Comparative Study of P&O and Incremental Conductance MPPT Algorithms for Photovoltaic System

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Abstract: The rising needs of power open the doors for many inventions. Among which renewable green energies is one with wide spread usage. But it has been suffering with many power quality drawbacks like power dripping, dropping and shading conditions and so on. Maximum Power Point Tracking (MPPT) algorithms are 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 presents à comparative 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.

Key Words: photovoltaic (PV), MPPT, perturb and observe, incremental conductance.

I. 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.

PV solar systems exist in many different configurations with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads. Regardless of the ultimate destination of the solar power, though, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency. This load characteristic is called the maximum power point and MPPT is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors

II. OPERATING SYSTEM

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 priory 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.

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. Of these, the two most popular MPPT techniques (Perturb and Observe (P&O) and Incremental Conductance methods) are studied.

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 Incremental Conductance MPPT algorithms in detail. The simulation results of PV array, MPPT algorithms and their comparison are discussed in section 4. Last section concludes.

III. PV ARRAY CHARACTERISTICS

3.1 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.

3.2 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 the equation. The basic equation from the theory of semiconductors that mathematically describes the I-V characteristic of the Ideal photovoltaic cell is given by

$$I = I_{pv,cell} - I_d$$

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

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

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.

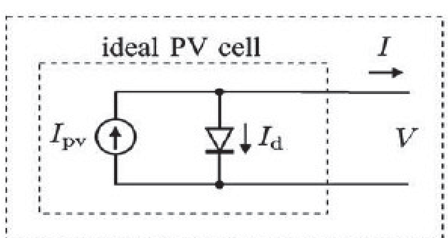

Fig: 1 Equivalent circuit of ideal PV cell

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:

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

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.

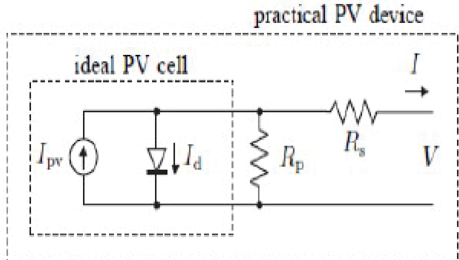

Fig: 2 Equivalent circuit of ideal PV cell with R_p and R

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.

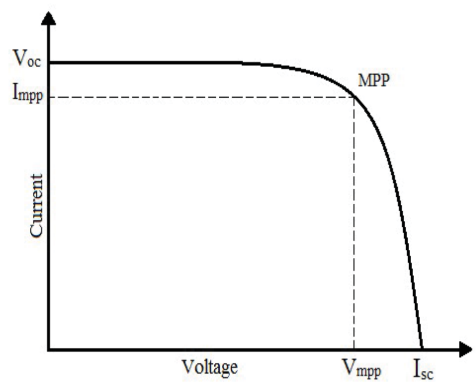

Figure 3.I-V characteristics of the PV cell

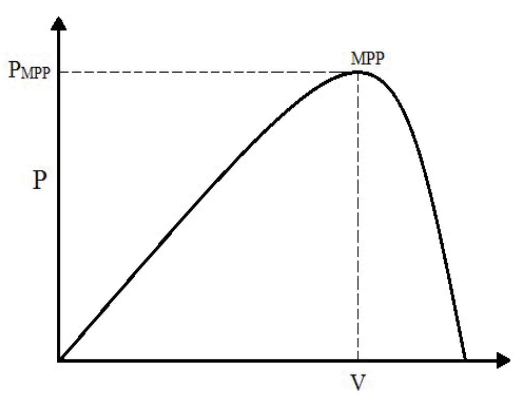

Figure 4.P-V characteristics of the PV cell

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).

IV. COMPARISON OF MPPT TECHNIQUES

Classifications of the MPPT techniques have been attempted based on features, like the number of control variables involved, the types of control strategies, circuitry, and approximate making cost.

a) According to Control Strategies

Control strategies can be of three types: indirect control, direct control, and probabilistic control. Indirect control techniques are based on the use of a database that includes parameters and data such as characteristics curves of the PV panel for different irradiances and temperatures or on using some mathematical empirical formula to estimate MPP. Direct control strategies can seek MPP directly by taking into account the variations of the PV panel operating points without any advanced knowledge of the PV panel characteristics. This is again of two types such as sampling methods and modulation methods. In sampling methods, first a sample is made from PV panel voltage and current. The sample comprises of power and Gathering the past and present information of the sample, the location of the MPP is tracked. In modulation methods, MPP can be tracked by generating oscillations automatically by the feedback control.

b) According to Number of Control Variables

Two different control variables such as voltage, current or solar irradiance, temperature etc. are often chosen to achieve the MPPT applications. According to the variables which need to be sensed, MPPT techniques can be classified into two types, such as one-variable techniques and two-variable techniques. It is easier and cheap to implement voltage sensor whereas current sensor is bulky and expensive and hence implementation of cur- rent sensor is inconvenient in PV power systems.

c) According to Types of Circuitry

The circuitry involved in MPPT techniques are of two types such as analog circuit and digital circuit. Preference of MPPT techniques is also dependent upon the fact that some users are comfortable with analog techniques while others like the digital techniques. Hence, the MPPT techniques are classified based on type of used circuitry (analog or digital) used.

a) According to Cost

Some applications need accurate MPPT and cost is not an issue, such as, solar vehicles, industry, large-scale residential. But some systems like small residential applications, water pumping for irrigation, etc., need a simple and cheap MPPT technique. Expensive applications generally use advanced and complex circuitry because accuracy and fast response are main priorities there. Considering the above facts, the MPPT techniques are categorized taking into account the cost involved for designing the MPPT circuit. It is very difficult to provide exact expenses in building each MPPT circuit due to unavailability of cost-data by the developer.

b) According Algorithms

It is popular and mathematically applicable comparative technique in wide use in every PV system used countries. MPPT technique is mathematically calculated with the help of algorithm and can compare to the efficiency of MPPT. It can be used under different conditions of atmosphere and weather conditions.

V. MPPT ALGORITHMS

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. The algorithm can be easily understood by the following flow chart which is shown in figure

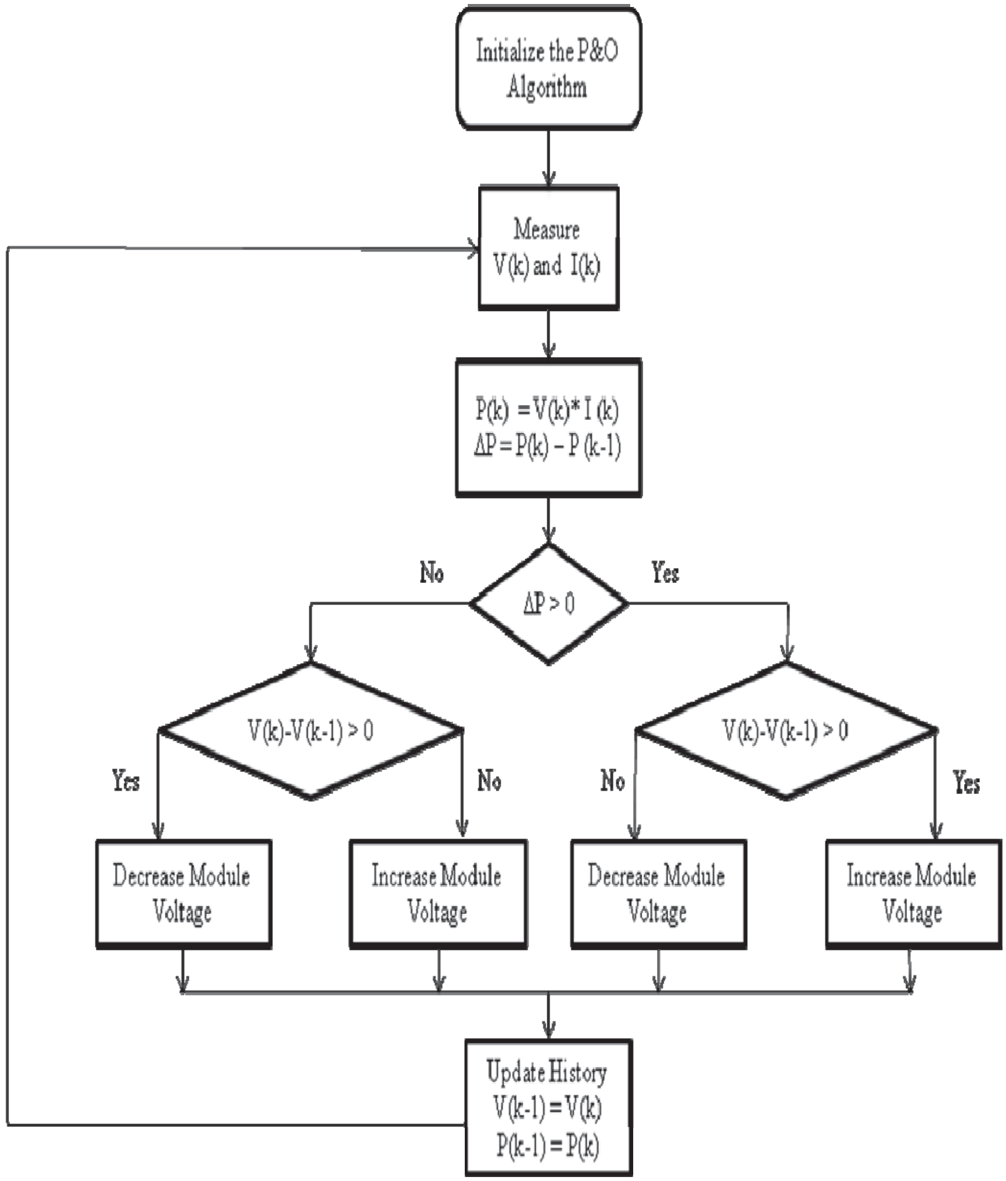

Fig: 5 Perturb and Observe Algorithm

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

VI. 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 perturb and observe 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. The disadvantage of this algorithm is that it is more complex when compared to perturb and observe. The algorithm can be easily understood by the following flow chart which is shown in figure

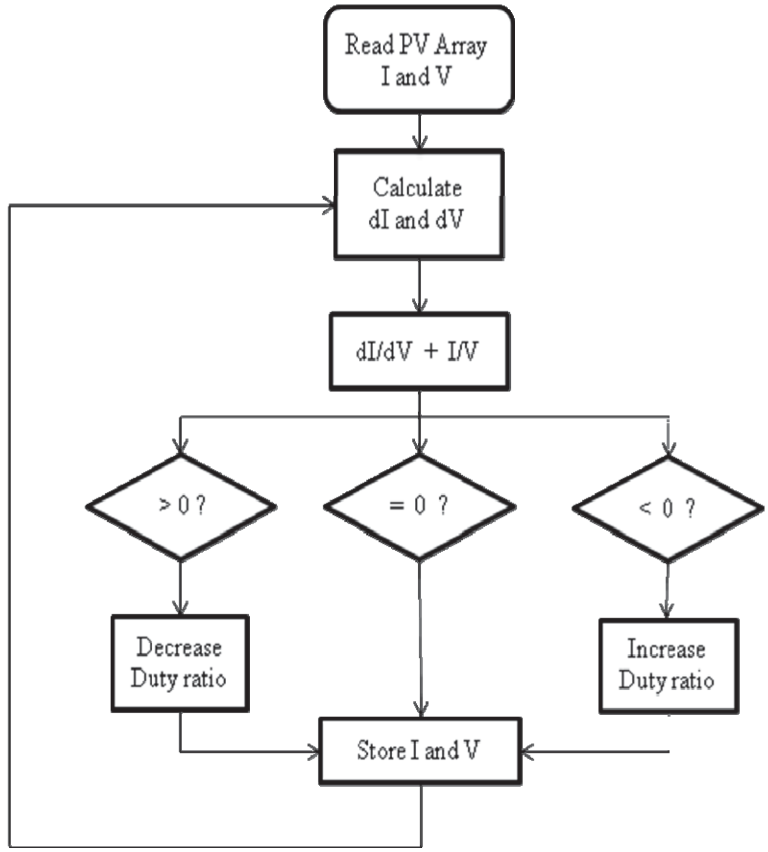

Fig: 6 Incremental Conductance Algorithms

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.

Parameter Specifications O\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 various equations describing the PV array characteristics are modeled.

VII. COMPARISON BETWEEN P&O AND INCREMENTAL CONDUCTANCE MPPT ALGORITHMS

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

Table:2 Comparison between P&O and Incremental conductance MPPT Algorithms

MPPT	Output Current	Output Voltage	Output Power	Time Respon	Accuracy	
P&O MPPT	0.073A	3	2.6	0.0175 sec	Le	
InC MPPT	0.087-0.093A	43-47V	3.7-4.7W	0.1 sec	Accurate	

VIII. MPPT TECHNIQUE APPLICATION

The following techniques are some of the widely used MPPT techniques applied on various PV applications such as space satellite, solar vehicles, and solar water plants and so on. Solar technologies are tested and validated by the National Renewable Energy Laboratory USA. MPPTs are primarily manufactured in Germany, Japan, Mainland China, Taiwan and USA. Some of the practical applications of MPPT techniques are in the solar water pumping system.

IX. CONCLUSION

Among many parameters to compare different techniques, algorithm technique is one of the best mathematical models in use based on features like, control variables involved and type of control strategies, circuitry and making cost so on. In this paper algorithm is used to compare the perturb and observe and Incremental conductance with a mathematical model of a 70W photovoltaic panel has been developed. This model is used for the maximum power point tracking algorithms. The perturb and observe and Incremental conductance MPPT algorithms are discussed and presented. It is proved that Incremental conductance method has better performance than perturb and observe 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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