Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

A Comprehensive Review on Maximum Power Point Tracking Techniques and Optimization Algorithms in Solar PV based Optimal Energy System

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Abstract: In order to maximize PV efficiency under partial shading conditions (PSCs), it is necessary to maximize the power extracted from the PV system. To make PV panels more cost-effective and efficient, their maximum power point (MPP) must be determined. Tracking maximum power points under PSCs requires a maximum power point tracking (MPPT) technique. In this paper, s review of MPPT techniques is presented based on existing research on hardware design methodologies as well as MPPT techniques found in the literature. MPPT algorithms come in a variety of types, including classical, intelligent, and optimization algorithms. P-V curves display a single peak during uniform insolation, making classical methods more effective. In contrast, PSCs exhibit multiple peaks, the largest of which corresponds to the global maximum power phase (GMPP), the smaller one to the local maximum power phase. GMPP differs from other local-based LMPPs by introducing intelligent and optimization techniques. There are strengths and weaknesses to every MPPT method, but streamlined MPPT combines several factors, such as sensors needed, hardware implementation, PSC tracking, cost, and tracking speed.
Keywords: MPPT techniques, global maximum power phase, Photo voltaic (PV), voltage control.

1. Introduction

Due to their eco-friendly nature and lack of fuel costs, renewable energy sources are more appealing than conventional energy sources. Solar power, wind power, tides, and biomass can all be used as fuels directly from the environment [1]. There will be an end to the use of fossil fuels in the future since they are going to deplete. A large amount of these sources can also degrade the environment if they are utilized extensively [2]. In a country where decentralized necessities are necessary, renewable energy sources are becoming increasingly important. Since solar energy-based photovoltaic (PV) energy is omnipresent, cost-free, non-hazardous, and low-maintenance, it is an attractive alternative to conventional energy sources [3]. By 2022, the Government of India (GoI) aims to generate 450 GW of renewable energy as a result of these merits. The Ministry of New and Renewable Energy (MNRE) estimates that India will install 175GW of renewable energy by 2019, which includes 100GW of solar energy, 60GW of wind energy, 9GW of biomass fuel, and 5GW of small hydroelectric power [4]. Solar power systems can generate pollution-free electricity from daylight in the residential, social insurance, horticulture, training, and health sectors. At this cutting-edge moment, PV innovations can radically alter how we charge our devices. Unfortunately, the total amount of energy that can be extracted from the sun is still not reached due to technical constraints. Carbon emissions are reduced as a result of mitigating these drawbacks to extract more and more clean solar energy. The continuous operation of a particular application can also be achieved with stand-alone hybrid solar-wind systems [5]. This paper presents a novel control approach that deals with hierarchical distributed model predictive control, with a focus on the control of wind/solar systems that are stand-alone.

A solar cell's efficiency also determines how much power can be extracted from it. It is estimated that PV cells of the type crystalline silicon modules operate at a rate of 13-15% efficiency [6]. According to the study, 16–22% of the efficiency comes from non-standard, high-quality designs. The highest averages of solar module efficiency were found for copper gallium indium diselenide and cadmium telluride, with 17.8% and 16.5%, respectively. [7]. In over 21.8% of commercial modules, silicon interdigitated back-contact technology is effective. The weather conditions and system conditions of PV systems can, however, cause additional losses if they are prominent enough.

By ignoring these losses in the design of PV systems, efficiency will decrease in the long run. An analysis of 71 Japanese PV systems by the University of Tokyo found a loss percentage of 25%. Due to the dynamic nature of solar insolation, modules and arrays harvest relatively little solar energy. By adjusting two parameters in real-time, maximum power was harnessed [8]. In order to maximize power, switching frequency and duty cycle (D) must be balanced. There is a need to increase the power generated by the PV panel in some way since it generates a small amount of power. This will be accomplished by the DC–DC converter. PV energy is used as input in this converter, and external loads or storage supplies are output. The converters can also convert an uncontrolled DC source into one that is regulated. In [9], the effects of partial shading and parasitic capacitance were reduced in a new high-gain converter. In the schematic diagram below, an MPPT controller is shown for a PV system.

Solar photovoltaic arrays, power converters, MPPT control algorithm blocks, and loads are among the components of this framework. PV modules usually deliver most of their yield power at the maximum power point (MPP) of solar arrays under conditions of uniform irradiance. A partial shading condition (PSC) shows a number of local maximum power points (LMPPs) on a module's P–V curve. It is common for PV modules to be equipped with bypass diodes in order to reduce hotspots [10]. By arranging diodes in this manner, different LMPPs are generated, and the controller must simultaneously monitor the global MPP (GMPP) in spite of these LMPPs. For hot-spot mitigation, a forward-looking IR i5 thermal camera was used in combination with MOSFETs. The hot-spot effect causes those diodes to lose a substantial amount of power. A traditional MPPT cannot distinguish the GMPP on the P-V curve due to the different LMPPs [11]. In order to achieve this highest level of productivity, PV frameworks incorporate some of the best MPPT algorithms. It has been difficult to propose strategies or techniques to mitigate these limitations, especially in PSCs.

In simulated particle swarms, in comparison with particle swarm optimization (PSO), GMPP tracking algorithms are more effective [12]. The MPP was predicted very quickly using a natural cubic-spline model by using an iterative search process based on the proposed algorithm. From the perspective of design, present an advanced MPPT sensor based on temperature. A PV panel's surface temperature directly influences module voltage, so this method is used [13]. A few of the methods discussed in the paper include three-point weight comparisons, parasitic comparisons, intelligent techniques, and optimized techniques. There is, however, an emphasis on algorithm tracking in this paper, which mainly compares five parameters. On the basis of tracking type, a comparison was made [14]. Block diagram of MPPT controller for solar PV is depicted in Figure 1.

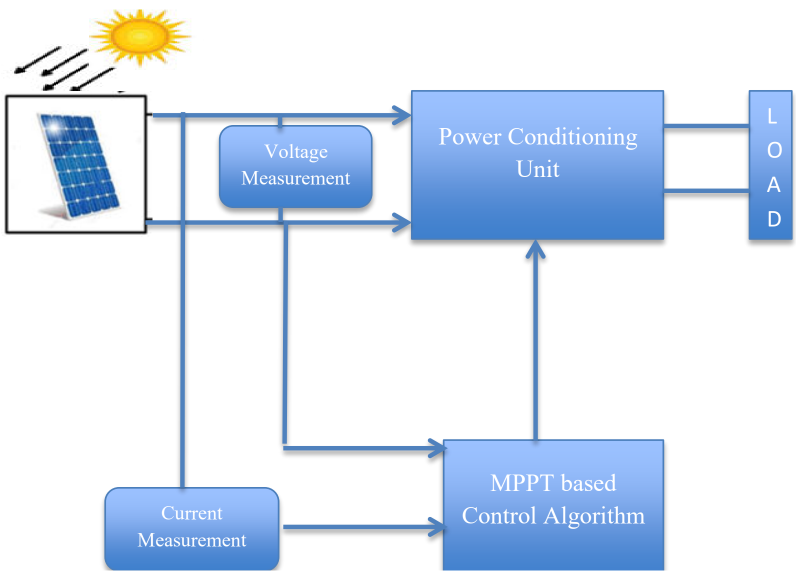

Figure: 1 Block diagram of MPPT controller for solar PV [17]

There is an assessment of almost 50 techniques, evaluating their merits and demerits. An analysis of different MPPTs based on mathematical calculations and metaheuristics. The right MPPT should be selected for the application in the design process. A few MPP parameters that have been reported in the literature are listed below [15]. There are, however, no real-time implementation procedures shown in the above review papers. As this paper discusses various platforms and the tracking speeds and efficiency of the particular technique as applied by different authors, it provides hardware information about the technique. As well as the parameters of these techniques and their flowcharts, we also explain how MPPT algorithm implementation works [16].

In this paper, MPPT techniques are classified and reviewed based on their performance. Comparisons are primarily made based on parameters including control strategies, especially MPPT, microcontrollers, and sensors that they used in their applications. Providing ongoing innovations in MPPT techniques is our fundamental goal.

Section 2 provides an overview of various PV tracking methods, emphasizing their distinctive features and applicability under different environmental conditions. Section 3, categorizes MPPT techniques based on their underlying principles, Classical based MPPT Techniques, discusses methods relying on maintaining constant voltages for MPPT, ARV MPPT technique and its operational mechanism. Section 4 evaluates the performance of Perturb and Observe method with different optimization MPPT strategies. Further MPPT for Optimal Parameter: Discusses MPPT techniques aimed at achieving optimal system parameters. The conclusion summarizes key findings from the review and outlines potential avenues for future research and development in MPPT techniques and optimization algorithms for solar PV systems.

2. MPP Tracking Methods and Their Features

MPP tracking under PSCs is one of the most challenging tasks for MPPT Controllers. When light is not evenly distributed across an array of solar panels, partial shading occurs [18]. There are many reasons why changing irradiation occurs, including clouds, bird droppings, and building shadows. Array size is primarily determined by the amount of power required by the application. All panels produce the same output current when the same amount of insolation strikes them under uniform irradiance. Power loss occurs when at least one array is shaded during PSCs, resulting in less current being generated. Because solar insolation, temperature, and shading affect processes, they can be quite complex. MPP also varies continuously as a result of these parameters.

The lamination of a solar module can be ruptured by variable solar insolation on one cell when it consists of many solar cells connected in series. Bypass diodes are connected antiparallel to the cells in order to reduce the effect of this operating condition. Due to this, there will be no significant voltage differences in reverse-current solar cells. 15–20 cells in this configuration require at least one antiparallel diode.

When PV modules are shaded or if voltage and power levels are inadequate, these diodes facilitate current flow through the modules [19]. Each row has a bypass diode and an end diode, and the panel contains four modules in three rows. KYOCERA uses KC200GT modules, which are multi-crystalline and highly efficient. Thus, shaded panels use anti-parallel diodes (D_1) to bypass them, thus minimizing hot-spots (abnormally high temperatures in a specific area). A blocking diode (D_2) also blocks surge penetration into the system in the same way. Due to shading, simulation results indicate multiple peaks, i.e. different MPPs. Two of these MPPs are GMPPs and the remaining three are LMPPs for the entire array. Their presence in the shaded panel's *I-V* and *P-V* curves indicates their presence. In both uniform and non-uniform conditions, they accounted for insolation and temperature [20]. As output power *(P)* depends on output voltage *(V)*, its derivative is equal to its derivative in MPP.

3. Techniques for MPPT

PV Depending on a variety of factors such as wind speed, shading, and solar insolation angle, cells and modules generate power differently. This means that maximum power cannot always be generated at all electrical loads. A MPPT technique consists of a controller that extracts the maximum amount of power from a PV configuration. PV modules can be run on maximum power using a variety of MPPT techniques [21]. It depends on the technique's ability to track rapidly changing weather conditions, though, to ensure its efficiency. Based on their tracking nature, these techniques are classified in PSCs. Using the following classification system, all classified techniques are discussed, as shown in Figure 2.

- Classical MPPT.
- Intelligence MPPT.
- Optimization MPPT.

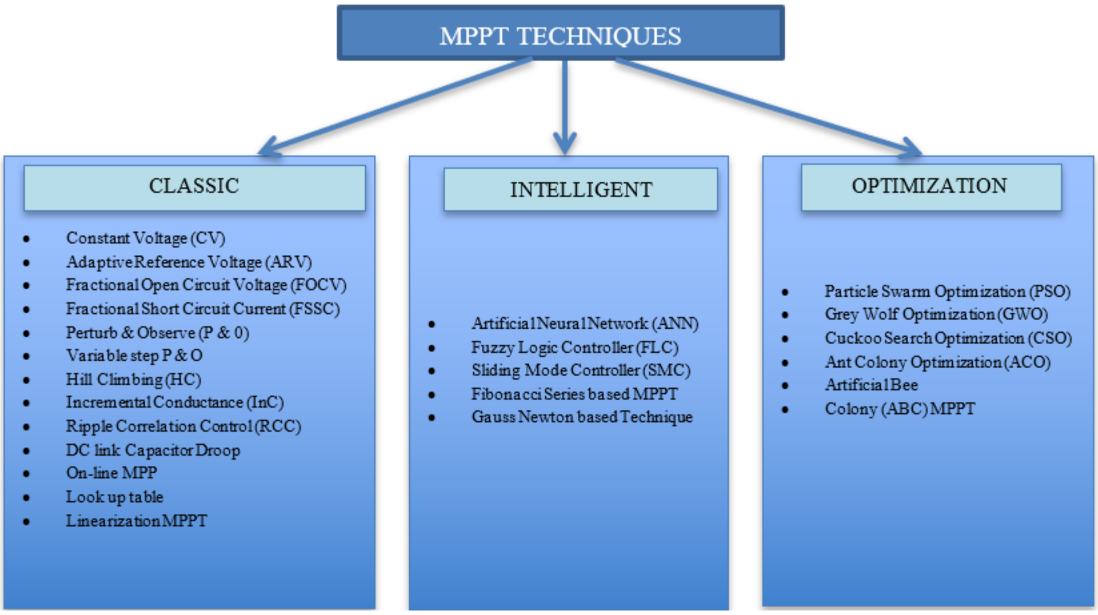

Figure: 2 MPPT Techniques Classification

3.1 Techniques of Tracking Classification

Using classical MPPT, incremental conductance is used, fractional open circuit voltages and fractional short circuit currents are applied [22]. Also, hill climbing is used, disturbance and observation are used, steps are variable, voltages are constant, reference voltages are adaptive, DC-link capacitor drop control is employed, ripple correlation control is employed, look-up tables are employed, linearization is implemented, and MPP is conducted online. The algorithms used in these techniques are less complex, so they can be implemented more easily. Due to the fact that each GMPP is generated by a single PV, PVs are most efficient under uniform irradiation conditions [23]. However, these algorithms oscillate rapidly around the MPP, and this causes power loss. As well as neglecting the effects of (PSCs), these classical strategies fail to track actual MPPs.

Aside from fuzzy logic controllers (FLCs), artificial neural networks (ANNs), sliding mode controllers (SMCs), and fibonacci series, artificial intelligence-based methods are also used. These techniques are designed to cope with weather changes that are highly dynamic with high accuracy. It is so efficient and fast to track them, as well as how efficient they are at tracking. For the system to be trained beforehand, these methods require a huge amount of data processing and a complex control circuit. An interesting aspect of FLC is that it does not require system knowledge in order to implement MPPT [24]. A large amount of data is needed for ANNs to become more accurate (for training). Inputs include dynamic irradiation and temperature, which are stored as data sets. Tracking speeds at higher rates are made easier with SMC's advanced technology. In addition to Fibonacci and Gauss-Newton, both methods track MPP instantaneously by updating the search range. There are several optimization-based methods to choose from, including PSO, gray wolf optimization (GWO), cuckoo search-based computational strategy (CS), and ant colony optimization (ACO). There is a tendency for these methods to search for true MPP under dynamic environmental conditions as well. With the PSO method, steady-state oscillations are reduced while tracking is faster. A low-cost microcontroller further simplifies the implementation of these techniques. Like a wolf searching for prey continuously, GWO can find optimum points of work at an accelerated rate. The GWO is the best evolutionary technique that is independent of the knowledge of the system. MPPT based on CS is a bio-inspired algorithm that applies levy flight methodology to obtain optimum MPP points based on the nature of brood parasitism [25]. Evolutionary-based algorithm implementation is also employed by ACO and ABC, two emerging methodologies. Temperature and voltage sensors are not needed as much in these techniques as in classical ones.

3.2 Classical based MPPT Techniques

3.2.1 Techniques for MPPT that are based on constant voltages (CVs)

It would be ideal if the MPPT could control PV voltages and compare them with RV equivalents to V MPPs to make PV power operate near MPPs. Insolation and temperature are not considered in this CV technique because it is used for uniform irradiation conditions. By using CV techniques, MPP points are estimated that are quite far from the real MPP points. It is important to consider other topographical positions, as well as the working point, when determining the best RV for decreasing error [26]. The CV MPPT technique can be illustrated schematically in the following block diagram. With only one sensor, namely a voltage measurement sensor, it is possible to calculate the converter duty ratio from the PV module voltage V_{PV}. However, the method demonstrates limited precision despite its simplicity, speed, and ease of implementation. At regular intervals, the V OC must be measured using this technique. As well as this, the technique is applicable to conditions with less temperature variation. The Texas Instruments TL494 IN was used for implementing this technique in hardware. Implemented a novel MPPT algorithm using CV constant current DC-DC converters. In order to test how effective this MPPT is, OutBack Power Systems' FM80-150V_{DC} is used as shown in Figure 3.

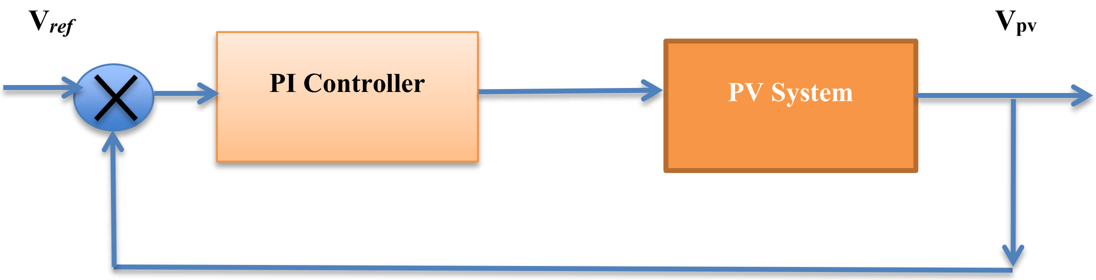

Figure: 3*The CV MPPT technique is shown in the diagram* [27]

3.2.2 ARV MPPT technique

As an extension of CV technology, ARV-based MPPT systems have the advantage of being flexible to dynamic climatic conditions. Temperature and radiation levels are deliberate factors in adjusting RVs for MPPT. Here is a schematic diagram showing how ARV MPPT works. An off-line truth table is used to compare RVs of radiation at a given temperature [28]. In order to compensate for the error between the reference voltage and the assessed PV voltage, the proportional-integral controller generates a duty cycle proportional to the fitted converter as shown in Figure 4.

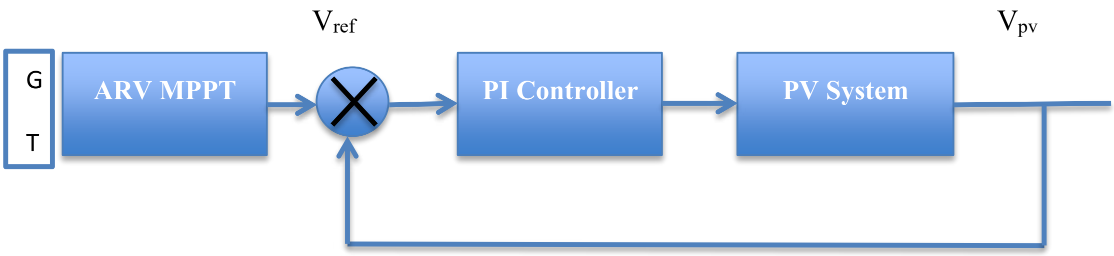

Figure 4:*The ARV MPPT technique block diagram* [29]

It is not necessary to interrupt the PV module transiently in the proposed ARV procedure. Two additional sensors are used in comparison to a traditional CV system and one extra sensor is used in comparison to a P&O system to estimate climatic conditions based on temperature (T) and irradiance (G). As a result, this system is a bit more expensive than the traditional CV system. This factor was compensated for, however, by an increase in efficiency.

This method is comparable to the CV method on the basis of simulations [30]. In constant radiation (nearly 1000 W/m^2), the efficiencies were almost identical for both techniques >99.7%. In variable radiation conditions, CV's efficiency drops to 98.3%, whereas ARV maintains the same efficiency regardless of variable radiation conditions.

3.2.3 MPPT for fractional short circuit currents

A simple algorithm appears to be used to track MPP in this off-line method, also called MPP tracking procedures [31]. When short circuit current I SC is near MPP AND MPP, current can occur at both MPP AND MPP under certain random environmental conditions. It can be used to calculate MPP's current.

$$I_{MPP} = K_I * I_{SC} \qquad (1)$$

In this case, factor K_I varies between 0.76 and 0.8. Figure 5 shows how this technique is implemented.

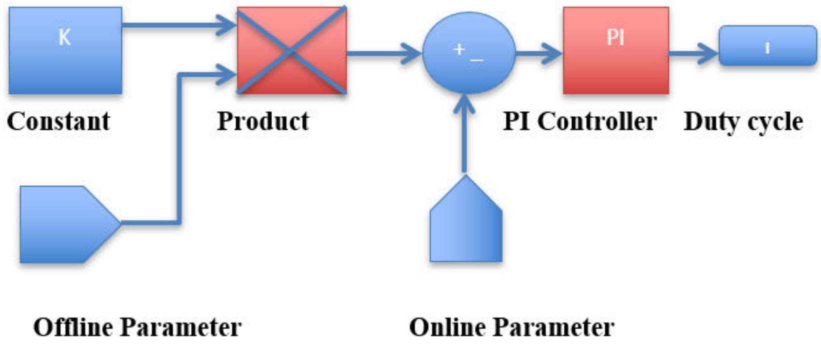

Figure: 5 An example of an off-line MPPT method is shown in the block diagram [32]

High voltage and low current applications are appropriate for this technique. Due to the conditions stated above, we can conclude that this approach is only an approximation, so it is not valid for definite MPPs. Additionally, there are irregular ISC estimations throughout the whole day, which results in power loss. There is a hybrid method described in this article that combines the FSCC method and the P&O method. A tracking efficiency of 92.4 percent is achieved under normal weather conditions and 90.92% is achieved under dynamic weather conditions [34]. DS1104 embedded cards can now be directly connected to Simulink without having to use the irradiation sensor to implement this method.

3.2.4 Fractional open circuit voltages Method

This method, which is called FOCV MPPT, considers the open circuit voltage V_{OC} as an off-line parameter [35]. This is the relationship between (V_{MMP}) and (V_{oc}) as shown in (2).

$$V_{MPP} = K_V * V_{OC} \qquad (2)$$

Using the data-sheet provided by the manufacturer, it is possible to estimate K V to be somewhere between 0.7-0.8. Similar to the above situation, this strategy relies on estimations as well. Low voltage, high current applications are the best candidates since it relies primarily on the rule of approximation. This method is feasible for uniform irradiation conditions since it relies on estimation. This method has the disadvantage of irregular V OC measurement, resulting in unnecessary power consumption. Using a closed-loop controller, V MPP is approximated before achieving the desired voltage. In fact, the PV array does not work at the MPP due to the fact that the connection is just an estimation. Among other things have improved FOCV techniques called smart timers that are capable of tracking MPP also in PSCs [36]. By estimating the frequency of the sample, this smart timer keeps the circuit running. It is studied whether this technique is more effective than conventional FOCV by implementing it on hardware and comparing its effectiveness. Low power consumption applications make this technique suitable for a wider range of applications. A smart timer NSL-19M51, a LTC1440 Estimator, and the DG412 Estimator are used to sample and store the values.

3.2.5 Hill Climbing (HC) Techniques

In this method, the optimum point is found using a mathematical algorithm. Basically, this method works by guessing an initial point, most likely an arbitrary one, to find the solution. Next, incremental changes are made to the solution obtained in order to reach the best solution. Should the obtained solution yield a new optimum, the search will be repeated with the same increments [37]. Until no further improvements can be

made, the solution will be improved in this way. Each of these strategies has the same basic way of working and is the same for the rest, but the calculations/algorithms are different. There are usually two techniques in this category, namely P & O and I & C. In an attempt to reach the optimal working point faster, [38] studied the initial stages of perturbation. Analogue-to-digital converters were implemented on microcontrollers.
HC and P & O differ primarily in their perturbation variables. As a control variable, voltage is used by P & O, whereas power–voltage curve slope is used by InC. In the HC technique, duty ratio (D) serves as the perturbation variable. A microcontroller can use this HC method, which is the most convenient and simplest method. Neither irradiation nor temperature sensors, nor solar PV knowledge are required for the system.

3.2.6 Perturb &Observe MPPT

Many authors use P&O in practice, and it is considered one of the most commonly used MPPT techniques. In this technique, the MPP is sought and followed by trial and error. The power and voltage can be calculated by comparing the positions of two points on a P-V curve. Depending on where the MPP is located (to the left or right of the P–V curve), the voltage is updated accordingly [39]. This P&O technique is shown as a block diagram in Figure 6.

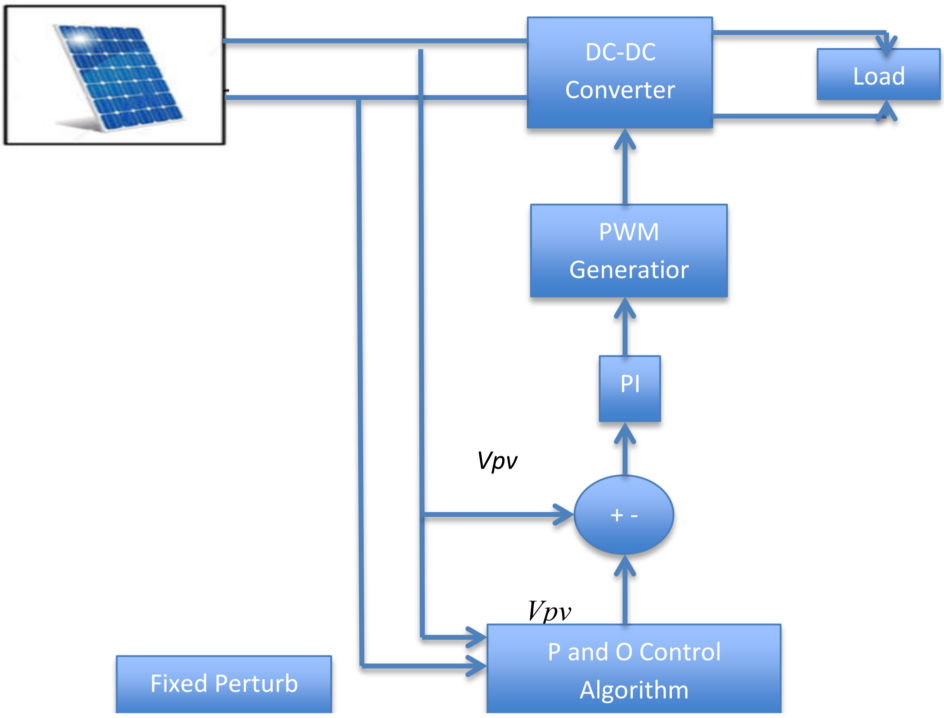

Figure: 6 Fixed perturbation steps for conventional P&O

The PV cell power *(dP)* is checked for a change based on this strategy, then the PV cell voltage *(dV)* is checked for a change as well [40]. *D* appears perturbed based on the obtained values. Depicted in Figure 6. By analyzing P-V curve data, one can determine how the operating point actually moves. *(dP/dV)* indicates where the actual point lies based on the curve; if it is negative, it appears on the right half; otherwise, it appears on the left half. In addition, *(dP/dV)* is equal to zero until the process is complete.

3.2.6.1 P&O method with variable step size

A major improvement over conventional P&O can be seen in this method. “Toward the beginning of the calculation, the RV (V_{REF}) is set at about 0.8*V_{VOC}, where V_{OC} is the open-circuit voltage of the array”. In MPP search, the voltage searches drive the operating point in the direction of the MPP whereas the voltage searches determine the accuracy of the MPP [41].
The first step in tracking the peak is to apply a modified/variable P&O calculation. Tracking the GMPP increases the likelihood of partial shading. Through this technique, GMPP is not followed up in a way that would be conventional in P&O. We can follow the true MPP with the proposed algorithm with a shorter effort. Jiang and colleagues developed a two-component MPPT algorithm that includes step size and perturbation frequency based on load-current. The LCASF MPPT and conventional P&O were also compared.

Both algorithms are nearly equal in response time and efficiency with small perturbations in step size (e.g. 10%). However, when perturbations are high (e.g. 5%), the LCASF algorithm is more efficient than conventional P&O, achieving 91% efficiency. The LCASF gives better results by utilizing hardware that is less costly and smaller, which means faster tracking and higher efficiency [42]. A P&O that is adaptive was developed by improving the factors that cause loss in classical P&Os. The dsPIC30F2010 microcontroller was used to implement control signals for a forward converter.

PV Using an FM forward converter operating at 40 kHz, modules are used in this system. A PV panel's voltage and current are measured by Hall sensors LV-25 and LA100. The efficiency of this conventional system has been increased by 95% as a result of this advancement.

3.3 On-line MPP search algorithm

In MPP search-identification calculations, MPPT blocks contain MPP identifiers and trackers. Calculation's primary objective is to compare the reference and current greatest powers. These errors are referred to as the most extreme power errors. In order for a PV system to perform at its full potential, the maximum power error needs to be zero or close to zero. In the case of smaller loads, however, this method cannot estimate the MPP accurately. PV modules generate extra current that can be fed into an extra load to overcome this load deficiency. This method updates the previous MPP whenever atmospheric conditions change. Texas TMS320C240 DSP control board was used to simulate this technique using a boost current converter. The DSPs are interfaced with Labview using an AT-MIO-16E-10 data acquisition board from National Instruments.

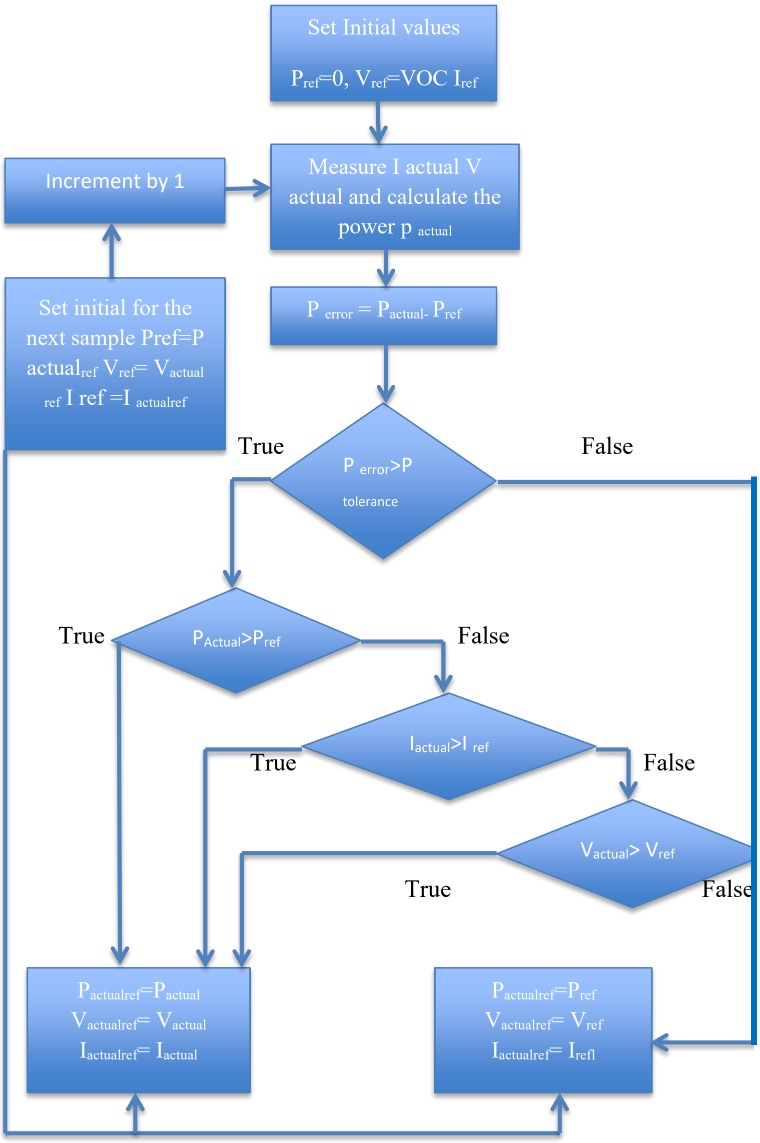

Figure: 7*Algorithm for on-line search*

3.4 Linearization-based MPPT

Solar PV and PE converters have non-linear characteristics, which require some conversion of this non-linearity. Linearization is performed using both the I-V and P-V curves to determine MPP. Between the intersecting points of two curves, f(P, I) = 0 easily distinguishes the PV system's power curve [43]. As a result, dp/Di = 0 represents the maximum power curve. The I-V and P-V curves can be examined and recognized using simple circuits. It is only possible to apply linear control strategies to nonlinear circuits after they have been converted into linear circuits. A small-signal analysis was performed on the system using mathematical equations. On the basis of input-output feedback linearization, have performed simulations on nonlinear control based on estimated and real conditions.

3.5 Incremental Conductance MPPT

In order for the InC strategy to work, the derivative of the output power P versus the panel voltage V must be zero during MPP. Flowcharts are used by InC to carry out its strategy, as shown in Figure 4. A system's MPP is calculated by using the slope of its P-V curve as the basis for all calculations [44]. This is the first approach that uses slope-based P-V curves, in which all data are determined by their slope, and the MPP is calculated according to that information. The P-V curve slope or PV array power (dP/dV) must be zero in order for tracking to be performed. MPP tracking becomes more difficult when atmospheric conditions change rapidly,

and tracking rates decrease exponentially when P-V curves change constantly. The operating point can be difficult to maintain under those circumstances. It is possible to extract MPP without oscillations by using a number of techniques that adapt the step size [45]. MATLAB's Simulink blocks are used to implement the same method shown in [45].
The current-voltage (I-V) curve is utilized in this strategy for achieving MPP in the same way as P & O. Here, current and voltage estimations are done, as well as derivatives of current and voltage (dI). In order to determine the working point trajectory, we need to know the PV current-voltage curve. In the literature, it is the most well-known model based on uniform conditions due to its medium predictability and better subsequent performance. By using the equations, MPP can be calculated on the P-V curve [46].

3.6 Ripple Correlation Control

MPP is calculated using dP/dV as its main parameter, which is the voltage derivative. Voltage and current controllers on power converters sense voltage coming from inverters so reference signals can be generated. To track the MPP point, ripples are used in the RCC technique. A PV array must have zero power slope if its power time derivative is taken into account along with its voltage or current time derivative. Thus, this method provides a means of tracking MPP [47]. Two sensors are used in this method to measure the PV's current and voltage. The ripple content of PV systems will also increase due to the low efficiency of power converters. Furthermore, the converter's switching actions will make the problem worse. Because of all these factors, the PV system's ripple content will increase, affecting its output directly.
This RCC technique to implement the grid-connected PV system, which includes an interface board and two slave processors, a dSPACE DS1104 controller board and an I/O interface board CP1104. In this method, the grid current can be controlled with good results using a P-Q controller. IEEE and IEC standards require a grid inverter's grid current to have a THD of 4.6%.

4 Performance Evaluation

The comparison of INC algorithm are as follows in Table 1.

Table: 1 INC algorithm comparison [48]

Parameters/INC MPPTs	**Adaptive-Based INC**	**INR-Based INC**	**ST-Based INC**	**FC-Based INC**	**PI-Based INC**	**FLC-Based INC**
Input variables	$V_{pv}$and I_{pv}	V_{pv} and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}
Control variables	Duty cycle (D)	*Reference current* (I_{ref})	*Reference voltage* (V_{ref})	$R_{load}$and D	D	$R_{load}$and D
Implementation cost	Lower	Lower	Lower	Lower	Lower	Lower
Controller types	PIC	Micro controller	Microprocessor based	PIC	DSP	dSPACE
Converter used	Boost-type	Boost-type	Buck-Boost	SEPIC	Fly Back	CUK
Complexity level	No	No	Higher	No	Higher	Average
System independence	Higher	Higher	Higher	Higher	Higher	Higher
Reliability for PSCs	Low	Higher	Higher	Higher	Higher	Higher
Convergence rate	Average	Faster	Faster	Faster	Medium	Faster
Oscillation around the MPP	No	Less	No	No	No	Less
Periodic based tuning	Available	No	Available	Available	Available	Available
Power efficiency	Avg.	More	More	More	More	More
Tracking speed	Slower	Faster	Faster	Faster	Faster	Faster

4.1 P&O with different optimization MPPTs

As part of a hill climbing algorithm (HC), the conventional P&O scheme is used. dP/dV will cause an operating point to be directed towards the MPP if it is greater than 0, and vice versa if it is greater than 0. It is necessary to perturb PV voltage and current both in directions in order to obtain the MPP locus [49]. A few of the drawbacks of the algorithm are that it occasionally deviates from the MPP, tracks slowly, and oscillates at steady-state near the MPP.

PV When the perturbation frequency is small enough, systems will perform better if they are accelerated to steady-state before the next perturbation. In order to reduce the trade-off between tracking speed and steady-state oscillations, a modified fixed-step P&O algorithm is introduced based on the selection of the appropriate scaling factor. Due to this trade-off, conventional adaptive P&O systems are introduced under PSCs. However, they suffer from the same problem since they are dependent on predetermined steps and fluctuating open circuit voltages (V_{-oc}). As well as improving tracking efficiency and convergence speed, we develop adaptive variable step-size P&O. A load current can be observed by perturbing the duty cycle and period of the duty cycle adaptively [50]. In adaptive perturbation, fractional short circuit currents (I_{sc}) are estimated, so the operating point can be brought close to MPP, and power oscillations can be reduced by controlling variable perturbations.
Adaptive and conventional P&O algorithms have poorer performance, as a result of an incorrect duty ratio selection and large perturbation changes. Consequently, several oscillations around the MPP result from the P&O algorithm searching for a PowerPoint consistently on both sides of a P-V curve. The tracking speed will be slowed if the smallest step size is selected. It is possible to reduce the oscillations by choosing the smallest step size. A delayed time in perturbation, however, overcomes the transient response. This combined method assumes that three animals will scale down computation complexity in order to produce a more precise MPP. All P&O algorithm parameters are listed in Table 2.

Table: 2 P&O MPPTs

Parameters/P&O MPPTs	**Adaptive P&O**	**FSCC-P&O**	**DA-P&O**	**PSO-P&O**	**FLC-P&O**	**ACO-P&O**	**ANN-P&O**	**MB-P&O**	**GWO-P&O**
Input variables	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}	$V_{pv}$and I_{pv}
Controlling variables	I_{ref}	$I_{ref}$and Duty cycle (D)	D, ΔI	V_{ref}	D, Dynamic load	D	V_{ref}, D	V_{ref}	D
Overall Implementation cost	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower	Lower
Controller types	dSPACE	dSPACE	Micro-controller	Micro-controller	dSPACE	PIC	DSP	PIC	dSPACE
Type of converter	Boost-type	Buck-Boost	SEPIC-based	Boost-type	Cuk-type	Boost-type	Buck-type	Boost-type	Boost-type
Complexity level	No	Avg.	Avg.	No	No	No	No	No	High
System Independence	Poor	Higher	Higher	Higher	Avg.	Higher	Higher	Higher	Higher
Reliability in PSCs	Avg.	Higher	Higher	Higher	Higher	Higher	Higher	Higher	higher
Convergence speed	Faster	Faster	Faster	Faster	Faster	Fastest	Faster	Faster	Faster
Oscillation around MPP	Low	Low	Low	Low	Low	Very Less	Very Less	Very Less	Very Less
Periodic based tuning	Available	Available	No	Available	No	No	Available	No	No
Power efficiency	Medium	High	High	High	High	High	High	High	High
Tracking speed	Faster	Fast	Fast	Fast	Fast	Faster	Fast	Faster	Faster

Through a combination of offline FSCCs and online P&Os, arrays are disconnected only during PSCs and at steady-state onsets [51]. Operating points are measured by the FSCC and sent to the algorithm via the P&O algorithms online. Furthermore, a hybrid drift avoidance P&O strategy is combined with adaptive and fixed techniques to determine the optimal duty ratio. PSCs' dV and dI values are increased through shifting the operating point adjacent to the MPP, which resolves drift problems. A P&O algorithm includes particle swarm optimization (PSO), which improves tracking efficiency, accelerates convergence speed, and reduces search space. By persistently searching for unique LMPPs under uniform environmental conditions, P&O can track LMPPs under non-uniform conditions.

Once the PSCs are determined, the perturbation size can be adjusted using the PSO technique at an instant. The combination of adaptive P&O and FLC can lead to high tracking accuracy while reducing computation time without requiring PIC. This hybrid technique improves system performance in both steady-state and dynamic conditions by increasing the MPP step-size in the right direction and reducing it in the wrong direction. The combination of P&O and ant colony optimization (ACO) allows detection of GMPPs as

LMPPs regardless of variations in duty ratio (ΔD) [52]. For classifying output reference voltages and sampling the position of operating points, the P&O algorithm uses artificial neural networks (ANNs). A new GMPP area is predicted using the P&O technique each time the irradiance changes.
For the purpose of locating the GMPP, the GMPP is perturbed into the area corresponding to an approximated duty cycle created by the ANN algorithm. This research implemented hybrid model-based (MB) and heuristic P&O algorithms in this study to improve tracking and dynamic measurements without requiring direct measurements of temperature and irradiance. In hybrid gray wolf optimization (GWO) and P&O methods, gray wolf optimization (GWO) reduces the search space for the operating point closest to the obvious MPP through offline optimization. Positions of wolves are tracked online when they are close to one another [53]. By combining the two approaches, the computation load at every change in atmospheric conditions is reduced, lowering the convergence time at the PSCs in the vicinity of the GMPP.

4.2 MPPT for Optimal Parameter

At PSC, eliminating the unimportant voltage intermissions (LMPP) using the search skip judge algorithm (SSJ) and rapid GMPPT algorithm. These results in an increase in accuracy and likelihood of tracking GMPPs. Adaptive perturbations step sizes are created by GAF (gaussian arctangent algorithm) to overcome the trade-off between tracking speed and MPP oscillations [54]. In addition to rapid dynamic performance, this system has fewer oscillations around MPP, robustness under harsh atmospheric conditions, and is capable of performing any similar function. With a double integral sliding mode controller (DISMC), the tracking voltage error section is integrated onto the sliding exterior, which eliminates steady-state errors (SSEs). Because this adds one more component to a controller's sliding surface, a converter can operate at PSCs and load variations with accurate voltage regulation. Through this technique, system stability can be maintained regardless of input values, parameters, or loads within a PV system.
A nature-inspired flower pollination algorithm is developed using an unconventional search space and flexible parameter adjustments (FPA). PSCs have a faster convergence speed than PSOs since the duty cycle is continuously adapted in each iteration.
Due to the assumption that a function is necessary to test the stability near the MPP, this is what has been done. Using a modified beta method, low power oscillations can be confirmed during the transient period and there is less complexity in the steady state. As long as the scaling factor N is selected correctly at the PSCs, GMPP tracking is more accurate than conventional hill climbing (HC) algorithms. The speed of the tracing at PSCs is accelerated by autotuning parameters, such as the scaling factor N. In order to validate the PV system's parameters, two different meteorological sites are used. The following Table 3 presents a brief comparison of MPPT parameters with those of other algorithms.

Table: 3 Comparison of other algorithms [55]

Parameters/Other MPPTs	**SSJ GMPPT**	**GAF**	**DISMC**	**FPA**	**ESC**	**Beta Method**
Inputs variables	V_{pv}, I_{pv}	E, ΔE	V_{pv}, I_{pv}	V_{pv}, I_{pv}	V_{pv}, I_{pv}	V_{pv}, I_{pv}
Controlling the variables	V_{ref}	D	D, V_{ref}	D	D	N, β
Overall Implementation cost	Lesser	Higher	Lesser	Lesser	Lesser	Lesser
Controller	Microcontroller	DSP	FPGA	Arduino	Arduino	dSPACE
Converter Type	Boost-type	Boost-type	Boost-type	Boost-type	Buck-Type	Buck-Boost-type
Algorithm complexity level	Low	Low	Low	Low	Low	Moderate
System independency	Higher	Higher	Higher	Higher	Higher	Higher
Tracking to PSCs	Yes	Yes	Yes	Faster	Fast	Fast
Convergence speed	Higher	Higher	Higher	Higher	Higher	Higher
Oscillation around the MPP	No	Lesser	Lesser	No	Lesser	No
Periodic tuning	No	No	No	No	No	Yes
Power based efficiency	Higher	Higher	Higher	Higher	Higher	Higher
Tracking speed	Vert Fast	High	Fast	Fast	Very Fast	High

Despite its second iteration out of 24, the FPA is able to locate LMPPs and GMPPs precisely regardless of the shade conditions, such as zero shade, low shade, or high shade. PSCs are faster to convergence and have better transient responses thanks to the model-less extremum seeking control (ESC) algorithm.

5 Conclusions and Future Scope

A variety of MPPT techniques were reviewed in this paper in order to maximize PV system power under PSCs. MPPT techniques are extensively reviewed with specific parameters considered for a variety of MPPT techniques. A large amount of research has been conducted on MPPT controllers as the most effective way of tracking the MPP when utilizing PSCs. This review provides detailed explanations of each MPPT technique's working procedures and flow representations. The tracking algorithm used to track MPP under PSCs is used to select and categorize some MPPT techniques into three groups. MPPT techniques can be made more effective with a little parameter knowledge. A number of factors should be taken into consideration during the design process, including algorithm complexity, sensed parameters, converter types, grid integration, tracking speed, MPP tracking, control parameters, and sensors required. These techniques are also ranked and discussed based on their merits and demerits. There has also been little discussion in the literature about the hardware platforms for all MPPT techniques. These techniques are discussed in terms of their software and hardware platforms. Aside from their tracking speeds, their efficiencies are also considered. In particular, classical algorithms have the best performance under uniform irradiation conditions due to their low algorithm complexity and slow tracking speed. Intelligent techniques are gaining traction with advancements in tracking, sensing, and storing enormous data at a faster rate, simplifying the system and eliminating the need for mathematical calculations to maintain MPP under different radiation conditions. Apart from that, optimization techniques can be applied to any PV system, no matter what the parameters are. Using bio-inspired algorithms, the technique has the advantage of being able to be applied to any PV system, regardless of its type. Consequently, researchers can use this study to choose the most appropriate MPPT for their particular needs. Thirteen factors were considered when comparing MPPT schemes, including merits and drawbacks, tracking performance, cost effectiveness, and implementation complexity. A MPPT approach is classified based upon input variables, sensor numbers, and tracking speeds, depending on whether it addresses transient or steady-state errors. With simple circuitry, P&O and INC algorithms provide good performance as maximum value algorithms.Observations of oscillations were made near MPP, however, and an approximated variable cannot be determined. It is possible to eliminate the oscillations across MPP by modifying INC techniques. In practice, however, modified techniques are difficult to control and expensive to implement. Although P&O techniques are considered the best choice due to their simple circuitry and low cost, they are inferior to INC methods due to increased oscillations at the MPP.

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