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A comprehensive overview of maximum power extraction methods for PV systems

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ABSTRACT

The power generated by photovoltaic (PV) system depends on environment irradiance and temperature parameters. Hence, PV panels have nonlinear characteristics. In uniform condition, there is only one maxima point called maximum power point (MPP) where the PV system operates in maximum efficiency. However, in non-uniform condition such as partial shading effects, the PV system presents multiple maxima points on the correspondence P-V curve due to bypass diodes which makes more difficult to estimate global MPP. That is why it makes maximum power point tracking (MPPT) more important for PV systems to operate in maximum efficiency. In the literature, various types of MPPT technique and alternative solutions are used to detect true global MPP point among the other local MPPs. In addition, different PV array topologies, architectures and configurations are proposed to remove local maxima on the P-V curve.

In this paper, most popular and used MPPT techniques, PV array configurations, system architectures and circuit topologies are discussed. In this context, this paper provides an overview of the operating principles discusses advantages and disadvantages and makes a general comparison between different solutions of each method.

1. Introduction

The growing energy demand with the possibility of reduced supply of conventional fuels, proved by high petroleum prices, along with growing concerns about polluting effects on environment, has driven researchers and their developments to alternative energy sources which are cleaner, renewable and produce less environmental impact.

Among the alternative sources, solar energy is one of the most used and readily available renewable energy sources. Solar energy supplied by the sun in one hour is equal to the energy required by the human population in one year. Power generated by PV module depends upon the solar irradiation, cell temperature and load impedance [1–4]. To efficiently utilize solar energy, maximum power point tracking (MPPT) technology is applied to operate PV systems at maximum power point. Various MPPT strategies are used in the literature to adjust power output of PV systems with the change of solar irradiance and temperature.

In general, there is only one maximum power point on P-V curve of a PV module where the PV module produces its maximum output power under uniform solar irradiance condition. Thus, in order to achieve maximum efficiency for PV systems, some conventional maximum power point tracking algorithms are used such as Hill – Climbing, Perturb & Observe (P & O), Incremental Conductance (Inc. Cond).

Under non-uniform condition such as in a partially shaded condition, the P-V curve of the PV module exhibits multiple maximum power points due to the bypass diodes which are used to prevent hotspots on PV modules. Due to multiple local maxima points, the conventional MPPTs do not perform well and they cannot detect global maxima point on the P-V curve. Without any intervention, the lost power due to non-uniform effects can be significant. To overcome these drawbacks, researchers have been proposed several methods and techniques in the literature. Therefore, this paper aims to review and classify used MPPT techniques, different PV array configuration types, system architectures and circuit topologies in the literature. In this study, advantages and disadvantages of the discussed methods are summarized and a general comparison table for each subject of the used methods has been created carefully.

In this context, this paper is organized as follows. Section 2 presents PV cell modelling and elemental characteristics of PV module under

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different solar irradiance and temperature. Section 3 provides partial shading effects on the characteristics of PV system. Section 4 reviews the most used MPPT techniques in the literature and explains them with their implementations and applications. In Section 5, different PV array configurations are discussed which reduce negative effects of partial shading. Section 6 presents various types of PV system architecture and Section 7 reviews different kind pf PV system circuit topologies. Section 8 gives an extensive analysis and comparison between discussed MPPT techniques and methods separately. Section 9 summarizes the potential new alternative methods which can alleviate partial shading effects on PV modules, increase the power extraction and efficiency on PV systems and concludes this paper.

2. PV modelling and characteristics

The solar photovoltaic (PV) technology is concerned with the conversion of the solar energy into electrical energy. The basic element of a PV system is a PV cell [5]. PV cells are p – n junction semiconductors like other electronic components. In the literature, there are various types of PV cell equivalent circuit representations. Commonly, single diode equivalent circuit model is used to express typical electrical characteristic of PV arrays [6].

By single diode model, non – linear characteristic of PV panel can be also expressed. A PV module is built from several PV cells which are connected in series and parallel. Fig. 1 shows a PV cell equivalent circuit and a PV module with 9 cells [6].

By using the equivalent circuit as shown in Fig. 1, the generated current from the PV cell can be expresses as:

$$I = I_{ph} - I_o\left(e^{\frac{q(V+R_sI)}{AKT}} - 1\right) - \frac{V + R_sI}{R_{sh}} \quad (1)$$

where I and V represent PV cell output current and voltage. R_s and R_{sh} are the PV cell series and shunt resistance respectively. I_{ph} is the PV cell photo current, I_o is the diode saturation current, A is the diode quality factor ($\cong$ 1.2), K is Boltzmann's constant ($1.38 \times 10^{-23} J/K$) and T is the PV cell temperature in kelvins.

The characteristic curves of a PV system depend on the solar irradiance and temperature [7]. For a given system, during uniform conditions where the solar irradiance is equally distributed among the PV modules, the output power curves depend on the PV voltage under different weather conditions are shown in Fig. 2. During uniform conditions, only one maxima point is observed in the characteristic power curves. However, when the solar irradiance or temperature varies, the power generated by PV module becomes different and the maxima point varies according to the previous value.

3. Effects of partial shading on PV system

Under uniform conditions on the PV array, the P-V curve of the PV module is unimodal, i.e. it has only one peak [8]. However, under non-uniform conditions where the solar irradiance is unequally distributed among the PV modules, each PV module can be exposed to different solar irradiance due to the shadows of buildings, trees, clouds, birds, dirt, etc. Fig. 3 shows different partial shading scenario for a PV system.

Under the partial shading conditions, if there is one module in a PV array which is less illuminated, the shaded module will dissipate some of the power generated by the rest of the modules [9]. If there is no bypass diode which is connected to the PV cells or PV module in parallel, the shaded PV cell or PV module can be exposed to higher currents because of the unshaded cells and it can cause hotspot condition for the shaded cells which can damage to the shaded PV cells. To prevent hotspot condition for the shaded cells, parallel connected bypass diode is preferred to connect to each PV cell or PV module. However, the resulting P – V curve have multiple local peaks and single global peak due to bypass diode. Fig. 4 illustrates the P – V characteristics of PV module under non-uniform condition. This reduces the maximum available power. Also, conventional MPPT techniques cannot find true global point and it hinders the efficient MPPT operation.

4. MPPT techniques

PV cells and modules generate different power depended on different environment condition and electrical load. Because of that, generation of maximum power is not guaranteed at all electrical loads [6]. To extract available maximum power from PV modules or arrays, maximum power point tracking (MPPT) algorithms are used for PV systems in the literature. There are various types of MPPT techniques used to run PV modules on maximum power.

In general, MPPT techniques are classified into two types.

- Conventional methods
- Soft computing methods

For conventional MPPT, the methods include perturb and observe (P & O), incremental conductance (Inc. Cond.), hill climbing, short circuit current, open circuit voltage, ripple correlation control, current sweep control [10]. Conventional MPPT methods are efficient for uniform environmental conditions. For PV systems which work in uniform condition, there is just one maximum power point and this point changes depending on solar irradiance or temperature. Therefore, it is easy to find the maximum power point by using these conventional methods. However these techniques have continuous oscillations around MPP and this causes loss of power. Also, conventional MPPTs are failing to track global MPP in non-uniform condition and they do not have enough ability to handle partial shading conditions.

Soft computing methods such as artificial neural network, fuzzy logic control, particle swarm optimization and differential evolution have ability to find GMPP in local MPPs for non-uniform environment conditions.

4.1. Perturb and observe method (P & O)

The P & O method operates by periodically incrementing or decrementing the output terminal voltage of the PV cell and compares the power obtained in the current cycle with the power of the previous one

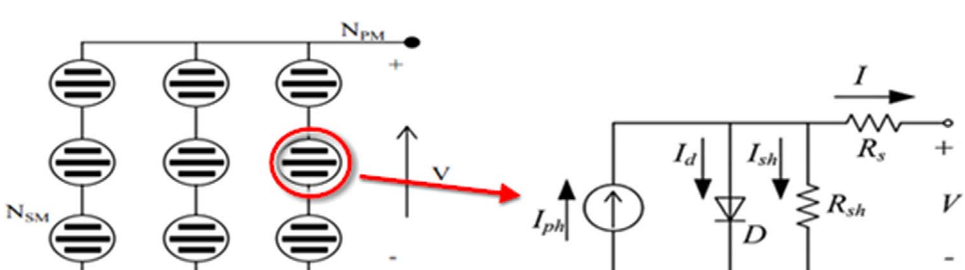

Fig. 1. Equivalent single diode circuit model of PV cell [6].