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A Structured Review of MPPT Techniques for Photovoltaic Systems

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Abstract: Photovoltaic (PV) energy has recently made significant headway in meeting the world's ever-increasing energy demand. Moreover, to reduce the effect of using fossil fuels. Solar system development and implementation continue to face considerable challenges because to the high cost of PV materials, which continues to be a substantial obstacle. Another obstacle limiting the widespread use of PV systems is the low conversion efficiency of PV modules. As a result, a power converter with maximum power point tracking (MPPT) capacity combined with PV systems is required to advance the technology. This paper presents a detailed review of the MPPT approaches that are currently available, including both uniform insolation and partial shaded circumstances. The possibility of tracking the (MPPT) under the effect of solar irradiation has been demonstrated using conventional MPPT techniques. The difficult of tracking the correct MPP with partial shaded circumstances under conventional techniques. As a result, robust and new algorithms based artificial intelligence have been created that can find the genuine MPP under numerous peaks. MPPT tracking capabilities, design complexity, economic considerations are all factors to consider. This paper analyzes both conventional and stochastic MPPT approaches have been studied and demonstrated in this review paper. In comparison, the tracking performance of stochastic algorithms and artificial intelligence is great. MPPT techniques are still being researched in order to increase their efficiency in terms of tracking efficiency, convenience of use, and cheap system costs.

Keywords: PV system, MPPT techniques, Intelligent algorithm

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INTRODUCTION

Solar PV is considering the better and suitable effective cost decision for power generation [1,2]. In the present and future, solar energy is predicted to be a nominated a potential source because the exist of the sun light as sustainability[3, 4]. The disadvantage of the solar panel based on the cost. Although having numerous advantages like as simplicity of installation, no noise with clean energy. The PV panels have a conversion efficiency of 15–18 percent because the difficulty of absorbing whole sun light [5]. Despite substantial research into improving PV cell efficiency, growth rates have yet to meet expectations. However, boosting the MPPT capabilities of a PV system is just as vital as increasing the system's power generation. To deliver electricity from PV panels to users are need power converters for controlling l the power from the PV systems, as well as manage the power at the load., and, most importantly, track the device's MPP. As a result, it is the most efficient and cost-effective method of increasing the overall efficiency of a PV system [3, 6]. The basic goal of an MPPT controller is to get the most power out of PV modules regardless of the temperature of the weather and sun irradiation [7-8]. MPPT controllers produce high power while minimizing cost per watt and increasing accuracy. In the literature, there are numerous controllers that can track MPP. The power is computed, and the converter's duty cycle is adjusted to track the MPP based on the recorded power of the PV array. There are different types of MPPT approaches, with different control variables, levels of complexity, costs, applications, and oscillations around the MPP point. However, with these advantages and disadvantages, MPPT is one of the most efficient techniques to enhance the total efficiency of a PV system by optimizing its components and

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operating parameters [9-11]. A significant number of studies was conducted on MPPT approaches. Take, for example: The P&O method [11]and the H&C method [12] They are often used because they are easy to set up and only need a small number of sensors. The IC approach [13, 14], which tracks the greatest power point of a photovoltaic (PV) system and transfers a high amount of PV energy to the load, compares the incremental conductance of PV arrays to the instantaneous conductance of those arrays. By switching the converter to regulate the MPPT, RCC [15] has incorporated ripple into its control technique. High levels of sun irradiance make this method work effectively; however, low levels of solar irradiance cause a decrease in tracking efficiency. Short-circuit current (ISC) [16], and open-circuit voltage (VOC) [17] approaches can be used to compute the IMPP and VMPP of the PV system. As evidenced by the approximate association between ISC and IMPP and VOC and VMPP, MPPT's fundamental flaw is its lack of precision. Chian-Song et al. [18] described a new approach for tracking maximum power in photovoltaic (PV) power systems with terminal sliding mode control (TSMC). Zainal et al. [19] summarized the present technology and state of the soft computing MPPT according to the numerous pieces of published literature. It also offered an evaluation of the performance of several SC methods based on multiple parameters, such as the capacity to handle partial shading circumstances, the ability to converge quickly, the complexity of the algorithm, and the hardware and practical implementation. Roberto F. et al. [20] described several types of converters, like Zeta converters are looked at to see which one works best as an MPPT. The radiation characteristics are taken into account in the proposed analysis. Analytical and simulation results are used to compare the related converters. In reference [21] a new MPPT method that can work with PSCs and do RMPPT is proposed. The RMPP position is used to find out how well the proposed MPPT method works, and simulation and experiment results are used to confirm this. Offline, online, and hybrid MPPT approaches are categorized in reference [5], this classification is based on the way of the control signal has generated and the PV power system's performance as it approaches steady state. Hadeed Ahmed, et al. [22] presented a new MPPT method for PV systems. Using the fractional short-circuit current (FSCC) method, the proposed method made the traditional P&O method work better when the environment changed. Ahmed M. Atallah et al. [23] implemented P & O utilizing special converters. the power are recorded for each combination. A novel technique is presented in reference [24] to control the duty cycle of the power converter in attempt to provide a fast MPPT process using a modified incremental conductance strategy. The purpose of this study is to look at some of the MPPT methodologies that have been used in the literature. In this study, the positives and negatives of each of the mentioned methods are listed, and a comparison table for each of the subjects is given. The next section of this paper describes the modeling of a PV array. The next section provides the maximum power point techniques, which are classified into three groups: traditional, intelligent, and optimization methods. At last, a result on the quality of the MPPT procedures are elucidated.

Photovoltaic cells use light energy to obtain the electrical power from the solar source [25]. As a result, the term "photovoltaic" connotes the production of electricity straight from sun light. The arrays of solar are made up of a variety of solar modules, which contain a number of solar cells. Solar cells are built up of layers of semiconductor material, the most common of which is crystal silicon [26]. There are just a few types of analogous circuit models, according to the literature that can be used to describe PV cells. A unique diode with a shunt resistance followed by series resistance and a is used in the generic circuit model, is a well-known circuit model [27, 28]. Parallel resistance R_{sh} denotes a constant resistance represents leakage resistance, which is greater than the ideal diode properties [29]. The single-diode approach achieves an excellent balance of simplicity and precision. The model's circuit diagram is shown in Fig.1[1].

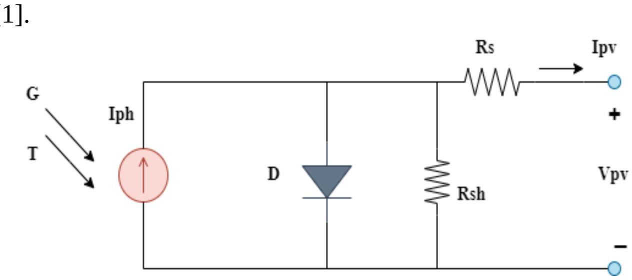

FIGURE 1. A single diode PV cell's equivalent circuit [30].

The generic current–voltage form is based on the single diode model of a PV panel is stated mathematically as[5, 30]:

$$I_{pv} = I_{ph} - I_o * \left[e^{\frac{V+I_{pv}}{n_s * V_t}} - 1\right] - \frac{V+IR_s}{R_{sh}} \quad (1)$$

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The variable definition as follows; I_{ph} represent the photo current, I_o represent the dark current cell saturation n_s represent the number of cells in a row or column, V_t represent the thermal voltage, R_s represent the series resistance, R_{sh} represent the shunt resistance.

MAXIMUM POWER POINT TRACKING (MPPT)

Due to the PV array's nonlinear features, the MPPT technique is used to satisfy that the PV array is always producing the highest power possible [20, 21]. The operating point of the PV cell can change from zero volts up to the voltage of the open circuit. The operating point rarely remain at maximum power but changes depending on the load. As a result, the system does not always provide the load with the maximum amount of solar energy available. A very simple solution to this problem is to expand the system's number of PV modules in the system to a level that exceeds the needed capacity. Nonetheless, system costs and energy losses will rise as a result of this [31]. An electronic power gadget known as the MPPT is utilized to discover the maximum operating point to address this issue. When a PV system is connected to an MPPT controller, the MPP may be found and the PV array can be used to its maximum potential. As a result, the PV system will always run at its maximum efficiency [31]. In the literature, many MPPT methods have been described and discussed [19, 32]. They are divided into three categories as shown in Fig.2. as Traditional MPPT, Intelligent MPPT, Optimization MPPT.

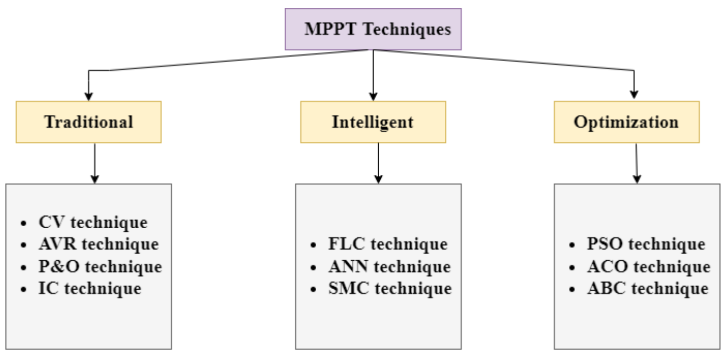

FIGURE 2. Classification of MPPT techniques.

Traditional MPPT Techniques

Constant Voltage (CV)

Simple method, quick, the tool is easy to use, but it lacks precision. The controlling mechanism involves comparing the PV voltage with a predetermined reference voltage equivalent to the VMPP in order to get the PV power to run near the MPP. This CV approach is utilized for uniform irradiation circumstances and ignores insolation and temperature effects. The CV MPPT approach is depicted schematically in Fig. 3 as a block diagram.

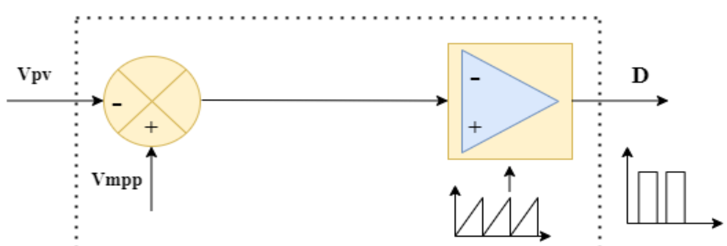

FIGURE 3. CV MPPT technique block diagram.

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Adaptive Reference Voltage (AVR)

Methodology of The ARV considers the weather conditions, unlike the CV MPPT. It estimates temperature (T) and radiation levels (G) with two more sensors than the classic CV system and one more sensor than the P&O approach, which leads the system a little more expensive. The gain in efficiency, on the other hand, compensated for the cost component. Because it provides the flexibility to function in varying weather circumstances, the ARV-based MPPT system is an extension approach to the constant voltage technique. Figure 4 shows the ARV MPPT method's schematic block model. There is a table of radiation values at different temperatures, and the relative radiation value is stored off-line. A proportional-integral (PI) controller is used to reduce the error between the reference and assessed PV voltages, resulting in a D proportionate to the fitted converter that is acceptable [33].This method is compared to the CV technique in a simulation. In constant radiation circumstances (around 1000 W/m^2), the efficiency for both approaches were nearly identical (> 99.7%). When irradiation is reduced to 400 W/m^2, however, CV efficiency drops to 98.3%, whereas our ARV approach maintains the same efficiency under all radiation circumstances.

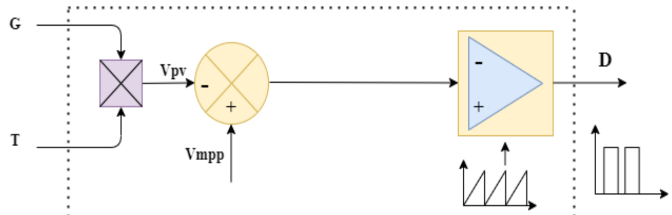

FIGURE 4. AVR MPPT technique block diagram.

Perturb & observe (P&O)

The P&O algorithm allows the PV panel to meet the MPP by adjusting the output voltage [9]. In this category, on a regular basis, the module voltage is perturbed [23]. As shown in Fig. 5, As the voltage increases (drops), the power grows (decreases). As a result, in order to attain the MPP, the power should be increased while the perturbation remains constant. As the power diminishes, the perturbation proportional reverses [34].

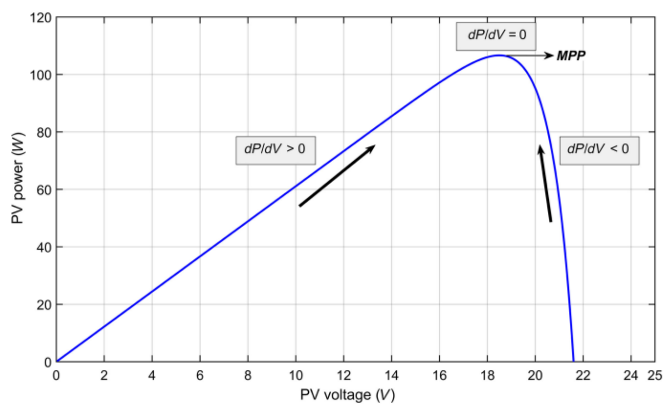

FIGURE 5. P-V curve for (P&O) algorithm.

This approach looks for a difference in power (dP) of PV with a PV cell voltage change (dV). When the dP/dV is appear positive, the real point appears in the MPP's left half. This operation is continued until (dP/dV) equals zero, as shown below.

$$dP/dV=0 \quad \text{at (MPP)} \tag{2}$$
$$dP/dV>0 \quad \text{at left side of (MPP)} \tag{3}$$
$$dP/dV<0 \quad \text{at right side of (MPP)} \tag{4}$$

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The benefits of the P&O algorithm include high tracking, simplicity, and rapid dynamic response. Oscillations, inability to measure actual MPP under partial shading conditions, and substantial power loss are among the drawbacks in the steady state conditions [35].

Incremental Conductance (IC)

The incremental conductance (IC) approach works by varying the PV power in relation to the voltage. When the division of the differentiation result is zero, the MPP is attained [24, 36]. Incremental conductance is calculated and compared between the two portions $\left(\frac{dI}{dV}\right)$ and $\left(\frac{I}{V}\right)$, The peak of the curve's power point is determined.

$$\frac{dP}{dV} = \frac{d(V\ I)}{dV} = I\ + V\left(\frac{dI}{dV}\right) = 0 \tag{5}$$

which means that:

$$\left(\frac{I}{V}\right) + \left(\frac{dI}{dV}\right) = 0 \tag{6}$$

The zero slope of the power of the PV array when the MPP is attained changing on the both sides of the MPP, according to this algorithm. The mathematical relationships of IC are as follows:

$$\frac{V}{I} = \left(-\frac{\Delta V}{\Delta I}\right) \qquad \text{at } (MPP) \tag{7}$$

$$\frac{V}{I} < \left(-\frac{\Delta V}{\Delta I}\right) \qquad \text{at left side of } (MPP) \tag{8}$$

$$\frac{V}{I} > \left(-\frac{\Delta V}{\Delta I}\right) \qquad \text{at right side of } (MPP) \tag{9}$$

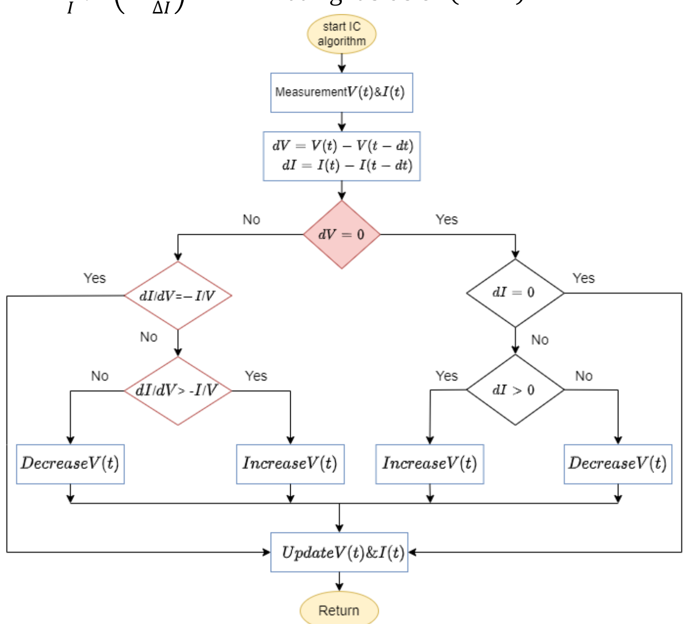

FIGURE 6. The flowchart of IC algorithm.

According to the flow chart above, the PV module must function at V_ref, which is the reference voltage. The voltage value at the MPP is equal to V_ref. The fundamental advantage of the INC approach is its capacity to quickly react to the conditions of the weather changing. Moreover, the oscillations in the vicinity of the MPP is considerably lower in this technique than in the P&O method [13, 37]. A comparison of the main parameters of the traditional based MPPT approach has shown in Table 1 below.

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TABLE 1. Traditional MPPT techniques [1-4].

Parameters	CV	ARV	P&O	IC
Tracking Speed	Slow	Medium	Slow	Slow
Tracking Accuracy	Low	Medium	Medium	Medium
Control strategy	IC	SM	SM	SM
Sensed Parameters	V	V&C	V&C	V&C
Complexity	Simple	Simple	Moderately complex	Complex
Parameter Tuning	Yes	Yes	No	No
Stability	No	No	No	Yes
Analog/Digital	A	A,D	A,D	D
Grid Integration	No	No	No	No
Cost	INEX	INEX	Affordable	EX
Ability to track under PSCs	No	No		No
Efficiency	72.80%	98%	97.8%	98.5%

Intelligent MPPT Techniques

Fuzzy Logic Controller (FLC)

The application of expert knowledge in the construction of a fuzzy logic controller is the basis of the fuzzy logic idea. The exact model does not require any technical understanding, and the design's simplicity allows it to track its maximum power point under various air circumstances. It uses linguistic phrases like (many), (low), (medium) (frequently) and (few) to deal with imprecision and information granularity [38].

The FLC is organized into four stages, as illustrated in the block diagram of FLC in Fig.6: (fuzzification), (rule base), (inference engine), and (defuzzification). For linguistic variables, membership function values are assigned. at the fuzzification stage. Furthermore, the fuzzy terms are based on the linguistic variables (PB). In the design, more linguistic variables yield more consistent and accurate findings [6]. More exact outcomes, on the other hand, take longer to solve. It's also possible to change the type of membership function [39]. Otherwise, as long as the supplied data covers the required region of interest, it could be picked through a trial-and-error process based on human knowledge [26]. As indicated in the Fig. 7, the inputs to fuzzy are variables, which are frequently. The user has free to calculate error and change in error; however, to have $\left(\frac{dP}{dV}\right)$ at MPP, as shown in equations below:

$$E(x) = \frac{P[x] - P[x-1]}{V[x] - V[x-1]} \tag{10}$$

$$\Delta E(k) = [E(k)] - [E(k-1)] \tag{11}$$

As follows are the variables' definition (x) is the duration of sampling, $P(x)$ is the PV system's instantaneous power and $V(x)$ is the instantaneous voltage. The E(x) value will indicate the position of the load power point from the MPP's point. The $\Delta E(x)$ denotes the direction in which the working power point is travelling. As shown in Table 2, the inputs E and E are calculated and transferred to linguistic variables, resulting in the output D from the search up rule base table. Another benefit of employing the FLC is that the spacing between each operational point for the membership function can be modified to achieve the best MPPT. To get more precise output, make the membership function denser towards the middle [40].

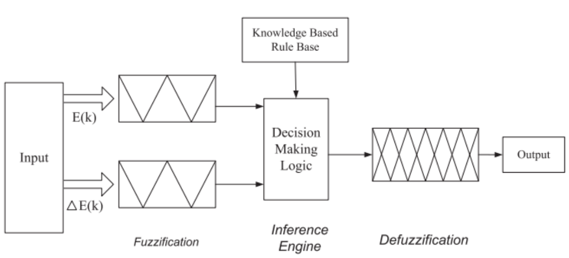

FIGURE 7. FLC block diagram.

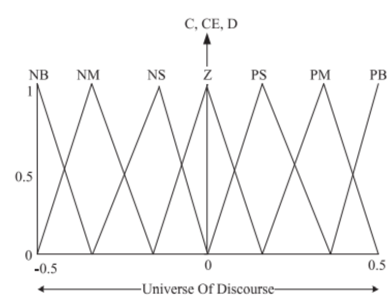

FIGURE 8. The FLC membership functions

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TABLE 2. FLC rule base.

de \ e	NB	NS	Z	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
Z	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

Both fuzzy output and input have linked and derived from the system's behavior. This is accomplished through the inference engine, which employs rules from Table 1's rules base. The rules base table, it should be emphasized, necessitates user knowledge in order to build fuzzy rules, which can be stated in the form of IF-THEN [41]. The P&O technique has been embedded with fuzzy logic to adjust the amount of perturbed voltage, (ΔV), so that the genuine MPP may be tracked and obtained faster, as described in literature[42]. According to the study, when the PV array was exposed to (50%) shadowing, the operating voltage was able to shift to the point where power was at its peak, as opposed to the traditional P&O, which trapped at any local peaks.

Artificial Neural Network (ANN)

Basically, the Artificial neural networks (ANNs) have inspired by human brain to find the solution for complicated systems. Mathematical modeling is used to model a biological brain network's structure in the operation principles of an ANN. Dendrites, cell body, and axon are the three main components of nerve cells.

Signals are sent from the dendrites to the cell body, where they are processed in the cell's core before being sent to the next nerve cell via the axon. As a result, neural networks must handle a large portion of signal processing and transmission. Information processing is at the core of NN's job [43]. This procedure heavily relies on cognitive patterns. One of this algorithm's advantages is its capacity to process a large amount of data. The four procedures that follow explain how the ANN algorithm works in general; Specify variables for input and output, Implement training into the system, Choose a network structure, and Training.

The layers of input, hidden and output of neural networks are depicted in Fig.9. The number of nodes varies related on the type of structure and system. Each node, as well as the links connecting them, has its own weight [44].

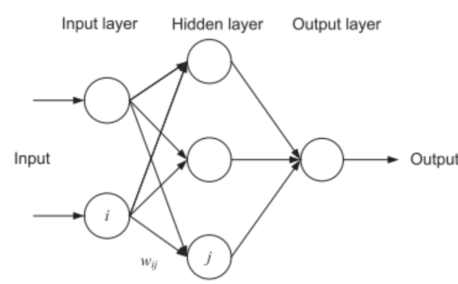

FIGURE 9. Neural network’s layers.

The (w_{ij}) is plainly utilized to illustrate the weight between the nodes (i) and (j). The specific MPP training process has been meticulously performed in order to establish the exact MPP training method. Because the module has been in use for many years, as well as the processes to be followed, must be preserved. Each photovoltaic module has its own set of characteristics. In a PV system, each module's ANN must be trained separately. According to the changing in the PV characteristic as the time or weather changes. It is necessary to learn the control algorithm on a regular basis to detect the exact location of MPP [38,39].

Sliding Mode Controller (SMC)

A smart intelligence-based SMC is meant to follow the MPP swiftly while maintaining its efficiency. The primary idea behind the technology is to regulate the DC-DC converter using the current from the DC link capacitor. The advantages of SMC include that it is extremely good for non-linear systems since it's precise in tracking. The

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disadvantage is that the sliding surface options have a significant impact on the SMC's efficiency [2, 35]. Figure. (10) show the flowchart of the SMC technique.

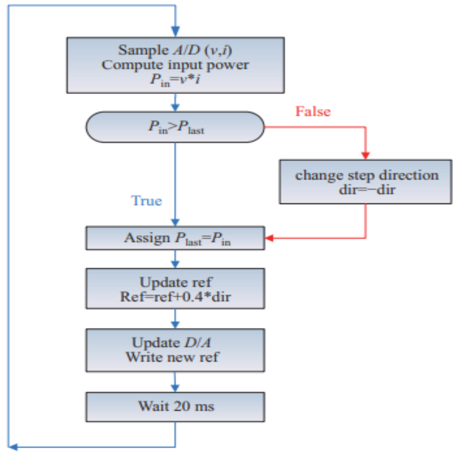

FIGURE 10. Flowchart of SMC [35].

Tables (3) show a comparison of the major parameters of this Intelligent based MPPT Technique

TABLE 3. Intelligent MPPT Techniques [5-7]

Parameters	FLC	ANN	SMC
Tracking Speed	Fast	Medium	Very Fast
Tracking Accuracy	High	High	Medium
Control strategy	Fuzzy Inference System.	Back Propagation.	Current Sensing.
Sensed Parameters	V&C	G&T	V&C
Complexity	Less	Medium	More
Parameter Tuning	Yes	Yes	No
Stability	Very stable	Very stable	Very stable
Analog/Digital	Digital	Digital	Digital
Grid Integration	Yes	Yes	Yes
Cost	Affordable	Expensive	Expensive
Ability to track under PSCs	Yes	Yes	Yes
Efficiency	97.87%	98%	-

Optimization MPPT Techniques

Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) [43-44], is a biologically or nature based on the application of the swarm's behavior, Eberhart and Kennedy developed a computational search and optimization approach in 1995. Basic PSO, is better suited to tackling static, simple optimization issues, on the other hand. PSO theory is fast growing in popularity. Many PSO applications have been used to solve a wide range of problems. The term PSO is referred to (a global swarm algorithm that uses many particles for seeking the space in order to discover the better solution). Looking for swarms of animals to provided the initial inspiration for PSO optimization. It incorporates information about each particle's p, not just in the direction in which it is currently moving, but also in the direction in which it is currently going (best) to move this particle about in the search space, as well as the search parameters (optimal solution in overall population) g is the name given to this value (best).

Ant Colony Optimization (ACO)

The advantages of ACO include convergence independent of beginning sample position, a simple control method, minimal cost, and the ability to manage a variety of partial shading conditions due to its robustness. The downsides

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include simultaneous optimization of four variables at once, which is a challenging task for the controller, as well as complex estimations [49, 50].

Artificial Bee Colony (ABC)

The right activation function is employed in PV systems to locate the optimum point using this food-finding strategy. It has a near-perfect efficiency rate of (99.99%) percent. When the shade patterns change in real time, efficiency suffers. ABC has the advantage of using fewer control parameters. Slow tracking, complex tracking, and less control settings may influence local maximum point tracking (LMPPT) [35, 50,51].

Table 4 shows a comparison of the main parameters of this Optimized based MPPT approach.

TABLE 4. Optimization MPPT Techniques [7-10].

Parameters	PSO	ACO	ABC
Tracking Speed	High	High	High
Tracking Accuracy	Medium	Medium	Medium
Control strategy	Particle tracking	Bio-inspired	Bio-inspired
Sensed Parameters	V and C	V&C	V&C
Complexity	Medium	Simple	Medium
Parameter Tuning	Yes	Yes	No
Stability	Stable	Stable	Stable
Analog/Digital	Digital	Digital	Digital
Grid Integration	Yes	No	Yes
Cost	Affordable	Affordable	Expensive
Ability to track under PSCs	High	High	High
Efficiency	99.91% [50]	99.97% [51]	99.78% [52]

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CONCLUSION

This paper focuses on the review for three types of MPP techniques: traditional, intelligent, and optimization, all of which are novel to their respective fields, particularly in this research topic. A detailed literature review of various MPPT approaches is offered, with specific factors taken into account. Furthermore, the literature suggests that using MPPT controllers is the best technique to track MPP under PSCs, paving the path for a large amount of study. For each MPPT technique, the current study contains a detailed description of the working operations as well as the flow representation process. Some parameters knowledge is beneficial for the design elements of using the MPPT technique in a PV system. Some parameters considered are tracking speed, stability, ability to track under partial shading conditions, efficiency, cost and sensed parameters. For uniform irradiation conditions, conventional algorithms are the most reliable, and they have a lower algorithm complexity and tracking speed than other techniques. Intelligent approaches are gaining popularity as the best MPP tracking techniques in varied radiation situations during this time period, with an increase in the speed of tracking, sensing, and storing massive amounts of data, making the system simpler and eliminating the need for mathematical computations. Without knowledge of PV panel parameters, optimization methods are most compatible with any system. To summarize, this research will be useful in assisting researchers in selecting the most advantageous MPPT for various applications.

For future work, an efficient arithmetic optimization algorithm (AOA) has been suggested to achieve optimal MPPT with the shifting temperature gradients of a centralized thermoelectric power generation system. Furthermore, to increase the exploitation of energy and usage.

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