

ANALYSIS OF MAXIMUM POWER POINT TRACKING (MPPT) IN SOLAR POWER GENERATION

S.K. Jaslin¹ & W.G.C.W. Kumara²

Correspondence: jaslinshaleem93@gmail.com

ABSTRACT

This paper focuses on the review of maximum power point tracking (MPPT) algorithms analysis in solar power generation systems. A theoretical study has been done with multiple algorithms to achieve the peak powerpoint with the aid of mat lab Simulink tools. MPPT is a fully electronic-based system which can track the maximum power accurately in the photovoltaic simulation model. This paper analyses the existing MPPT algorithms under the categories; the types of sensors required, convergence speed, cost, range of effectiveness, implementation hardware requirements and popularity in the photovoltaic system.

Keywords: Maximum Power Point Tracking (MPPT), perturb and observation, incremental conductance, open circuit voltage, short circuit current, solar power generation

INTRODUCTION

One of the major concerns in our country's power and energy sector is the day-to-day increasing power demand and lack of availability in efficient resources to fulfill the demand with conventional energy sources.

The rapid increment in fuel price and environmental impacts are the main driving forces to utilize the various renewable sources (Reza Reisi, Hassan Moradi, & Jamasb, 2013). In Sri Lanka, the vision of the power and energy sector is to capture the full potential of all renewable and other indigenous resources to make our country, a self-sufficient nation (Ministry of power and energy, 2015).

Sri Lanka has adequate 12 hours of day light. The efficient power extraction from the solar radiation is the suitable option to tackle the present energy crises. Maximum Power Point Tracking (MPPT) is the newest mechanism, which has led to the increase in the efficiency of operation of the solar modules and thus is effective in the field of utilization of renewable sources of energy (Satpathy, 2012).

MPPT is done to maximize the energy extracted from the Photovoltaic (PV) array which increase the efficiency and the stability as well. MPP is a single operating point enabling attainment of maximum power, tracking of which

¹ Department of Electrical and Telecommunication Engineering, South Eastern University of Sri Lanka.

² Department of Computer Science and Engineering, South Eastern University of Sri Lanka.

through variations in radiation intensity and temperature is essential to achieve.(Reza Reisi et al., 2013), (Dash, Verma, Nema, & Nema, 2014).

The purpose of MPPT is to generate a near sinusoidal current and voltage with minimum harmonic distortion under all operating conditions as load mismatching, environmental causes etc. (Zain, Shen, Govinda, Albert, & Al-Talib, 2018).

Many existing MPPT algorithms have been discussed here. Those algorithms are grouped as online methods, offline methods and hybrid methods (Reza Reisi et al., 2013).This review paper highlights the features and issues in the MPPT algorithms as a review based on Matlab® Simulink results.

THEORITICAL BACKGROUND

2.1 System Overview

Electrical power is generated as hydro, coal power, thermal as well as non-conventional renewable energy sources such as wind, mini hydro, biomass and solar power plants. Solar power production is from the sunlight using the PV cells, when exposed to light, the photovoltaic effect creates the DC current varies linearly with solar irradiance. A solar cell is a p-n semiconductor junction which is operating as a current source in parallel and inverted diode connected along with a series and a parallel resistances. The ideal solar cell is depicted in the Figure 1 below (Atallah, Abdelaziz, & Jumaah, 2014)- (Dris & Djilani, 2013).

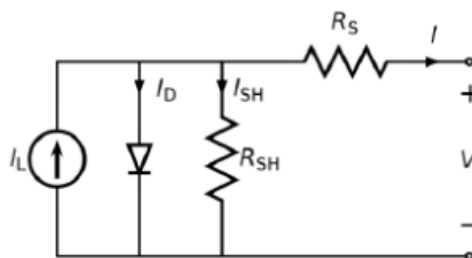


Figure 1: The Equivalent Circuit of A Solar Cell (Dris & Djilani, 2013).

The relationship between the generated current (I) and voltage can be described using the equations (1), (2), (3) shown below (Atallah et al., 2014),

$$I = I_L - I_0 \left[\exp\left(\frac{q(V + I R_s)}{KT}\right) - 1 \right] - (V + I R_s) / R_{sh} \quad (1)$$

$$I_D = I_0 \left[e^{\left(\frac{q(V + I R_s)}{KT}\right)} - 1 \right] \quad (2)$$

$$I_0 = I_L - I_D - I_{sh} \quad (3)$$

Where,

- | | |
|--|---|
| I : Solar cell current (A) | T : Cell temperature in Kelvin (K) |
| I_L : Light generated current (A) | V : Solar cell output voltage (V) |
| I_o : Diode saturation current (A) | R_s : Solar cell series resistance (Ω) |
| q : Electron charge (1.6×10^{-19} C) | R_{sh} : Solar cell shunt resistance (Ω) |
| K : Boltzmann constant (1.38×10^{-23} J/K) | |

The produced output power is nonlinear with ambient temperature and light intensity. The environmental fluctuations make the variation in the solar intensity, if the intensity increase which will conduct the higher excitation energy to the electrons. There by more power is generated from the PV arrays. The variation between the intensity and power, current outputs are plotted in below **Error! Reference source not found.** (Satpathy, 2012).

The temperature increment has the inverse effect as increase the band gap of the material which causes the higher energy requirement to cross the barrier. There by efficiency is reduced. The relationship between the temperature and effects in power and current is plotted below Figure 2.(Satpathy, 2012).

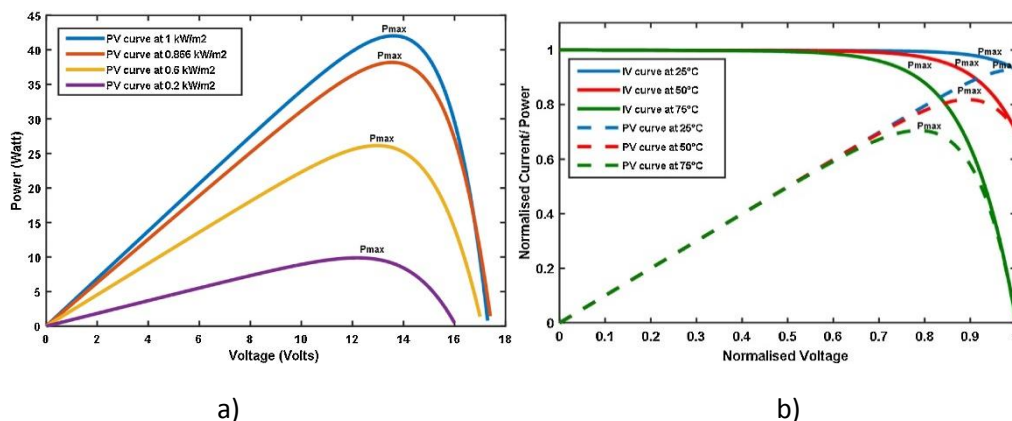


Figure 2: The Variation of a) P-V Curve With Variable Solar Irradiations and b) V-I curve with temperature variation (Adel et al., 2016).

The PV system is combined with DC-DC converters, controllers and batteries. DC-DC voltage converters are used for matching the characteristics of the load where we have to change the voltage from one voltage level to another. Generally, Non-isolating converters are used for solar panel applications, which are categorized as the buck, boost, buck-boost, Cuk and Sepic converters (Sharma & Jain, n.d.)

Buck Converter is step down the voltage, Boost Converters are step down or increase the output as well as, Buck-Boost Converters are step up and down the voltages. Cuk Converter that allows voltage at its output to be higher than,

less than, or equal to that at its input. Sepic Converter which uses to sweep up the output from the solar panel with high current than Buck-Boost Converter.

When compared, Simulink outputs obtained for continuous and discrete time signal of various converters (with and without phase delay) is tabulated below in Figure 3. (Sharma & Jain, n.d.).

Figure 3: The comparison summary for various converters (Sharma & Jain, n.d.)

S.No.	Converter	GUI Output without phase delay	GUI Output with phase delay
	$V_{IN} = 21V$	V_{OUT}	V_{OUT}
1	BUCK	18.92	18.92
2	BOOST	12.47	6.515
3	BUCK-BOOST	1.564×10^{-12}	5.149×10^{-11}
4	CUK	0.02191	0.03881
5	SEPIC	0.2944	8.135×10^4

The structure of a PV system with MPPT shows in Figure 4. The maximum power from the solar PV module is achieved with MPPT control procedure module by changing the duty cycle of a converter with MPPT algorithms effectively. So that, the load impedance is varied and matched at the point of peak power with the source (Pakkiraiah & Sukumar, 2016).

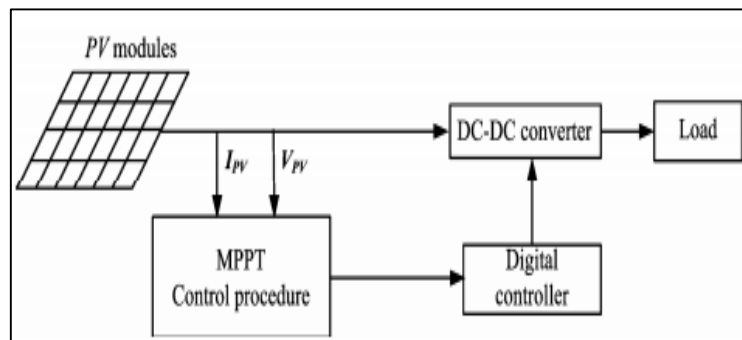


Figure 4: The PV system with MPPT(Pakkiraiah & Sukumar, 2016).

2.2 MPPT Algorithms- Existing Solutions

In order to achieve the maximum power the PV system, wide variety of algorithms have been proposed and implemented. In our review paper, the available algorithms are summarized as below

Figure 5.

These methods are categorized as three: Online methods, Offline methods, Hybrid methods based on sampling input data update functionality which is described in Figure 6. (Reza Reisi et al., 2013).

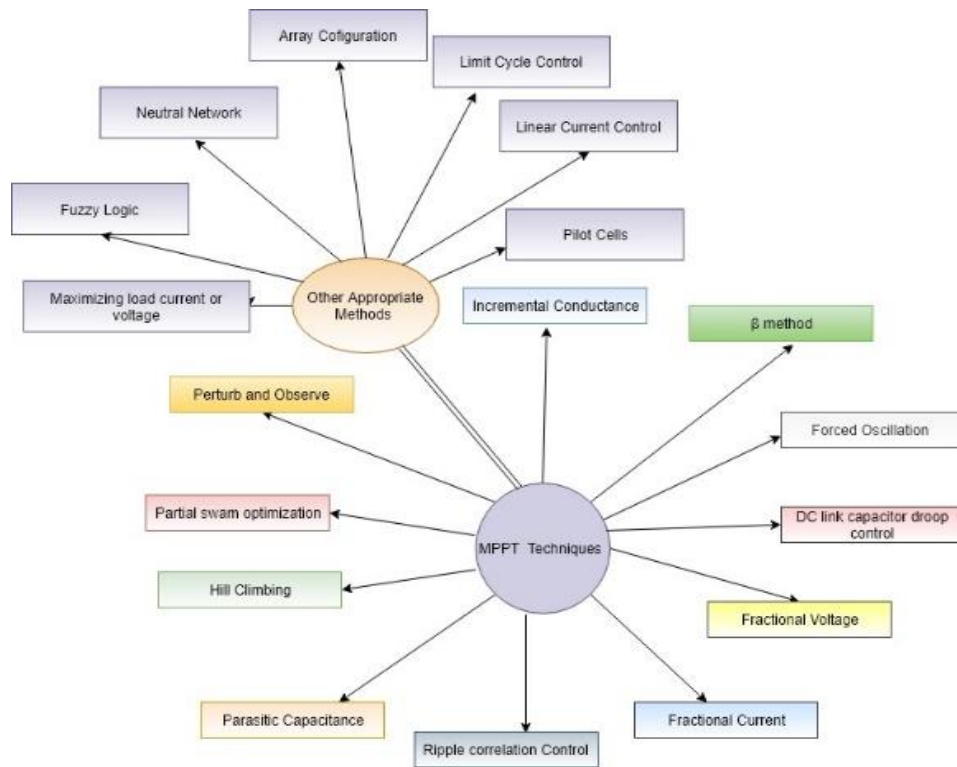


Figure 5: The summary of available MPPT algorithms.

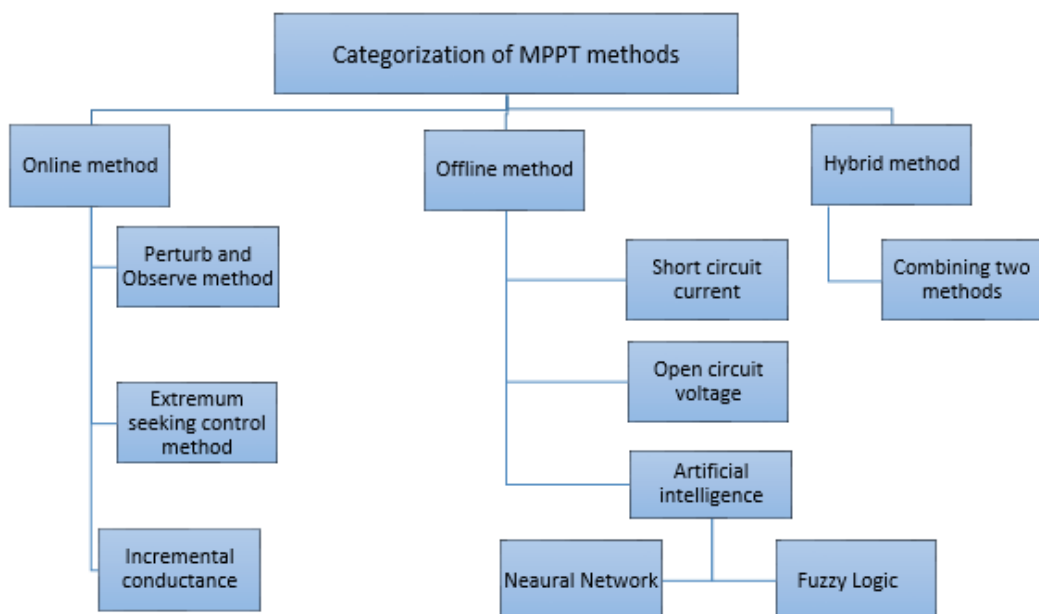


Figure 6: The categorization of MPPT techniques (Dash et al., 2014).

Online Methods: Which is a model-free method as that, usually the instantaneous values of the PV output voltage or current are used to generate the control signals. The techniques under the online methods are based on the principle of the optimal control theory. Under that, the most popular methods are analyzed below.

Perturb and Observe method (P&O): It is simplest form of algorithm based on iterative method with perturbing, observing and comparing procedure. Within the fixed period of time, the duty cycle of the PV system is adjusted, in order to get the terminal voltage and output power.

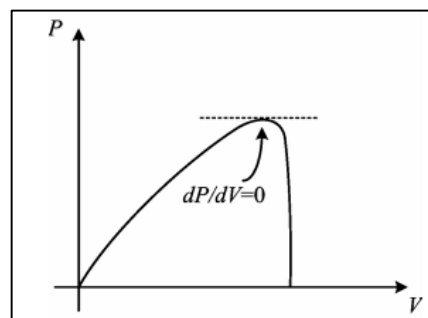


Figure 7: P-V characteristic of a PV module (Yu & Lin, 2015).

The variation of the output power and terminal voltage are observed before and after changes and compared with reference value to identify the next step increment or decrement. If the output power is less than that before variation, it indicates that the varying direction in the next step should be changed. If the perturbation in this time results in greater output power than that before the variation, the output voltage of PV modules will be varied toward the same direction in P vs V curve in Figure 7. The functionality of P&O method is described in Figure 9 (Kumar, Choudhary, Koundal, Singh, & Yadav, 2017), (Reza Reisi et al., 2013).

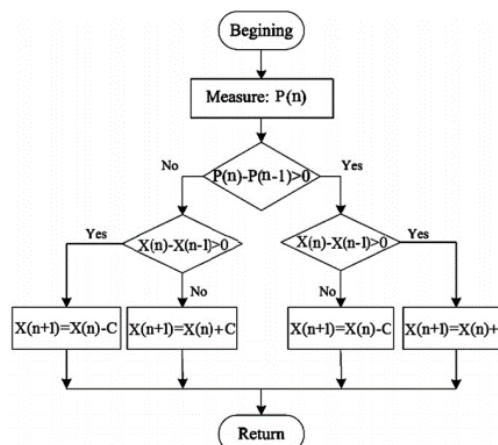


Figure 8: Flow chart for perturb and observe method (Reza Reisi et al., 2013).

Incremental Conductance method: where the concept is used as, the slope of the PV array power curve is zero at the MPP, positive for values of output power smaller than MPP, and negative for values of the output power greater than MPP. The relationship is gained from P-V graph for P - PV output power, V - Output voltage, I - Output current of PV module.

The PV output is differentiating with respect to voltage and equal to zero which is coming as;

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I \frac{dV}{dV} + V \frac{dI}{dV} = I + V \frac{dI}{dV} \tag{4}$$

When $dP/dV = 0$ as in Figure 7 and the equation (4) can be rearranged as;

$$\frac{dI}{dV} = -\frac{I}{V} \tag{5}$$

At this point Incremental Conductance (IncCond) algorithm knows the maximum power point is reached and thus it terminates and returns the corresponding value of operating voltage for MPP. The corresponding IncCond algorithm is described in Figure 9. (Reza Reisi et al., 2013), (Satpathy, 2012), (Atallah et al., 2014).

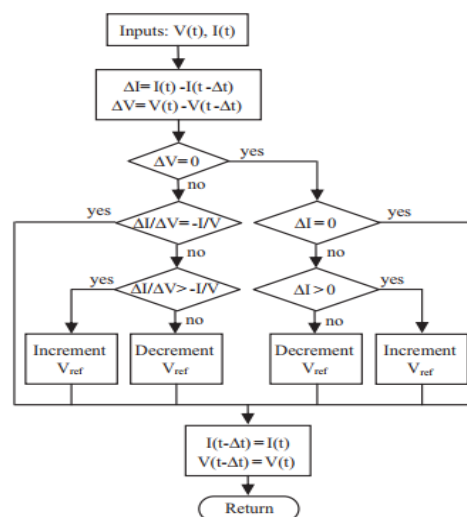


Figure 9: The Algorithm of Incremental Conductance Method (Reza Reisi et al., 2013).

Offline Methods: which is known as model based method. Usually the physical values of the PV panel are used to generate the control signals.

Open circuit voltage (OCV) and Short circuit current method: For the both methods, the linearity relationship is used to get the MPP V and I . With the various irradiance and temperature conditions.

V_{mpp} is calculated with the periodic measurements by momentarily shutting down the power converter of the system,

$$V_{mpp} = K_1 * V_{oc} \quad , \quad \text{where } K_1 = 0.71 - 0.78 \quad (6)$$

The short circuit current measuring I_{sc} during problematic condition of operation as load interruption with current sensor. As a result seen an additional switch added to the power converter to periodically short the PV system (Kumar et al., 2017).

$$I_{mpp} = K_2 * I_{sc} \quad , \quad \text{where } K_2 = 0.78 - 0.92 \quad (7)$$

Artificial Intelligence: These methods are used to solve the complicated practical problems in various areas

- **Artificial neural networks method (ANN):** This system is mainly based on identification and modelling of the system using nonlinear and complex functions. The trained neural network is used to identify the MPPT which can provide the sufficient and accurate output. In order to implement periodical training, new data has to be collected, which is a time-consuming process.
- **Fuzzy Logic:** These methods are based on trial and error method which contains much time. This system implements the fuzzy logic control in three stages: fuzzification, decision-making, and defuzzification.

Hybrid Methods: These are expected to track MPP more efficiently. In these methods, the control signal associated with the algorithm consists of two parts. Each part is generated based on a separate algorithmic loop.

3. COMPARATIVE ANALYSIS OF ALGORITHMS

In this section, the comparative analysis is concluded with the simulation results of the existing algorithms as a summary of previous related research papers (Reza Reisi et al., 2013),

Table 1: The comparison summary for existing MPPT techniques

MPPT Method	Type	Complexity	Convergence speed	Sensed parameters	Digital and Analog	Efficiency
Open Circuit Voltage	offline	Low	Medium	Voltage	Both	Low (=86%)
Short circuit Current	offline	Medium	Medium	Current	Both	Low (=89%)
Artificial Neural Network	offline	High	Fast	Depends	Digital	High (=98%)
Fuzzy Logic	offline	High	Fast	Depends	Digital	High
P&O (fixed turbation size)	online	Low	Low	Voltage & Current	Both	Low

P&O (Variable turbation size)	online	Medium	Fast	Voltage & Current	Digital	High (=96%)
IncCond	online	Medium	Depends	Voltage & Current	Digital	High
Extremum Seeking Control	online	Medium	Fast	Voltage & Current	Both	High (=97%)

4. DISCUSSION

The MPPT techniques are analyzed based on the advantages and disadvantages with the Simulink results of previous researches where steady and dynamic response and implementation methods are considered it includes in Table 2 (Adel, Abdelhady, & Ibrahim, 2016), (Kachhiya, 2011), (Dash et al., 2014).

Table 2: The summarized features for existing MPPT algorithm

MPPT techniques	Advantages	Disadvantages
Perturb and Observe	Simplicity	Less efficiency with limitation
	Ease of implementation	Cannot track the peak power under fast varying atmosphere
	Low cost implementation	Power losses with in the oscillating range of tracking
	High efficiency (variable perturbed size)	
	Need only one sensor to measure voltage	
Incremental Conductance	Can track rapidly increasing and decreasing irradiance conditions	Complexity in algorithm than P&O method
	Medium implementation cost	Need two sensors as voltage and current
		Longest elapsed time
Open circuit voltage & Short circuit current	Ease of implementation	Poor dynamic response
		High implementation cost
		Incapability of tracking power in sloping irradiance
		Power loss due to momentarily stoppage of power converters
		Low efficiency (even it has constant K values)
	Simplicity	load interruption occurring during measurement of I_{sc} or V_{oc}
Hill Climbing	perform with true MPPT	Long elapsed time
Fuzzy logic	Better performance	
	Robust and simple design	
	High efficiency	

5. CONCLUSION

In this review, the existing MPPT methods have been analyzed and concluded based on Matlab/Simulink results. The overall performance of the algorithms are categorized in Table 1. The advantages and disadvantages of the methods are concluded in Table 2. During the selection of MPPT method for PV system this review paper will serve as a guide.

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