Study of Maximum Power Point Tracking (MPPT) Techniques

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Abstract--- The need for renewable energy sources is on the rise because of the acute energy crisis in the world today. India plans to produce 20 Gigawatts Solar power by the year 2020, whereas we have only realized less than half a Gigawatt of our potential as of March 2010. Solar energy is a vital untapped resource in a tropical country like ours. The main hindrance for the penetration and reach of solar PV systems is their low efficiency and high capital cost. In this paper, we examine a schematic to extract maximum obtainable solar power from a PV module and use the energy for a DC application. This Paper investigates in detail the concept of Maximum Power Point Tracking (MPPT) which significantly increases the efficiency of the solar photovoltaic system. The Perturb and Observe (P&O), and Incremental Conductance (IncCond) algorithms used for Maximum Power Point Tracking (MPPT), are perhaps the two most popular methods in use. The latter method is typically claimed as the Preferred algorithm, but this is not well justified. The reason for the differences between the two closely related hill climbing methods is shown.

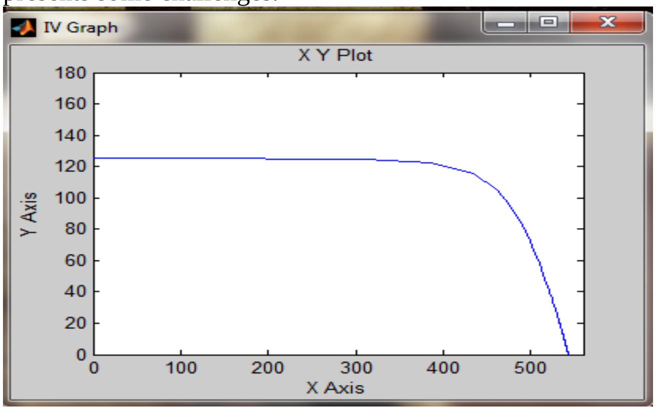
Keyword: - Maximum Power Point Tracking (MPPT), Photovoltaic (PV) System, Perturb and Observer, Incremental Conductance

I. INTRODUCTION

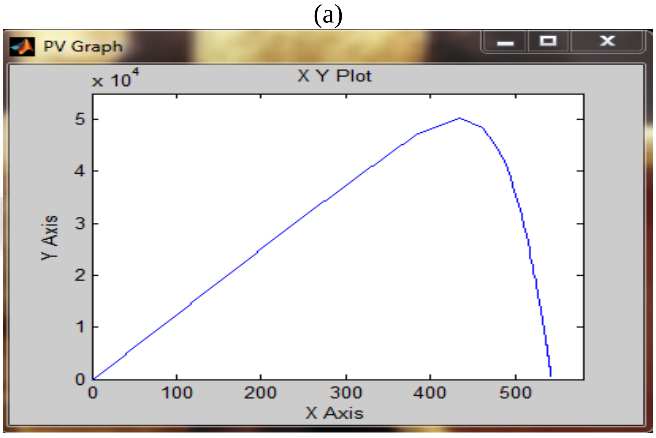
Maximum Power Point Tracking (MPPT) refers to the process of maintaining the maximum power output of an energy source, when its power output changes in time. A PV module can increase its output greatly, when coupled with a converter that uses MPPT. Like a battery or fuel cell, a PV module has an IV curve of different current-voltage pairs where it can operate for a fixed environment (i.e. fixed irradiance and temperature). In fuel cells and batteries, using a higher current relates to using up more of the chemical fuel, and so maximizing output does not coincide with optimizing (increasing the efficiency of) the system. This is not so for a PV module; having the maximum output power is desired; since only energy from the sun gets used (otherwise it would be converted to heat or reflected). Consider a typical IV curve of a PV module shown in Figure 1 (effects due to partial shading will not be discussed in this paper). The power is zero when either the voltage or current is zero (i.e. at open-circuit voltage or short-circuit current). The function is concave, zero on the endpoints, and positive. At some point, the percent increase in voltage is equal to that of the percent decrease in current. That is:

$$\frac{di}{i} = \frac{dv}{v}$$

Thus, there is a maximum power value. See Figure,
Changing atmospheric conditions, the IV curve, and hence the maximum power point (MPP) changes; increasing irradiance mostly causes the graph to shift up, and increasing temperature mostly causes the graph to shift to the left. Consequently, Rm needs to be variable. In order to track the MPP, a converter with a controllable duty cycle is typically used (either DC/DC or DC/AC). The output voltage is typically fixed (or nearly so), allowing the input (PV) voltage to be changed by the duty cycle of the attached converter. However, trying to operate the PV array at Vm presents some challenges.



(a)



(b)

Fig. 1: (a) I-V curve; (b) P-V curve

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A. I-V curve

Solar cell I-V curves where a line intersects the knee of the curves where the maximum power point is located. Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, more commonly known by its abbreviation *FF*, is a parameter which characterizes the nonlinear electrical behaviour of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}, and in tabulated data it is often used to estimate the power that a cell can provide with an optimal load under given conditions, $P=FF*V_{oc}*I_{sc}$. For most purposes, FF, V_{oc}, and I_{sc} are enough information to give a useful approximate model of the electrical behavior of a photovoltaic cell under typical conditions. For any given set of operational conditions, cells usually have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to V/I as specified by Ohm's Law. The power P is given by $P=V*I$. A photovoltaic cell has an approximately exponential relationship between current and voltage (taking all the device physics into account, the model can become substantially more complicated though). As is well known from basic circuit theory, the power delivered from or to a device is optimized where the derivative (graphically, the slope) dI/dV of the I-V curve is equal and opposite the I/V ratio (where $dP/dV=0$). This is known as the **maximum power point** (MPP) and corresponds to the "knee" of the curve. A load with resistance $R=V/I$ equal to the reciprocal of this value is the load which draws maximum power from the device, and this is sometimes called the **characteristic resistance** of the cell. Note however that this is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be. Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

B. The Mppt Control Algorithms

Following are:

- Perturb and Observe (hill climbing method)
- Incremental Conductance method
- Fractional short circuit current
- Fractional open circuit voltage
- Neural networks
- Fuzzy logic

II. CLASSIFICATION

There are three main types of MPPT algorithms: perturb-and-observe, incremental conductance and constant voltage.

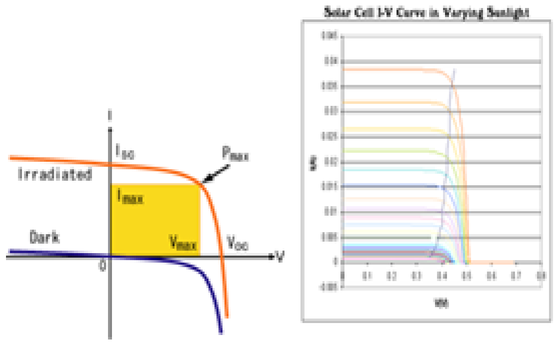

Fig. 2: Effect on I-V curve

The first two methods are often referred to as *hill climbing* methods, because they depend on the fact that on the left side of the MPP, the curve is rising (dP/dV > 0) while on the right side of the MPP the curve is falling (dP/dV < 0).

A. Perturb-and-observe (P&O) method

This method is the most common. The algorithm perturbs the operating voltage in a given direction and samples dP/dV. If dP/dV is positive, then the algorithm knows it adjusted the voltage in the direction toward the MPP. It keeps adjusting the voltage in that direction until dP/dV is negative. P&O algorithms are easy to implement, but they sometimes result in oscillations around the MPP in steady-state operation. They also have slow response times and can even track in the wrong direction under rapidly changing atmospheric conditions.

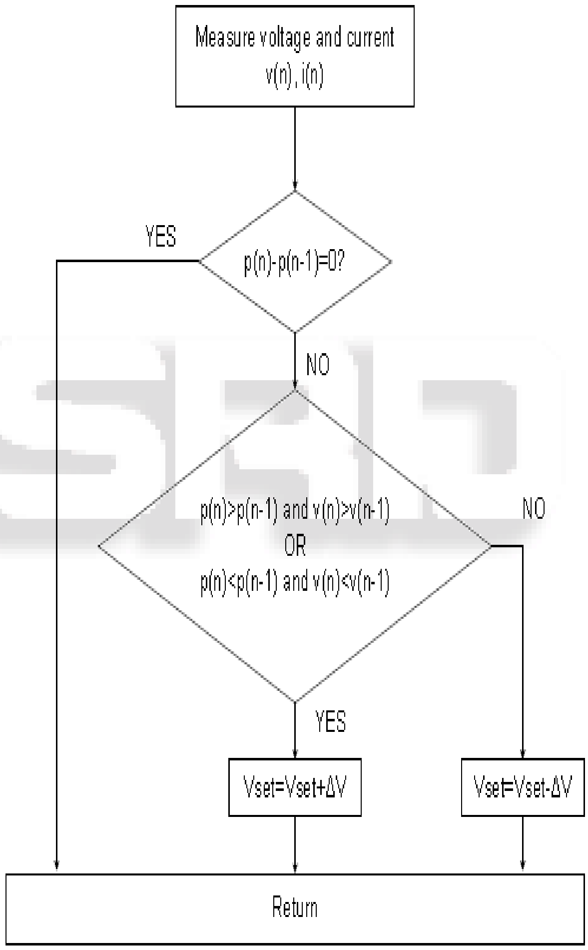

Fig. 3: P&O algorithm.

B. Incremental conductance (INC) method

This method uses the PV array's incremental conductance dI/dV to compute the sign of dP/dV. INC tracks rapidly changing irradiance conditions more accurately than the P&O method. However, like the P&O method, it can produce oscillations and be confused by rapidly changing atmospheric conditions. Another disadvantage is that its increased complexity increases computational time and slows down the sampling frequency.

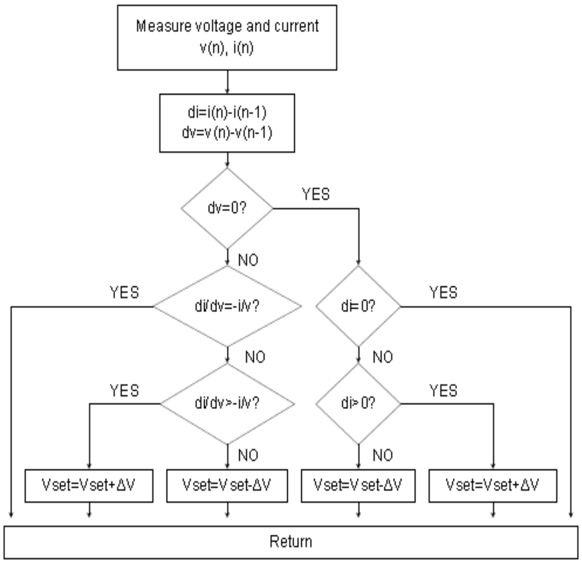

Fig. 4: Incremental conductance algorithm.

C. Constant voltage method

This method makes use of the fact that the ratio of maximum power point voltage to the open circuit voltage is often close to a constant value, with 0.76 being a common estimate. One problem with this method arises from the fact that it requires momentarily setting the PV array current to 0 to measure the array's open circuit voltage. The array's operating voltage is then set to (for example) 76% of this measured value. But during the time the array is disconnected, the available energy is wasted. It has also been found that while 76% of the open circuit voltage is often a very good approximation, it does not always coincide with the maximum power point. Thus this method may not give as much efficiency as others, especially if conditions are highly variable or the physical behaviour of the cell deviates from expectations. Its main advantage is that it is relatively simple to implement and thus usually less expensive.

D. Fractional open circuit voltage

The near linear relationship between VMPP and VOC of the PV array, under varying irradiance and temperature levels, has given rise to the fractional VOC method.

$$V_{mpp} = k1\ V_{oc}$$

where k1 is a constant of proportionality. Since k1 is dependent on the characteristics of the PV array being used, it usually has to be computed beforehand by empirically determining *Vmpp* and *Voc* for the specific PV array at different irradiance and temperature levels. The factor k1 has been reported to be between 0.71 and 0.78. Once k1 is known, *Vmpp* can be computed with *Voc* measured periodically by momentarily shutting down the power converter. However, this incurs some disadvantages, including temporary loss of power.

E. Fractional short circuit current

Fractional ISC results from the fact that, under varying atmospheric conditions, IMPP is approximately linearly related to the ISC of the PV array.

$$I_{mpp} = k2\ I_{sc}$$

Where

k2 is a proportionality constant. Just like in the fractional VOC technique, k2 has to be determined according to the PV array in use. The constant k2 is generally found to be between 0.78 and 0.92. Measuring ISC during operation is problematic. An additional switch usually has to be added to the power converter to periodically short the PV array so that ISC can be measured using a current sensor.

F. Fuzzy Logic Control

Microcontrollers have made using fuzzy logic control popular for MPPT over last decade. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity.

G. Neural Network

Another technique of implementing MPPT which are also well adapted for microcontrollers is neural networks. Neural networks commonly have three layers: input, hidden, and output layers. The number nodes in each layer vary and are user-dependent. The input variables can be PV array parameters like *Voc* and *Isc*, atmospheric data like irradiance and temperature, or any combination of these. The output is usually one or several reference signals like a duty cycle signal used to drive the power converter to operate at or close to the MPP.

H. MPPT placement

Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows through all panels in the string. But because different panels have different IV curves, i.e. different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy. Some companies (see power optimizer) are now placing peak power point converters into individual panels, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch.

I. Operation with batteries

At night, an off-grid PV power system uses batteries to supply its loads. Although the battery pack voltage when fully charged may be close to the PV array's peak power point, this is unlikely to be true at sunrise when the battery is partially discharged. Charging may begin at a voltage considerably below the array peak power point, and a MPPT can resolve this mismatch. When the batteries in an off-grid system are full and PV production exceeds local loads, a MPPT can no longer operate the array at its peak power point as the excess power has nowhere to go. The MPPT must then shift the array operating point away from the peak power point until production exactly matches demand. (An alternative approach commonly used in spacecraft is to divert surplus PV power into a resistive load, allowing the array to operate continuously at its peak power point.)

III. CONCLUSIONS

Column1	Column2	Column3	Column4	Column5
MPPT technique	Convergence speed	Implementation complexit	Periodic tuning	Sensed parameters
Perturb & observe	Varies	Low	No	Voltage
Incremental conductance	Varies	Medium	No	Voltage, current
Fractional Voc	Medium	Low	Yes	Voltage
Fractional Isc	Medium	Medium	Yes	Current
Fuzzy logic control	Fast	High	Yes	Varies
Neural network	Fast	High	Yes	Varies

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