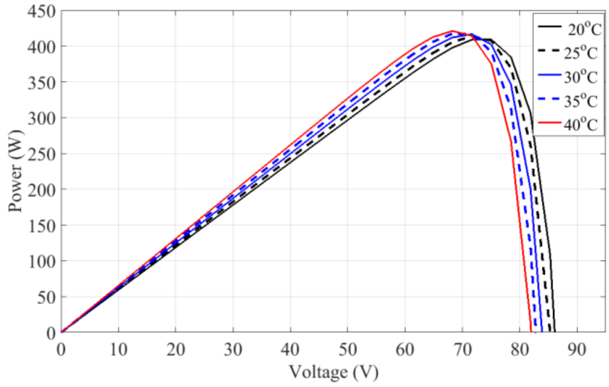


Fig. Fig.11: Power-Voltage (P-V) characteristics at constant Irradiance (1000 W/m2) and different Temperatures.

C. Performance analysis of MPPT technique

The maximum power achieved by controlling the duty cycle of the boost converter, as the duty cycle controls the solar cell output voltage which in turn affects the cell output power in the direction of reaching the maximum power.

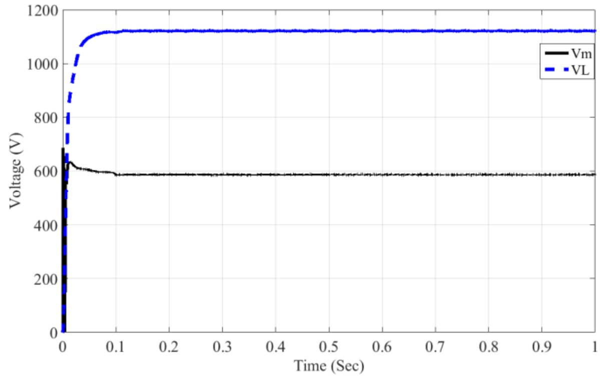


Fig. 12: Voltage at MPP and the output load voltage.

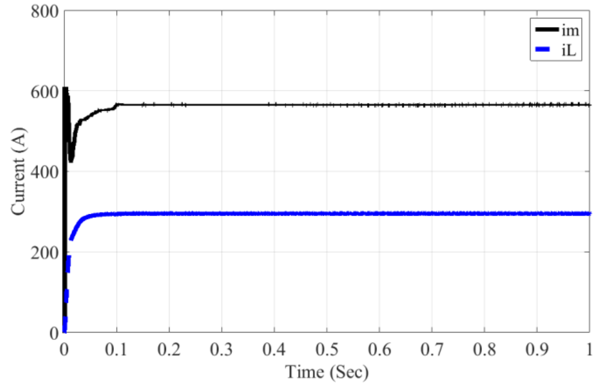


Fig. 13: Current at MPP and the output load current.

The cell voltage at the maximum power and the corresponding load side voltage after the boost converter are shown in Figure.12. The load side voltage is higher than the voltage at MPP. The cell current and the load current are shown in Figure 13. The cell output power is constant at its maximum value and equal to the load power as depicted by Fig.14. The power is constant due to the constant irradiation and temperature.

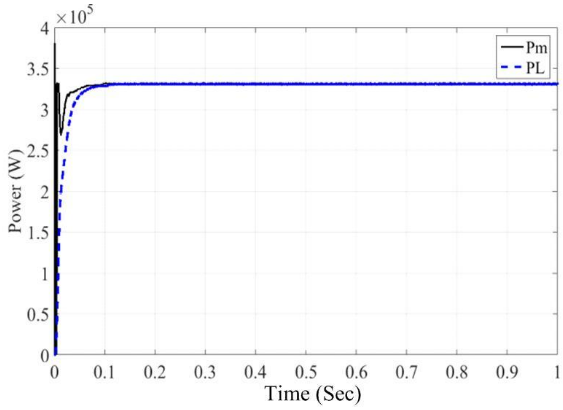
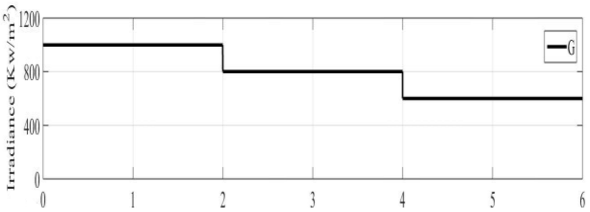
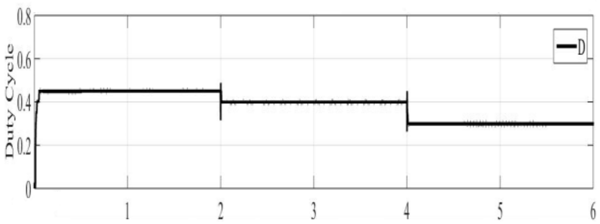


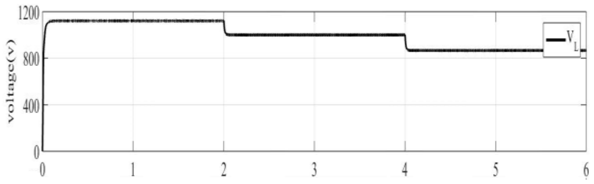
Fig. 14:Powerat MPP and the Output load power.



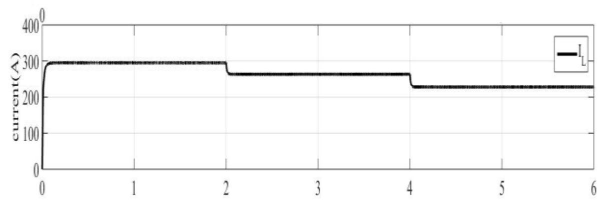
(a) Irradiance



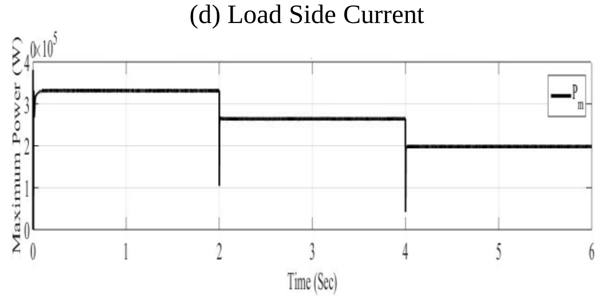
(b) Duty Cycle



(c) Load Side Voltage



(d) Load Side Current



(e) The Maximum Power

Fig.15: Different Irradiation Levels with Corresponding MPPT Response.

Figure.15 shows the impact of changing the solar irradiance on the power at MPP.

The output power increases in proportion way with the solar irradiance as illustrated before in Figure 7 and Figure 8. When the irradiance is suddenly decreased from 1 Kw/m2 to 0.8 Kw/m2 at time of 2 Sec as shown in Figure 15 (a), the P&O algorithm modifies the duty cycle. The duty cycle changes the cell voltage and hence the current. The change of the voltage and current is directed to the way of obtaining the maximum power from the PV arrays.

VIII. CONCLUSION

The nonlinear modeling and simulation of a PV system with MPPT was represented in this paper using Matlab/Simulink environment. The simulation is conducted to calculate the PV characteristics. It has been shown that the I-V relationship for the PV cell is nonlinear characteristics. The PV cell output power is greatly affected by the solar radiation in proportional way as well as it is increased with increasing the temperature. The nonlinear I-V characteristics have a unique point which can give maximum output power from the PV system. MPPT technique based on P&O has been simulated; the results illustrates efficient performance in transient conditions.

APPENDIX

Parameters for Sun Power SPR-415E-WHT-D (1kW/m2, 25oC) Solar Photovoltaic System

Parameter	Value
P_m (W)	414.801
V_{oc} (V)	85.3
V_{amp} (V)	72.9
I_{sc} (A)	6.09
I_{amp} (A)	5.69
Cells per module N_{cell}	128
Series-connected modules per string	8
Parallel strings	100
R_s (Ω)	0.5371
R_{sh} (Ω)	419.781
f (KHz)	10
L (mH)	2.56

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