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MAXIMUM POWEWR POINT TRACKING SYSTEM FOR PHOTOVOLTAIC STATION: A REVIEW

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In recent years there has been a growing attention towards the use of renewable energy sources. Among them solar energy is one of the most promising green energy resources due to its environment sustainability and inexhaustibility .However photovoltaic systems (PhV) suffer from big cost of equipment and low efficiency. Moreover, the solar cell V-I characteristic is nonlinear and varies with respect to irradiation and temperature. In general, there is a unique point of PhV operation, called the Maximum Power Point (MPP), the PV system operates with maximum efficiency and produces its maximum output power. The location of the MPP is not known in advance, but can be located, either through calculation models or by search algorithms. Therefore MPPT techniques are important to maintain the PV array's high efficiency. Many different techniques for MPPT are discussed. This review paper hopefully will serve as a convenient tool for future work in PhV power conversion.

1. INTRODUCTION

Solar Energy is one of the most promising green energy resources due to its environment sustainability and inexhaustibility. Solar Energy has certain advantage over other "Renewable Energy" recourses such as wind and ocean water and hydro power station. Photovoltaic energy is a sort of solar energy that is available in almost all parts of the world and has the least maintenance since it attracts many researches toward this kind of clean and renewable energy.

Due to the severity of the global energy crisis and environmental pollution, the photovoltaic (PV) system has become one kind of important renewable energy source. Solar energy has the advantages of maximum reserve, inexhaustibleness, and is free from geographical restrictions. Solar energy stations have been built in all areas of the Planet-from Alaska to Egypt and Saudi Arabia.

At the same time despite mentioned advantages photovoltaic (PV) cell has low energy conversion efficiency. Typically, a PV cell generates a voltage around 0.5 to 0.8 volts depending on the semiconductors and the built-up technology. This voltage cannot be used as it is too low. The solution comes with a help of parallel-serious connection of tens of PV cells, involving up to 72 cells are connected to form a PV panel. In case of parallel connection their currents are added while the voltage is the same, while in case the modules are connected in series their voltages are added with the same current.

Three major families of PV cells are available; monocrystalline technology, polycrystalline technology and thin film technologies. The monocrystalline and polycrystalline technologies are based on microelectronic manufacturing technology and their efficiency is in general between 10% and 15% for monocrystalline and between 9% and 12% for polycrystalline. For thin film cells, the efficiency is 10% for a-Si, 12% for $CuInSe_2$ and 9% for Cd Te.

Improving the efficiency of the PV panel is not easy as it depends on the technology available, it may require better components, which can increase drastically the cost of the installation.

The efficiency of a PV plant is affected mainly by three factors: the efficiency of the PV panel (in commercial PV panels it is between 8-15% [1], the efficiency of the inverter (95-98 % [2]) and the efficiency of the maximum power point tracking (MPPT) algorithm (which is over 98% [3]).

Solar photovoltaic is phenomenon where the solar irradiation is converted directly into electricity via solar cell [2] and the process does not have any materials to be consumed or emitted. Solar electrification can be applied even in rural areas where stand-alone PV system can supply adequate electricity for certain area independently without the need of having connection with utility grid.

Improving the efficiency of the PV panel and the inverter is not easy as it depends on the technology available, it may require better components, which can increase the total cost of installation.

The PV array has a particular operating point that can supply the maximum power to the load which is generally called maximum power point (MPP).

The maximum power point has a non-linear locus where it varies according to the solar irradiance and the cell temperature [2]. To boost the efficiency of PV system, the MPP has to be tracked followed by regulating the PV panel to operate at MPP operating voltage point, thus optimizing the production of electricity. This process can draw as much power as possible that the PV panel can produce.

Instead, improving the tracking of the maximum power point (MPP) with new control algorithms is easier, not expensive and can be done even in plants which are already in use by updating their control algorithms, which would lead to an immediate increase in PV power generation and consequently a reduction in its price.

One paper presents a survey and a discussion of several MPPT methods. Another paper presents a ranking of ten widely adopted MPPT algorithms (P&O, modified P&O, Three Point Weight Comparison [4-7].

Constant Voltage, IC, IC and CV combined, Short Current Pulse , Open Circuit Voltage, the Temperature Method and methods derived from it, based on simulations, under the energy production point of view. The MPPT techniques are evaluated considering different types of insulation and solar irradiance variations and calculating the energy supplied by a complete PV array. Currently more research works has been focused on how to extract more power effectively from the PV cells.

2. System description. Problem overview

Solar PhV station can be illustrated as shown in Fig. 1. The system consists of a PhV panel (a number of PhV modules, connected in series-parallel mode), power DC-DC converter (mostly buck, boost or buck- boost converter), number of sensors to measure current and voltage, MPPT control unit and a load. The electric power produced by PhV panel is supplied to the load through a DC-DC converter, controlled by PWM signal. The output voltage and current from the PhV panel are fed to the MPPT control unit to determine the controlled voltage reference for DC-DC converter.

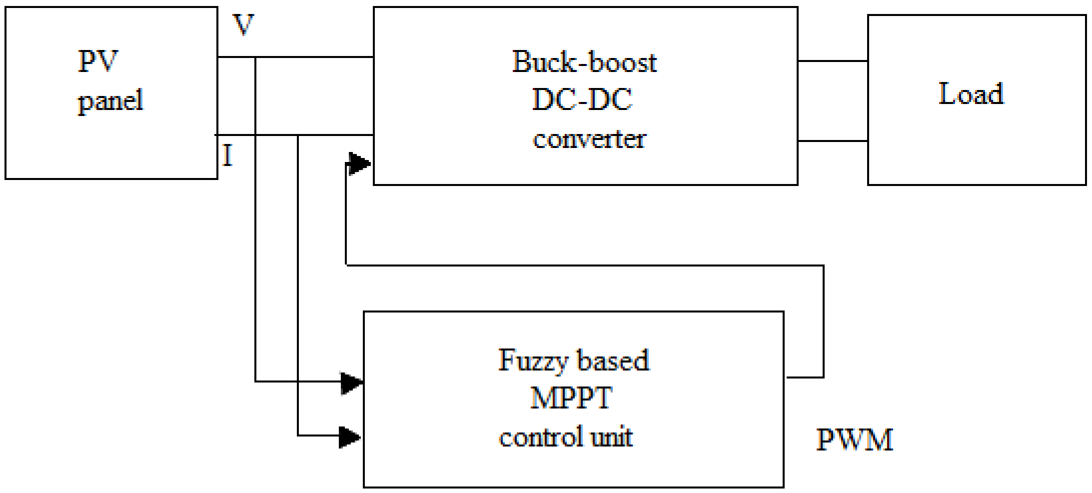

Fig. 1. Solar PhV station block diagram

Fig. 2 and Fig.3 show V- I (Volt-Ampere) characteristic at constant temperature and constant irradiance respectively. Fig. 4 and Fig.5 present power curve of the PhV array. As it follows from Fig.4 and Fig.5 the output power is highly nonlinear to current and voltage [5, 6, and 7]. The problem considered by MPPT techniques is to automatically trace the voltage VMPP or current IMPP at which a PhV array should operate to obtain the maximum power output PMPP under a given temperature and irradiance. It is noted that under partial shading conditions, in some cases it is possible to have multiple local maxima, but overall there is still only one true MPP. Most developed techniques respond to changes in both irradiance and temperature, but some are specifically more useful if temperature is approximately constant. Most techniques would automatically respond to changes in the array due to aging, though some are open-loop and would require periodic on-line tuning. In our context, the array will typically be connected to a power converter that can vary the current coming from the PV array.

Through a DC-DC converter, MPPT control unit is able to vary the PhV operating voltage and search with accordance to the built in algorithm for the maximum power that the PV panel can deliver.

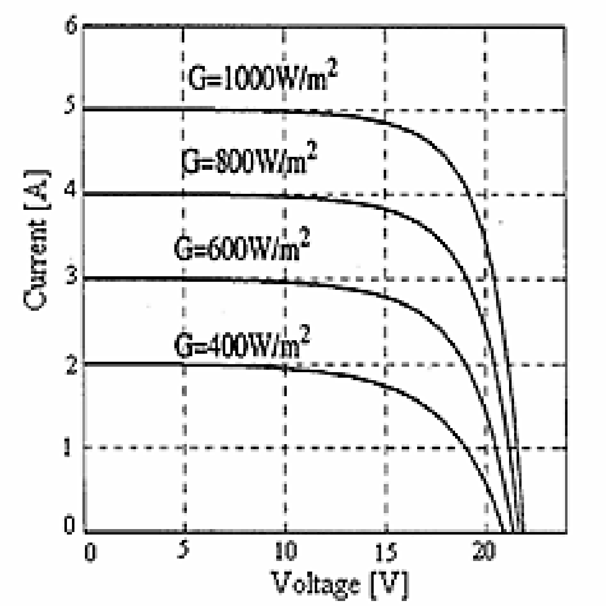

Fig. 2. I-V solar cell characteristics irradiance

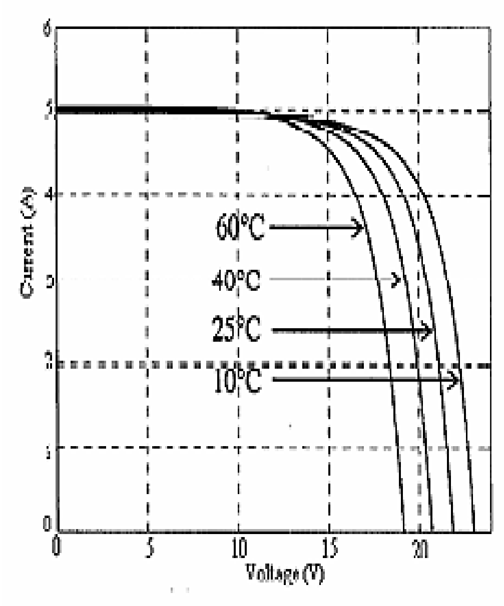

Fig.3. I-V characteristics-at constant temperature

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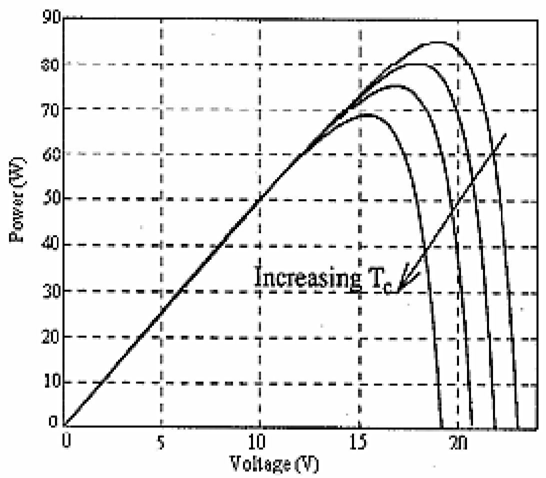

Fig. 4. P-V characteristics at constant temperature.

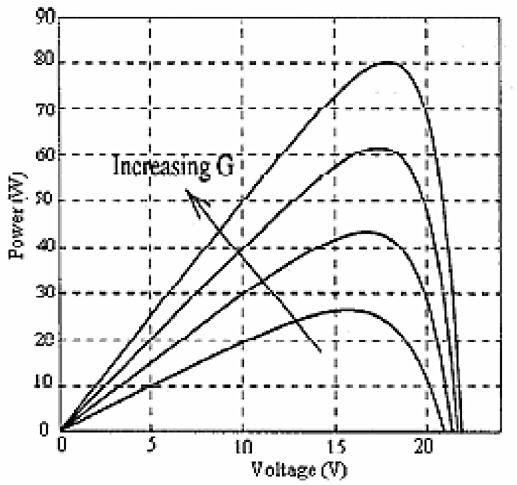

Fig. 5. P-V characteristics at constant irradiance.

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3. Maximum Power Point Tracking: Methods and Algorithms.

Utilizing PV systems as an alternative source of energy requires a substantial amount of investment. In order to reduce the overall cost of PV systems, therefore, extraction of the maximum power from a solar cell turns out to be a vital consideration for optimal system design.

At the appropriate operating point for a solar cell, assuming a given cell efficiency, the maximum output power depends on the radiation intensity, ambient temperature and load impedance.

There is a single operating point enabling attainment of maximum power, tracking of which through variations in radiation efficient operation of the solar cell array (Fig. 2). The fundamental problem addressed by MPPT is to automatically determine the PV output voltage or output current for which the PV array produces maximum output power under a given temperature and irradiance.

Attainment of maximum power involves load-line adjustment under variations in irradiation level and temperature. The maximum power point tracking, MPPT not only enables an increase in the power delivered from the PV module to the load, but also enhances the operating lifetime of the PV system [1].

A variety of MPPT methods have been developed and implemented [4,6]. They range from the almost obvious (but not necessarily ineffective) to the most creative (not necessarily most effective). In fact, so many methods have been developed that it has become difficult to adequately determine which method, newly proposed or existing, is most appropriate for a given PV system [6].

These method can be differentiated based on various features including the types of sensors required, convergence speed, cost, range of effectiveness, implementation hardware requirements, popularity, reliability, cost of maintenance.

In its variety, however, different MPPT methods can futher be categorized on:

-offline methods, which are dependent on solar cell models,

-online methods, which do not specifically rely on modeling of the solar cell behavior, and

-hybrid methods, which are a combination of the aforementioned methods. The offline and online methods can also be referred to as the model-based and model-free methods, respectively.

3.1. Offline methods

In particular, the given method is identified as offline if they are depended on the physical data model of the solar cells to track the maximum power point [8].

Offline methods generally require to one or more of the solar panel values, such as the open circuit voltage (VOC), short circuit current (ISC), temperature and irradiation. These values are employed to generate the control signal necessary for driving the solar cell to its maximum power point (MPP). In the course of the tracking operation, this control signal remains constant if ambient conditions can be regarded as fixed and there are no attempts to regulate the output power of the PV system.

The behavior of a Solar Cell can be modeled by a 1-diode/2- resistor electric circuit [8]. The more accurate 2-diode/2 resistor model introduce the effect of recombination of electrons and holes.

The analytical approach is usually based on data from the most representative points-short circuit: V=0, I=I_{SC};

and open circuit: V=V_{oc}, I=0; and maximum power V=V_{mp}, I=I_{mp} of the measured $I-V$ curve of the solar cell/panel (as an example see Fig.6)

As a result there is well known equations [8] to calculate photovoltaic current

$$I = I_{pv} - I_0[\exp(\frac{V+IR}{aV_T}) - 1] - \frac{V+IR_S}{R_{sh}} \quad (1)$$

and thermal voltage $V_T = kT/q$, (2)

where Ipv, I_0-photovoltaic and saturation current; R_s, R_{sh} –series and shunt resistance. Other notations can be found in [7,8]. The analytical approach is usually based on data from the most representative points: short circuit; V=0, I=I_{sc}; open circuit: V=V_{oc}; I=0; maximum power:

V=V_{mp}, I=I_{mp} of the measured I-V curve of the solar cell/panel, as it is shown on Fig 6. of a triple –junction solar cell (Emcore ZTJ), developed for space application [8]. From this data it is possible to define I_{pv}, I_0 and I_{mp}. Finally as it is concluded in [8], analytical model requires rather complicated calculation, which should be proved by experimental data for given type of a solar cell/panel.

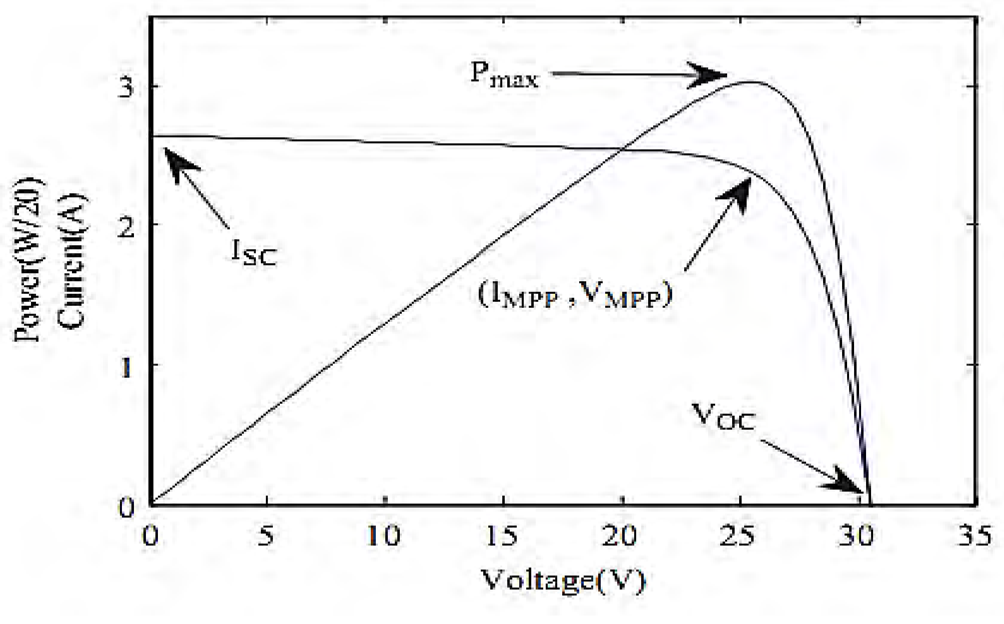

Fig.6. Triple-junction solar cell current-voltage (I-V) and power-voltage curves, [8].

3.2. Online methods

If an MPPT method does not rely on a model, but instead employs measured instantaneous values of PV output current and output voltage in order to track MPP with higher accuracy, it is referred to as an online method.

In these methods, the instantaneous values of the PV output voltage or current (Fig.2-Fig.5) are usually used to generate the control signals.

The control signal is applied to the PhV system along with a small methodical and premeditated perturbation in voltage or current or duty cycle (control signal) and the resulting output power is determined. By analyzing response of perturbation on output power of PV panel, the direction of change (decrease or increase) of the control signal is determined. Hence, unlike offline methods, with a perturbation applied, the control signal can no longer be regarded as constant. Therefore, tracking the maximum output power involves oscillations around the optimum value.

There are several methods that have been widely implemented to track the MPP. The most widely used methods are Perturb and Observe (P&O), incremental conductance and three-point weight.

3.3. Hybrid Methods.

Finally, MPPT methods which combine the offline and online approaches are grouped under hybrid MPPT methods based on the proposed classification scheme. Furthermore, in order to facilitate selection of MPPT algorithms, the MPPT methods presented are compared based on simulation of PV systems.

In order to assess MPPT techniques including the offline, online and hybrid methods using simulations, the solar cell is modeled in an environment including the converter and load.

In hybrid methods that represent a combination of the offline and online methods, tracking of the MPP is performed in two steps: estimation and exact regulation of MPP. The First step ,which involves estimation of MPP, relies on offline methods to place the set point close to MPP. The second step, which can be regarded as a fine-tuning step, is based on online methods and attempts to reach the actual value of MPP.

4. Artificial Intelligence-Based MPPT Algorithms.

In recent years, fuzzy logic (FL), artificial neural networks (ANNs), and genetic algorithm (GA) techniques known as artificial intelligence techniques have been used widely in engineering problems [9-14], particularly in the MPPT process for a satisfactory result, all environmental conditions such as instantaneous climate changes, PhV cell aging and parameter fluctuation which must be taken into account in the design process of MPPT. Artificial intelligence can suggest adequate solutions for these conditions. In [14] presented an efficient MPPT algorithm developed under non-uniform conditions that are based on a trained ANN, according to the occurring temperature and solar radiation changes. In many engineering applications combination of FL, ANN and genetic algorithms bring the most effectiveness [9, 12].

Well known drawbacks of fixed step size of conventional P&O systems on the way to maximum power point can be minimized by using a modified FL MPPT algorithm suggested in [13,14,15] which has improved steady-state performance by using of variable step size.

Authors have also presented a new MPPT algorithm that uses fuzzy cognitive networks (FCNs), which is actually an extension model of well-known fuzzy cognitive maps (FCMs). In application, FCNs consist of nodes that represent system characteristics and possible controller movements. In addition FCNs interact with the physical system in on-line mode and develop signals to control movement and feedback from the system. Thus, FCNs accumulates knowledge and experience in the operation of the system. FCN nodes define the control and actual operating variables (voltage, current, radiation, and temperature).

7. Conclusion

MPPT algorithms used in PV systems are one of the most important factors for electrical efficiency of the system. Decision to use MPPT system by the designer should be based on criteria important in application, such as efficiency, reliability, oscillation, stability and implementation based on well-known hardware.

In this analysis, a general classification of the most studied MPPT algorithms are conferred. Operating principles and application processes of MPPT on-line, off-line and hybrid algorithms, were discussed. Attention was paid to algorithms based on the theory of artificial intelligence. Further, detailed study of the MPPT systems can be found in references.

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