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Modeling, Control and Maximum Power Point Tracking (MPPT) for optimal Battery charging from Solar Photovoltaic (SPV) system

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MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array.Over the past decades many methods to find the MPP have been developed and published. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature change, hardware needed for the implementation or popularity, among others. Among these techniques, the P&O and the InCond algorithms are the most common. These techniques have the advantage of an easy implementation but they also have drawbacks, as will be shown later. Other techniques based on different principles are fuzzy logic control, neural network, fractional open circuit voltage or short circuit current, current sweep, etc. Most of these methods yield a local maximum and some, like the fractional open circuit voltage or short circuit current, give an approximated MPP, not the exact one. In normal conditions the V-P curve has only one maximum, so it is not a problem. However, if the PV array is partially shaded, there are multiple maxima in these curves.

Key words: *Battery energy storage system, Maximum power point, Optimal charging*

1.0 INTRODUCTION

Battery energy storage systems (BESS) refer to secondary chemical battery technologies. They have been used in many areas for power grid and renewable energy system like solar photovoltaic and wind, which have evolved from flooded lead acid to valve-regulated lead acid (VRLA), nickel cadmium (NiCd), nickel metal hydride (NiMH) and lithium-ion (Li-ion). Newer designs, which are at different stages of development, include sodium-sulphur (NaS) and sodium nickel chloride (ZEBRA). Electrochemical flow cell systems or flow batteries, such as vanadium redox (VRB) and zinc bromine (ZnBr), are also promising technologies because their rated power and storage capacity are scalable depending on the reactor size and electrolyte tanks. However, flow batteries are currently still a new technology and considered a costly investment. In general, batteries can be used for both power and energy applications with discharge durations from minutes up to a few hours.

The power output from the solar panel is a function of insolation level and temperature. But for a given operating condition, we have a curve which gives the voltage level maintained by the panel for a particular value of current. This plot is known as the characteristics of the cell. From the characteristics plot, we will be able to derive the power output with respect to the outputcurrent. The efficiency of any semiconductor device drops steeply with the temperature. In order to

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ensure that the photovoltaic modules always act supplying the maximum power as possible and dictated by ambient operating conditions, a specific circuit known as Maximum Power Point Tracker is employed.In most common applications, the MPPT is a DC-DC (Direct current) converter controlled through a strategy that allows imposing the photovoltaic module operation point on the Maximum Power Point (MPP) or close to it.

2.0 SOLAR PHOTOVOLTAIC

Solar Photovoltaic (SPV) system is gaining increased importance as a renewable source due toadvantages such as the absence of fuel cost, little maintenance and no noise and wear due tothe absence of moving parts. But there are still two principal barriers to the use of photovoltaic systems: the high installation cost and the low energy conversion efficiency.A solar cell is a semiconducting device that absorbs light and converts it into electrical energy. A simple mathematical model for a photovoltaic cell is given by

$$I = I_{ph} - I_S[e^{\frac{qV}{2kT}} - 1] \quad \ldots(1)$$

Where I and V are output current and voltage of the cell, I_{ph} is the generated photo-current, I_s is the reverse saturation current of the diode, T is the temperature, k is the Boltzmann's constant (1.380×10^{-23}J/K) and q is the elementary charge(1.602×10^{-19}C).

A PV panel is a non-linear power source, i.e. its output current and voltage (power) dependson the terminal operating point. The maximum power generated by the PV panel changes with the intensity of the solar radiation and the operating temperature. To increase the ratio output power/cost of the installation it is important that PV panel operates in the maximum output power point (MPP). The block diagram of the Solar Photovoltaic system is shown in Figure 1.

3.0 SOLAR ARRAY CHARACTERISTICS

The maximum power point of a solar panel changes in accordance with changes in the solarirradiance intensity, angle and panel temperature.It consists of two regions: one is the current source region, and the other is the voltage source region. In the voltage source region, the internal impedance of the panel is low. That region is the right side of the current-voltage curve. The current source region, in which the internal impedance of the panel is high, is at the left side of the current-voltage curve. The MPP of the panel is located at the knee of the current-voltage curve. According to the maximum power transfer theory, the power delivered to the load is maximum when the source internal impedance matches the load impedance. Thus, the impedance seen from the converter input side (can be adjusted by PWM control signal) needs to match the internal impedance of the panel if the system is required to operate at or near the MPP of the solar array. If the system operates on the voltage source region (namely low impedance region) of panel characteristic curve, the panel terminal voltage will collapse.

In the power v/s voltage curve, it can be observed that each curve has a maximum power point,which is the optimal point for the efficient use of the panel. This point depends of the values of irradiance and working temperature. The main function of a MPPT is to adjust the panel output voltage to a value which the panel supplies the maximum energy to the load.

4.0 MAXIMUM POWER POINT TRACKING

For any given set of operational conditions, cells 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, R= V/I, as specified by Ohm's Law. The power P is given by P = VI. From basic circuit theory, the power delivered from or to a device is optimized where the derivative of the I-V curve is equal and opposite the I/V ratio. This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve.

The load with resistance R=V/I, which is equal to the reciprocal of this value and draws the maximum power from the device is sometimes called the characteristic resistance of the cell. 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.

The different types of MPPT algorithms are

1. Open Circuit Voltage Method
2. Short Circuit Current Method
3. Incremental Conductance Method
4. Perturb and Observe Method
5. Usage of a pilot cell
6. Forced oscillation --- auto oscillation
7. The current-feedback method
8. Analog MPPT methods

4.1 Open Circuit Voltage Method

An improvement on this method uses V_{oc} to calculate V_{mp}. Once the system obtains the V_{oc} value, V_{mp} is calculated by,

$$V_{MPP} = k_v V_{oc} \quad \text{...(2)}$$

Where V_{oc} is the open circuit Voltage, V_{mp} is the Voltage at maximum point. The k value is typically between to 0.7 to 0.8. It is necessary to update V_{oc} occasionally to compensate for any temperature change. Sampling the V_{oc} value can also help correct for temperature changes and to some degree changes in irradiance. Monitoring the input current can indicate when the V_{oc} should be re-measured. The k value is a function of the logarithmic function of the irradiance, increasing in value as the irradiance increases. An improvement to the V_{oc} method is to also take this into account.

Benefits

1. Relatively lower cost.
2. Very simple and easy to implement.

Drawbacks

1. Not accurate and may not operate exactly at MPP.
2. Slower response as V_{mp} is proportional to the V_{oc}.

4.2 Short Circuit Current Method

The short circuit current method uses a value of short circuit current I_{sc} to estimate current at maximum point I_{mp}.

$$I_{MPP} = k_I I_{SC} \quad \text{...(3)}$$

Where $I_{mp}$is the current at maximum point, I_{sc} is the short circuit current and k is the constant typically close to 0.9 to 0.98.This method uses a short load pulse to generate a short circuit condition. During the short circuit pulse, the input voltage will go to zero, so the power conversion circuit must be powered from some other source. One advantage of this system is the tolerance for input capacitance compared to the V_{oc} method. The k values are typically close to 0.9 to 0.98.

Benefits

1. It is simple and low cost to implement.
2. This method does not require an input.
3. In low insulation conditions, it is better than others.

Drawbacks

1. Irradiation is never exactly at the MPP due to variations on the array that are not considered (it is not always accurate).
2. Data varies under different weather conditions and locations.
3. It has low efficiency.

4.3 Incremental Conductance Method

The incremental conductance method based on the fact that, the slope of the PV array of the power curve is zero at the MPP, positive on the left of the MPP. And negative on the right on the MPP. This can be given by,

$$\frac{dP}{dV} = 0 \text{, at MPP} \quad \ldots(4)$$

$$\frac{dP}{dV} > 0 \text{, left of MPP} \quad \ldots(5)$$

$$\frac{dP}{dV} < 0 \text{, right of MPP} \quad \ldots(6)$$

The power derivative can be also written as:

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = (I * \frac{dV}{dV}) + (V * \frac{dI}{dV}) = I + (V * \frac{dI}{dV}) \approx I + (V * \frac{\Delta I}{\Delta V}) \quad \ldots(7)$$

So the first bundle of equations can be rewritten as:

$$\frac{\Delta I}{\Delta V} = \frac{-I}{V} \text{, at MPP} \quad \ldots(8)$$

$$\frac{\Delta I}{\Delta V} > \frac{-I}{V} \text{, left of MPP} \quad \ldots(9)$$

$$\frac{\Delta I}{\Delta V} < \frac{-I}{V} \text{, right of MPP} \quad \ldots(10)$$

The main idea is to compare the incremental conductance (ΔI/ΔV) to theinstantaneous conductance (I/V).

Depending on the result, the paneloperating voltage is either increased, or decreased until the MPP is reached. Unlike the P&O algorithm, which naturally oscillates around the MPP, incremental conductance stops modifying the operatingvoltage when the correct value is reached. A change in the panel current will restart the MPP tracking. Depending on the ambient conditions, the same functionality may be achieved by using the initial equation (ΔP/ΔV). The power v/s voltage curve is shown in figure 2.

Benefits

It can determine the maximum power point without oscillating around this value.

Drawbacks

1. The incremental conductance method can produce oscillations and can perform erratically under rapidly changing atmospheric conditions.
2. The computational time is increased due to slowing down of the sampling frequency resulting from the higher complexity of the algorithm compared to the P&O method.

4.4 Perturb and Observe Method

In this method the controller adjusts the voltage by a small amount from the array and measures power, if the power increases, further adjustments in the direction are tried until power no longer increases. This is called P&O method. As the name of the P&O method states, this process works by perturbing thesystem by increasing or decreasing the array operating voltage and observing its impact on the array output power. Due to ease of implementation it is the most commonly used MPPT method. Thepower v/s Voltage curve is shown in figure 3.

The voltage to a cell is increased initially, if the output power increase, the voltage is continually increased until the output power starts decreasing. Once the output power starts decreasing, the voltage to the cell decreased until maximum power oscillation of the output power around the MPP.

Benefits

P&O is very popular and most commonly used in practice because of

1. Its simplicity in algorithm.
2. Ease of implementation.
3. Low cost
4. It is a comparatively an accurate method

Drawbacks

There are some limitations that reduce its MPPT efficiency.

It cannot determine when it has actually reached the MPP. Under steady state operation the output power oscillates around the MPP.

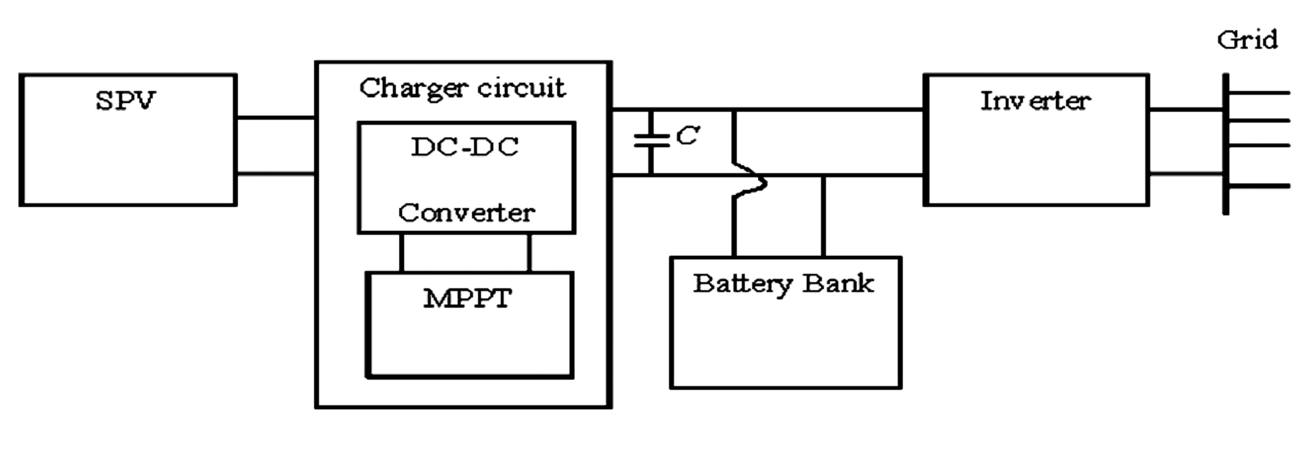

FIG.1 BLOCK DIAGRAM OF THE SOLAR PHOTOVOLTAIC SYSTEM

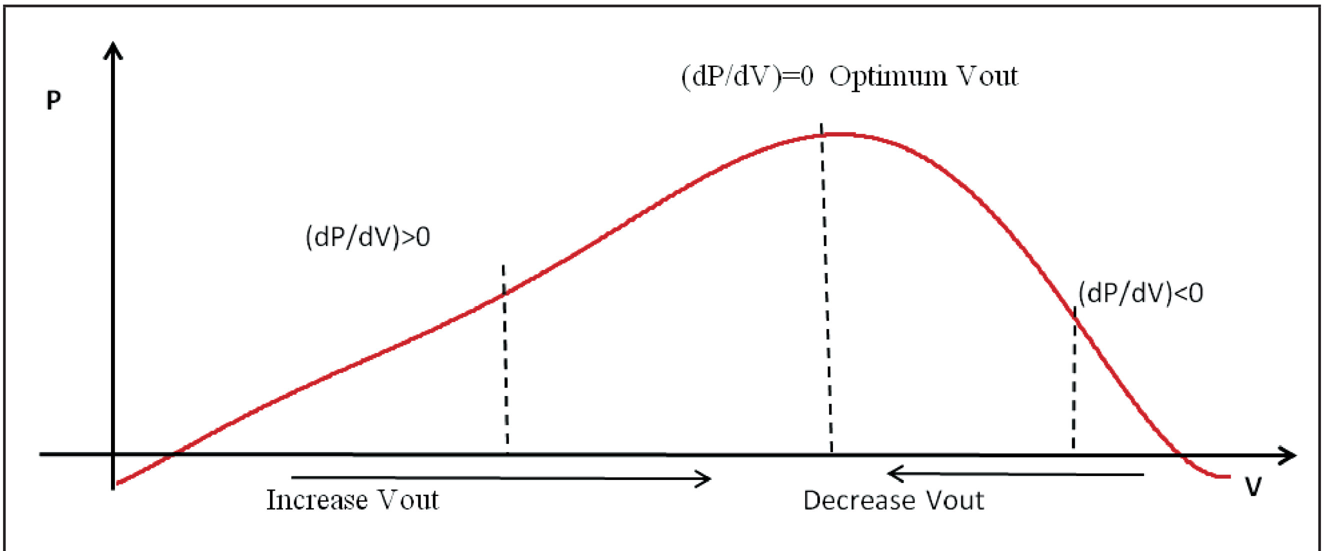

FIG. 2 P-V CURVE AND INCCOND ALGORITHM

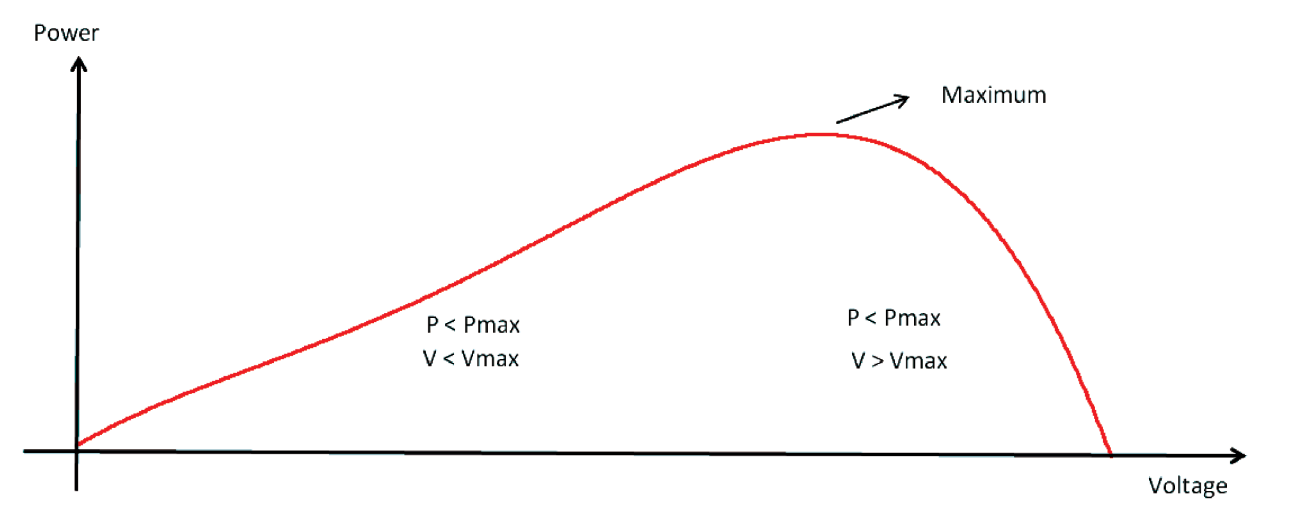

FIG. 3 OUTPUT POWER USING P&O ALGORITH

5.0 CONCLUSIONS

This paper proposes the different types of MPPT algorithms for tracking the maximum power point in a Solar Photovoltaic system. The non-optimal charging of the battery will lead to the high maintenance cost because which will reduce the life span of the Battery. So the best way to increase the efficiency and performance of the battery is the optimal charging. In the Solar Photovoltaic system the electrical energy can be stored using batteries, so the MPPT algorithm can be used for optimal charging of batteries which can reduce the maintenance cost of the batteries and improve the efficiency of the batteries.

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