

# GRID-CONNECTED PV SYSTEM WITH MPPT CONTROL AND P&O TECHNIQUE

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## ABSTRACT

As the use of energy is increasing, the requirements for the quality of the supplied electrical energy are more tighten. Energy is the most basic and essential of all resources. As conventional sources of energy are rapidly depleting and the cost of energy is rising, photovoltaic energy becomes a promising alternative source. Photovoltaic (PV) generation is becoming increasingly important as a renewable source since it exhibits a great many merit such as cleanness, little maintenance and no noise. The output power of PV arrays is always changing with weather conditions, i.e., solar irradiation and atmospheric temperature. Therefore, a Maximum Power Point Tracking (MPPT) control to extract maximum power from the PV arrays at real time becomes indispensable in PV generation system. In recent years, a large number of techniques have been proposed for tracking the maximum power point (MPP). MPPT is used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and radiation conditions and of the load electrical characteristics the PV array output power is used to directly control the dc/dc converter, thus reducing the complexity of the system. The resulting system has high-efficiency. This paper presents in details of most popular MPPT algorithms techniques which are Perturb & Observe algorithm (P&O). Perturb & Observe algorithm (IPO). Modeling and designing a PV system with Perturb & Observe algorithm (PO) is remarkably more complex than implementing a standard MPPT technique.

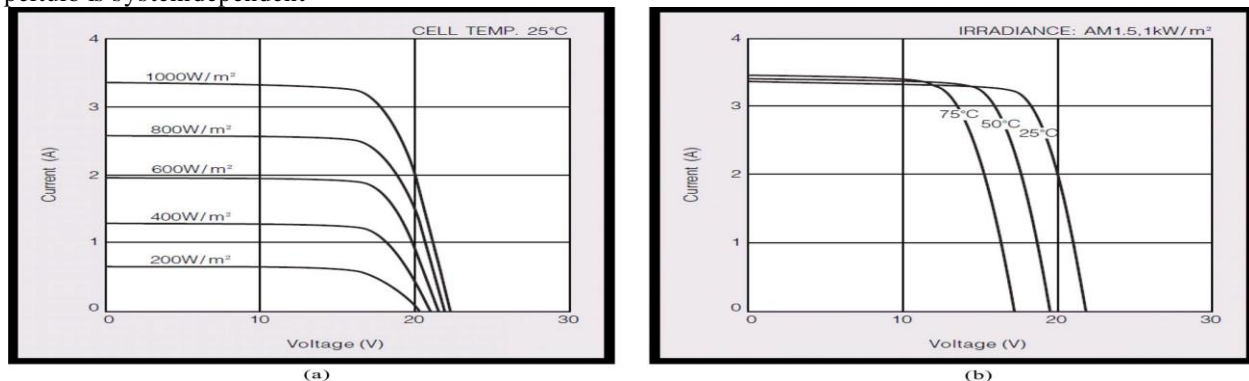
**Key words:** PV system, MPPT controller, P&O technique, modeling of Array

## 1. INTRODUCTION

The increasing of the world energy demand, due to the modern industrial society and population growth, is motivating a lot of investments in alternative energy solutions, in order to improve energy efficiency and power quality issues. The use of photovoltaic energy is considered to be a primary resource, because there are several countries located in tropical and temperate regions, where the direct solar density may reach up to 1000 W/m<sup>2</sup>. At present, photovoltaic (PV) generation is assuming increased importance as a renewable energy sources application because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts.

Micro grid, a recently emerging power technology, is expected to possess an increasing role in future power systems due to its immense advantages. The need for more flexible electricity systems, energy savings, and environmental impact are driving the development of micro grids. The micro grid concept has been proposed as a solution to the conundrum of integrating several power generations without disturbing the utility, especially when renewable energy sources are Utilized [1]–[3]. Renewable energy sources involve many aspects: efficiency, reliability, cost, safe connection to the electric grid, capability to manage micro grids, energy storage, low environmental impact, and development of advanced control and monitoring algorithms. The most common renewable energy sources are hydroelectric, photovoltaic (PV), and wind. Despite that hydroelectric energy production is the dominant; the PV energy sector is growing at more than 30% per year [4]. Connecting multiple of these sources to the utility introduces varying dynamics. As PV sources are intermittent, nonlinear, and produce power that varies with environmental conditions, an adequate maximum power point tracking (MPPT) is needed [4], [5].

The nonlinear characteristic of a PV panel is a function of irradiance and temperature, as shown in Fig. 1. For best utilization of the available energy, it is necessary to operate the system at its MPP. Several techniques have been proposed for maximum power tracking [5]–[7]. Among them, the perturb and observe (P&O) method is the most common for simplicity, ease of implementation, and good performance [5], [6]. Many researches investigate the PV array nonlinear behavior [8] and associated grid-connected inverters [9], [10]. It is reported that P&O techniques suffer several demerits [5]–[7]. For fixed perturb values, the steady-state oscillations are proportional to the perturb value. Large perturb values cause higher oscillation. Unfortunately, smaller perturb values result in slower response. Hence, the famous tradeoff problem between faster response and steady-state oscillations is inherent. Moreover, the perturb value is not generic, therefore, MPPT using a fixed perturb is system dependent



## 2. MODELLING OF PV ARRAY

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity. It has an equivalent circuit [2] as shown figure 2. The current source  $I_{ph}$  represents the cell photo current;  $R_j$  is used to represent the non-linear impedance of the p-n junction;  $R_{sh}$  and  $R_s$  are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of  $R_{sh}$  is very large and that of  $R_s$  is very small, hence they may be neglected to simplify the analysis.

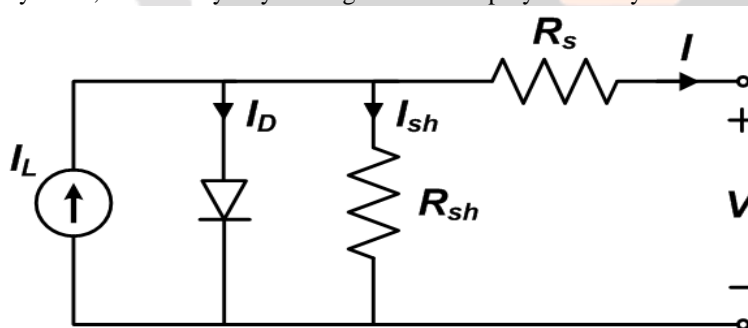


Fig. 3 One diode model of solar cell

PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators. The PV mathematical model [3] used to simplify our PV array is represented by the equation (1). - (1) where  $I$  is the PV array output current;  $V$  is the PV array output voltage;  $n_s$  is the number of cells in series and  $n_p$  is the number of cells in parallel;  $q$  is the charge of an electron;  $k$  is the Boltzmann's constant;  $A$  is the p-n junction ideality factor;  $T$  is the cell temperature (K);  $I_{rs}$  is the cell reverse saturation current. The factor  $A$  in equation determines the cell deviation from the ideal p-n junction characteristics ranges 1-5 The cell reverse saturation current  $I_{rs}$  varies with temperature according to the following equation (2) (2) Where  $T_r$  is the cell reference temperature,  $I_{rr}$  is the cell reverse saturation temperature at  $T_r$  and  $E_G$  is the band gap of the semiconductor used in the cell. The photo current  $I_{ph}$  depends on the solar radiation and cell temperature as in equation (3). (3) Where  $I_{scr}$  is the cell short circuit current at reference temperature and radiation,  $K_i$  is the short

circuit current temperature coefficient, and  $S$  is the solar radiation in  $\text{mW}/\text{cm}^2$ . The PV power can be calculated using equation (4)

### 3. METHODS FOR PV MAXIMUM POWER POINT TRACKING

When using P&O method, the PV array current (or voltage) is perturbed by a small Increment ( $\Delta I$  or  $\Delta V$ ) and the resulting change in power ( $\Delta P$ ) is measured. If  $P$  is positive, the next perturbation is also in this direction (with same algebraic sign). If  $\Delta P$  is negative, the system's operating point has moved away from the MPP, thus the sign of the perturbation will be changed in order to step back, towards the MPP (see fig.1 and fig.2). Despite of its advantages, this method has certain limitations: - It becomes difficult for the MPPT algorithm to find the location of the MPP at low solar irradiances because the MPP curve flattens out. - The P&O algorithm doesn't locate the MPP, but oscillates around it, changing the sign of the perturbation after each measurement. Finally, it is known that most of the P&O implementations can have random behavior under rapidly changing solar irradiance [1]. Other popular MPPT methods are: - Open circuit voltage, which uses the ratio of the array's MPP voltage to its open-circuit voltage [2]. - Short-circuit current method [3]: uses short-circuit current instead of open-circuit voltage. - Pilot cell method. Here the open circuit voltage or short-circuit current method is used, but on a single PV cell rather than on the whole array. - Incremental conductance method is based on the fact, that at the MPP the derivative of the power, as a function of the voltage is zero (fig.1 and fig.2) [4]. The main advantage of this method against the P&O method is that it can decide in which direction to perturb and can locate the MPP exactly, instead of oscillating around it. - Parasitic capacitance. This method is similar to the incremental conductance but the effect of the cell's parasitic junction capacitance is taken into account [4].

### 4. PROPOSED P&O TECHNIQUE

As discussed in the presented review, all attempts seek either sophisticated performance with the penalty of cost/complexity or moderate performance with acceptable cost and relative simplicity. Hence, the proposed P&O technique attempts to achieve improved performance with moderate cost, simple implementation, and a generic core that does not depend on preset constant values.

#### A. Theory

The block diagram of the proposed P&O technique is shown in Fig. 3. The main idea behind the proposed technique is that at the start of any hill climbing technique, large perturb steps are needed to quickly reach the MPP, and as the MPP is approached, the perturb value needs to be decreased to avoid large oscillations around this maximum output power operating point. As explained in Section II, P&O techniques, either conventional or modified, are not capable of achieving this target if the perturb value is fixed. Therefore, adaptive techniques are the only solutions.

The proposed adaptive technique utilizes the error between two successive array power signals calculated from the measured array voltage and current signals to create an adaptive perturb. Basically, at the start of the hill climbing process, this error is large and decreases as the maximum power operating point is approached at steady state. Therefore, this error can be treated like an error signal in a closed-loop system that needs to be minimized at steady state, prevented from overshoot at startup, and free from steady-state oscillations. The simplest clue to achieve all these targets is to treat this error signal using a conventional PI controller, which is the main core of the proposed technique. Hence the name PI-P&O technique is being proposed. This PI controller is utilized as the adaptive perturb value generator for the reference array voltage. Another PI controller is used for the boost converter. Its function is to force the PV array input voltage to track the reference voltage from the MPPT block. The proposed system requires two signals to be measured: PV array voltage and current. Therefore, by tuning both PI controllers, good performance is achieved with less computational load and no predefined constants. The boost converter is modulated at 25 KHz to minimize oscillations in the converter output voltage. The effect of this high switching frequency on switching losses is considered in the insulated gate bipolar transistor and fast diode selection. Also, the whole control algorithm runs at this sampling frequency. The measured array voltage and current are filtered using a low pass filter tuned at 1000 Hz to mitigate any associated/picked-up noise on the measured signals. In order to generate two successive samples for the array power, a delay of 100 samples ( $100 \times 40 \mu\text{s}$ ) is used. This relatively long delay effect on the control algorithm is irrelevant due to the long time constant of the array power variation.

**5. Presentation of the studied system**

In this research two PV systems have been studied. A common block diagram of the two systems is presented in fig.5. In both systems the PV array is connected to the inverter via a step-up DC-DC converter, which carries out the MPPT control. The first system is connected to the grid through a three-phase inverter and has 8 parallel PV strings, each of 25 panels with total maximum power 9kWp. The second system is connected to the grid through a single phase inverter. It has 2 Parallel strings, each of 3 panels with total peak power of 270Wp. The studied systems are modeled in Matlab/Simulink. Models of the system components are presented below.

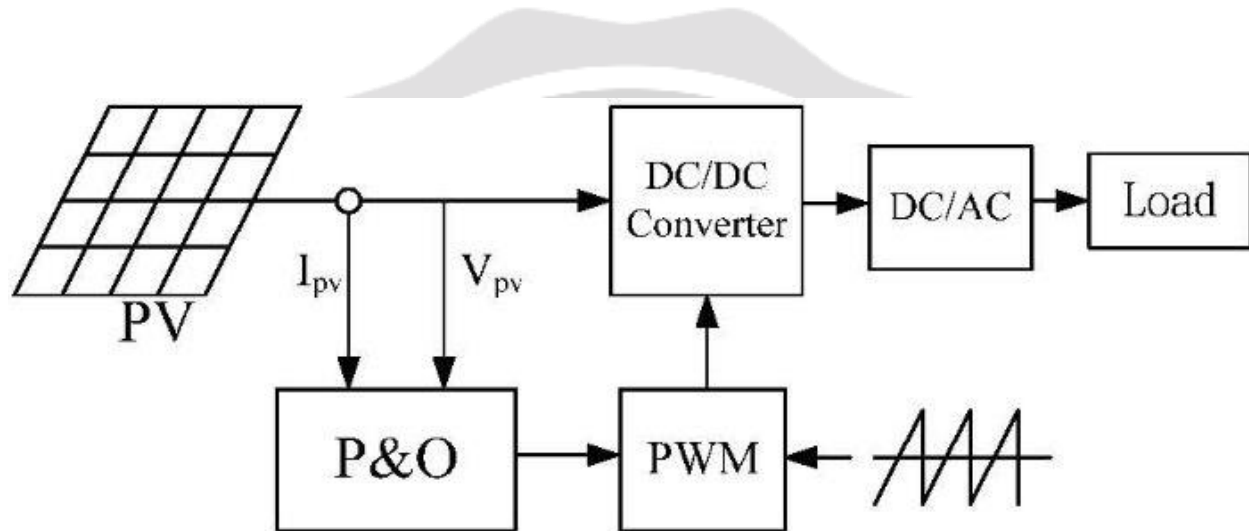


Fig.5. Block diagram of the studied system with MPPT controller

**5.1. Photovoltaic array model**

The model of the photovoltaic panel is based on the one-diode equivalent circuit detailed in our other publications [9]. This model uses as input variables the solar radiation  $G$ , the ambient temperature  $T$  and the module voltage  $V_M$  to calculate the module current  $I_M$ . It is considered that all panels are identical and are subject to the same meteorological conditions. The PV modules used in the simulation are of type PWX500 from Photo watt, France.

**5.2. DC-DC converter model**

The DC-DC converter is "step-up" (boost) type in order to increase the PV array voltage to a level, which ensures correct operation of the inverter. The circuit is presented in fig.6.i

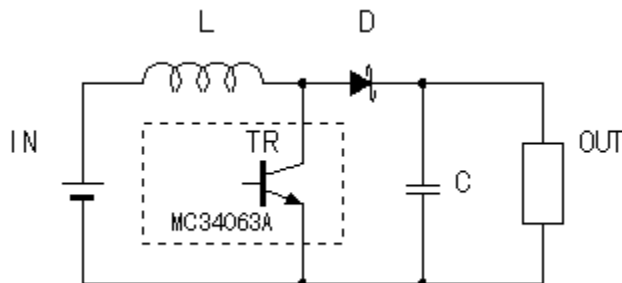


Fig.6. Step-up converter circuit

The modelling equations, obtained by the Kirchhoff's laws, are where  $i_L$  is the input current (equal to the PV array current),  $L_b$  is the boost inductance,  $V_{bi}$  is the input voltage (equal to the PV array voltage),  $d$  is the switch state,  $V_{DC}$  is the boost output voltage,  $C_{DC}$  is the DC-link capacitor and  $i_{inv}$  is the inverter input DC current. This model

uses the input voltage and the output current as input variables and the input current and the output voltage are calculated.

## Conclusion

PPT algorithms used in PV systems are one of the most important factors affecting the electrical efficiency of system. As a result of cost optimization, after decided to use an MPPT system by the designer, it is important to decide which algorithm will be used in application.

In this study, general classification and descriptions of the most widely used MPPT algorithms are analyzed in detail. Operating principles and application processes of MPPT algorithms such as perturb and observe, constant voltage and current, incremental conductance, parasitic capacity, three-point weight comparison, and artificial intelligence have been discussed. As results of analysis, obtained efficiency ranges and other criteria for comparison are given in Table 1. As shown, different benefits may be selection reason for each algorithm. Parasitic capacity, modified P&O, and artificial intelligence-based MPPT algorithms are the most advantageous systems in terms of electrical efficiency. However, in practice, the most widely used commercial designs are P&O and IC algorithms due to their simple structures and low cost. Recently, the using areas of software-based artificial intelligent techniques such as FL, ANN, and GA are growing in MPPT applications. As noted above, varied MPPT techniques are suitable for different applications. In each system, an algorithm may not give the same result.

In this paper, a 100 kW grid connected photovoltaic array is studied under steady state and transient conditions while utilizing three different maximum power point tracking algorithms. The three algorithms employed in this paper are: the perturb and observe (P&O) algorithm; the incremental conductance (ICT) algorithm and the fuzzy logic control (FLC) algorithm. The simulated results under steady state condition show the effectiveness of the MPPT on increasing the output power of the PV array for the three techniques. However the FLC algorithm offers accurate and faster compared to the conventional techniques. The simulation results under transient conditions show that the output power injected to grid from PV array is approximately constant while utilizing the proposed FLC and the PV system can still connect to grid and deliver power to grid without any damage to the inverter switches.

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