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# A review on maximum power point tracker methods and their applications

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**A B S T R A C T**

In recent years renewable energy i.e. wind and solar energy has received worldwide attention. The determination of the photovoltaic system is dependent on various factors mostly to cost, complexity and efficiency. One of the most interesting areas among the various research area in solar photovoltaic (PV) system is extracting maximum power from solar PV system. The maximum power point tracking (MPPT) is the control algorithm that adjusts the power interfaces automatically and produces the most power available. In this study, multiple maximum power point techniques for solar PV systems are presented. The MPPT methods are discussed as follows: tracking speed, algorithm complexity, dynamic tracking under partial shading condition and hardware implementation. A significant corresponding table has been presented at the end of this paper to simplify the classification of the different methods for practicing engineers as well as for new researchers.



## 1. Introduction

A photovoltaic (PV) system converts solar energy into direct current (DC) electrical energy straightly, which is assembled by the solar cell as the main device of the PV panel. Meanwhile, power electronic converters have been evolved as an interface between renewable energy sources and power electric grid to improve the power extraction. As Yang and Zhao have shown in [1], using converters and inverters not only adjust the low DC voltage produced by the PV module in the electric grid to the voltage level, but also they should merge functionally for tracking the MPPT inasmuch as the power conveyed from the modules to the point of operation is very delicate. MPPT is an electrical device which is used to match the characteristics of the module to obtain the maximum power by adjusting the duty cycle of the DC-DC converter, inasmuch as avoiding the power loss of the system. MPPT is a critical device in a solar system since PV systems efficiency is low, comparatively.

The major problem of PV systems is the amount of electrical power that a PV panel can be generated may be varied in different weather condition [2], furthermore, another drawback of the PV systems is their costly energy generation process compare to the cost that needed to generate energy by conventional power generation systems.

Verma et al. [3] discussed a summary of 31 different kinds of MPPT methods. They claimed that the features of the solar cell are mostly influenced by insolation, temperature and partial shading condition (PSC). Moreover, in this paper, MPPT methods are classified under Indirect

Control (IND) that is a mathematical method based on the empirical data, Direct Control (DIC) that is based on the sampling based control or modulation based control strategy and Soft computing techniques based method that is based on soft computing techniques like genetic algorithm, artificial neural network and particle swarm optimization.

Ramli et al. [4] considered MPPT methods not only under uniform insolation but also under PSC. Some of these methods are the same for both conditions, however, some of the methods are not suitable for shading condition and need to improve. Also the considered MPPT methods with reconfigurable field programmable gate array (FPGA) technology. One of the most important issues in using MPPT methods practically is using a proper converter that is discussed in this paper.

Wu et al. [5] posited an MPPT based three-point-weighting method for stand-alone PV system configurations that merges mid-point tracking to develop the disadvantage of perturbation and observation method.

Ouoba et al. [6] investigated a new auto-scaling variable step-size MPPT method for a PV to gain concurrently a rapid dynamic response and stable steady state power. As it is claimed, it is necessary to propose the variable step-size inasmuch as the system cannot generate stable output power particularly when the step size that is used is too large even though the MPP can be reached. This is because of the inability to change the fixed step-size in the proximity of the MPP. Although the tracking time of the variable step-size is not as good as fixed step-size, the simulation of the proposed method showed good dynamic response and also good steady-state power regardless the irradiation is increased or decreased even if the condition change suddenly. Accordingly, in the proposed step-size scaling method, not only the tacking speed develop in stable output power, but also the decision-making algorithm takes into account an unexpected alter of the irradiation.

Salah and Ouali [7] examined two methods of MPPT methods using fuzzy logic and neural network controllers for a PV system imposing a boost DC-DC inverter which are suitable for variant conditions like changing PV cell temperature and solar radiation. The simulation results for both constant radiation and constant temperature are considered to find the I-V and P-V curves of a proposed PV panel. Henceforth both simulation by MATLAB and experimental results have shown that the power can be delivered by the fuzzy logic controller is more than the neural network. Albeit neural network controller has many good profits.

Reisi et al. [8] classified several MPPT methods into three categories that are offline models which are called model-based, online models which are called model-free and hybrid methods which are an alliance of the two previous methods. Checking out the implementation considerations in terms of the expense, hardware demand and the most important factor is contingently eased of implementation, they induce both the efficiency and the dynamic response of the system. Their results denoted that the efficiency and dynamic response of the methods with low cost, low hardware demand, and easy implementation are relevantly feeble. Under the relatively same condition of implementation, the authors claimed that the execution of the hybrid methods is better than offline and online methods.

Bahgat et al. [9] proposed a PC-based MPPT by using artificial neural networks (ANN) and implement it under the diverse practical condition for a PV system. Regarding their experimental results, they presumed that using MPPT in the PV system not only facilitate to boost the PV module's power which is delivered to the grid, but causes that PV system serving for a longer time. Moreover, the authors investigated that neither the module temperature nor the radiation level does not affect the enforcement of the MPPT.

In [10], Rezaee Jordehi carried out a review of different MPPT methods that are categorized into two classical and modern MPPT methods. The author classified perturb and observe, hill climbing, fractional open circuit voltage and fractional short-circuit current in the classical category. On the other hand, the modern MPPT methods category includes fuzzy logic, artificial neural network and metaheuristic-based techniques. The paper claims that the metaheuristic methods, unlike the classical methods, are serviceable in PSC where local optimum is not unique. This paper also discusses uniform radiation condition as well as PSC.

Eltawil and Zhao [11] highlighted MPPT techniques for PV applications and grid-connected power generation. As they claimed, although conventional methods are easy to implement, however, because of the fixed step-size, their tracking speed is low. Nevertheless, intelligent methods can be tracked rapidly as well as being efficient. Besides, it has a discussion between control diagram of the MPPT by regulation the PV current and voltage and as it is outlined in [12], the one which is operating with PV voltage is superior.

Karami et al. [13] surveyed the various MPPT methods and classified tracking techniques regarding constant parameters, measurement and comparison, trial and error, mathematical calculation and intelligent prediction. This paper has a discussion about the criteria for the selecting MPPT. The authors have been categorized the MPPT methods regarding implementation, sensors, efficiency, cost and application to find out which method has a better operation at the specific condition inasmuch as the operating condition purely effects on the execution of a PV system. As the PV output voltage is affected by varying the temperature and the PV output current is affected by varying the solar radiation.

Ram et al. [14] classified the MPPT methods into conventional methods that are P&O, IC, HC and global MPPT; and soft computing techniques that are FLC, GA, ANN, PSO, CB, ACO, FA, and ABC based MPPT. In this paper, the various procedure of P&O, IC, FLC, ANN and PSO techniques are discussed together. All MPPT methods are compared to each other regarding these criteria: tracking speed, algorithm complexity, dynamic tracking under partial shading and hardware implementation. As they declared in this paper, P&O method is a great method for the applications with low power, however for the location with changing weather condition is useless like as IC. Moreover, the ANN is a useful network preferably in hybrid algorithms since its difficult implementation and high computational time.

In [15], Joshi and Arora carried out an MPPT review paper which includes several different methods. The MPPT algorithm's efficiency can be expressed in different ways as conversion efficiency, European efficiency, static efficiency describes and dynamic efficiency. Different MPPT methods that are described in this paper, are classified as follows: PV array dependent, true MPPT, prior training, application, complexity, digital or analog, convergence speed, sensed parameter, periodic tuning, efficiency, cost.

Villalva et al. [16] explained a method of modeling and simulation of single-diode PV array model by setting the PV characteristics at three points which is simple, accurate, quick, to find the parameter of the equation on a functional PV array. Although some assumptions that were used in previous papers are impractical, the authors here proposed the relation between $I_{PV}$ and $I_{SC}$ that allows delimiting the PV current. By this way, it is evident that the PV current is different from the short-circuit current of the system.

Chauhan and Saini [17] outlined a comprehensive review of numerous issues associated with integrated renewable energy system (IRES) based power generation. Stand-alone applications are accomplished through AC coupled, DC coupled or hybrid DC-AC coupled configurations for various types of renewable energy. The following equation, determine the hourly power output of the photovoltaic system (PVS):

$$P_{PVS} = \varepsilon H_T A \quad (1)$$

where $\varepsilon$ is the conversion efficiency of PVS, A is the surface areas of PVS and $H_T$ is hthe ourly power output of PVS in kWh/m$^2$ that is calculated as [18]:

$$H_T = H_b R_b + H_d R_d + (H_b + H_d) R_r \quad (2)$$

where $H_b$ is the beam radiation, $H_d$ is the diffuse radiation, $R_b$, $R_d$, $R_r$ are the tilt factors for the beam, diffuse and reflected solar radiation, respectively.

As they insisted, among all type renewable energy, PV system's efficiency is the lowest. As a result, using an optimization method to increase the power output of the system is essential. One of the best methods is artificial intelligence which has a simple configuration.

Bounechba et al. [19] delved into an intelligent method for MPPT of a PV system using Simulink/MATLAB to compare conventional perturb and observe (P&O) method with a fuzzy logic controller (FLC) using boost converter. To have the maximum power output of the system, the duty cycle of the boost converter should be controlled. By using the result of the simulation, they claimed that for nonlinear loads, FLC is more stable and hence, can increase the power output of the system.

Kollimala and Mishra [20] investigated a new variable perturbation size adaptive P&O method which helps the MPPT, track the maximum power under unexpected irradiance changes. The proposed method consists of three algorithms that not only improves the steady state tracks the MPPT under normal condition but also accelerates the dynamic operation when the operating condition changes immediately. The variable perturbation can diminish the oscillations around MPP as well, as a result, the final tracking response is faster than the conventional method.

A new PV generation model that is carried out in [21] is using P&O method as a controller. However, unlike the conventional P&O method that $V_{PV}$ is the value factor, in this method, $I_{PV}$ is considered. The output of the proposed method is relatively like the simulated final results of the system for both small and fast changes in solar radiation and voltage of AC grid as respects that P&O method doesn't have an accurate result in fast input changes.

Tey and Mekhilef [22] aimed to propose a modified incremental conductance (IC) MPPT method to develop the tracking speed and also, improve the accuracy of the tracking to a global maximum power point (GMPP) under PSC by changing the duty cycle of the DC-DC converter for assuring fast MPPT. The proposed method that is both simulated and experimented, is based on three cases regarding the position of the GMPP. Furthermore, by using the proposed algorithm, the response is faster and more accurate, not only during PSC but also when the load is not constant.

Patel and Agarwal in [23] claimed that in the P-V curve, the $V_{peak}$, where the peak of the power occurs, is approaching equal to $0.8*V_{OC}$. The authors proposed the model to track to the global peak faster than conventional P&O method. This method is based on the remark that the power of the system in the P-V curve increments until the global point (GP) approaches and after this point, the slope of the curve that is the power of the system, continuously diminishes.

## 2. PV array modeling

### *2.1. PV array source under uniform condition*

PV systems are made of solar panel which contains several series, parallel or series-parallel solar cells, and DC-DC voltage converters and in some cases DC-AC voltage inverters, controllers and batteries. Besides, some PV modules that are connected in series and parallel are called a PV array [24]. By using the battery, not only the PV system can be yield as a real source to the grid, but also it is needed for saving power in the case that because of power variations, the system needs temporary compensation. Furthermore, as it is outlined in [25], it is obvious that by connecting the PV cells in series, their voltages are adding together and as a result, the output voltage is too large. In contrast, if we want to have a large current in the cell's output, the cells should be connected in parallel.

Figure 1 illustrates the one-diode equivalent circuit of a solar panel that is constituted of many PV cells as mentioned before. Equation (3) measures the current of the one-diode equivalent PV panel [16]:

$$I = I_{PV} - I_O \left[\exp\left(\frac{V+R_S I}{aV_t}\right) - 1\right] - \frac{V+R_S I}{R_P} \quad (3)$$

where $I_{PV}$ is the PV current, $I_O$ is the saturated reverse current, α is a diode ideality constant, $V_t$ is the thermal voltage related to the number of cells connected in series ($N_S$) and the absolute temperature of the p-n junction, and $R_p$ and $R_S$ are the parallel and series equivalent resistances of the solar PV panel, sequentially.

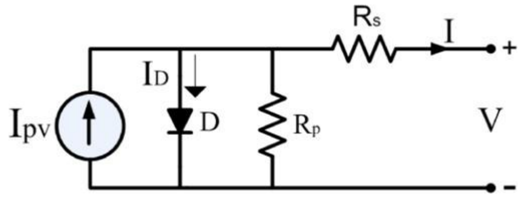


Figure1. The equivalent circuit of the one-diode solar panel [26]

The authors in [26, 27], indicated the two-diode model. This model is more accurate than the previous equivalent. Figure 2 illustrated the two-diode model and the current of it can be calculated by the equation below:

$$I = I_{PV} - I_{S1}\left[\exp\left(\frac{q(V+R_S I)}{\alpha_1 KT}\right) - 1\right] - I_{S2}\left[\exp\left(\frac{q(V+R_S I)}{\alpha_2 KT}\right) - 1\right] - \frac{V+R_S I}{R_P} \quad (4)$$

where $I_{S1}$ and $I_{S2}$ are the currents of the diodes, and $\alpha_1$ and $\alpha_2$ are the ideally constant of the diode.

As it is obvious from equation (1) and (2), increasing the irradiation can meaningfully progress the power of the PV cell. In contrast, if the temperature rises, the power of the PV cell diminishes significantly.

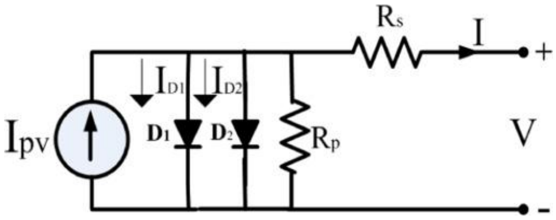


Figure2. The equivalent circuit of the two-diode solar panel [26]

*2.2. PV array source under partial shading condition*

Under some condition such as clouds or obstacle, the amount of irradiation that every part of the PV module receive is not equal, that is called partial shading condition (PSC).

In some cases, the PV characteristics may have multiple local optima under PSC. Figure 3 illustrates a standard PV array, where three distinguished groups having shaded and non-shaded series modules array is comprised [28].

A configuration of series-parallel PV array carried on under PSC is shown in figure 3(a). It supposed that group 1 and 2 are controlled by shading, as a result, their insolation is lower than group 3. Consequently, the global peak of group 3, $P_{G3}$, is higher than other global peaks of group 1 and 2 (Figure 3(b)). Figure 3(c) depicts the final P-V curve of the whole array.

Many researchers have proposed several methods for PV array under PSC. Nevertheless, there are still some problems regarding this situation. The structure of hot spots is one of the problems that exist in the PV module which is partially shaded [29].

## 3. MPPT Methods

As it is illustrated in the figure4, the I-V and P-V characteristics of a simulated PV panel are shown [14].

Although it is feasible to change the operating point of the PV system with varying not only the load but also the I-V characteristics, practically none of them can be changed. Consequently, a PV interface should be organized to adjust the effective resistance seen by the PV panel adequately. In MPPT techniques, either PV voltage or PV current should be tracked. As the authors in [30] highlighted, controlling the PV array voltage is a better choice inasmuch as unlike the current that fluctuates, the voltage remains fixed.

*3.1. Classical methods*

Classical methods are easy to implement, however, they suffer from oscillations at MPP and also their tracking speed is less in order to fix perturb size. In contrast, they are relatively cheap and easy to implement.

*3.1.1.Constant voltage method*

Constant voltage method is an offline method that is also called the open circuit voltage (OCV) method. Inasmuch as its equation is nearly linear between the reference voltage and open circuit voltage, this method is almost the most uncomplicated offline method [31, 32]. In addition, it can be implemented with analog hardware readily.

By using this method, PV voltage is equal to:

$$V_{ref} = K_1 * V_{oc} \quad (5)$$

Where $K_1$ is 0.72 to 0.80.

This method is fast, simple, cheap and easy to implement, however, it has some drawbacks such as limited tracking accuracy, using only at the places which lethargic temperature variation and needs periodic molting of the load for measuring the $V_{OC}$ are observed.

*3.1.2. Constant current method*

This method like constant voltage method is an offline method which is also called a short-circuit current (SCC) method. In this method, the sensed parameter is short-circuited current:

$$I_{ref} = K_2 * I_{sc} \quad (6)$$

Where $K_2$ is 0.80 to 0.92.

Inasmuch as by using OCV and SCC methods, not only through calculation of $V_{OC}$ and $I_{SC}$ load interruption transpires, but also MPPT tracking accuracy is poor, these methods unable to deliver the most output power to the grid. Nevertheless, these two methods are proper for use in hybrid methods [33].

*Perturb and observe (P&O) method*

One of the simplest online methods is perturb and observe (P&O) method. P&O is applied by perturbing the operating voltage or current at regular internal and oscillating around dP/dV is zero. It is easy to implement, the operating point oscillates around MPP and it needs less sensor.

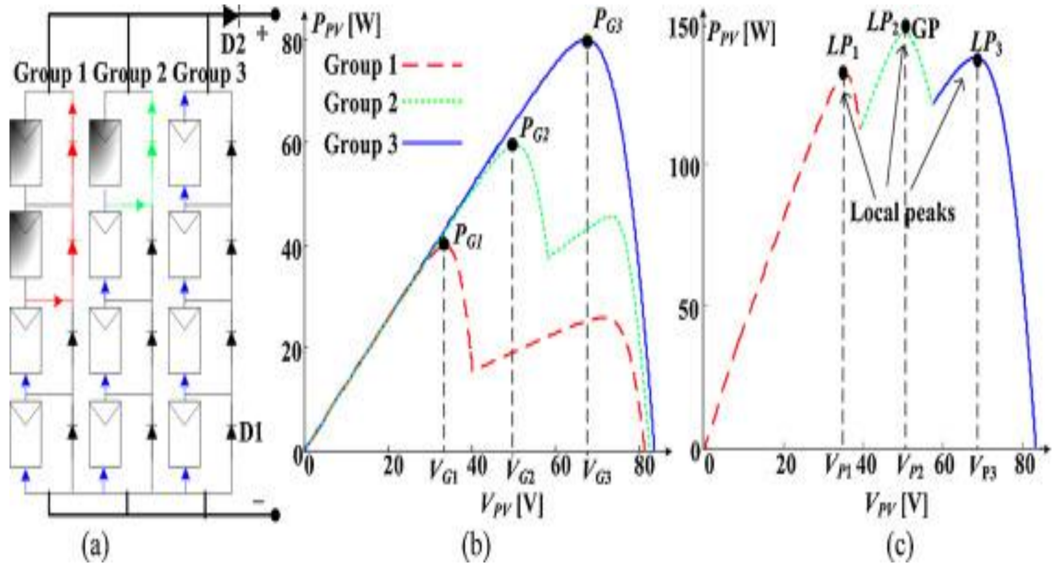


Fig. 3. (a) PV array configuration. (b) P-V curves of every group. (c) Ultimate P-V curve of whole array [28]

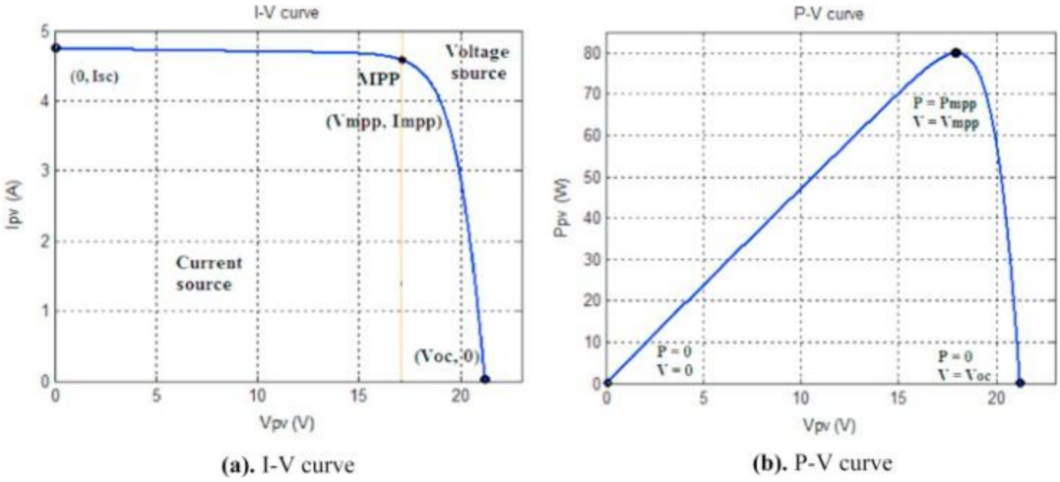


Figure 4 : (a) I-V curve, (b) P-V curve [14]

However, this method is slow and unsuitable for the fast-changing condition [34-36]. Furthermore, this method has a low convergence speed of the output power to the MPP. A vast perturbation can increase the amount oscillation amplitude. On the other hand, applying insignificant perturbation, the rate of tracking convergence is diminished. As a result, it is feasible to use variable step-size perturbation to overcome this problem [6]. The methodology is explained in Table 1.

*3.1.3. Hill climbing method (HC)*

In some references like [3], this method is one of the sub-classified methods of P&O since their fundamental principle is the same, even though HL

Table 1. The methodology of the P&O method [3]

| Perturbation in the voltage terminal | Change in power | Next perturbation |
|---|---|---|
| Positive | Positive | Positive |
| Positive | Negative | Negative |
| Negative | Positive | Negative |
| Negative | Negative | Positive |

and P&O method are two different methods. HL method comprises perturbation in the duty cycle of the converter whilst the terminal voltage is perturbed in P&O method to accomplish MPP [37-39]. In this method, the duty cycle will be enhanced if the increase in duty cycle causes the PV output to have more power, otherwise, it will be diminished [40]. Although the HL method is more practical in low power applications, it is serviceable in limited irradiation change.

### *3.1.4. Incremental conductance (INC) method*

The principal of incremental conductance (IC) method is almost like P&O method, howbeit it is based on the basis that the derivative of the power over derivative of the voltage of the PV output. The equation of the IC method is shown in the follows:

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V\frac{dI}{dV} \cong 0 \quad \text{at the MPP} \qquad (7)$$

As a result

$$\frac{dI}{dV} = -\frac{I}{V} \text{ at MPP} \qquad (8)$$

$$\frac{dI}{dV} > -\frac{I}{V} \text{ left of MPP} \qquad (9)$$

$$\frac{dI}{dV} < -\frac{I}{V} \text{ right of MPP} \qquad (10)$$

Although this algorithm's final result is almost effective under the swiftly switching condition, its control circuity is complex to some extent.

The MPP moves to the left when the radiation on the PV array decreases. To atone for this MPP changing, the array's operating voltage should be diminished.

To overcome these drawbacks, researchers evidenced the adaptive IC [41-43]. It this state, the step size is variable and can be calculated by the equation below:

$$D(n) = D(n-1) \pm \left|\frac{dP}{dV}\right| + \frac{N}{I} \qquad (11)$$

Where N is the scaling factor, $\Delta D_{max}$ is the maximum step size for the MPPT process, and $\left|\frac{dP}{dV}\right| > I * \frac{\Delta Dmax}{N}$.

### *3.1.5. dP/dI or dP/dV feedback control method*

This method compares two successive power and also the magnitude of the slope is deliberated in opposite to conventional methods [44]. In this method, $P_2$ is equal to $P_1$ at MPP, greater that $P_1$ before MPP and less $P_1$ after MPP.

### *3.1.6. Temperature based method*

The temperature of solar PV is calculated in this method. As it is carried out in [45], the cell temperature and the open-circuit voltage of the PV panel have an indirect linear relationship. The equation below, control the temperature method [45]:

$$V_{MPP}(t) = V_{MPP}(T_{ref}) + T_{KVMPP}(T - T_{ref}) \qquad (12)$$

This method is easy to implement and simplistic circuitry is needed. Furthermore, for using this method, the temperature and voltage of the PV array should be measured.

## *3.2. Soft computing method*

Soft computing techniques are the superior choice in manipulating the non-linear problem. Consequently, for the condition like PSC, these techniques assure faster convergence and high reliability. Meanwhile, it should be noticed that the high cost and complexity of implementation are two main drawbacks of these methods.

### *3.2.1. Fuzzy logic control (FLC) method*

Fuzzy logic controller (FLC) is implemented in three stages as follows: fuzzification, decision making, and defuzzification. The normal error ε and delta ε which is a change in error, are the inputs of this controller. The output of this controller is the difference in voltage (ΔV) or current ($\Delta d$). The equations of this MPPT method are as follows [46]:

$$\varepsilon(K) = \frac{P(K) - P(K-1)}{V(K) - V(K-1)} \qquad (13)$$

$$\Delta\varepsilon(K) = \varepsilon(K) - \varepsilon(K-1) \qquad (14)$$

By using FLC, not only it is probable to accomplishing with inputs and a mathematical model that are not accurate but its error detection is accurate. However, FLC is not proper for PSC inasmuch as in this condition, FLC cannot recognize the local MPP's and global MPP. Moreover, it is not possible to change the rules after the operation starts.

Linguistic variables are used in this method in five fuzzy subsets: NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big). Figure 5 depicts the membership functions of this method.

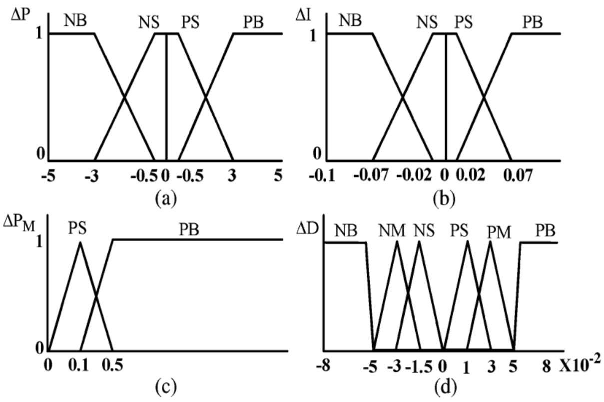


Figure 5: Membership functions: (a) input ΔP, (b) input ΔI, (c) input $\Delta P_M$, (d) output ΔD [47]

*3.2.2. Artificial neural network (ANN) based method*

ANN is such a soft computing technique invigorated by the central nervous system. The authors in [8] presumed that the ANN method's tracking accuracy is entirely better than OCV and SCC, particularly when the irradiance is unstable. ANN consists of three layers, called input, hidden and output. Although by adding the number of hidden layers, the tracking efficiency is raised, it reduces the tracking speed.

Generally, using NN doesn't require to know the internal parameters of the system. Moreover, not only its computational endeavor is low, but also its solution for the multivariable problems are not complex [7]. ANN controller compares to the FL controller generate less power, as a result, its power generation is less than the FL controller. Nevertheless, using this method needs high memory.

*3.3. Hybrid MPPT methods*

In these methods, generally, the algorithm of the control system at least consists of two levels to increment the efficiency of MPPT. Ordinarily, the first level of the controller that is necessary to proffer a rapid response to the environmental variation, consists of the offline methods. The second level which is an endeavor to track the MPP precisely can be acquired based on the online methods. For instance, in [48], the first level is classical P&O and the second level is the ANN method which is used to selecting the step size for the first level.

**4. Comparison and discussion of MPPT methods**

In this work, we have discussed several methods on MPPT. It is evident that each method has its own advantages and drawbacks concerning the tracking speed, the tracking precision, the component cost and the implementation complexity.

Moreover, the power plant size forces limitations, therefore, regarding the application and objective, the simplest and the most efficient method should be implemented.

As a result, one must take into account the tradeoff between the cost of the tracker and the amount of the extra power obtained. Despite the installation cost of the PV systems are high, its conversion efficiency is not good enough. Consequently, implementing the proper MPPT method seems one of the best way to improve the conversion efficiency.

Some shortcomings of MPPT applications are declared in this section:

- If a power plant generates just few hundred watts, it is not efficient to implement a neural network tracker even though it is more precise than constant voltage method or even P&O method.
- Although the artificial intelligence-based methods are the faster and more durable than conventional methods, they are just proper for digital applications. On the other hand, classic methods like P&O, IC, and HC do not have a proper procedure to find global MPP in PSC because of their poor tracking speed and week convergence.
- FLC and ANN are knowledge-based systems; it means that for implementing the algorithm, it needs a comprehensive knowledge. In addition, ANN and FLC are important when the panel is huge and we do not know exactly the weather condition, by applying these methods, it is feasible to precisely track the sun.
- Toward a simple roof-top project, it is not logical to have FLC or ANN since they are too expensive, also partial shading is not too much important in this case inasmuch as the process is not huge and all the modules approximately have an equal condition.
- Power lost is a very important matter. For example, if there is a huge solar panel in a desert, the power lost is too much while we want to transfer this electricity to the city, by the way in this case MPPT is not a critical issue, however, the cost is very important. Inasmuch as the power loss

is too much in this case. The tracker tracks the sun anyway, accordingly, it seems that tracking speed is not a significant category for selecting the best MPPT method.

A comprehensive analysis of MPPT methods is settled in the following table.

Table 2. Main properties of MPPT techniques [3, 11, 14]

| MPPT Methods | A / D | Sensors | Tracking Accuracy | Tracking Speed | Convergence Speed | Complexity | Cost | Efficiency |
|---|---|---|---|---|---|---|---|---|
| Constant Voltage Method | A / D | V | Medium | Fast | Low | Low | Low | Low |
| Constant Current Method | A / D | C | Medium | Fast | Low | Low | Low | Low |
| P & O | A / D | V & C | Medium | Slow | Normal | Low | Low | Moderate |
| Hill Climbing Method | A / D | V & C | Medium | Slow | Normal | Low | Low | Moderate |
| INC | D | V & C | High | Medium | Normal | Low | High | Good |
| dP/dI or dP/dV feedback control method | D | V & C | Medium | Medium | Fast | Medium | High | Good |
| Temperature-based Method | D | T & V | Medium | Medium | Fast | Medium | High | Good |
| FLC | D | V & C | Very High | Very Fast | Fast | Very High | High | Moderate |
| ANN | D | V & C | Very High | Very Fast | Fast | Very High | High | Moderate |
| Hybrid Method | D | Depends | High | Fast | Fast | High | High | Good |

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