A Comprehensive Review on Latest State of the Art Practices in MPPT Algorithm

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Abstract

The performance of the solar charge controller depends largely on the maximum power point (MPPT) tracking algorithms. The review paper emphasis on the factors that influence the selection of MPPT, and performance of the charge controller employed in PV system. An efficient MPPT technique can achieve the purpose of energy saving, better extraction of power from solar. This paper presents a literature review on the basic MPPT techniques in detail along with their variants published by various researchers. The detailed study of MPPT techniques for improving the PV system performance, has been presented in this paper with emphasis on design and future MPPT techniques based on Moving Average Filter.

Keywords: Maximum power point tracking (MPPT), charge controller, P & O, incremental conductance, energy, PV system, factors.

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1 Introduction

Go green initiative in the globe created a buzz in the field of energy. The problems associated with the use of fossil fuel has revolutionized the alternative energy resources such as solar, wind power etc. These resources provide clean energy to various sectors there by improving the quality of life on the earth. The solar is ever lasting source of energy. The systems required to harvest energy from this source is simple and relatively easy to control. These systems are reliable, durable due to the absence of rotating parts. The solar irradiation is almost uniform but depends upon the environment and terrains [1]. The photovoltaic cell technology used in the conversion of light energy into electric energy directly. There are various types of PV Cell like monocrystalline, polycrystalline etc. To achieve high conversion efficiency an algorithm known as Maximum Power Point Tracking (MPPT) is employed in energy conversion systems. These algorithms regulate the power flow from the solar panels and tries to keep the operating point on a PV curve at maximum peak depending on the operating conditions at the place of generation [2]. The percentage of renewable energy generation in India is about 36.3% as reported in [3] of which 9.9% is from solar source. The solar power generation is increasing day by day due to the green emissions.

The commercialization of photovoltaic technologies are slower because of high initial cost and low conversion efficiency. The conversion efficiency with available monocrystalline, polycrystalline, and other variants of cell technologies is about 15%–27%. The conversion efficiency also depends upon parameters like temperature, irradiance, and terrain [4–6]. The power output of the PV panels is intermittent in nature due to various well-known reasons. The changing climatic conditions such as temperature, relative humidity, irradiance and positioning of PV panels results in poor performance of PV panels i.e. power output is not at rated capacities of the panels. The PV panels in order to be used at maximum power point a technique known as Maximum Power Point Tracking abbreviated as MPPT is being employed [7, 8]. The PV systems have been developed with these MPPT control algorithms to improve their efficiency and performance. There are about 68 MPPT variants available as per the literature and are reviewed with respect to different parameters of climatic and PV cell technologies [8–11]. In [12–14] the MPPT techniques have been studied and characterized with respect to the way MPPT operates. MPP algorithms are required to produce maximum output from the PV panels at any given point of a time during the day. In other words, MPPT control algorithms are used to produce maximum output under all atmospheric conditions [15]. MPPT techniques are classified into three categories; namely Conventional, Global and Power Electronics based [16]. The paper does not high light the effect of atmospheric conditions in detail but indicates their ability to yield better output. The literature review is indicating that the main goal of all the existing MPPT control algorithms to achieve high output from the PV cell technologies. Moreover, all MPPT revolve around the maximum operating point of power under various changing operating conditions and the terrain where the PV system is installed.

2 Motivation

The efficiency of a solar PV grid interconnection can be increased by using some electronic devices along with MPPT controller. A number of research and several algorithms have been developed in the last decade to improve the efficiency of converter so as to extract maximum power from PV Panel. However, most of the MPPT algorithm suffer from slow convergence on tracking response. Again, this is happening due to close loop tracking of solar power. Therefore, in this paper various MPPT algorithm were discussed in detail to find out their efficiency in tracking and converting solar power in an usable form.

3 Maximum Power Point Tracking (MPPT)

Figure 1 depicts the current-voltage and power-voltage characteristics of a typical crystalline solar cell under normal operating conditions. These characteristics describe the panel parameters such as V_{OC} (open-circuit voltage), I_{SC} (short-circuit current), MPP (maximum power point), fill factor and percent of efficiency. The maximum power point tracking is the process of harvesting PV panel's maximum power under tough weather conditions. The MPPT is an algorithm- based technique implemented in a charge controller that compares the panel output with that of load (generally battery) and decides to deliver an optimum power required to the load (battery). MPPT is a digital electronic technique that delivers maximum power to the load with the help of DC-DC converter when implemented in charge controller. The problems associated with an MPPT algorithms is the oscillation of operating point around the MPP as shown in Figure 1. The MPP oscillates between points 3 and 4 affecting the power output of the panel as shown in Figure 1. This would cause fluctuations in PV panel power output. There are number of MPPT

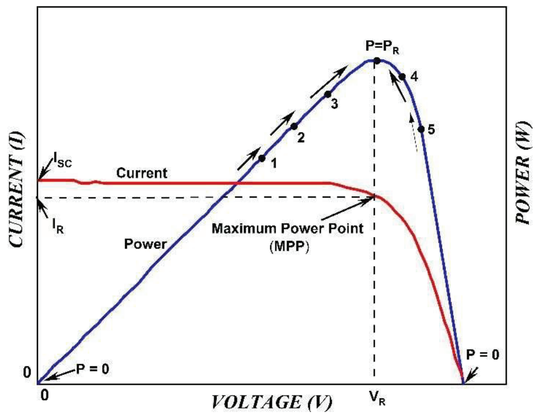

Figure 1 IV & PV characteristic of PV Cell [17].

Table 1 Factors considered for comparative study of various MPPT techniques

Factors	Description
Intensity of Dependence/ Independence on PV array	Configuration and parameter value doesn't affect the techniques that can be applied to the PV array
MPPT – True/Not True	The used technique operates and reaches MPP if it's a true MPPT, if not a true MPPT, output power will not be able reach the maximum point of extraction.
Circuitry used type	If the circuitry is analog or digital based.
Periodic tuning	Oscillations are present at Maximum Power Point or not
Speed of Convergence	Total time taken by the algorithm to reach the MPP
Implementation complexity	Level of complexity in implementing the particular technique
Sensors	Types and number sensors used for measurement, depends on control variables

techniques (as discussed in introductory section of this paper) proposed by various researchers earlier and are reviewed. The factors considered for the study and comparative analysis of various MPPT techniques are summarized in Table 1. The various conditions under which these parameters considered are also included in table.

4 Overview of MPPT Techniques for PV System

The most common and popular MPPT algorithms employed in PV system development are classified into two categories: namely, Direct, and Indirect MPPT Techniques. These are reviewed in proceeding sections.

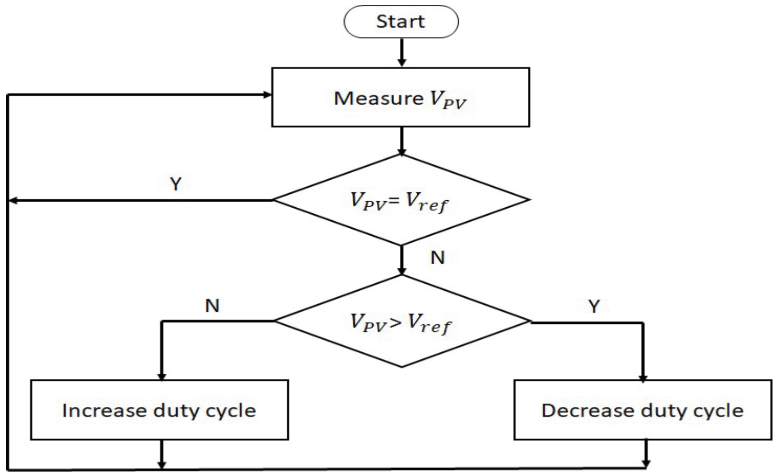

Figure 2 Constant voltage method flow chart.

4.1 Indirect MPPT Techniques

These techniques utilize empirical data or mathematical expressions to achieve MPP by applying numerical corrections and approximations. The overview of major indirect techniques of MPPT algorithm are presented in the proceeding sections.

4.1.1 Constant voltage method (CVM)

A simple and a quick response MPPT control algorithm is constant voltage method. In this method the measured maximum PV panel voltage under standard test conditions (STC) is used as a constant reference voltage (V_{ref}) to regulate the PV panel output voltage (V_{pv}) nearest to maximum output voltage. This control algorithm requires a PI controller to regulate PV panel output [99]. The flow chart is shown in Figure 2.

4.1.2 Open circuit voltage method (OCVM)

The constant voltage technique involves the measurement of open circuit voltage with zero current when power delivered to the load is momentarily interrupted. In this method the open circuit voltage is used to determine reference voltage. In other words, the ratio of maximum power output of PV panel to its open circuit voltage is approximated to a constant.

Mathematically,

$$V_{mpp} \cong kV_{oc} \tag{1}$$

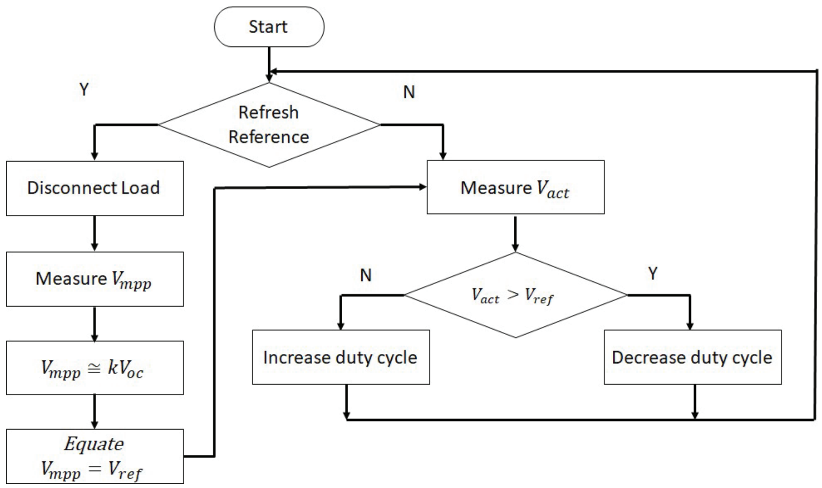

Figure 3 Open circuit voltage method flow chart.

Where

V_{mpp} is Panel voltage at maxim power point.
V_{oc} is Panel open circuit voltage.
k is voltage ratio constant.

The value of 'k' is depended on the type of the material and technology adopted to manufacture the Photovoltaic cell or panel. As stated previously, the V_{oc} (open-circuit voltage) is calculated and tabulated momentarily disconnecting the module from load. This measured value is used to calculate the reference voltage. The value of the voltage constant lies between 0.7–0.9 [98]. This has been indicated by most of the researchers in their publications. This method is also known as fractional open voltage method. The value of V_{mpp} determined as shown in Equation (1) serves as reference voltage V_{ref} for the control algorithm. The open circuit voltage method flow chart is shown in Figure 3.

4.1.3 Short circuit current method

As the name suggest, in this method short circuit current is considered to control the PV system output. This method involves the measurement of short circuit current of PV panel when its output voltage is zero. It is also indicated that, MPP at maximum current is linearly proportional to I_{SC} (short-circuit current). In this method, the I_{MP} (maximum current) at MPP to I_{SC} (short circuit current) ratio is constant.

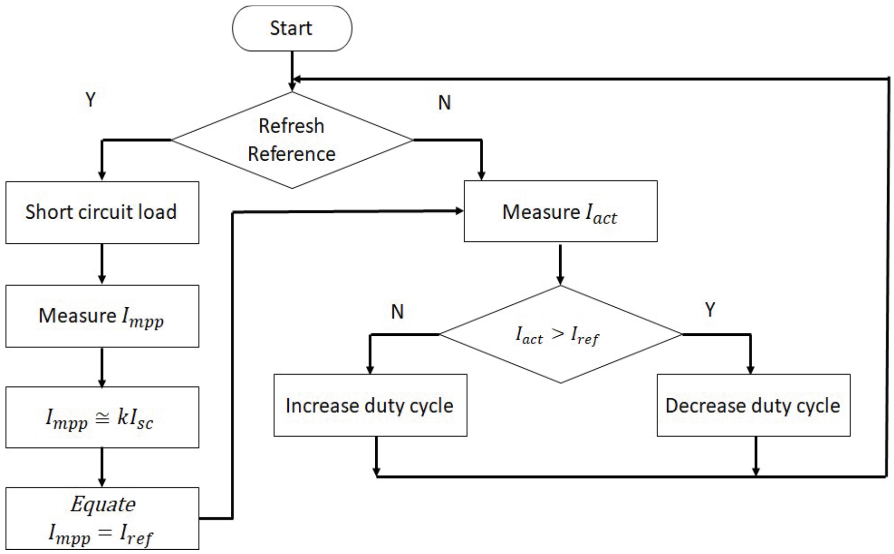

Figure 4 Constant current method-process chart.

Mathematically,

$$I_{mpp} \cong kiI_{sc} \tag{2}$$

Where

I_{mpp} is Panel current at maxim power point.
I_{sc} is Panel short circuit current.
ki is current ratio constant.

Therefore, the control strategy is developed in such a way that the difference of maximum current at MPP and the short circuit current is used to regulate the PWM controller. It has been found that the current at maximum power point is about 92% of its short circuit current. Generally, it varies between 0.78 to 0.92. The flow chart for constant current method is as shown Figure 4.

4.2 Direct MPPT Techniques

In these methods, the instantaneous values of voltage and current of PV panel are measured and maximum power point is tracked in accordance with algorithm evolved. Overview of various MPPT algorithms under this category are presented in proceeding sections.

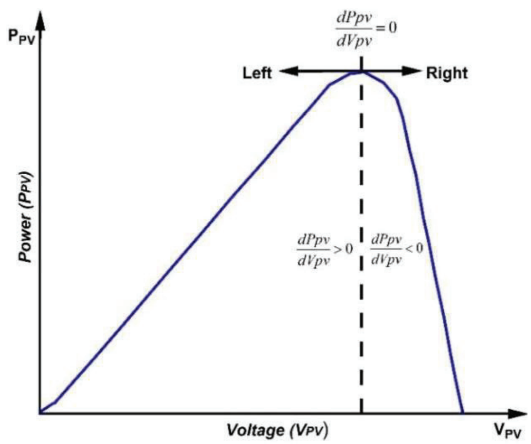

Figure 5 Power and voltage characteristics of PV panel.

4.2.1 Perturb and observe (P&O) MPPT technique

In this method the control strategy revolves around the relation between the PV Panel output power and voltage. The panel voltage and current are the two parameters need to be measured during the operation of the PV system. The MPPT controller changes its output power in a very small step in each and every control cycle. The step size is either constant or variable. The control parameter can be either voltage or current.

The condition for maximum power is given by:

$$\frac{dP}{V} = 0 \text{ at MPP} \tag{3}$$

dP is the differential change in output power of PV panel and also known as operating point.
dV is the differential change in output voltage of PV panel

Again, from the Figure 5 if operating point dP is at the left-hand side of the curve i.e. positive then the power is increasing. Further the perturbation of the voltage is in positive direction. If the operating point dP is at the right of the curve i.e., negative then the power is decreasing. Then the perturbation is in negative direction. The MPPT controller would control the PV panel output depending on the operating point at any given point of time during day. This is a fundamental MPPT technique, simple, easy to implement and very cost effective. It has a drawback of operating point oscillating at MPP during rapidly changing atmospheric conditions. The process chart of P & O MPPT

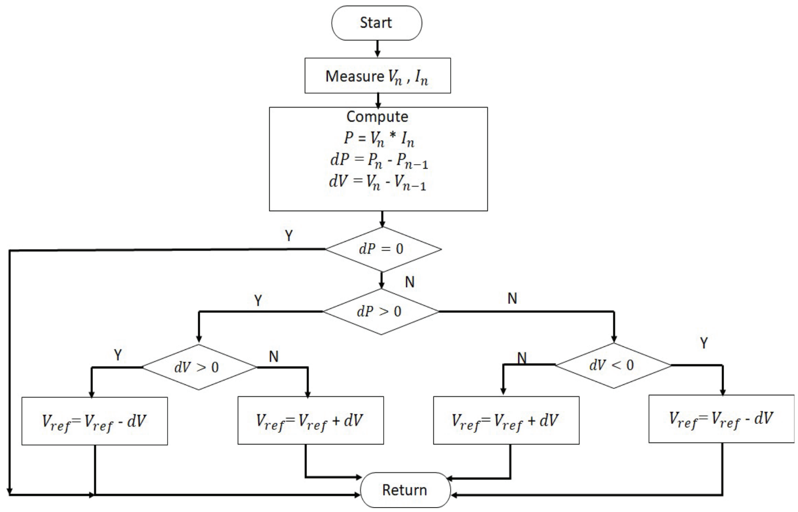

Figure 6 P & O MPPT-process chart.

Table 2 Operating point movement

Prior Perturbation	Change in Power	Next Perturbation
P_{N-1}	$P_N - P_{N-1}$	P_{N+1}
$+VE$	$+VE$	$+VE$
$+VE$	$-VE$	$-VE$
$-VE$	$+VE$	$-VE$

technique is shown in Figure 6 and Table 2 shows the different possibilities of operating point direction of movement.

Table 2 summarizes the possible combinations for prior and next perturbation with change in power. It can be noticed that, when both prior perturbation and change in power are same i.e., either positive or negative, next perturbation remains positive only. But if any one of them is positive or negative, then next perturbation remains negative.

4.2.2 Incremental conductance (IC) MPPT technique

Since the P & O MPPT method suffers from operating point oscillations at MPP under rapidly changing environmental conditions, the efforts were made to resolve the same. The process of resolving the problem of oscillations of operating point at MPP resulted in a new technique called Incremental Conductance (IC) MPPT. The IV-PV curves with regions marked are shown in Figure 7.

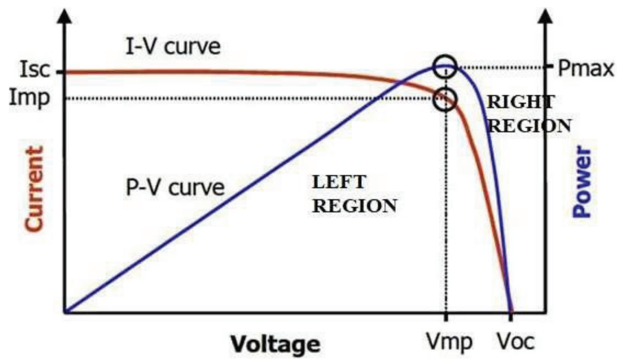

Figure 7 IV-PV curve of PV module with regions.

As seen from the Figure 7 The movement of operating point dP on either side of the MPP results in differential increase or decrease of panel voltage. If the operating point dP is in the left region, the panel voltage is increased by an amount of dV, if it is on the right region than panel voltage is decreased by an amount of dV. The method involves the measurement of voltage, current and computation of its direct conductance during operation of PV system. The mathematical relations explaining the relationship between the conductance, and differential change in voltage and power are important.

It has been shown that

$$\frac{dP}{dV} = 0 \text{ at MPP} \tag{4}$$

The conductance G is the ratio of panel current to voltage and is reciprocal of panel resistance at any given point of time during the day.

Mathematically.

$$G = \frac{I}{V} \tag{5}$$

Where

I is the panel current.
V is the panel voltage
G is the conductance.

At any other point of time the ratio of differential change in power to that of voltage is given by:

$$\frac{dP}{dV} = \frac{d(IV)}{dV} \tag{6}$$

Where $P = IV$

(5) can be written as:

$$\frac{dP}{dV} = I + V\frac{dI}{dV} \tag{7}$$

At MPP Equation (6) can be equated to zero.

$$\frac{dP}{dV} = I + V\frac{dI}{dV} = 0 \text{ at MPP} \tag{8}$$

$$\frac{dI}{dV} = -\frac{I}{V} \tag{9}$$

Further,

$$\frac{dI}{dV} > -\frac{I}{V} \quad \text{when dP is on the left region of PV curve} \tag{10}$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \text{when dP is on the right region of PV curve} \tag{11}$$

The process chart of Incremental Conductance (INC) MPPT technique is depicted in Figure 8 Here the movement of maximum power point (Operating Point) depends on the slope of the curve, i.e., if the slope of the curve is -1, then movement is towards left hand side. Again, the movement for maximum power point depends on the previous state of operation apart from negative slope characteristics.

The PWM control signal from the MPPT is regulated until $(dI/dV) + (I/V) = 0$ condition is satisfied. If the nth iteration from the algorithm is considered as a reference, then from the above equations, n + 1 iteration can be determined. Figure 8 shows the flowchart of Incremental Conduction MPPT. The voltage reference of the PV array is adjusted by output control signal either by increasing or decreasing constant value (ΔV = δ) to the earlier reference voltage. Here the MPP is achieved by using a fixed step side (+δ), without consideration for gap between operating point of MPP location and PV. Modules peak power is about 97% of its incremental conductance [100]. The variants of various MPPT algorithms have been studied reviewed by the authors and the comparative analysis of those algorithms is tabulated in Table 3 and Legends in Table 4 respectively.

Table 3 shows a detailed comparison analysis of MPPT techniques available in literature. After detailed study it is found that digital MPPT algorithm are more robust in terms of MPP tracking as compared to analog technologies. Again, some ANN based MPPT were also reported in the literature.

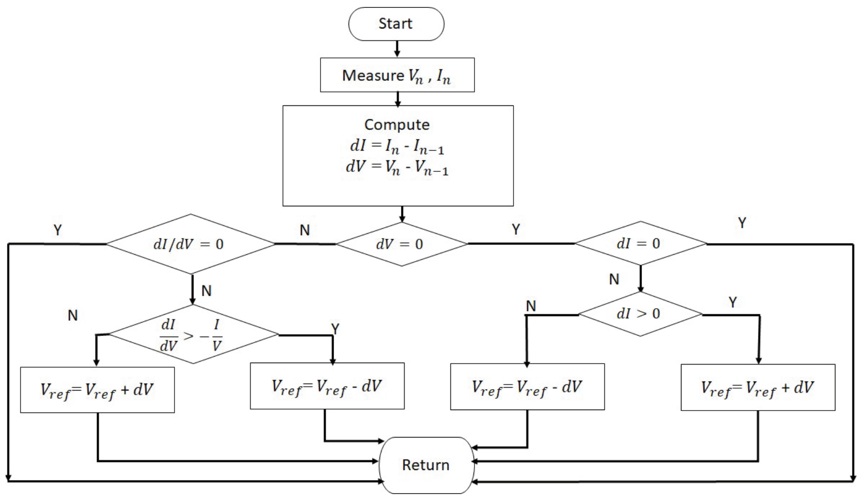

Figure 8 Incremental conductance MPPT-flow chart.

If a comparison among ANN based MPPT with digital MPP is to be done, then ANN enabled MPPT will show superior performance against all other technologies.

Fractional order MPPT based techniques, were also noticed in the literature where the advantage is that it has 5 operating point against 2 operating point in traditional MPPT system. However, the fractional order MPPT will suffer from stability problem.

5 Criteria to Select MPPT Technique

The review of various MPPT techniques and their variants indicate that the selection of a particular MPPT technique to develop a PV system for various applications is a challenge by itself. Therefore, the authors have carried out the review of around 68 variants of MPPT techniques and found that there appears to be perturb in choosing the best variant of MPPT for a particular PV system of application. The few important factors which need to be considered for the selection of MPPT algorithm are briefed in the proceeding sections.

5.1 Geographical Conditions

Geographical conditions or natural physical environment conditions are the main parameters which decides the economy of system. Since solar panel

Table 3 Detailed comparative review MPPT techniques

Reference	MPPT	Dependence on PV Array	TRUE MPPT	Analog/ Digital	Periodic Tuning	Speed of Convergence	Implementation Complexity	Sensors	Research Gaps
[18–30, 41, 46]	Hill-climbing P&O	N	Y	A & D	N	Differing	L	V & I	Drifting
[31–46]	Incremental conductance	N	Y	D	N	Differing	M	V & I	Convergence Time and Oscillations
[47–49]	Fractional Voc	Y	N	A & D	Y	M	L	V	Exact MPP can't be traced
[47–49]	Fractional Isc	Y	N	A & D	Yes	M	M	I	Exact MPP can't be traced
[48–52, 12]	Fuzzy logic control	Y	Y	D	Y	F	H	V	Lower Speed and Longer run time
[12, 49]	Neural Network	Y	Y	D	Y	F	H	V	High cost, Complex
[12, 48]	Ripple Co-relation Control	N	Y	A	N	F	L	V & I	Oscillations and Efficiency is based on simulation results
[12]	Current weep	Y	Y	D	Y	S	H	V & I	Rapid Change in climate
[12]	DC link capacitor droop control	N	N	A & D	N	M	L	V	NA
[12]	Load I or V maximization	N/A	N	A	N/A	F	L	N/A	NA
[12]	dP/dV or dP/dI feedback control	N	Y	D	N	F	M	V & I	NA
[12]	β method	N/A	N/A	N/A	N	F	H	V & I	NA
[12]	System oscillation method	Y	Y	A	N	N/A	L	V	NA
[12, 53]	Constant voltage tracker	Y	N	D	Y	M	L	V	NA
[12, 54]	Lookup table method	Y	Y	D	Y	F	M	V, I, T, Ir	NA
[12]	Online MPP search algorithm	N	Y	D	N	F	H	V & I	NA
[12, 55]	Array reconfiguration	Y	N	D	Y	S	H	V & I	NA
[12]	Linear current control	Y	N	D	Y	F	M	Ir	NA

Table 3 Continued

Reference	MPPT	Dependence on PV Array	TRUE MPPT	Analog/ Digital	Periodic Tuning	Speed of Convergence	Implementation Complexity	Sensors	Research Gaps
[56]	IMPP and VMPP computation	Y	Y	D	Y	N/A	M	Ir, T	NA
[12]	State based MPPT	Y	Y	A & D	Y	F	H	V & I	NA
[12]	OCC MPPT	Y	N	A & D	Y	F	M	I	NA
[12]	The Best Fixed Voltage (BFV) Algorithm	Y	N	A & D	Y	N/A	L	None	NA
[57]	LRCM	Y	N	D	N	N/A	H	V & I	NA
[12, 17–19, 53–68]	Slide control	N	Y	Dl	N	F	M	V & I	NA
[12, 60, 69]	Temperature method	Y	Y	D	Y	M	L	V & T	NA
[69, 70]	IC Based on PI	N	Y	D	N	F	M	V & I	NA
[12, 61, 71]	Three-point weight comparison	N	Y	D	N	L	L	V & I	NA
[12]	POS control	N	Y	D	N	N/A	L	I	NA
[12]	Biological swarm chasing MPPT	N	Y	D	N	Differing	H	V, I, T, Ir	NA
[12]	Variable inductor MPPT	N	Y	D	N	Differing	M	V & I	NA
[12]	INR method	N	Y	D	N	H	M	V &I	NA
[67, 72, 73]	Parasitic capacitances	N	Y	A	N	H	L	V & I	NA
[18, 74]	dP-P&O MPPT	N	Y	D	N	H	M	V & I	NA
[74]	Modified INC algorithm	N	Y	D	N	M	H	V & I	NA
[75]	Pilot cell	Y	N	A & D	Y	M	L	V & I	NA
[76]	Modified Perturb and Observe	N	Y	D	N	H	M	V & I	NA

[76, 77]	Estimate, Perturb and Perturb	N	Y		N	H	M	V & I	NA
[78]	Numerical method quadratic interpolation (QI)	N	Y	D	N	H	M	V & I	NA
[55, 79]	MPP locus characterization	N/A	Y	N/A	N/A	H	L	V & I	NA
[80]	CVT + INC CON (P&O) + VSS method	Y	Y	A & D	N	H	M	V	NA
[81]	Piecewise linear approximation with temperature compensated method	Y	Y	A & D	Y	H	L	V, I, T, Ir	NA
[16, 82]	Particle swarm optimization PSO algorithm	N	Y	D	N	H	L	V & I	NA
[82]	PSO-INC structure	N	Y	D	N	H	L	V & I	NA
[83]	Dual carrier chaos search algorithm	N	Y	D		H	M	V & I	NA
[84]	Algorithm for stimulated annealing (SA)	Y	Y	D	N	H	H	V & I	NA
[85]	VH-P&O MPPT algorithm	N	Y	D	N	M	M	V	NA
[49, 86]	Artificial neural network (ANN) based P&O MPPT	N	Y	A & D	N	H	M	V & I	NA
[87]	Ant colony algorithm	N	Y	D	N	H	M	V & I	NA
[88]	Variable DC link voltage algorithm	N	Y	D	N	M	M	V	NA

(*Continued*)

Table 3 Continued

Reference	MPPT	Dependence on PV Array	TRUE MPPT	Analog/ Digital	Periodic Tuning	Speed of Convergence	Implementation Complexity	Sensors	Research Gaps
[89]	Extremum seeking control method (ESC)	N	Y	B	N	F	M	V & I	NA
[90]	Gauss–Newton method	N	Yes		N	F	L	V & I	NA
[90]	Steepest-descent method	N	Yes	D	N	F	M	V & I	NA
[91]	Analytic method	Y	N	A & D	Y	M	H	V & I	NA
[92]	Azab method	Y	Y	D	Y	M	L	N/A	NA
[93]	Newton-like extremum seeking control method	N	Y	A	N	F	H	V	NA
[94]	Sinusoidal extremum seeking control method [94]	N	Y	A	Y	F	H	V & I	NA
[95]	low-power (<1 W)	Y	Y	A	N	F	L	V	NA
[96]	GA-optimized ANN	N	Y	D	Y	F	H	V, T and Ir	NA
[49]	Differential evolution (DE)	N	Y	D	N	F	L	V & I	Hardware prototype
[16]	Ripple correlation control	N	N	N/A	N	F	L	N/A	Oscillations and Efficiency is based on simulation results
[16]	Chaos search	N	Y	N/A	N	F	M	N/A	Hardware prototype
[16]	Simulated annealing	N	Y	N/A	N	Differing	L & M	N/A	Hardware prototype
[97]	P & 0 with MAF	N	Y	A & D	N	Differing	L	V & I	Rapid change in climatic conditions

Table 4 Legends for comparative review MPPT techniques

SL.NO	Legend	Meaning
1	Y	Yes
2	N	No
3	A & D	Analog and Digital
4	L	Low
5	V & I	Voltage and Current
6	D	Digital
7	A	Analog
8	F	Fast
9	L	Low
10	M	Medium
11	H	High
12	N/A	Not Applicable
13	V, I, T, Ir	Voltage, Current, Irradiance and Temperature

remain in direct contact with open environmental conditions causing heat, rise in temperature resulting in reduction of power generation and eventually life of the device. Some of these effects are visible and some are not. The effects such as corrosion, cracks on panels, surface browning of cells, open circuit, short circuit are all at the back of the panels. The effect of shadow of building, trees deposition of snow is not visible. Hence, there should be a mechanism to keep track on these environmental effects on the power generation from the PV systems naturally.

5.2 Complexity

The execution of the strategic MPPT algorithm during the operation of the PV system must be flaw less, faster to achieve the best performance and efficiency. Many of the variants of MPPT suffer from being complex, difficult to implement, speed of execution and many more issues. The MPPT algorithm or techniques must be simple, easy to implement, must have fast execution speed. The parameters of PV panel required to be measured in real time must be minimum in any of the MPPT Technique to achieve highest performance and efficiency from the PV system. If the number of parameters to be measured are less than the number of sensors require will be less resulting in low complexity, improved execution speed, ease of control. The control strategies employed in any PV system with MPPT technique must be simple irrespective of being direct or indirect method.

5.3 Cost of Implementation

The cost of system development needs to be low, and it depends upon the complexity of the MPPT algorithm developed for the purpose. The implementation can either in hardware or software. To achieve the expected level of execution speed MPPT technique needs to be implemented in hardware. The MPPT technique implementation in software is not preferred/recommended due to sequential execution of steps leading to slower execution speed. If the complexity of the developed MPPT is high, then it results in low execution speed, high implementation cost, system performance will be at stake.

5.4 Fill Factor of PV Cell/System

The most important factor that decides the PV cell efficiency is its fill factor. This factor is a measure of PV array quality. It is defined as the ratio of maximum power at MPP to the product of open circuit voltage and short circuit current of PV array.

Mathematically.

$$FF = \frac{P_{mp}}{V_{oc} \times I_{sc}} \tag{12}$$

Where:

P_{mp} is the PV system power at MPP under standard test conditions (STC).
V_{oc} is the PV system open circuit voltage.
I_{sc} is the PV system short circuit current.

5.5 Accuracy and Efficiency

The operation and execution of the PV system depends upon the accuracy of implementation of MPPT algorithm to fast-track MPP always under changing and differing climatic conditions. The power of the PV system at any instant and at MPP during day are given by;

$$P_n = V_n \times I_n \tag{13}$$

Where:

P_n is the PV system power at any instant of a time during day.
V_n is the PV system voltage at any instant of a time during day.
I_n is the PV system current at any instant of a time during day.

$$P_{mp} = V_{mp} \times I_{mp} \tag{14}$$

Where:

P_{mp} is the PV system power at MPP under standard test conditions (STC).
V_{mp} is the PV system voltage at MPP under standard test conditions (STC).
I_{mp} is the PV system current at MPP under standard test conditions (STC).

The efficiency of the solar PV system is defined as the ratio of power output at any instant of a time to the power output at MPP under standard test conditions and from Equations (13) & (14) efficiency is given by:

$$\eta_{PV} = \frac{P_n}{P_{mp}} \times 100 \tag{15}$$

6 Proposed MPPT Technique

The detailed literature review on MPPT techniques presented in earlier sections reveals that the MPPT algorithm plays an important role in harvesting maximum power from the PV system under varying climatic conditions. The selection of MPPT technique depends upon various factors as describer under Section 4. In order to develop an idealistic PV system that can deliver expected results must have an MPPT algorithm. The various MPPT variants when relooked with respect to the criteria of selection reveals that there needs to be deeper research to make them viable, efficient, reliable, cost effective. Some of them have remained as laboratory experimental techniques, some of them are application specific and so on. In order to make them to be more effective and simpler to implement, control the fundamental MPPT techniques must be reinvented to do better job with modifications. Especially keeping in mind, the criteria discussed in Section 4, the fundamental MPPT techniques have to be researched further. Therefore, the further research on the MPPT techniques must include:

i. P & O with Moving Average Filter to eliminate oscillations at MPP.
ii. I & C with Moving Average Filter to eliminate oscillations at MPP.
iii. Artificial intelligence-based Hybrid control strategies for PV system output control.

The basic algorithms like P & O and IC are simple, effective, and hence they can be modified to yield better results. Authors have already published a work on P & O with additional technique called Moving Average Filter (MAF) was implemented to remove oscillations at MPP [97]. Which has resulted in considerable amount of increase in efficiency and improved the performance of battery charger from solar source. Since IC also suffers from the oscillations at MPP, authors recommend using MAF.

A moving average is a technique to get the mid value calculated over a period of time. It's the unweighted mean of the preceding "n" values. But in science and engineering, the mean is usually taken as an equal amount of data on each side of a central value. This makes sure that change in the mean is aligned with the change in the data rather than being shifted in time. The mathematical equation for MAF becomes:

$$S_t = S_{t-1} + \alpha(P_t - S_{t-1}) \tag{16}$$

Where

P = Power
t = Time
S = Number of samples

7 Conclusion

This paper presents a comprehensive review on fundamental, and variants of maximum power point tracking (MPPT) techniques published by various researchers. The papers were selected in such a way that the review of variants of MPPT techniques are given a fair importance in adopting to applications. Many of the techniques remained as laboratory experimental techniques. The selection criteria detailed in Section 4 makes many of the MPPT variants to be not cost effective to select them to be used in charge controller design and development. Many of the variants of MPPT techniques are not suitable for real time applications due to the selection criteria. The paper also described the need for further research on modified fundamental MPPT techniques to offer cost effective solutions of charge controllers. The paper also emphasizes on the possible technique moving average filter (MAF) that could be applied to both P & O, Incremental conductance MPPT to resolve the issue of oscillations ate MPP. Looking at the requirements and selection criteria, the future development directions of MPPT variants to harvest maximum power from PV system are proposed. These variants definitely provide cost effective, efficient MPPT technique.

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