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Comparative Study of P&O and InC MPPT Algorithms

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Abstract: - Maximum Power Point Tracking (MPPT) algorithms is important in PV systems because it reduces the PV array cost by reducing the number of PV panels required to achieve the desired output power. This paper présents à comparative simulation study of two important MPPT algorithms specifically perturb and observe and incremental conductance. These algorithms are widely used because of its low-cost and ease of realization. Some important parameters such as voltage, current and power output for each different combination has been traced for both algorithms. Matlab simulink tool box has been used for performance evaluation by a 70W photovoltaic (PV) array.

Keywords: - *Photovoltaic (PV), Maximum Power Point Tracking (MPPT), Perturb and Observe (P&O), Incremental Conductance (InC).*

1. INTRODUCTION

Photovoltaic (PV) generation represents currently one of the most promising sources of renewable green energy. Due to the environmental and economic benefits, PV generation is preferred over other renewable energy sources, since they are clean, inexhaustible and require little maintenance. PV cells generate electric power by directly converting solar energy to electrical energy. PV panels and arrays, generate DC power that has to be converted to AC at standard power frequency in order to feed the loads. Therefore PV systems require interfacing power converters between the PV arrays and the grid. Photovoltaic-generated energy can be delivered to power system networks through grid-connected inverters. One significant problem in PV systems is the probable mismatch between the operating characteristics of the load and the PV array.

The system's operating point is at the intersection of the I-V curves of the PV array and load, when a PV array is directly connected to a load. The Maximum Power Point (MPP) of PV array is not attained most of the time. This problem is overcome by using an MPPT which maintains the PV array's operating point at the MPP. The occurrence of MPP in the I-V plane is not known priorly; therefore it is calculated using a model of the PV array and measurements of irradiance and array temperature. Calculating these measurements are often too expensive and the required parameters for the PV array model are not known adequately. Thus, the MPPT continuously searches for MPP. There are several MPPT continuously searches algorithms that have been proposed which uses different characteristics of solar panels and the location of the MPP [1,4].

To extract the maximum power from the solar PV module and transfer that power to the load, a MPPT is used. A dc/dc converter (step up/step down) transfers maximum power from the solar PV module to the load and it acts as an interface between the load and the module.Maximum power is transferred by varying the load impedance as seen by the source and matching it at the peak power of it when the duty cycle is changed. In order to maintain PV array's operating at its MPP, different MPPT techniques are required.In the literature many MPPT techniques are proposed such as, the Perturb and Observe (P&O) method, Incremental Conductance (IC) method, Fuzzy Logic Method etc [3]. Of these, the two most popular MPPT techniques (Perturb and Observe (P&O) and Incremental Conductance methods) are studied [4].The paper has been organized in the following manner. The basic principle of PV cell and the characteristics of PV array are discussed in section 2. Section 3 presents the P&O and InC MPPT algorithms in detail. The simulation results of PV array, MPPT algorithms and their comparison are discussed in section 4. Last section concludes with the scope for further work.

2. PV ARRAY CHARACTERISTICS

2.1 Basic Principle of PV Cell

PV cells are essentially a very large area p-n junction diode where such a diode is created by forming a junction between the n-type and p-type regions. As sunlight strikes a PV cell, the incident energy is converted directly into electrical energy. Transmitted light is absorbed within the semiconductor by using the energy to excite free electrons from a low energy status to an unoccupied higher energy level. When a PV cell is illuminated, excess electron-hold pairs are generated by light throughout the material, hence the p-n junction is electrically shorted and current will flow [2].

2. 2 PV array Characteristics

The use of single diode equivalent electric circuit makes it possible to model the characteristics of a PV cell. The mathematical model of a photovoltaic cell can be developed using MATLAB simullink toolbox. The basic equation from the theory of semiconductors that mathematically describes the I-V characteristic of the Ideal photovoltaic cell is given by

$$I = I_{pv,cell} - I_d \tag{1}$$

Where,

$$I_d = I_{0,cell}[\exp(\frac{qv}{akT})-1] \tag{2}$$

Therefore

$$I = I_{pv,cell} - I_{0,cell}[\exp(\frac{qv}{akT})-1] \tag{3}$$

Where, '$I_{PV,\ Cell}$' is the current generated by the incident light (it is directly proportional to the Sun irradiation), I_d is the diode equation, $I_{o,\ cell}$' is the reverse saturation or leakage current of the diode, 'q' is the electron charge [1.60217646* 10^{-19C}], k is the Boltzmann constant [1.3806503 *10^{-23}J/K], 'T' is the temperature of the *p-n* junction, and 'a' is the diode ideality constant. Figure 1 shows the equivalent circuit of ideal PV cell.

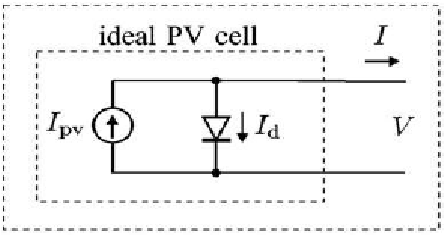

Figure 1. Equivalent circuit of ideal PV cell

Practical arrays are composed of several connected PV cells and the observation of the characteristics at the terminals of the PV array requires the inclusion of additional parameters (as shown in figure. 2) to the basic equation:

$$I = I_{pv} - I_o[\exp\left(\frac{V+IR_s}{V_t a}\right) - 1] - \frac{V+IR_s}{R_p} \tag{4}$$

Where Vt = NskT/q is the thermal voltage of the array with 'Ns' cells are connected in series. Cells connected in parallel increases the current and cells connected in series provide greater output voltages. *V* and *I* are the terminal voltage and current. The equivalent circuit of ideal PV cell with the series resistance (R_s) and parallel resistance (R_p) is shown in figure.2.

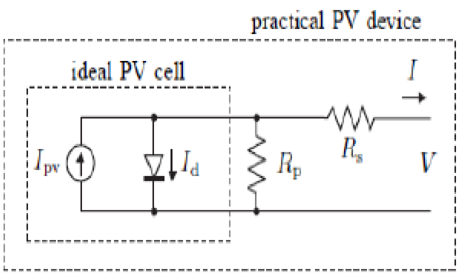

Figure 2.Equivalent circuit of ideal PV cell with R_p and R_s.

For a good solar cell, the series resistance (R_s), should be very small and the shunt (parallel) resistance (R_p), should be very large. For commercial solar cells (R_p) is much greater than the forward resistance of a diode. The I-V curve is shown in Figure 3. The curve has three important parameters namely open circuit voltage (V_{oc}), short circuit current (I_{sc}) and maximum power point (MPP). In this model single diode equivalent circuit is considered. The I-V characteristic of the photovoltaic device depends on the internal characteristics of the device and on external influences such as irradiation level and the temperature.

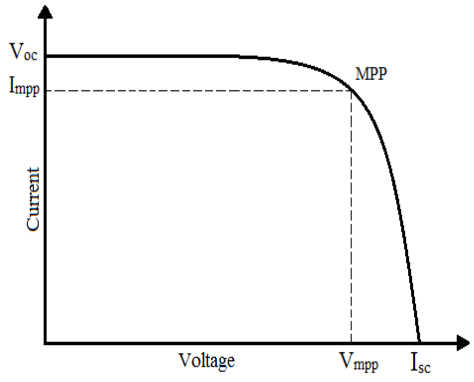

Figure 3.I-V characteristics of the PV cell

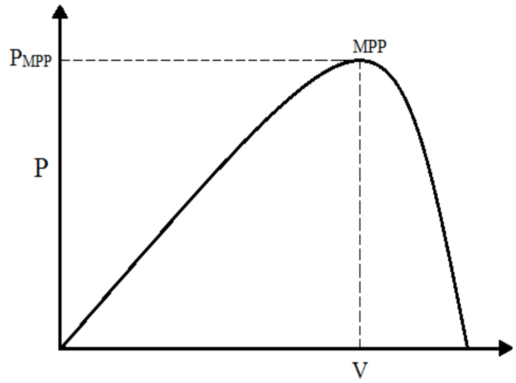

Figure 4.P-V characteristics of the PV cell

The P-V characteristics of the PV cell are illustrated in figure 4. It depends on the open circuit voltage (V_{oc}), the short circuit current (I_{sc}) and the maximum power point (MPP).

3. MPPT ALGORITHMS

3.1 Perturb and Observe (P&O) Algorithm

A slight perturbation is introduced in this algorithm. The perturbation causes the power of the solar module to change continuously. If the power increases due to the perturbation then the perturbation is continued in the same direction. The power at the next instant decreases after the peak power is reached, and after that the perturbation reverses. The algorithm oscillates around the peak point when the steady state is reached. The perturbation size is kept very small in order to keep the power variation small [4]. The algorithm can be easily understood by the following flow chart which is shown in figure 5.

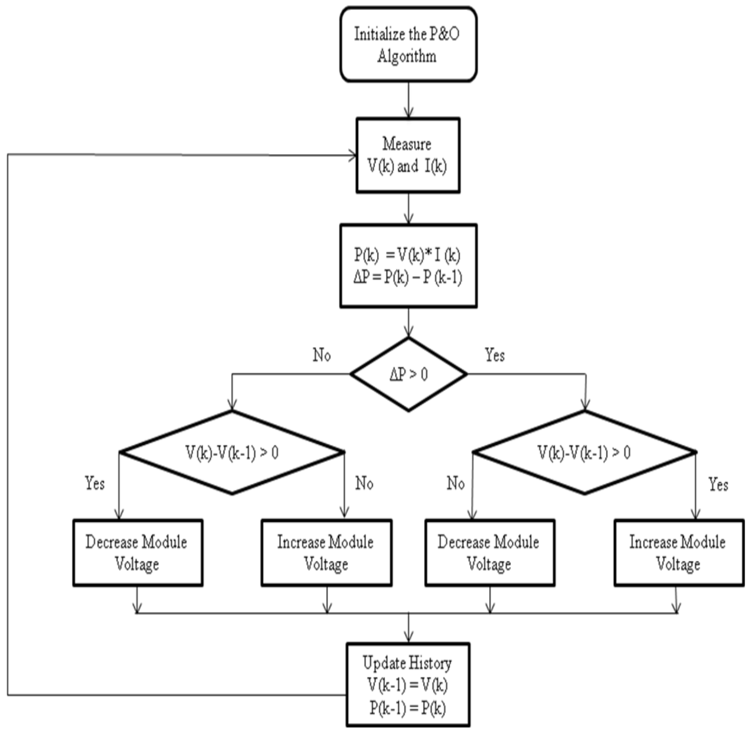

Figure 5 Perturb and Observe Algorithm

The algorithm is developed in such a manner that it sets a reference voltage of the module corresponding to the peak voltage of the module. A PI controller is used to move the operating point of the module to that particular voltage level. It is observed that there is some power loss due to this perturbation and it also fails to track the power under fast varying atmospheric conditions. But still this algorithm is very popular because of its simplicity.

3.2 Incremental Conductance (IC) Algorithm

Incremental Conductance (IC) method overcomes the disadvantage of the perturb and observe method in tracking the peak power under fast varying atmospheric condition. This method can determine whether the MPPT has reached the MPP and also stops perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V.

This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm determines when the MPPT has reached the MPP, where as P&O oscillates around the MPP. This is clearly an advantage over P&O. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe method [4]. The disadvantage of this algorithm is that it is more complex when compared to P&O. The algorithm can be easily understood by the following flow chart which is shown in figure 6.

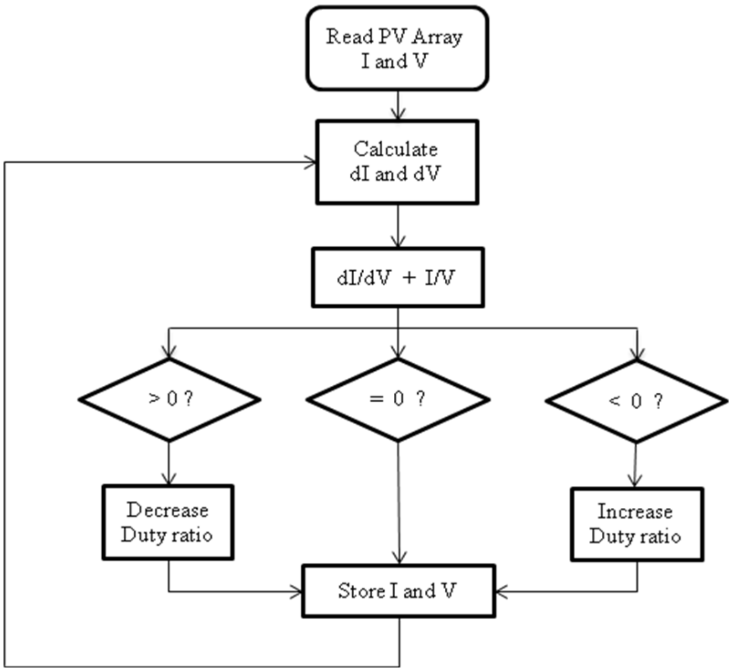

Figure 6 Incremental Conductance Algorithm

4. SIMULATION RESULTS AND DISCUSSIONS

4.1 PV Array Characteristics

The mathematical model of PV array is developed using MATLAB Simulink tool box. Various parameters of the PV array are determined and chosen. Series resistance (R_s) is iteratively chosen by incrementing from zero value. Decreasing the value of parallel resistance (R_p) too much will lead 'V_{oc}' to decrease and increasing the value of series resistance (R_s) too much will lead 'I_{sc}' to drop. 'I_o' strongly depends on the temperature and hence the simulation circuit of 'I_o' includes Kv and Ki which are the voltage and current coefficients.

TABLE I

PARAMETER SPECIFICATIONS OF 70W PV MODULE

Parameters	Specifications
Open circuit voltage V_{oc}	21.4V
Short circuit current I_{sc}	4.53A
Maximum output power	70W
Voltage at maximum power	17.7V
Current at maximum power	3.96A

The light generated by the PV is modeled as an equivalent current source. The series and parallel resistances are connected and simulated. The various equations describing the PV array characteristics are modeled using suitable blocks from the simulink library. The complete simulink model of PV module is shown in Figure 7.

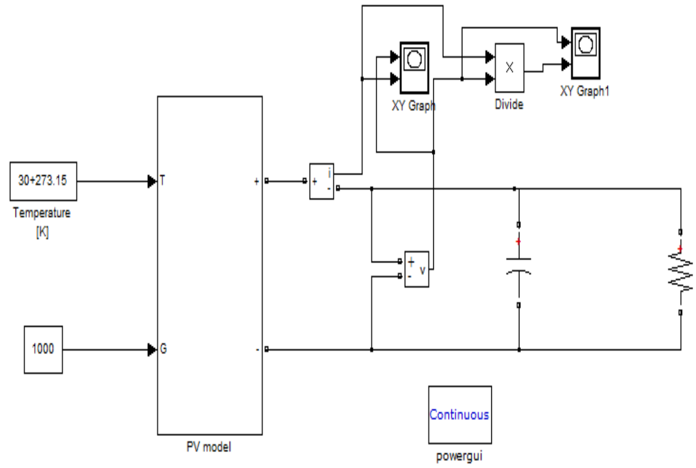

Figure.7.Simulation Model of PV Model

This simulation study is done for the standard test condition (STC) i.e. temperature is 30˚C and the Irradiation is 1000 W/m^2 with the simulation model.

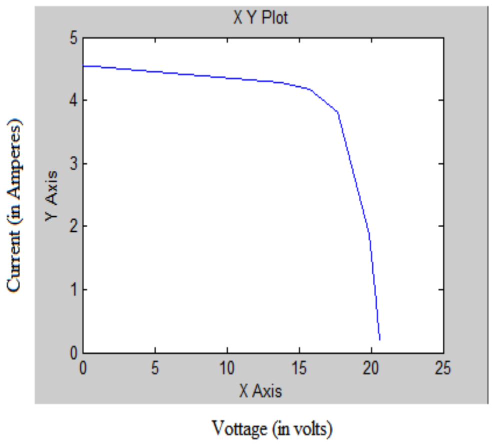

Figure.8. Simulated I-V Characteristic

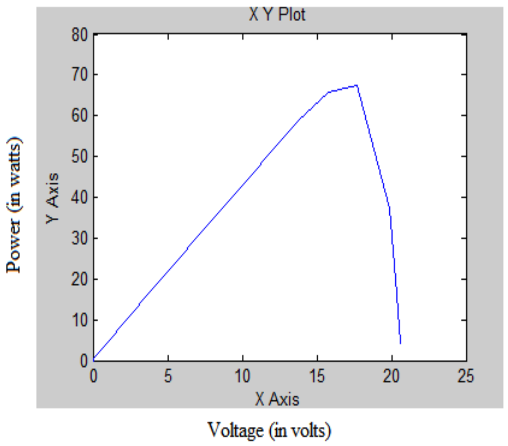

Figure.9. Simulated P-V Characteristic

The 70W PV module is simulated in MATLAB and the simulated I-V and P-V characteristics are shown in Figures 8 and 9 respectively. The open circuit voltage V_{oc} = 21.4V, the short circuit current I_{sc} = 4.53A are obtained for the corresponding maximum output power of 70W.

4.2 Simulink Model of P&O Algorithm

The MATLAB subsystem includes the 70W PV array and it also contains the equations required for modeling it. DC voltage source of the dc-dc boost converter is replaced by the MATLAB subsystem integrated with PV array. Perturbing the duty ratio of dc-dc boost converter perturbs the PV array current and consequently perturbs the PV array voltage. To compute the power at various duty cycles and to compare it with the power of the current operating point, the MPPT subsystem is used. The duty cycle either increases or decreases or remains the same. Figure 10 shows the simulink model of PV array with dc-dc boost converter and P&O MPPT.

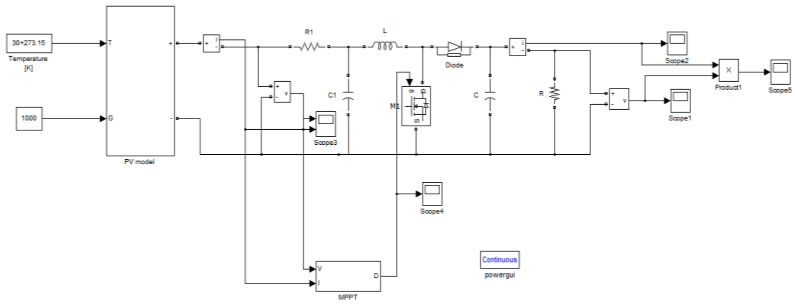

Figure.10. Simulink Model of P&O MPPT with dc-dc converter

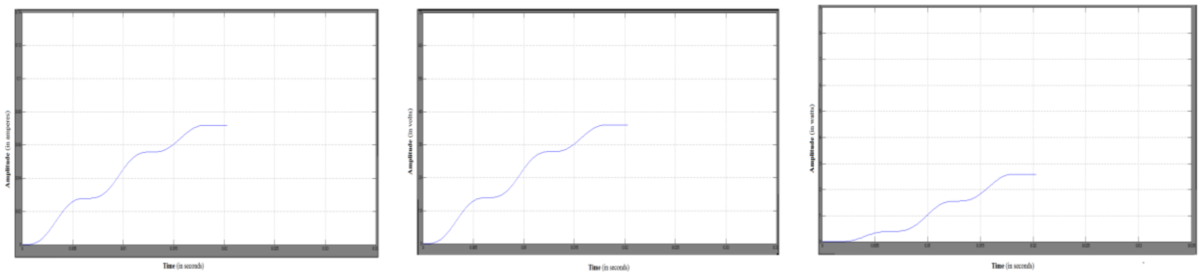

Figure (a) Current output Figure (b) Voltage output Figure (c) Power output

Figure.11. Simulation results of P&O MPPT algorithm

The simulation results of P&O MPPT algorithm are illustrated in figure 11. The results show that the current output of 0.073amperes and the voltage output of 36votls and an output power of 2.6watts for a time period of 0.0175 seconds.

4.3 Simulink Model of Incremental Conductance Algorithm

The simulink model of PV array with dc-dc boost converter and InC MPPT algorithm is shown in figure 12, under the same conditions as the P & O algorithm is simulated.

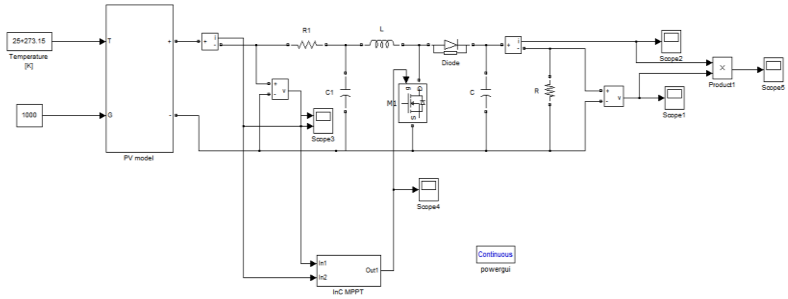

Figure.12. Simulink Model of InC MPPT with dc-dc Converter

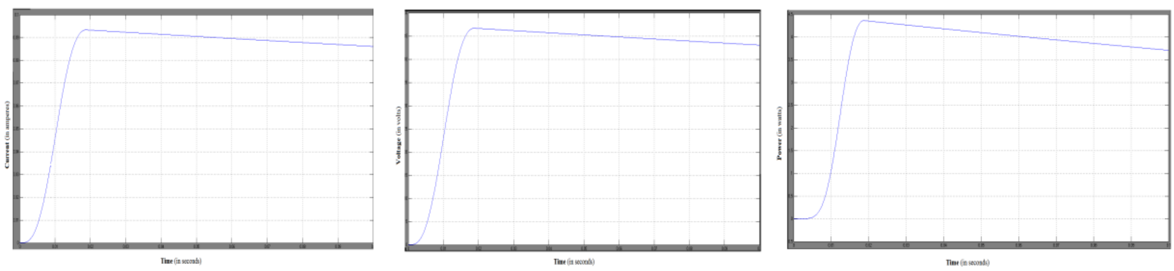

Figure (a) Current output Figure (b) Voltage output Figure (c) Power output

Figure.13. Simulation results of InC MPPT algorithm

The simulation results of InC MPPT algorithm are illustrated in figure 13. The results show that the output current varies from 0.093A to 0.087A and the output voltage varies from 47V to 43V and an output power varies from 4.7W to 3.7W for a time period of 0.1 seconds.

4.4 Comparison between P&O and InC MPPT Algorithms

The P & O and InC MPPT algorithms are simulated and compared using the same conditions. When atmospheric conditions are constant or change slowly, the P&O MPPT oscillates close to MPP but InC finds the MPP accurately at changing atmospheric conditions also. Comparisons between the two algorithms for various parameters are given in table 2.

TABLE II COMPARISON BETWEEN P&O AND INC MPPT ALGORITHMS

MPPT	Output Current	Output Voltage	Output Power	Time Response	Accuracy
P&O MPPT	0.073A	36V	2.6W	0.0175 sec	Less
InC MPPT	0.087-0.093A	43-47V	3.7-4.7W	0.1 sec	Accurate

5. CONCLUSIONS

In this paper a mathematical model of a 70W photovoltaic panel has been developed using MATLAB Simulink. This model is used for the maximum power point tracking algorithms. The P&O and Incremental conductance MPPT algorithms are discussed and their simulation results are presented. It is proved that Incremental conductance method has better performance than P&O algorithm. These algorithms improve the dynamics and steady state performance of the photovoltaic system as well as it improves the efficiency of the dc-dc converter system.

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