Design and Simulation of Photovoltaic Cell Using Incremental Conductance Algorithm

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Abstract

The Renewable energy is important part of power generation system due to diminution of fossils fuel. Energy production from photovoltaic (PV) is widely accepted as it is clean, available in abundance, and free of cost .This paper presents the design and simulation of a photovoltaic cell using incremental algorithm for maximum power point tracking. The current-voltage (I-V) and power-voltage (P-V) characteristics are obtained for solar module. The MPPT algorithm, which is based on the incremental conductance method, is also described. The entire system is simulated in MATLAB and simulation results are presented.

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1-Introduction

Solar energy which is free and abundant in most parts of the world has proven to be a challenging source of energy in many developing and developed countries [1]. The rapid increase in the demand for electricity and the recent change in the environmental conditions such as global warming led to a need for a new source of energy that is cheaper and sustainable with less carbon emissions. Solar energy has offered promising results in the quest of finding the solution to the problem. The harnessing of solar energy using PV modules comes with its own problems that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the PV modules [2-3].

Solar energy obtained from a solar PV cell is not constant all the time. Solar energy is affected by external conditions like solar irradiance and temperature. Solar irradiance and cell temperature are pointed out to be affecting PV cell output to a much greater extent than the other conditions. Moreover, the amount of extracted power from a PV system is a function of the PV array voltage and current set point. Due to these reasons stated above, it is crucial to maximize the output electric power available from the PV cell [4].The solar PV power system can be operated as a standalone, hybrid or grid connected systems. The solar PV cell has nonlinear V-I and P-V characteristics, which depends on the irradiance, the operating temperature and load condition of the cell [5].

Over the years, several researchers have studied the characteristics of PV modules and the factors that affect them. Walker [6] has proposed a MATLAB-based model of a PV module to simulate its characteristics for studying the effect of temperature, insulation and load variation on the available power. However, the model does not consider the effect of shading on the PV characteristics. H. Patel and V. Agarwal [7] proposed the MATLAB based modeling and study the effects of partial shading on PV array characteristics. PV module characteristics and mathematical modeling are comprehensively discussed in [8-10], which indicate an exponential and nonlinear relation between the output current and voltage of PV module.

The solar energy is a dilute source of energy and its availability varies widely with time. So, it is very necessary to make a complete utilization of solar energy in available time. Many maximum power point tracking algorithms are available for a solar panel in order to produce maximum output. It is very necessary that it is operated consistently at the maximum power point. The Incremental Conductance Method of MPPT is described here with its maximum power point.

2-PV Module

This module of a photovoltaic system is based in a MATLAB. A simple module of a PV cell consist of an ideal current source in parallel with an ideal diode is shown as an equivalent circuit below "Figure 1". [11].
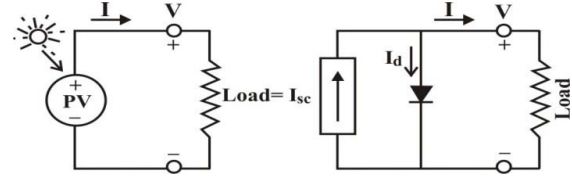

Figure (1) The equivalent circuit of a simple PV cell.

The two key parameters most often used to characterized a PV cell are it's short-circuit current (I_{sc}) and its open-circuit voltage (V_{oc}) as shown in "Figure 1". The Module manufacturer usually provides the values of these parameters in their datasheets [12]. The output current (I) from the equivalent circuit of a simple PV cell is found by applying the Kirchhoff's Current Law (KCL).

$$I = I_{sc} - I_d \tag{1}$$

where I is the module current, I_{sc} is the short-circuit current that is equal to the photon generated current, and Id is the current shunted through intrinsic diode. The diode current Id is given by the Shockley's diode equation:

$$I_d = I_o (e^{\frac{q*v}{k*t}} - 1) \tag{2}$$

where Io is the reverse saturation current of diode (A); q is the electron charge (1.602 × 10-19C); V is the voltage across the PV cell (V); k is the Boltzmann's constant (1.38 × 10-23 J/K); T is the junction temperature in Kelvin (K). Combining the diode equation with the equation of the output current of the PV cell

$$I = I_{sc} - I_o (e^{\frac{q*v}{k*t}} - 1) \tag{3}$$

The reverse saturation current of diode (Io) is constant under the constant temperature, let I = 0 (no output current)

$$I_o = \frac{I_{sc}}{(e^{\frac{q*v}{k*t}} - 1)} \tag{4}$$

There are a few things that have not been taken into account in the simple model and that will affect the performance of a PV cell in practice. In order to create more accurate model, series resistance (R_s),

parallel resistance (R_p), and recombination must be factored into the equation as shown in "Figure 2" [11].
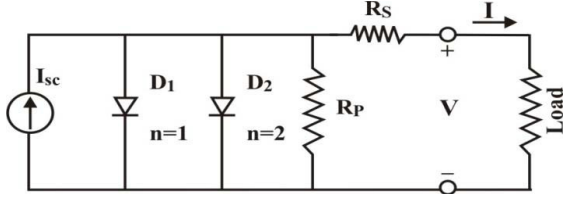

Figure (2) More accurate equivalent circuit of PV cell.

Taking into account these additional elements add to the equation, the two diodes can be recombined to simplify the equation to:

$$I = I_{sc} - I_o (e^{\frac{q*(V+Rs*I)}{n*k*t}} - 1) - \frac{(V+Rs*I)}{Rp} \quad \textbf{(5)}$$

where n is known as the ideality factor and takes the value between 1 and 2. The equivalent circuit with diodes combined and $R_p = \infty$ is shown in "Figure 3". Science it does not include the effect of parallel resistance (R_p), letting $R_p = \infty$ in the equation (5) gives the equation [11] that describes the current-voltage relationship of the PV cell, and it shows below

$$I = I_{sc} - I_o (e^{\frac{q*(V+Rs*I)}{n*k*t}} - 1) \quad (6)$$

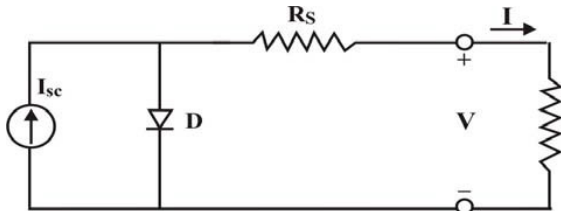**Figure (3) Equivalent circuit with diodes combined and Rp = ∞.**

The value of the photon generated current Isc can be directly proportional to the irradiance, and the short circuit current is given under standard test conditions, Go = 1000W/m2, which is provided on the data sheet [12]. Therefore the photon generated current at any other irradiance, G(W/m2) is given by [13]

$$I_{sc} * I_G = I_{sc} * I_{Go} * (\frac{G}{G_o}) \quad \textbf{(7)}$$

where I_G and I_{Go} are the currents at irradiance of G and Go, respectively. Since a single PV cell produces an output voltage of less than 1 volt, it is necessary to string together a number of PV cell in series to achieve a desired output voltage. Generally, 36 cells in series will provide a large enough voltage to charge a 12 volt battery, and 72 cells would be suitable for a 24 volt battery. The BP SX 150S PV module, which contains 72 cells, is selected for the purpose of this paper.

3-Simulation of PV Module in MATLAB

The characteristic equations (3), (4), (5), (6), & (7) for the PV module is implemented in MATLAB. The parameters chosen for modeling corresponds to the BP SX150s module as listed in "Table 1". The voltage V is considered varying from 0 to Voc corresponding to the variation in current from Isc to 0. "Figure 4, 5, & 6" shows the I-V, P-V, and P-I curves at various module temperatures simulated with the MATLAB model for BP SX 150s PV module.

Table(1) Parameters of BP SX 150S Solar Module (GO = 1KW/M2, 25OC)

| Electrical Characteristics	BP SX 150S
Maximum Power (P_{max})	150W
Voltage at Pmax (V_{mp})	34.5V
Current at Pmax (I_{mp})	4.35A
Warrented minimum P_{max}	140W
Short-circuit Current (I_{sc})	4.75A
Open- Circuit Voltage (V_{oc})	43.5V
Temperature coefficient of I_{sc}	$0.065 \pm 0.015\%$ ^oC
Temperature coefficient of V_{oc}	$-160 + 20$ mV ^oC
Temperature coefficient of Power	$-0.5 \pm 0.05\%$ ^oC
NOCT	47 ± 2 ^oC
Max. System Voltage	600V
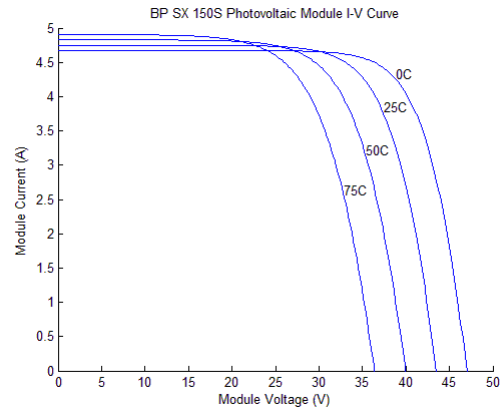
Figure (4) I-V curves of BP SX 150s PV module at various temperatures simulated with the MATLAB (1KW/m2).
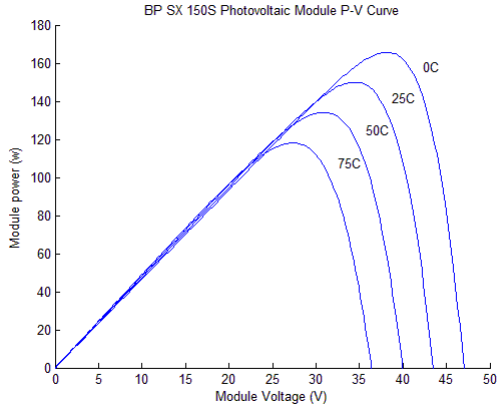
Figure (5) P-V curves of BP SX 150s PV module at various Temperatures simulated with the MATLAB (1KW/m2).
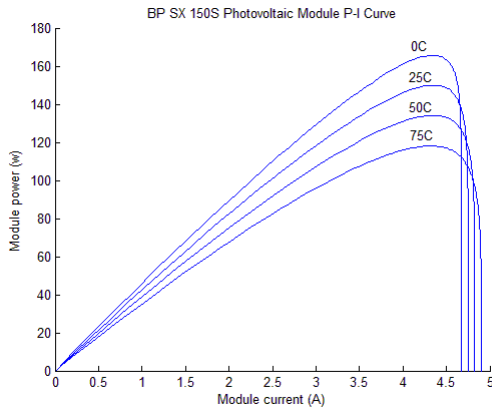

Figure (6) P-I curves of BP SX 150s PV module at various Temperatures simulated with the MATLAB (1KW/m2).

4- Incremental Conductance Algorithm

In 1993 Hussein, Muta, Hoshino, and Osakada of Saga University, Japan, proposed the incremental conductance (IncCond) algorithm intending to solve the problem of the P&O algorithm under rapidly changing atmospheric conditions [14].

The basic idea is that the slope of *P-V* curve becomes zero at the MPP, as shown in "Figure 7". It is also possible to find a relative location of the operating point to the MPP by looking at the slopes. The slope is the derivative of the PV module's power with respect to its voltage and has the following relationships with the MPP.

$$\frac{dP}{dV} = 0 \qquad \text{att MPP,}$$

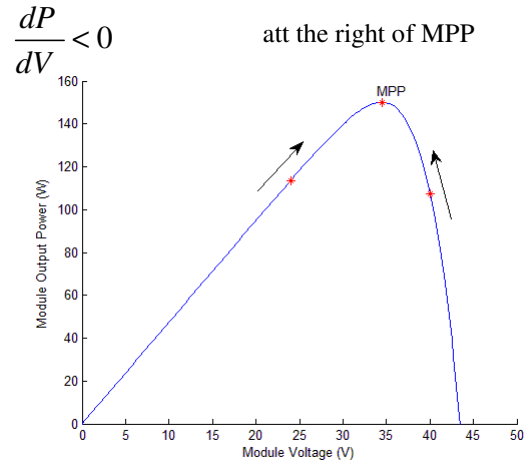$$\frac{dP}{dV} > 0 \qquad \text{att the left of MPP}$$

$$\frac{dP}{dV} < 0 \qquad \text{att the right of MPP}$$

Figure (7) Plot of power vs. voltage for BP SX150s PV module (1KW/m2, 25℃).

The above equations are written in terms of voltage and current as follows.

$$\frac{dP}{dV} = \frac{d(\text{V.I})}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \quad \textbf{(8)}$$

If the operating point is at the MPP, the equation (8) becomes:

$$I + V\frac{dI}{dV} = 0$$

$$\frac{dI}{dV} = -\frac{I}{V} \qquad\qquad\qquad \textbf{(9)}$$

If the operating point is at the left side of the MPP, the equation (8) becomes:

$$I + V\frac{dI}{dV} > 0$$

$$\frac{dI}{dV} > -\frac{I}{V} \qquad\qquad\qquad \textbf{(10)}$$

If the operating point is at the right side of the MPP, the equation (8) becomes:

$$I + V\frac{dI}{dV} < 0$$

$$\frac{dI}{dV} < -\frac{I}{V} \qquad\qquad\qquad \textbf{(11)}$$

Note that the left side of the equations (9), (10), and (11) represents incremental conductance of the PV module, and the right side of the equations represents its instantaneous conductance.

The flowchart shown in "Figure 8" explains the operation of this algorithm. It starts with measuring the present values of PV module voltage and current. Then, it calculates the incremental changes, *dI* and *dV*, using the present values and previous

values of voltage and current. The main check is carried out using the relationships in the equations (9),(10),and (11). If the condition satisfies the inequality (10), it is assumed that the operating point is at the left side of the MPP thus must be moved to the right by increasing the module voltage. Similarly, if the condition satisfies the inequality (11), it is assumed that the operating point is at the right side of the MPP, thus must be moved to the left by decreasing 46 the module voltage. When the operating point reaches at the MPP, the condition satisfies the equation (9), and the algorithm bypasses the voltage adjustment. At the end of cycle, it updates the history by storing the voltage and current data that will be used as previous values in the next cycle. Another important check included in this algorithm is to detect atmospheric conditions. If the MPPT is still operating at the MPP (condition: $dV = 0$) and the irradiation has not changed (condition: $dI = 0$), it takes no action. If the irradiation has increased (condition: $dI > 0$), it raises the MPP voltage. Then, the algorithm will increase the operating voltage to track the MPP. Similarly, if the irradiation has decreased (condition: $dI < 0$), it lowers the MPP voltage. Then, the algorithm will decrease the operating voltage. In practice, the condition $dP/dV = 0$ (or $dI/dV = -I/V$) seldom occurs because of the approximation made in the calculation of dI and dV . Thus, a small margin of error (E) should be allowed, for example: $dP/dV = \pm E$. The value of E is optimized with exchange between an amount of the steady-sate tracking error and a risk of oscillation of the operating point[11].
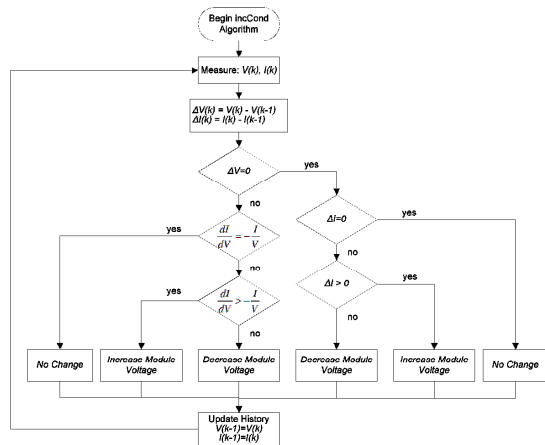

Figure (8) Flowchart of incremental conductance algorithm.

5-Simulation Result

Simulation of PV module using incremental conductance algorithm was done in MATLAb, the simulation results are shown in "Figure 9–11" . The P-V characteristic for the BP SX150s module using incremental conductance algorithm with maximum

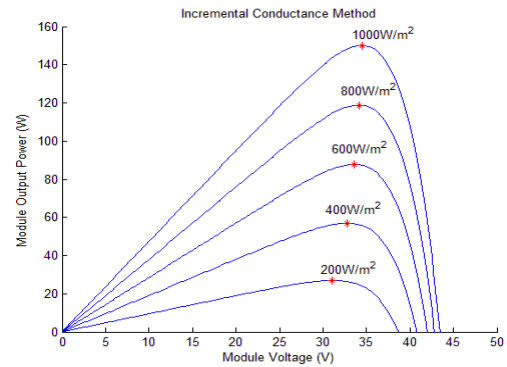power tracking at different irradiance is shown in "Figure 9".

Figure (9) P-V curves for incremental algorithm at various irradiance.

"Figure 10"shows the I-V characteristics for the BP SX150s module using incremental algorithm with maximum current and voltage tracking at different irradiance.
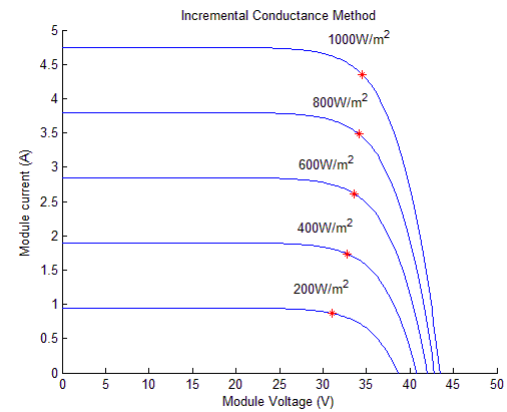

Figure (10) I-V curves for incremental algorithm at various irradiance.

"Figure 11"shows the P-I characteristics for the BP SX150S module using incremental conductance algorithm with maximum power and current tracking at different irradiance.
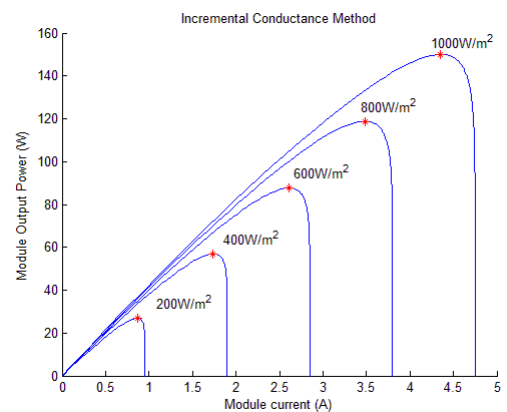

Figure (11) P-I curves for incremental algorithm at various irradiance.

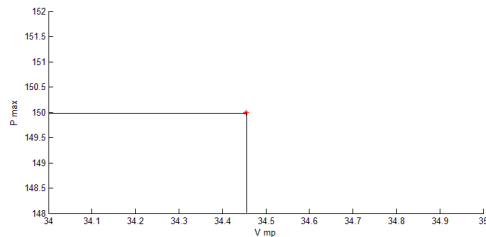"Figure 12, & 13" show the module voltage Vmp and Current Imp at the maximum power Pmax.

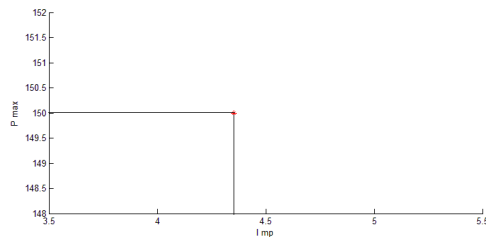**Figure (12) Module voltage at maximum power, Vmp.**

Figure (13) Module voltage at maximum power, Imp.

6-Conclusions

The V-I and P-V characteristics of BP SX 150s module are obtained using the MATLAB/Simulation for different values of irradiance. It is observed that the characteristics obtained by incremental conductance algorithm are better than simple PV characteristics of module & theoretical Characteristics. Also the module voltage V_{mp} and Current Imp at the maximum power P_{max} are obtained which are fairly same as indicated by the manufacturer of BP SX150S solar panel. Thus the proposed simulation model in conjunction with MPPT algorithm can be used with DC-DC Boost converter to obtain the required dc voltage to supply the dc load.

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