Photovoltaic MPPT techniques comparative review

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***Abstract*— This paper critically reviews some of the most recent maximum power point tracking (MPPT) techniques developed. It outlines the methods proposed in the papers published. The different techniques are grouped for comparison into the following groups: Direct and indirect power point tracking, artificial intelligence tracking techniques and other developed methods. The paper also critically summarises the findings in terms of dynamic performance in maximum power extraction.**

***Index Terms*—MPPT, PV, Grid Connected,**

I. Introduction

Photovoltaics (PV) have become an increasingly important solution for increasing global energy. The installed capacity of PV systems is 627 GW globally until 2019 and is easily implemented in remote locations [1]. However a major challenge is the non-linearity introduced in the PV system characteristics due to variations in environmental conditions. A major effect of these variations is partial shadings, which lead to having multiple peaks in the PV power curve, and detection of global peak becomes a challenging task [2].

Over the years, different techniques have been proposed and developed to ensure PVs operate at its maximum capacity through tracking the maximum possible operating power for reference input. These maximum power point tracking (MPPT) techniques vary in their approach to solving the tracking problem due to different factors such as implementation method, sensors used, existence of multiple peaks, cost and application.

- The implementation depends on the actual platform in which the Maximum Power Point (MPP) is determined. This is either in analogue circuitry or digital circuitry or a combination of both.
- Depending on the approach to MPPT, different sensors can be required. The variables that are usually sensed are PV current, PV voltage, PV insolation temperature and solar irradiance.
- Due to multiple peaks caused by variations in the solar conditions and partial shading some of the techniques find it difficult to locate the real global maxima of the PV power curve. Moreover those that are able to locate the MPP do not fully converge at the exact MPP.
- The cost of these techniques depends on the actual components required to implement them. This includes sensors, controller and associated circuits. Techniques are proposed to reduce the cost of implementation by reducing number of components needed.
- The techniques also vary according to the actual application of the PV system. An example is the speed of tracking the MPP. This is a key requirement for space satellites or orbital stations. However, this results in increasing the cost and implementation complexity. On the other hand, the application might not need a strict and fast system as in solar powered streetlight.

This paper reviews the most recent MPPT techniques proposed in literature since the year 2008 due to existence of other review paper for the period preceding [2]. Section 2 categorises the different MPPT techniques and compares between the different techniques falling under each category in terms of some of aspects aforementioned such as implementation method, number of sensors, suitability for varying weather conditions and speed of tracking. Section 3 presents a summative comparative analysis of the publications reviewed.

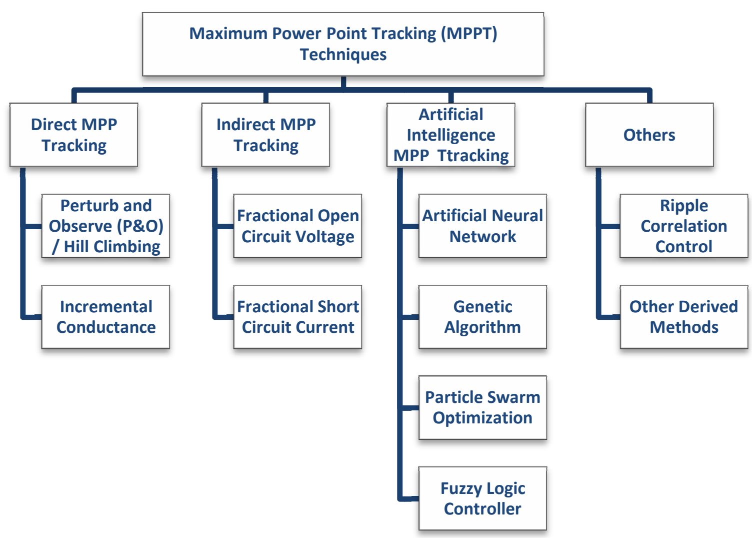

Figure 1. Maximum Power Point Tracking (MPPT) Techniques

II. MPPT TECHNIQUES

A. Perturb and Observe (P&O) / Hill Climbing

This method depends on the P-V power curves. The MPP is found by increasing/decreasing the power continuously and checking for when the MPP is reached from previous model data [3]. According to [4], P&O is the most implemented approach due to its simplicity and compatibility to different systems. However its limitations are slow performance in rapidly changing environmental conditions and oscillations around the maximum power point (MPP) due to its fixed perturbation size. In [5], distributed MPPT methods were used to increase efficiency of PV modules for non-uniform conditions. However, this approach is usually expensive to be implemented compared to a single controller approach. In [6], MPP was tracked by setting a non-convex feasibility operating region, which is governed by exogenous variables such as temperature and radiance. Analytical modelling of the PV system was used in [7] to control the voltage for MPP by reading the voltage with a scaling factor to vary the step size. In order to circumvent the drawback caused by fixed perturbation size with P&O, a fractional open circuit voltage has been added in [8] to detect changes in both temperature and irradiance. This also made the perturbation size to be adaptive relative to its distance from the maxima. In [9], the concept of sub-module distributed MPPT was exploited using micro-inverters and overpowered the effects of mismatching current from the PV cells. In [10], combined two loops have been proposed in order to adapt the perturbation size due to rapid change in the solar conditions. In [11], a scaling window technique (SWT) method was used to implement a model of the module's temperature, solar irradiance and curve angle. The model developed a scaling window around MPP feasible region and used P&O to determine the exact location of the MPP. The work in [12] used a modified P&O method to extract power from sub watt PV modules by introducing additional control cycles. The MPPT algorithm was added to the closed loop control scheme in [13]. It controls the voltage by giving the reference voltage for the output voltage control. The online parameter adjustment formula was used to adjust the step size when the power change is large to allow faster convergence [14]. In [15], a multilevel dc-link inverter was used for the first time to extract the maximum power from a distributed PV system under partial shading. Authors in [16] have explored the hill-climbing algorithm further to efficiently extract maximum power for low powered devices from a small PV solar cell. The developed algorithm tunes the system impedance for maximum power transfer efficiently under varying solar conditions. In [17], an MPPT technique has been proposed for faster convergence to global maximum power point (GMPP) under partial shading. This method ensures there are no blind spots in the search algorithm. Work in [18] aims to improve the P&O MPPT technique under varying environmental conditions using fractional short-circuit current (FSCC). The technique is able to detect change in irradiance without the need for a dedicated sensor. It eliminates the oscillation around MPP. The MPPT algorithm proposed in [19] aims to improve conventional P&O limitations by optimizing the inhomogeneous power source instantaneously. The power is continuously evaluated using P&O until the maxima is reached. In [20], through identifying the change caused by the input variables, a better directional decision is made in the system. A zero-oscillation adaptive step P&O method was developed to improve the transient and steady state. A proportional-integral (PI) controller was used to suppress oscillations around MPP in steady state. Table I shows a brief summary of different P&O MPPT approaches.

B. Incremental Conductance (INC)

This method depends on the slope of the power curve by establishing that at MPP the slope is zero, on the right side of the MPP its less than zero and greater than zero on the left. The voltage is varied depending on the position of the slope until the MPP is reached [2]. In [21], a modified incremental conductance (INC) MPPT algorithm was presented with variability of the step size for faster and accurate tracking. The proposed MPPT algorithm indicated an efficiency of more than 0.3% compared to fixed step size INC MPPT at 98.9% [21]. In [22], an enhanced incremental conductance MPPT has been proposed for mobile applications. The algorithm is able to eliminate degrading resistive changes due to its ability to distinguish between variations in dp/dv caused by duty cycle regulation and variations due to irradiance. In [23], the implementation of a fast and accurate incremental conductance (IC) algorithm has been proposed with an adaptive variable step size for MPPT. In [24], the MPP is achieved by comparing instantaneous conductance and incremental conductance ($\Delta I/\Delta V$) using a micro controller. This approach resulted in higher gain of 20 times the input along with 96.7% operational efficiency. In [25], a fractional-order calculus has been presented, which made possible to express the dynamic behaviour of a PV system in rapidly changing environmental conditions. A voltage detector was implemented from studies of sprott's system synchronization, which is used to control the converters duty cycle and trace voltage at which the system is operating at MPP with less than 2% error. In [26], authors used an interleaved SEPIC converter for Distributed MPPT (DMPPT) by compensating the mismatching current in series connected PV modules. A DMPPT setup has "n" power outputs from all PV modules in the string and one voltage input. The voltage is derived from the differential power compensation from mismatching currents in the PV modules and overall string power. In [27], an improved incremental conductance has been proposed for accurate Global MPP (GMPP) under partial shading conditions. This is called multifaceted duty cycle control which does not need additional control loop for the converter voltage.

C. Fractional Open Circuit Voltage

This technique exploits the linear relationship between open circuit voltage (V_{oc}) and voltage at maximum power (V_{mpp}) as follows:

$$V_{mpp} \approx k_0 . V_{oc} \quad (1)$$

Table I. Summary of different P&O MPPT approaches

Year	Paper	MPPT Controller	Remarks on methods proposed
2010	[4]	Digital	The perturbation amplitudes are varied in relation to the position of the MPP. Prior MPP knowledge of the PV array is required. The proposed algorithm gave 0.45% more energy than the conventional P&O algorithm.
2012	[5]	Digital/Analogue	A less expensive DMPPT under partial shading conditions using two separate control algorithms. In the first algorithm the MPP of each module is tracked while in the second, relative duty cycle is determined.
2011	[6]	Digital/Analogue	A one-cycle controlled inverter was implemented for the MPPT control loop. The multivariable perturbing approach increased the PV power extracted by 30% according to simulations compared to single perturbs.
2012	[7]	Digital	In this work an analytical approach was adapted to determine the step size. The result from simulation show an increased efficiency of 0.2% compared to conventional MPPT.
2013	[8]	Digital	Whenever the system detects deviation in the solar density or cell temperature, it would reset the initial searching point in accordance with the new physical conditions. It also adapts the perturbation size accordingly. The method increased the efficiency of the power extraction from the PV by 7.31%.
2013	[9]	Digital/Analogue	Overall cost-to-power ratio of 0.065 is achieved, which is very low and commercially viable.
2013	[10]	Digital/Analogue	Two separate control loops were implemented to regulate the current at the MPP, the paper proved the efficacy of the adaptive control algorithm and current perturbation algorithm.
2014	[11]	Digital/Analogue	Thin-film PV modules have multiple peaks of power due to it's bend/curve. The scaling window technique (SWT) was used to control the MPP. It is a combination of direct methods (such as P&O) and indirect methods (model based).
2012	[12]	Digital	A conventional P&O method was enhanced with two consecutive change cycles perturbed and unperturbed. To avoid large oscillation around V_{mpp}. It achieved overall power efficiency higher than 90.8% for a 40mw PV panel.
2013	[13]	Digital/Analogue	The MPPT algorithm was added to the closed loop control scheme to control the PV voltage input. It gives the reference voltage for output voltage control. The experiments supported the viability of the theory proposed in the paper.
2012	[14]	Digital	An online parameter adjustment formula allows the adjustment of the step size when the power change is large to allow faster convergence. This approach demonstrates stability and reduces steady state error.
2013	[15]	Digital/Analogue	A 7-inverter system with P&O method embedded along with a PI controller for each PV module was used for MPPT. It shows high efficiency in power extracted.
2015	[16]	Digital and analogue Circuitry	An improvement of the hill climbing algorithm is demonstrated to efficiently extract maximum power for low powered devices from a small PV solar cell. The efficiently developed algorithm tunes the system impedance for adaptive max power transfer under varying solar conditions. It has power conversion efficiency (PCE) of about 89%.
2014	[17]	Digital	A faster convergence to global maximum power point (GMPP) under partial shading was designed using a search method that ensures there are no blind spots.
2015	[18]	Digital electronics	Improves existing P&O MPPT technique under varying environmental conditions using fractional short-circuit current (FSCC). This gives the system a fast tracking capability.
2009	[19]	Digital	The algorithm compares the instantaneous power to the maximum power reference then P&O is used until the real global maxima is reached. The approach showed 33% increase in relative power produced.
2014	[20]	Digital Control	A zero-oscillation adaptive step P&O (ZA-P&O) method was developed to improve the transient and steady state response. Overall efficiency of the ZA-P&O MPPT is 99.3%.

where, k_0 is a constant of proportion, which is around 0.71 – 0.78 [2]. When k_0 is determined instantaneously from V_{oc}, V_{mpp} is computed as a reference voltage for the power converter. In [28], the change in voltage due to irradiance variation was detected. In [29], the Total Cross-tied (TCT) PV array arrangement was modified to mitigate max power drop due to partial shading variations. In [30], a ramp charged PV was used to mitigate power loss caused by inrush current, LC oscillations, and magnetic saturation. In [31], a V_{oc} MPPT is implemented with DC bus voltage control to extract optimum power from PV source. The PV operation point is raised from the MPP to avoid overloading of grid-side converter during harsh environmental conditions. In [32], the MPPT is achieved by implementing the incremental conductance approach in order to control the inverter. The MPPT proposed in [33] combines P&O and fractional open circuit voltage method to ensure the system operates at global peak using a feed forward control scheme for faster operation. In [34], an MPPT method using power hysteresis aimed was developed to reduce the reverse recovery losses. In [35], P&O method was adapted where the power generated by string of cells at sampled time 'n' is determined leading to power efficiency up to 93%. Checking the duty cycle and voltage to ensure save operation regions uses a limiting loop. In [36], a forth-order converter (FOBC) has been proposed for MPPT applications. At MPP the effective equivalent input impedance (R_{eq}) (duty ratio modulation) is equal to load line resistance at MPP (R_{mpp}). Hence R_{mpp} is used to determine the MPP. In [37], a one cycle approach was used to automatically adjust the inverter input power according to variations in temperature and irradiance. In [38 46], the duty cycle of the boost converter was used to control the input current using 2 degrees of freedom using the voltage and current from a standalone PV array. The duty cycle of the boost converter is used to control the input current in both charge and discharge mode. In [39], a bi-directional DC-DC converter in a standalone PV system has been proposed. The controller regulates the battery charge/discharge current command valve using the error between the DC-link and voltage and its command value. In [40], a MPPT has been proposed using quadratic polynomial by shifting the duty cycle for a PV array, which achieves fast convergence in 30 ms. In [41], an MPPT approach was proposed for low powered PV panels. The MPP is determined by nullifying the difference of the panel average power in two consecutive time intervals within a given time. In [42], a double capacitor interface (DCI) converter was used to track the MPP by varying the DC Link voltage of the inverter. In [43], an improved linear sinusoidal tracer (ILST) control algorithm has been. The MPPT control algorithm is based on variable DC-link voltage.

D. Fractional Short Circuit Current

This is similar to fractional open circuit voltage approach, however short circuit current I_{sc} is linearly related to I_{mpp} instead.

$$I_{mpp} \approx k_1.I_{sc} \tag{2}$$

where, k_1 is the proportionality constant from the PV short circuit current. However in both fractional methods the MPP is never truly reached, as it is an approximation so it would always be close to MPP. In [44], a hybrid technique has been proposed by combining a current base P&O algorithm and an adaptive step size. This produced a fast settling time of max power point and reduced oscillations at the MPP due to adaptive step size of duty ratio. In [45], the proposed DMPPT used the current and power curve to determine slow changes in atmospheric conditions. The paper exploited the fact that a number of converters can be controlled through an inductor current easily due to the dynamic model relating the current to rapid change. In [46], a digitally predictive current programmed finite state (FS) and a valley current control (VCC) were integrated into a current oriented P&O MPPT algorithm. In [47], a current compensation along with DMPPT under partial shading conditions has been proposed to achieve max power output. An overall intelligent array controller (IAC) was used to determine the overall MPPT of the PV array. The results show a 14.6% power improvement. However, it is more expensive when compared to bypass diode scheme [48].

E. Ripple Correlation Current (RCC)

The ripple output of the power caused by the switching action of a power converter imposes a ripple effect on the voltage and current of a PV array. This rippling effect is used to track the MPP. The time varying power ($\dot{p}$) at the MPP is zero. Hence, the time varying current ($\dot{I}$) or voltage (v) is used along with $\dot{p}$ to derive the power to maximum. The used equations are:

$$d(t) = -k_2 \int \dot{p}\dot{I}\, dt \tag{3}$$

Or $$d(t) = -k_2 \int \dot{p}v\, dt \tag{4}$$

where, k_2 is a constant, which controls the duty ratio.

To harvest the maximum power, a MPPT control was integrated into a passive ripple cancelling circuit (PRCC) designed in [49] to eliminate output power reduction effect in the PV system. The proposed control achieved a 7% higher efficiency compared to conventional system without RCC at 97.8%. In [50], a digital dithering has been exploited to develop a fast and highly accurate MPPT. The digital dithering RCC achieved an efficiency of 2% higher than an un-dithered P&O algorithm at 99.8%. The current based ripple orientation is used to extract the MPP by continuously defecting the phase difference in [51]. In current ripple based MPPT the hysteresis contour occurrence is used to find the power point, but by detecting the phase deviation the MPP can be achieved. This approach had a fast convergence time about 100ms compared to conventional RCC method with several seconds [52]. In [53], an MPP tracking using an extremum-seeking (ES) controller along with inverter ripple as current and power input through high pass filters has been implemented. The scheme showed efficiency above 99% and convergence time within 0.1s. The proposed method in [54] exploits the implementation of RCC in the discrete-time domain, thereby reducing it to a simple sampling problem for MPPT, with a tracking accuracy of 98.3% at an update rate of 1 kHz. In [55], RCC and model reference adaptive control have been used to handle MPPT under rapid changing environmental conditions. In [56], both ripple correlation control (RCC) and extremum seeking control are combined for MPPT in a PV system. The individual control is both good at improving transient and steady state performances. Hence, it is not surprising the results showed efficiency up to 99.4% when combined.

F. Artificial Neural Network (ANN)

This is an Artificial Intelligence (AI) computing approach to solve non-linear control problems. It is structured as a human neural network in 3 layers, which varies in number according to the complexity of the problem. They do not require previous data from the PV modules; however, they have to be trained beforehand with a range of inputs and outputs to compute the values of the weights. In [57], a hybrid controller of three layers was used to maximize the power management of the PV array in real-time. A feed-forward neural network with back-propagation algorithm was implemented in the first layer to determine the voltage required to operate at MPP with the temperature and irradiance as inputs. The simulations showed zero steady state error with better transient state compared to classical P&O [58]. In [59], a combination of an artificial neural network (ANN) along with a fuzzy logic controller has been proposed for partial shading conditions. The fuzzy logic controller uses the voltage required to operate at the global maximum power point (GMPP) with polar information and controls the converter, while the ANN is trained to determine the GMPP at various partial-shading conditions. The ANN proposed in [60] for MPPT was trained with feed-forward data to identify the MPP at various operational conditions. This ensures the PV system operates at the global MPP always. In [61], an extremely fast and accurate MPPT has been proposed for a quasi-Z-source inverter (qZSI) PV system using an adaptive neuro-fuzzy inference system (ANFIS). The ANFIS is trained initially to give out crisp voltage corresponding to the maximum power to be extracted at varying temperatures and irradiance.

G. Genetic algorithm (GA) and particle swarm optimization (PSO)

This is an artificial intelligence approach that mimics the evolution of living organisms. It uses objective function to determine the fitness of chromosomes as output to the system controlled. It goes through reproduction process by selecting parents from previous generations to crossover genes/attributes and mutates them. This process ends with a population of fit individuals after several generations

Table II. Other techniques summary

Year	Paper	Publication Aim and Motivation	Propose MPPT Solution Approach	Power extraction and Tracking Improvements (efficiency)
2008	**[78]**	To improve performance of the PV system at both high and low insolation levels	Combined the One-Cycle-Controlled (OCC) control technique and P&O MPPT for a multi-objective optimization (MOP) based design of a single stage inverter (SSI).	PV power extracted increased by more than 30% of the P&O MPPT
2011	**[79]**	To use a parabolic convex function for MPPT in a PV system	The downward parabolic function uses previous states of the duty cycle and the corresponding power to outline a parabolic curve for the MPPs.	Approach yielded Power efficiency between 97.8%- 99.4% in simulations
2012	**[80]**	Fast and accurate analogue implementation of existing MPPT technique	Wide-range current multipliers were used to detect the slope of the P-V curve for MPP operation.	Simulations produced Power efficiency of 88.97% and a tracking accuracy higher than 97.3%
2013	**[81]**	To eliminate the need for an MPPT in that it uses fixed firing angle and constant duty cycle for all irradiations	Combines multilevel boost converter (MBC) and line commutated inverter (LCI) to achieve MPPT from a PV array	Overall system efficiency is found to be 91% – 92%.
2014	**[82]**	To reduce the tracking time of the voltage search window (VWS) at MPP	The power operating triangle (POT), the global voltage step and voltage window were used to reduce the search window.	Design achieved power efficiency between 97.97% to 99.33% from simulations
2014	**[83]**	A thermograph-based approach to MPPT in a PV system under partial shading condition	A thermal camera was used to capture data from the environment, which is used to locate the global MPP using analytical approach.	Improvement on power extraction error of 3.9%
2015	**[84]**	Using isolated differential power processing (DPP) converters with little communication among the power converters to save cost	The sub-module voltage is multiplied by sub-module current received to get the sub-module maximum power at MPP	Power extraction efficiency of 99.12% with an improvement of 19.45% was achieved for larger MPP compared to conventional system without DPP approach
2016	**[85]**	To enhance MPPT efficiency and dynamic response	Switching ripple detection using a digital lock-in amplifier (LIA) to extract the amplitude of the oscillation ripple even in noisy conditions	Efficiency within 98% all the time and within 99% in steady state
2017	**[86]**	Maximum extraction of the power from PV panel and efficiently charging the storage battery	Using a hybrid “Cauchy and Gaussian sine cosine optimization algorithm for MPPT	Tracking efficiency is 97.86%
2019	**[87]**	To eliminate the overshoot during fast changes in solar irradiation and to minimize the steady-state fluctuation.	It uses the adaptive integral derivative sliding mode controller for MPP tracking.	Fast tracking and with almost zero oscillations
2019	**[88]**	Develop a method to detect global maximum power point	It includes Fibonacci based approach to decrease the searching range	Better efficiency under non-uniform radiation
2020	**[89]**	To design a fast and accurate MPPT	It uses ant colony optimisation to extract MPP	It yielded higher efficiency. Faster than conventional Technique

(iteration) based on the objective function used. A modified particle swarm optimization (PSO) for MPPT aimed at reducing MPP steady state oscillations to zero is presented in [62]. In [63], a combination of fuzzy logic controller (FLC) and modified queen-bee genetic algorithm has been proposed. In [64], a modified PSO for MPPT in an unknown PV model was proposed. The temperature effect has been modelled in to the PV system. The results showed less than 0.02% error at maximum power point extraction. In [65], the GA and P&O algorithm have been combined. In [66], a PSO algorithm along with conventional single stage (CSS) tracking using only a single sensor has been proposed. In [67], a hybrid evolutionary approach has been proposed by combining differential evolutionary (DE) algorithm and PSO. The PV terminal voltage is set as a vector for the search space of the algorithm for N particles hired. In [68], an MPPT for a decentralized PV system based on collective behaviours of biological swarm (Bio-MPPT) has been proposed. In [69], a firefly algorithm for PV system MPPT under partially shaded conditions was presented. Without any prior knowledge of the PV system, the new method was able to track the global MPP fast and increases the efficiency to 99.5%. A deterministic particle swarm optimization algorithm was designed for PV system MPPT in [70].

H. Fuzzy Logic Controller (FLC)

These are microcontroller based control techniques that depend on a decision-making knowledge base. It is fundamentally staged into: Fuzzification, Inference Engine, Rule Base and De-Fuzzification [2]. Due to speed limitations of P&O, an adaptive approach using a Takagi-Sugeno fuzzy along with incremental conductance was proposed by [71]. However, given the complexity of the design, efficiency is less than P&O approach. In [72], a fuzzy controller was proposed to extract MPP from PV system under partial shading. The approach achieves a fast convergence speed with smaller oscillations with multiple local peaks. In [73], both conventional P&O and fuzzy logic controller (FLC) were combined, which enables the implementation of an adaptive tracking for faster convergences to MPP. Results show fast and highly accurate tracking. To achieve a robust and efficient stand alone solar PV system, a unified T-S fuzzy controller, which uses both maximum power voltage method and direct maximum power (DMP) fuzzy controls was proposed in [74]. In [75], a stand-alone solar system with dual

Table III. Comparative analysis of reviewed MPPT techniques dynamic performance.

MPPT Technique	Converge to MPP?	Power extraction efficiency	Tracking Speed	Steady State Oscillation
Perturb and Observe / Hill-Climbing	**Yes**	**Moderately Low**	**Slow**	**Yes**
		High	**Fast**	**No**
Incremental Conductance	**Yes**	**Moderately Low**	**Slow**	**Yes**
		High	**Fast**	**No**
Fractional Open circuit Voltage	**No** Due to approximation in formula	**Moderately Low**	**Slow**	**Yes**
		High	**Fast**	**No**
Fractional Short circuit Current	**No** Due to approximation in formula	**Moderately Low**	**Slow**	**Yes**
		High	**Fast**	**No**
Ripple correlation Current	**Yes**	**Moderately Low**	**Slow**	**Yes**
		High	**Fast**	**No**
Fuzzy Logic Controllers	**Yes**	**Moderately Low**	**Slow**	**Yes**
		High	**Fast**	**No**
Genetic Algorithm and Particle Swarm Optimization	**Yes**	**Moderately Low**	**Slow**	**Yes**
		High	**Fast**	**No**
Artificial Neural Network	**Yes**	**Moderately Low**	**Slow**	**Yes**
		High	**Fast**	**No**

MPPT controllers has been presented. The first MPPT is a sun tracker fixed to the panel, while the second is an MPPT using a P&O based fuzzy logic controller (FLC-MPPT). This allows for the exploitation of a variable step size for conveying the MPP with lesser or no oscillations. In [76], a T-S fuzzy model based controller was designed for a stand-alone solar PV system to operate at MPP. An observer fuzzy was developed for state feedback in partial state measurements. In [77], a method of improving the conventional hill climbing MPPT using fuzzy logic controller has been proposed. Table II presents other MPPT techniques, which are not classified under any of the previous techniques.

III. CRITICAL COMPARATIVE ANALYSIS

Table III shows a comparative analysis of reviewed MPPT techniques dynamic performance. These techniques vary in complexity, sensors required, convergence speed, cost, range of effectiveness, implementation hardware, and popularity. It has been confirmed that the application is the most dominant factor in selecting the suitable MPPT technique. For example, in PV system for street lighting, fractional open circuit voltage or short circuit current is the most suitable MPPT technique as the accuracy and efficiency are not critical. However, for aerospace satellite applications, advance techniques are essential such as incremental conductance, fuzzy logic, and genetic/artificial MPPT techniques. In addition, in recent years, more research has been focused on combined or improved techniques. These techniques use an existing approach with a more sophisticated control algorithm in order to improve performance, particularly under partially shaded or fast-changing conditions. Maximum power point tracking in PV systems continues to be a fast-growing area of research and development and many innovative approaches continue to be proposed annually. This will continue to result in refinement and improvement in maximum power point tracking techniques, leading to wider scale commercial implementation.

IV. CONCLUSION

The paper has derived a summary of the MPPT techniques proposed in the papers reviewed. This information was used to compare similar approach to identify any improvement in the techniques proposed. The paper outlines the dynamic performance improved by the MPPT techniques. By using this study an individual can select a technique according to a specific application.

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