Overview of Maximum Power Point Tracking Techniques for PV System

Khairul Eahsun Fahim^{1,*}, Shaikh M Farabi², Shaikh Shahrukh Farhan³, Ishrat Jahan Esha⁴ and Taseen Muhtadi⁵

¹East China University of Technology, Jiangxi, China

²Kyoto Sangyo University, Japan

³North South University, Bangladesh

⁴American International University, Bangladesh

⁵BRAC University, Dhaka, Bangladesh

Abstract. Fossil fuel is one of the major sources of the world's energy generation. Greenhouse gases are increasing in the atmosphere due to the excessive use of fossil fuels. To tackle global warming and the shortage of natural gases, researchers are always looking for alternative sources of clean energy. Solar energy is becoming popular due to its inexhaustible nature. To get the most of out of a solar system and to generate maximum power, it is important to operate the panel at maximum power point. In other words, it can be said that MPP techniques are used to maximize the output power. There is a wide range of MPPT algorithm available to calculate MPP. This paper gives a broad overview of the existing MPPT techniques used in practice.

1 Introduction

The growing demand for energy combined with the diminishing fossil fuels has given rise to the search for alternative energy sources. Compared to other energy sources PV is considered a green source of energy due to its Eco friendly and inexhaustible nature. On top of that solar is a natural energy source that is available all over the globe. Solar energy incident on the earth's surface is ten thousand times greater than the consumption of energy worldwide despite of the presence of the phenomenon of reflection and absorption of sunlight. Compared to other energy sources PV cells emit less carbon dioxide. Due to the usage of PV cells instead of another source emission reduction of carbon dioxide is projected to get curbed by 1Gton per year, which is equivalent to the total emission of India in the year 2004 [1]. Experts in the field of energy believe that within the next twenty years solar energy will become the major source of alternative energy. Although it has many advantages, it has some disadvantages too, such as low efficiency and the high upfront cost of establishment. That's why it is needed to apply some techniques to extract the maximum possible power from the panel. Under uniform irradiation condition, there is a unique operating point in the IV curve that corresponds to the maximum power. On the contrary, under varying irradiance and temperature condition the characteristics become nonlinear and there is no single operating point can be found that corresponds to the maximum power which makes to the extraction of maximum power troublesome. This characteristic is shown in figure 1. Till

now researchers have mentioned several methods for extracting maximum power. [2-10]. An idea for designing this system can be acquired from these papers. This paper gives an overview of the most common techniques in practice for extracting maximum power from PV. Comparative analysis of PV systems can be found in the literature [11] - [12]. However, this paper also gives a brief overview of some other improved MPPT techniques such as modified MPPT PI based IC and P&O algorithm which shows extraordinary performance due to their adaptive nature

2 Modelling of panel

The equivalent circuit of a PV cell can be represented with a single diode model shown in figure 2. Circuit losses are represented by R_{sh} (series resistance) and R_p (parallel resistance) Based on the output current of one PV equivalent model, the PV panel's simulation model is represented. Mathematical representation of this model is as follows

$$I = I_{ph} - I_r \left[e^{q(V + \frac{IR_s}{\eta \, \mathrm{kT}}} - 1 \right] - \frac{V + IR_s}{R_p}$$

Where, $I_{ph} = Photocurrent$

 $I_{sh} = Saturation Current$

^{*} Corresponding author: <u>khairulehsanfahim@gmail.com</u>

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- $I_d = diode \ current$
- $q = Electrical Charge (1.6 \times 10^{-19})$
- $k = boltzman \ constant \ (1.38 \times 10^{-23} \ I/K)$
- T = temperature (kelvin)



Fig 1. Equivalent circuit of PV model.

3 Overview of various mppt algorithms

Efficiency of solar cells is relatively low, so there is a need to extract maximum power from the solar cell. Maximum power is extracted from the solar cell using an algorithm called the maximum power point tracking algorithm. Some of the famous algorithms are Perturb and Observe algorithm, hill climbing method, hybrid method e.tc. In this review work numerous MPPT techniques have been explained based on their tracking nature.

Conventional methods

Among all the other methods such as P&O, hill climbing, hybrid method, P&O is one of the best methods by far. But, there are some problems in this method as well such as high convergence rate and erroneous result during ambient temperature change. Bianconi et al., proposed a sliding mode control for MPPT algorithm.[13] Xiao and Dunford have proposed adaptive perturb and observe MPPT[14]. De Britto talked about a constant gain P&O method. [15]

3.1. P&O algorithm

Perturb and observe (P&O) method tracks the MPP by continuously increasing or decreasing the output voltage at the maximum power point of the Photovoltaic. Compared to other methods this method is easier to implement, but it cannot track the MPP when the irradiance varies quickly with time. Flowchart of P&O algorithm is given below.



Fig 2. Flowchart for P&O algorithm

3.2. Incremental conductance method

There are several problems in perturb and observe MPPT method. This method suffers from inaccuracy under fast varying atmospheric conditions. But in the incremental conductance method when MPPT reaches the maximum power point perturbation can be stopped. Using the $\frac{dI}{v}$ and $\frac{I}{v}$ is used to find out the direction of the perturbation if the previous MPPT $\frac{dp}{dv}$ condition is not met. It is evident from the graph that $\frac{dp}{dv}$ is negative when MPPT is to the right of MPP and $\frac{dp}{dv}$ is positive when MPPT is to the right. [16]

The MPPT regulates the Pulse Width Modulation control signal of the DC-DC boost converter when

$$\frac{dI}{dv} + \frac{I}{v} = 0$$
 Condition is satisfied.

Shruti et al., proposed an incremental conductance simulation technique where she used an irradiance of 1000 W/m^2 and temperature of 25°C and simulated the circuit without a maximum power point controller. This method computes the maximum power by controlling the extracted power. It has certain advantages such as good tracking efficiency, fast response and robust control.

Table 1. Characteristics of different MPPT algorithm									
MPPT Methods	Dynamic response	Transient	Steady	Static	Control Accuracy	Overall	Tracking	Temperature characteristics	System complexity
		Fluctuation	Oscillation	Error		Efficiency	speed		
P&O	Poor	Bad	Large	High	Low	Medium	Slow	Poor	Simple
INC	Medium	Bad	Moderate	High	Accurate	Medium	Slow	Poor	Simple
ANN	High	Good	Zero	Low	Accurate	High	Moderate	Good	Medium
FLC	Medium	Good	Small	Low	Accurate	High	Fast	Good	Medium
Proposed VUFLC	High	Good	Zero	Low	Excellent	High	Very Fast	Excellent	Medium



Fig 3. Flowchart for incremental conductance method

3.3. Variable step size method

Lio et al., proposes a technique to calculate the maximum power point using variable step size. All of the methods mentioned above uses fixed step size to reach MPP. On the contrary this method uses variable steps to reach the peak. There are some other methods like this but those suffer from accuracy and efficiency as tracking the exact MPP under varying irradiance is quite a cumbersome task. In this method large steps are adopted if the system is far away from the MPP. On the contrary small steps are adopted if it is near to the MPP. This method offers a fast response and excellent steady-

state performance. The step size is calculated using the following equations [17]

$$V_{step} = e \times \Delta V \cong e \times dV$$
$$e = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} = \frac{\Delta P}{\Delta V} \cong \frac{dP}{dV}$$

3.4. Hill climbing method

Hill climbing method is almost similar to the perturb and observe method. The only difference here is that instead of iterating voltage (V) and current (I), it perturbs the duty cycle d(k) which is the fraction of one period in which a signal or system is active another name of this method is direct duty cycle procedure. There are some disadvantages of this method such as increased oscillation at the ideal working point and the convergence time to MPP dependence on the initial duty cycle and step size. [18-20]



Fig 4. Flowchart for hill climbing method

Methods based on mathematical calculation

There are different mathematical methods in practice to locate the maximum power point.[21]

3.5. Incremental resistance method

The perturb and observe (P&O) method tracks the MPP by continuously increasing or decreasing the output voltage at the maximum power point of the Photovoltaic. Compared to other methods this method is easier to implement, but it cannot track the MPP when the irradiance varies quickly with time.

3.6. Beta method

Beta method is believed to be one of the fastest tracking method. In this method variable coefficient β is used to accomplish MPP. β is calculated using a reference and a closed loop control and measuring the voltage and current of the PV panel.

3.7. Curve fitting method

To implement curve fitting based MPPT different manufacturing parameters of a solar panel required. Unlike other methods, this method doesn't require any derivative term. The only drawback of this method is its necessity for huge computing memory.

3.8. Variable step size incremental conductance method

INR method is believed to be the best tracking algorithm for MPPT in terms of speed and accuracy. But it suffers from oscillations around the MPP. This problem can be mitigated using the variable step size INR method. In this method step size is varied continuously until it reaches the maximum power point.

3.9. Analytical solution method

Analytical solution method is also known as the bracketed method. This method is based on the principle of the mean value theorem. It provides an approximation using an analytical solution. This method considers PV panel's voltage and current and the converter's duty cycle as input. Output power is considered as output.

3.10. Linear reoriented coordinate's method

Several iterations are done to find out the MPP in this method. An equation is controlled to find out a representation of the MPP.

Methods based on constant parameters

In this category a predefined fixed value is utilized to track the maximum power point. Some of the prominent methods are described below

3.11. Fractional short circuit current FSCC

It is simple and fast way of tracking MPP. But it is unable to find out the exact MPPT. This technique is implementable using both digital and analog methods. This method works on the principle that the current at the maximum power point is equal to the short circuit current time k.

$$I_{mpp} \cong kI_{sc}$$

where k is a constant of proportionality which depends on the characteristics of the PV panels





3.12. Fractional open circuit current MPPT

Fractional open circuit voltage method is almost similar to fractional short circuit current. Like FSCC, this algorithm is also incapable of finding the exact MPPT point. Both analog and digital methods can be used for implementing this technique. However, this technique is slightly easier to implement than compared to FSCC. According to this method the voltage at MPP is equal to the open circuit voltage times proportionality constant k.

$$V_{mpp} \cong k V_{oc}$$

Similar to FSCC method the k value can be obtained from data sheet. This value of k varies in between the range 0.70 to 0.85. One voltage sensor is needed to implement this method.

In practicality the two inputs for FSCC are the short circuit current I_{sc} and the PV array's current I_{pv} . For FOCV the two inputs are the open circuit voltage V_{oc} and PV array's voltage V_{pv} .



Fig 6: FOCV

In this method PV array is first isolated to calculate the values of I_{sc} or V_{oc} . These values are then

multiplied with k_1 for finding out the parameters at maximum power point. These parameters I_{mpp} and V_{mpp} are then compared with I_{SC} and V_{OC} . At the same time error is computed and fed back in to the PI controller. This process is repeatedly done until the error is zero. Once the error becomes zero, the interrupt flag is cleared. Interrupt flag is being monitored continuously during this time. The moment the value of the interrupt

flag becomes zero again, this process of measuring I_{SC} or V_{OC} and minimizing error starts once again.

Interrupt loop:

This loop continuously tries to calculate the values of I_{PV} or V_{PV} and updates the proportionality constant K_2 . K_2 is then compared with K_1 . If K_2 is less than the preset limit of 0.05, the process is repeated. If difference is higher than 0.05, the interrupt flag is set to 1 and the loop then becomes standby until that interrupt flag is cleared by the normal loop. Once the flag is cleared it then again enters into interrupt loop and the routine accordingly.

Villalva et al., proposed an intelligent SCC/OCV simulation technique to find out the MPP. Following parameters are used for the simulation [22]

Methods based on intelligent calculation

These methods are mainly based on soft computing based algorithm. These methods are becoming practical and implementable due to access to reasonable micro controller and computing devices. Particle swarm algorithm is one such algorithm. The working principle of this algorithm is described below

3.13. Particle swarm MPPT

PSO algorithm is a population based stochastic algorithm. This algorithm is inspired by the social behavior of birds flocking or fish schooling. A group of flocking birds are in search of food. They don't know the exact location of the food. The only information that they have is they know how far the food particle is from them. So, they try to reach the food particle by multiple iterations. In first iteration they try to reach close to food particles. And the second iteration, they try to reach the particle closer and so on. The best thing to reach to the food particle/ best solution is to follow the bird that is near to the food particle. That means the rest of the birds should follow the one particular bird that is close to the food particle. All the other birds should update their position according to their neighboring bird. This is how the PSO algorithm is implemented. There are some similarities between genetic algorithms and PSO algorithms. In this PSO algorithm, we are considering a random population for particle. Then the fitness values of all particles are measured. Then we update the population. [23]

The two most important parameters in PSO algorithm are P_{best} (Individual best) and G_{best} (global best value). P_{best} is calculated at the individual level. G_{best} is calculated at the global level. That actually means that the G_{best} is calculated on a group wise level.

To understand the algorithm better, a pseudo code can be implemented.

Pseudo Code:

For eachparticle Initialize Particle

END

DO

For eachparticle

Calculate fitness value

If the fitness value is better than the P_{best} in history

Store the current value as the new P_{best}

END

Choose the particle having the best fitness value among all particles as the G_{best}

For eachparticle

Calculate particlevelocity

Update particlePosition

END

While maxiteration or min error criteria is not attained.

Once P_{best} and G_{best} is found, we can calculate particle velocity



Fig 7. Flowchart for PSO algorithm [24]

4 PV system simulation using using P&O and incremental conductance methods

A diagram of a standalone PV system is shown in figure 8. The system modelled is simulated on SIMULINK. A boost converter is used in between the PV array and resistive load as an interface. To track the maximum power point, both P &O and incremental conductance methods are used. Through this simulation, we have tried to test the relative performance and feasibility of the P&O and INC algorithm. The main aspect here is to test the convergence speed to the maximum power point and the power ripple due to the steady-state condition at the maximum power point. Components used in this simulation are listed below:

Table 2. List of components used in Simulation

Components	Parameter
Inductor	$2\mu F$
Input Capacitor	9.4µF
Output Capacitor	144µF

The output power of the solar panel is mainly dependent on the temperature and solar irradiance. However, the change in solar irradiance is quite drastic compared to the variation in temperature. Keeping this in mind the temperature of the solar panel is kept fixed at 25° Celsius. Due to the cloud cover and changing weather conditions solar irradiance changes from time to time. Hence, the output power of the solar panel changes due to this varying solar radiation.

Simulation results are shown below. In the simulation irradiation is changed to 500 W/m^2 from 200 W/m² 1s. Then again in the next second, it is increased to 1000 W/m² . A fixed step size is used in these simulation figures. When the solar radiation changes, both algorithms adjusts duty cycle that is applied to the boost converter to track the new maximum power point.

In practical applications load connected to the PV is often changed. So to get an overall idea both the algorithms are tested on different load profiles. Both the algorithms perform quite well in terms of tracking the maximum power. But a close observation reveals that the P&O method is slightly better in terms of convergence speed and fewer oscillations around the maximum power point. Below figure illustrates a standalone PV system block which is helpful in understanding and visualizing the whole system.



Fig 8. Standalone PV system block diagram



Fig 9. Maximum PV power graph of 210 watt vs Time (in seconds) for Perturb and Observe algorithm



Fig 10. Maximum PV power graph of 210 watt vs Time (in seconds) for INC algorithm



Fig 11. PV module having 210 watt output power vs Time (in seconds) with a load of 195 ohms

5 Conclusion

This paper talks about the MPPT methods and tries to find out their appropriateness for a wide range of conditions. From this paper, it is evident there are several advantages and disadvantages of each MPPT method and choice of it depends on different parameters such as weather condition, load, line and application. To use solar panels at home, payback time needs to be kept in mind. For doing that tracking the maximum power point efficiently is a must. Moreover, the MPPT technique should be able to minimize the ripple effect around the maximum power point. Perturb and observe suitable methods are because of their easy implementation. On the other hand particle swarm algorithm is faster than these two algorithms, but it takes more amount of computational space. Simulations have been carried out for a standalone PV system where a boost converter is used as an interface between the load and the panel. The performance of several techniques has been observed for a wide range of irradiance conditions. Finally, it is being observed that the enhanced perturb and observe algorithm shows faster dynamic performance in terms of convergence to a steady state level compared to other conventional methods over a wide range of solar irradiation and load variations.

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