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General review and classification of different MPPT Techniques

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ABSTRACT

In this paper, the concept of power tracking for PV systems is highlighted and an overview on 40 old and recent Maximum Power Point Tracking (MPPT) methods, available in the literature, is presented and classified. These methods are mathematically modeled and presented in such a way the reader can select the most appropriate method for his own application. A comparative table is presented at the end of the paper to simplify the classification of the different methods.

1. Introduction

A few years ago, researchers started to develop strategies to extract as much power as possible from renewable energy sources and especially from the PV panels. They are used for stand-alone and grid-connected system. First, mechanical systems were developed that move the PV panels so that they receive the maximum solar radiations. Another type of tracker, called electrical Maximum Power Point Tracker (MPPT), is based on moving the operating PV voltage, or current, in order to get the maximum power. This tracker usually requires a switching converter to sweep the PV power. To date, a big number of MPPT algorithms and designs are available in the literature. Each method has its own specifications, limitations and applications. It is convenient to mention that MPPT is not only applied to extract power from PV panels, but also used for different types of renewable energy sources such as fuel cells [1,2], thermoelectric devices [3], etc. In this paper, the MPPT is developed mathematically and a list of 40 different tracking methods, dedicated for PV systems, are discussed.

In general, PV systems are divided into three categories: the stand-alone systems [4,5], the grid-connected systems [6] and the hybrid systems in which PV systems are merged into other types of energy source systems [7,8].

The performance of a PV system depends on the operating conditions. Then, the maximum power extracted from the PV generator depends strongly on three factors: irradiance, cell temperature (ambient temperature), and load profile (load impedance). The output $I-V$ characteristic of a PV module is a function of irradiation and temperature. The irradiation changes affect the PV output current while the temperature changes affect the PV output voltage.

However, PV systems are designed to operate at their maximum output power levels for any solar irradiation intensity and temperature. The factor that determines the PV output power is the load impedance, which can be a DC load with or without batteries. However, it should be noted that such impedance is not constant. When a PV generator is directly connected to a load, the system will operate at the intersection of the $I-V$ curve with the load line, which can be far from the Maximum Power Point (MPP). The maximum power production is based on the load-line adjustment under unstable climatic conditions.

To overcome the undesired effects on the output PV power and draw its maximum power, it is possible to insert a DC/DC converter between the PV panel and the batteries, which can control the seeking of the MPP, besides including the typical functions assigned to the controllers. These converters are normally named as Maximum Power Point Trackers (MPPTs). The input of the DC/DC converter part is formed by the PV array and the output is formed by the batteries and load. A computing system will modify the duty-cycle and implicitly the input impedance of the converter until the system reaches the MPP. On the other hand, their losses have to be small enough so that the efficiency of the overall system is recovered. This could increase the gap between the PV peak power voltage and the voltage at which they are forced to operate in a system without a peak power tracking system.

There are multiple ways to achieve the PV panel and load impedance matching. The system is composed of a DC/DC or DC/AC converter and an MPP computing system. The converter acts as an impedance matching circuit. The MPPT computing system measures the input and/or output voltage and current as well as the climatological variations then computes the power to control the converter input impedance by changing the duty-cycle of the control signal. The PV

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system scheme is shown in Fig. 1.

The efficiency of a PV plant is affected by the efficiency of the PV panel, the converter/inverter and the efficiency of the MPPT algorithm. The efficiencies of the PV panel and the converter/inverter are not easily improved as they depend on the available hardware technology, but improving the tracking of the MPP with new control algorithms is easier and leads to an increase in the PV power generation.

To date, several MPPT algorithms have been published [9]. They differ in many aspects such as efficiency, convergence speed, complexity, sensors required, cost, hardware implementation, and as well as various other aspects. However, it is pointless to use a more complex or more expensive method if a simpler and less expensive one leads to similar results. This is why some published techniques are not used.

Measuring the efficiency of MPPT algorithms had not been standardized until the European Standard EN 50530 was published at the end of May 2010 [10]. It specifies how to test the efficiency of MPPT methods both statically and dynamically. In any case, there are no publications comparing the results of the different MPPT algorithms under the proposed standard conditions. One of the most important reasons for this is the lack of comprehensive comparative analysis of these algorithms in terms of efficiency. In literature, most of the comparative studies are realized between the systems that include MPPT and those that do not.

2. MPPT modeling

As mentioned before, the irradiation and the temperature affect the PV output power. These atmospheric conditions are not constant during a single day. This causes the MPP to move depending on the temperature and irradiation conditions. Great power losses occur when the operating point is not close to the MPP. Hence, it is essential to track the MPP in any conditions to ensure that the maximum available power is obtained from the PV panel.

When examining the typical PV power and polarization illustrated in Figs. 2 and 3, the point of the maximum power is observed. This point depends mainly on irradiance and temperature. The location of the MPP is unknown, but can be located, either through search algorithms or by calculation models. The curves expressing the behavior of PV power can be written as:

$$P_{PV}(t) = F(V_{PV}(t), I_{PV}(t), \gamma(t)) \tag{1}$$

where γ denotes all the variables other than the current and the voltage and hence defines the power curve at time t. It depends on the PV parameters and on climatological variables.

An MPP tracking technique consists in adjusting the output voltage of the PV to extract the maximum available power at any change in the input (temperature, irradiance). The MPPT is based on the fact that the derivative of the output power with respect to the output voltage is zero at the MPP, positive on the left of the MPP and negative on the right of the MPP (see Fig. 2).

It is convenient to mention that the curves defined by Eq. (1)verify the following property:

$$\begin{cases} \dfrac{dP_{PV}}{dV_{PV}} = 0 \quad \text{when} \quad V_{PV} = V_{MPP} \\ \dfrac{dP_{PV}}{dV_{PV}} > 0 \quad \text{when} \quad V_{PV} < V_{MPP} \\ \dfrac{dP_{PV}}{dV_{PV}} < 0 \quad \text{when} \quad V_{PV} > V_{MPP} \end{cases} \tag{2}$$

Regarding the properties of the curves defined by Eqs. (1) and (2), the tracker strategy consists in respecting the following rule:

$$\frac{dP_{PV}}{dV_{PV}} \cdot \frac{dV_{PV}}{dt} > 0 \tag{3}$$

Deriving the output power with respect to the output voltage leads to:

$$\frac{dP_{PV}}{dV_{PV}} = \frac{d(V_{PV} I_{PV})}{dV_{PV}} = I_{PV} + V_{PV}\frac{dI_{PV}}{dV_{PV}} \tag{4}$$

At MPP, the derivative of power with respect to voltage is zero, therefore:

$$\frac{dP_{PV}}{dV_{PV}} = 0 \Rightarrow \frac{V_{PV}}{I_{PV}} = -\frac{dV_{PV}}{dI_{PV}} \tag{5}$$

The error between the instantaneous and the derivative values is expressed as:

$$\varepsilon = \frac{V_{PV}}{I_{PV}} + \frac{dV_{PV}}{dI_{PV}} \tag{6}$$

Combining Eqs. (2) and (6), the MPP can be tracked by comparing V_{PV}/I_{PV} to dV_{PV}/dI_{PV} as follows:

$$\varepsilon = 0 \leftrightarrow \frac{V_{PV}}{I_{PV}} = -\frac{dV_{PV}}{dI_{PV}} \quad \text{at the MPP}\varepsilon > 0 \leftrightarrow \frac{V_{PV}}{I_{PV}} > -\frac{dV_{PV}}{dI_{PV}} \quad \text{left to the MPP}\varepsilon < 0 \leftrightarrow \frac{V_{PV}}{I_{PV}} < -\frac{dV_{PV}}{dI_{PV}} \quad \text{right to the MPP} \tag{7}$$

Eq. (7) is illustrated by Fig. 3. MPP exists on the peak of the power graph at $I_{PV} = I_{MPP}$ which corresponds to the intersection of dP_{PV}/dV_{PV} curves with the current axis and the intersection of V_{PV}/I_{PV} with the dV_{PV}/dI_{PV} curve.

The dV_{PV}/dI_{PV} and the V_{PV}/I_{PV} curves intersect at the MPP that refers to V_{MPP} on the voltage axis (see Fig. 4). The optimum current I_{MPP} is located at the intersection of the current curve at V_{MPP}.

3. MPPT selection criteria

Having lot of tracking techniques available for PV system, it is not evident to decide which one is the best. when selecting the MPP techniques, the following criteria have to be considered,

3.1. Implementation

The ease of implementation is an important factor in deciding which MPPT technique to use. Some techniques are easily implemented with no need for on-site adjustment or calibration. Other techniques are more complex and their calibration varies with site location and climatic conditions.

3.2. Sensors

The number of sensors required to implement the MPPTs also affects the decision process. In order to track the maximum power, it is

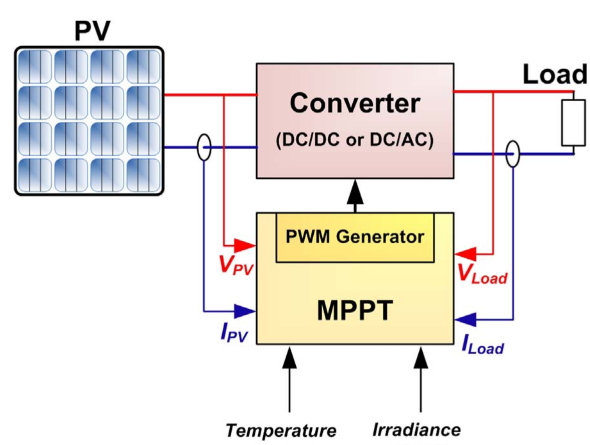

Fig. 1. General scheme of a PV with an MPPT system.