Solar Energy 169 (2018) 535–555

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Review

Hybrid maximum power point tracking techniques: A comparative survey, suggested classification and uninvestigated combinations

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ARTICLE INFO

Keywords:
Photovoltaic systems
PV array
Maximum power point tracking techniques (MPPT)

ABSTRACT

Maximum Power Point Tracking (MPPT) of Photovoltaic (PV) arrays is inevitable to maximize the power transfer and improve the system efficiency. Many MPPT techniques were proposed in literature with diverse algorithms and methodologies; offline, online, estimation, computational and intelligent methods were examined to drag the system operating state to the maximum power point (MPP) under different weather conditions. High accuracy, fast tracking speed, ease of implementation and ability to track the Global Maximum Power Point (GMPP) under partial shading conditions are the most important and desirable yet rather complementary features of any individual MPPT technique; meaning, high accuracy in most cases is associated with slow tracking speed as in the online Perturb and Observe (P&O) method. Most single or individual MPPT techniques manage to achieve one or two of those desired aforementioned traits, while fail to accomplish the others. Thus, Hybrid MPPT systems are introduced, combining two individual MPPT techniques and aiming at attaining in the overall the merits of each individual technique while eliminating their drawbacks. Hybrid MPPT surpassed in performance individual techniques whether in combing accuracy with speed or even tracking the GMPP under partial shading at no added complexity. For this reason, this work focuses mainly on Hybrid MPPT techniques, starting by the most common individual MPPT methods and surveying 20 examined Hybrid combinations listed in literature with a proposed classification and a comparison of their overall performance. Moreover, it presents, via a Conceptual Map (C-Map),[1] a suggested pattern followed into combining two MPPT techniques into one Hybrid MPPT system. In addition, a list of uninvestigated Hybrid combinations is proposed exploring further potential enhancement.

1. Introduction

Recently, there has been a growing attention towards the use of solar energy due to the demand of a clean and renewable source of energy. The main advantages of photovoltaic (PV) systems employed for exploiting solar energy are the elimination of greenhouse emissions, reduced maintenance costs, less limitations with regard to site of installation and absence of mechanical noise arising from moving parts (Femia, 2013). On the other hand, the PV generation systems suffer two major problems; low conversion efficiency, weather-dependency and intermittency of the generated electric power. Furthermore, there is a unique point on the nonlinear I-V curve of the solar array called Maximum Power Point (MPP), at which the entire PV system operates with maximum efficiency. This MPP location is weather dependent and changes with the varying irradiation and temperature; therefore, tracking of the maximum power point (MPP) of the PV array is usually an essential part of the whole systems. Fig. 1a demonstrates the decrease in the current provided by the PV panel with lower irradiance levels, whereas, Fig. 1b, shows that V_{OC} decreases with increasing, hence affecting the MPP location. For enhanced efficiency, operation at MPP should always be satisfied regardless of changing solar conditions, which can be achieved by implementing an MPPT algorithm. The location of the MPP is not known beforehand but can be located, either through searching algorithms, or by computational models (Baimel et al., 2016; Masters, 2013).

More than 50 MPPT algorithms have been employed, with different features and characteristics in terms of accuracy, convergence speed and implementation complexity. The most important of which are tracking with higher accuracy and faster convergence; therefore, Hybrid MPPT techniques are being developed in order to locate the MPP rapidly and accurately at the same time.

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[1] C-Map was introduced by the "ENEPLAN – Developing skills in the field of integrated energy planning in MED landscapes" project funded by Erasmus +.

https://doi.org/10.1016/j.solener.2018.04.045
Received 28 December 2017; Received in revised form 12 April 2018; Accepted 22 April 2018
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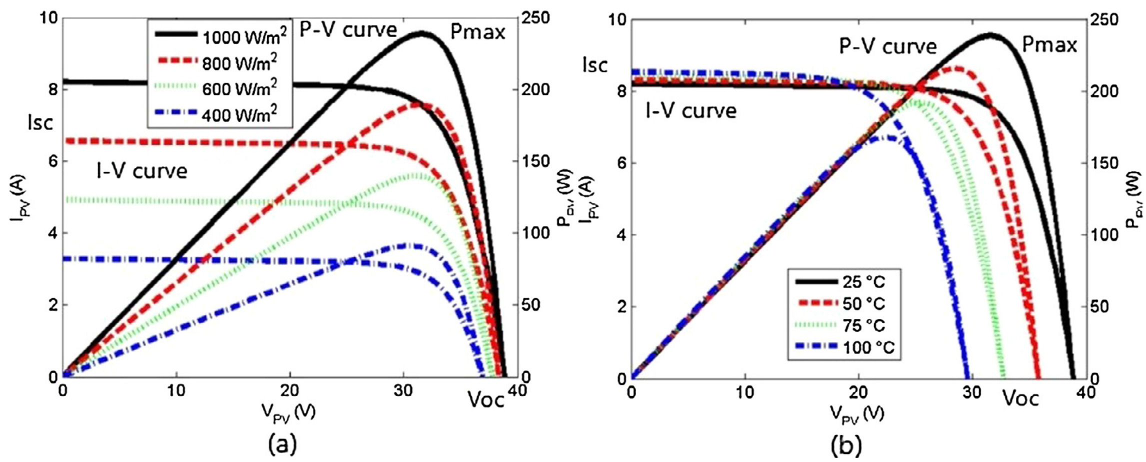

Fig. 1. (a) I-V and P-V curves under different irradiance levels. (b) I-V and P-V curves under different temperature levels (Marco Tina, 2016).

1.1. Theory of MPPT

The basic principle behind any MPPT tracking technique is based on Maximum Power Transfer theorem, which states that the power to be transferred from source to load is maximum when the load resistance matches that of the source. Thus, MPPT trackers in principle should guarantee the match of the load resistance to the PV source resistance at the maximum power point. The resistance at MPP can be calculated as in (1):

$$R_{mpp} = \frac{V_{mpp}}{I_{mpp}} \tag{1}$$

where R_{mpp} is the PV resistance at MPP, V_{mpp} and I_{mpp} are the voltage and current at MPP respectively (Green, 1982).

Thus, for maximum power transfer from PV source to load, the load resistance should match that of the PV source at MPP (*Rmpp*). Nevertheless, since the whole I-V curve of the PV source is weather dependent and changes with irradiance and temperature, the MPP and consequently the *Rmpp* is not fixed. Therefore, to achieve the tracking of the MPP; direct powering of the load from the PV is not efficient but rather a DC – DC converter is inserted between the PV source and the load in order to compensate for the mismatch between the fixed load resistance and the variable PV resistance.

The duty cycle D of the converter is adjusted, through MPPT algorithms, such that the fixed load resistance together with the modified D of the DC -DC converter as seen by the PV source, match the weather dependent *Rmpp*, which inherently guarantees the operation of the PV at *Vmpp* and *Impp* at that weather condition (Hart, 2011).

Therefore, an MPP tracker is implemented to control the duty cycle of the converter through different models and algorithms as depicted in Fig. 2.

In general, MPPT techniques have major characteristics such as; convergence speed, accuracy and implementation complexity. It is perceived that the use of two MPPT algorithms together will help overcome the drawbacks of individual MPPT algorithms used alone (Al-Soeidat et al., 2016). Therefore, the Hybrid MPPT techniques were developed and implemented to integrate the advantages of two separate MPPT algorithms. Moreover, Hybrid MPPT algorithms target the issue of partial shading conditions of the PV array. Fig. 3 shows one example of the P-V curve displaying multiple maxima when exposed to partial shading conditions. Many MPPT techniques fail to identify the Global Maximum Power Point (GMPP), where some MPPT algorithms have the ability to locate the GMPP but lack accuracy or speed (Ramli et al., 2017). The purpose of hybridizing algorithms is to obtain an easily implemented and optimum tracking of the MPP in terms of speed, accuracy and partial shading under various weather conditions (Babu et al., 2017).

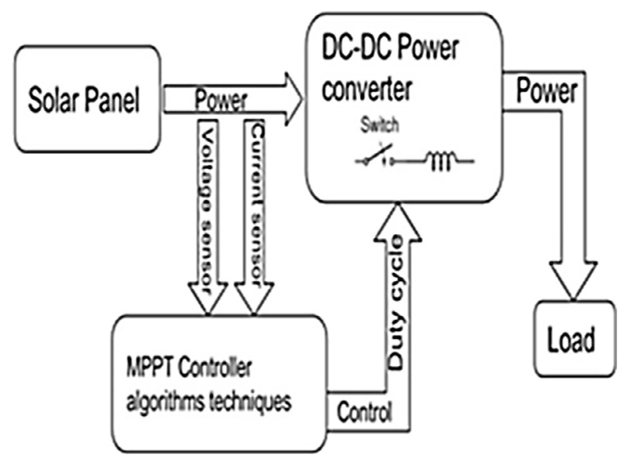

Fig. 2. PV system with MPPT controller.

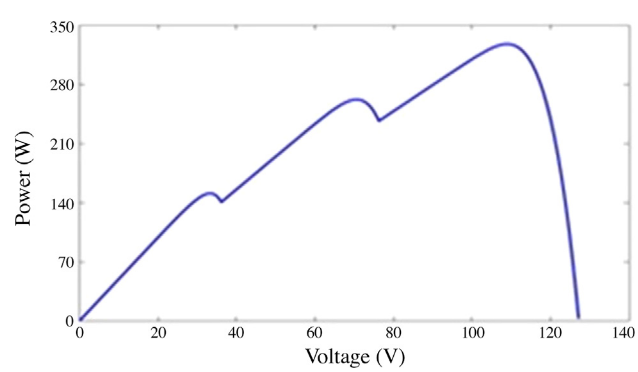

Fig. 3. PV curve under partial shading conditions (Kotti and Shireen, 2015).

This paper presents the main individual MPPT methods and introduces a survey of the 20 different Hybrid MPPT techniques mentioned in literature proposing a classification based on the pattern followed in hybridizing two single MPPT techniques as illustrated in the Conceptual Map (C-Map) given in Fig. 4. This work also categorizes the 20 surveyed Hybrid MPPT techniques in this study into 17 Sequential (or two-stage) nine of which are Intelligent and eight Non-Intelligent methods in addition to three Simultaneous techniques as illustrated in Fig. 4. Section 2 starts by presenting the four main (two offline and two online) single non-hybrid MPPT methods and their different staging combinations in making Sequential Hybrid yet Non-Intelligent MPPT systems. Section 3 investigates the 17 Sequential Intelligent methods into tracking the MPP while Section 4 lists three simultaneous