

# A review on promising MPPT control methods of Photovoltaic System

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**Abstract.** The use of renewable energy is rapidly developing, especially the solar energy. Photovoltaic is one of the most promising energy sources. This paper presents a brief review on promising MPPT control methods of the Photovoltaic System. First, the overview of the basic photovoltaic system, the concept and basic theory of the widely used P&O MPPT control method is discussed. Then three of the promising improved MPPT control methods are chosen. Meaningful research on the main concept and basic theory of the three methods is covered. This paper collects some of the research results of these methods for comparison. At last, these three methods are compared in three important indexes: the tracking time, the complexity of implementation and the accuracy. These indexes indicate the efficiency, accuracy, and usability of these methods, which can be a meaningful reference for future applications and further research.

**Keywords:** Photovoltaic System, MPPT algorithm, artificial neural networks.

## 1. Introduction

According to the data from British Petroleum, the share of solar and wind energy has increased by 226 GW in 2021 [1]. The contribution of renewable energy (excluding hydro) to global power generation is rapidly increasing since 2018. In 2021, renewable energy shares almost 13% of global power generation since the solar and wind energy area has been enormously expanded [2]. In 2020, renewable energy took 83% of the newly installed generating capacity, which includes solar, wind and hydroelectric [3]. The data indicates that a clean and sustainable energy system is expected in the future and renewable energy will take more share in global power. In this process, Photovoltaic (PV) is the most important alternative renewable energy source until 2040 by many governments and companies [4].

In the application of the photovoltaic grid-connected inverter system, due to complex weather conditions, the light intensity is variable and the power is unfixed. The production of energy by the photovoltaic system is highly related to temperature and irradiation [5]. However, these factors are so random and hard to be controlled manually, so a control method called Maximum Power Point Tracking (MPPT) is widely used in PV systems to adjust the operating point of PV system timely to keep the system working always almost at the maximum power point [6].

In previous research, there are some widely used techniques, such as Perturbe and Observer (P&O), Incremental Conductance (INC), Fuzzy Logic Commands and other techniques. For example, Perturbe and Observer(P&O) is implemented through observing and adjusting the output voltage of the photovoltaic generator to move the operating point towards the maximum power point [7]. However, P&O is proven that it will cause the loss of power due to the perturbation. INC can make inaccurate responses since binary floating-point numbers cannot represent real values precisely, which has difficulty in finding the zero-value point on the slope of the P–V characteristic as the theory. Fuzzy Logic Commands can track MPP effectively and obtain a consistent MPPT algorithm, but a large memory and large scale of training are required and have poor adaptability to different environments [8].

Recently, some improved MPPT control methods have been published, which can enhance the performance of PV systems. This paper will focus on the comparison of several promising MPPT

control methods. The aim of this paper is to review these methods and provide ideas for further research and industrial application in the future.

The main research method is to summarize from previous research and collect data for comparison.

This paper starts with the basic theory of MPPT, and then focuses on three promising improved MPPT methods, including Golden Section Search-based MPPT Algorithm, Artificial Fish Swarm MTTP Algorithm, and a comparison of these methods. The basic concept and performance index of these MPPT control methods will be covered. Finally, a conclusion is given.

## 2. PV System Modeling

### 2.1. PV system

Figure 1 displays the main structure of the two-stage three-phase photovoltaic grid-connected inverter. It includes a PV array, a boost converter, a DC-AC converter, and an RL filter. A MPPT control model is applied to adjust the operation point timely according to the detected  $I_{pv}$  and  $V_{pv}$ . This two-stage topology structure has been proved to have good performance of independent adjustment of grid-connected control and maximum power tracking control [9].

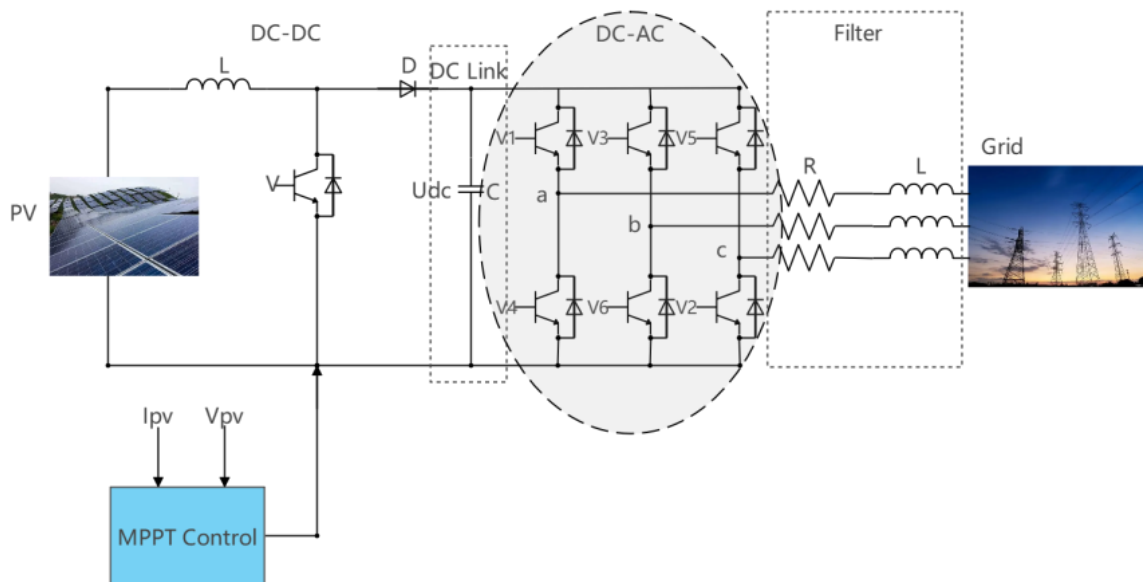


**Figure 1.** The grid-connected PV plant

### 2.2. Traditional MPPT algorithm

P&O method is a relatively mature algorithm at present, the basic working principle is: first, different directions and different sizes of disturbance are applied to the output voltage or current of the PV cell. Then, the output power difference after the disturbance in two adjacent periods is recorded. Finally, the direction of disturbance in the next period is determined by the comparison of difference and the direction of disturbance in the current period. After constant perturbation and observation, the system will gradually run to the maximum power point (MPP) [10].

However, different types of PV cells have different output characteristics, so the P&O control algorithm should adopt different disturbance step sizes according to different types of photovoltaic cells and different external environments. When the step size is small, the tracking speed of the MPPT algorithm decreases, but when it is close to the MPPT point, the power fluctuation is very low, which can improve the utilization efficiency of energy. When the step size is large, the tracking speed of the MPPT algorithm is fast, but when it is close to the MPPT, the power fluctuation is large, which brings a large power loss. Therefore, it is difficult to consider both the dynamic and steady performance of

the fixed-step algorithm [11]. The most used solution is called the variable step size of the MPPT algorithm. In Ref. [9], a more improved algorithm is given.

### 3. Improved MPPT algorithm

Based on the traditional P&O, INC, and other artificial algorithms, some promising improved MPPT algorithms have been published.

#### 3.1. Golden Section Search-based MPPT Algorithm

Ref. [12] put forward a method named golden section search (GSS) to combine with P&O and INC to build a multi-stage MPPT algorithm. This method can be combined with P&O and INC to build a multi-stage MPPT algorithm. In the first stage, according to the characteristic of P&O, a relatively large perturbation step should be chosen to quickly locate the MPP in a narrow range. Then, the second stage uses GSS to further narrow the range. After the interval width satisfies the GSS, the third stage uses INC to verify the MPP. When MPP changes, the system will repeat the whole process and start from the first stage to find the MPP again [12].

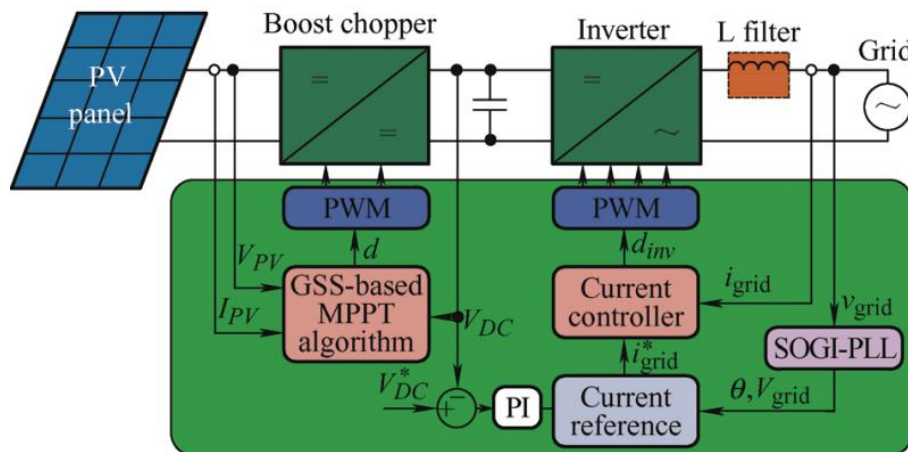


**Figure 2.** The diagram of a PV system equipped with GSS-based MPPT algorithm

Figure 2 presents the diagram of the single-phase grid-connected PV system equipped with GSS-based MPPT algorithm. PI compensators are used in both the boost chopper's voltage controller and the inverter's voltage controller. The Vref of the boost chopper's voltage controller is from the MPPT algorithm. However, the Vref of the inverter's voltage controller is set according to the amplitude of the grid voltage.

#### 3.2. Artificial Fish Swarm MTTP Algorithm (AFSA)

The Artificial Fish Swarm MTTP Algorithm is based on the previous swarm intelligence algorithm to realize the global optimization [13]. This algorithm is based on the behaviour of fish in nature and abstracts four principles from the behaviour.

The first is called AF-Random behavior, which means individual artificial fish often swims randomly in the water, in order to find a wider area of food or nearby companions.

This principle can be expressed as the following mathematical formula:

$$X_{i/\text{next}} = X_i + r \times \text{Sight} \quad (1)$$

Where  $r$  is the random number with domain  $[-1,1]$ , Sight is the maximum distance the artificial fish can detect.  $X$  is an  $n$ -dimensional vector which expresses the position of artificial fish, so  $X = (x_1, x_2, x_3, \dots, x_n)$ .  $X_i$  mean the position of the artificial fish and  $X_{i/\text{next}}$  means the next position.

The second is called AF-Swarm behaviour, which includes three rules. The separation rule means that artificial fish will try to avoid crowding with nearby partners. The alignment rule means that they will try to be consistent with the average direction of neighbouring partners. The cohesion rule means that they will move as close to the center as possible.

This principle can be expressed as the following mathematical formula:

$$X_{i/next} = X_i + rand() \times Step \times \frac{X_c - X_i}{\|X_c - X_i\|} \quad (2)$$

Where Step is the length that the artificial fish move at one time,  $X_c$  is the position of the center and  $\|X_c - X_i\|$  is the distance between the individual artificial fish and center.

The third is called AF-Prey behaviour, which means when artificial fish find food, they will swim quickly in the direction of increasing food. Suppose an  $X_j$  is randomly selected, the artificial fish will calculate the food density  $Y_j$ . If  $Y_j > Y_i$ , it will move in the  $X_j$  direction. This process can be expressed as the following mathematical formula:

$$X_{i/next} = X_i + rand() \times Step \times \frac{X_j - X_i}{\|X_j - X_i\|} \quad (3)$$

If  $Y_j$  does not satisfy the condition, it will perform as formula 4:

$$X_{i/next} = X_i + rand() \times Step \quad (4)$$

The fourth is called AF-Follow behaviour, which means when one or more artificial fish find food, its nearby partner will follow it quickly to the food spot. The mathematical formula is the same as formula 3. However,  $X_j$  in this situation is the position of another artificial fish whose  $Y_j$  is the largest in the range of detection.

### 3.3. An improved ANN based MPPT method

The artificial neural networks (ANNs) have been widely used in various areas. This technology can get the accurate solution in a short time from complex mathematical models. Many researchers have applied ANNs to MPPT systems to track the MPP more efficient and more accurate in various environments. ANN is tested to have better performance than P&O and ANFIS according to Ref. [13]. However, some researchers put forward improved ANN based MPPT methods to get a better performance.

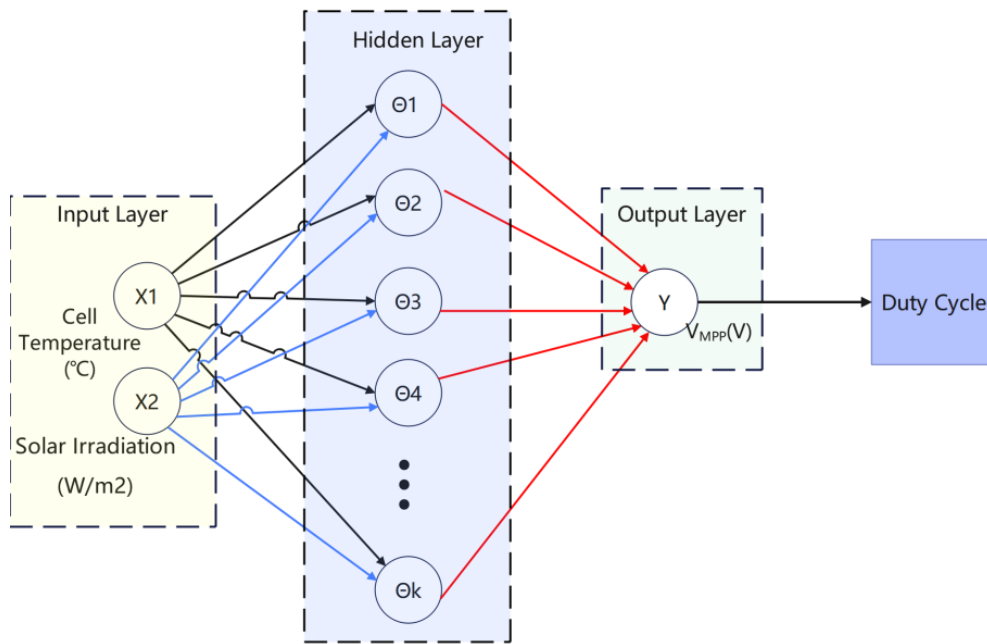


**Figure 3.** The basic ANN architecture for MPPT.

In traditional ANN based MPPT, cell temperature and solar irradiation are often chosen as the input parameters, which are applied to the DC-DC boost converter to adjust the PV voltage in order to achieve MPP.

M.Nour Ali introduces two alternative parameters called error signal ( $E$ ) and error signal change ( $\Delta E$ ) [14]. He can be calculated as formula 5.

$$E = \frac{dP_{dc}}{dV_{pv}} \quad (5)$$

This design detects the small change of  $E$  and responds to the tendency of  $\Delta E$ , which is more sensitive than using cell temperature and solar irradiation as inputs. When  $E = 0$ , the MPP is found. The GA optimization is also used to improve the ANN performance.

## 4. Comparison of the improved MPPT methods

In this section, the three improved MPPY methods are compared in four main aspects, including the structure, the tracking time, the complexity of implementation and the accuracy.

### 4.1. The comparison of the structure

These three methods are different in their structure.

The Golden Section Search-based MPPT consists of three main parts. This method combines P&O, INC together to build a multi-stage algorithm. The stages are ordered with the following sequence: P&O, GSS and INC.

The Artificial Fish Swarm MTTP Algorithm is a single-stage algorithm that uses AFS to find the MPP. AFSA is not a complex algorithm, but it has high efficiency and accuracy.

The improved ANN based MPPT method uses an improved ANN which uses different input from conventional ANN and equips with GA optimization to search the MPP, which is also a single-stage algorithm. However, ANN can have various structures according to the design for various applications.

In comparison, the golden section search-based MPPT is a multi-stage algorithm, while the others are single-stage algorithms.

#### 4.2. The comparison of the tracking time, the complexity of implementation and the accuracy

According to Ref. [6], [12], [14], the research results are shown in Figure 4.

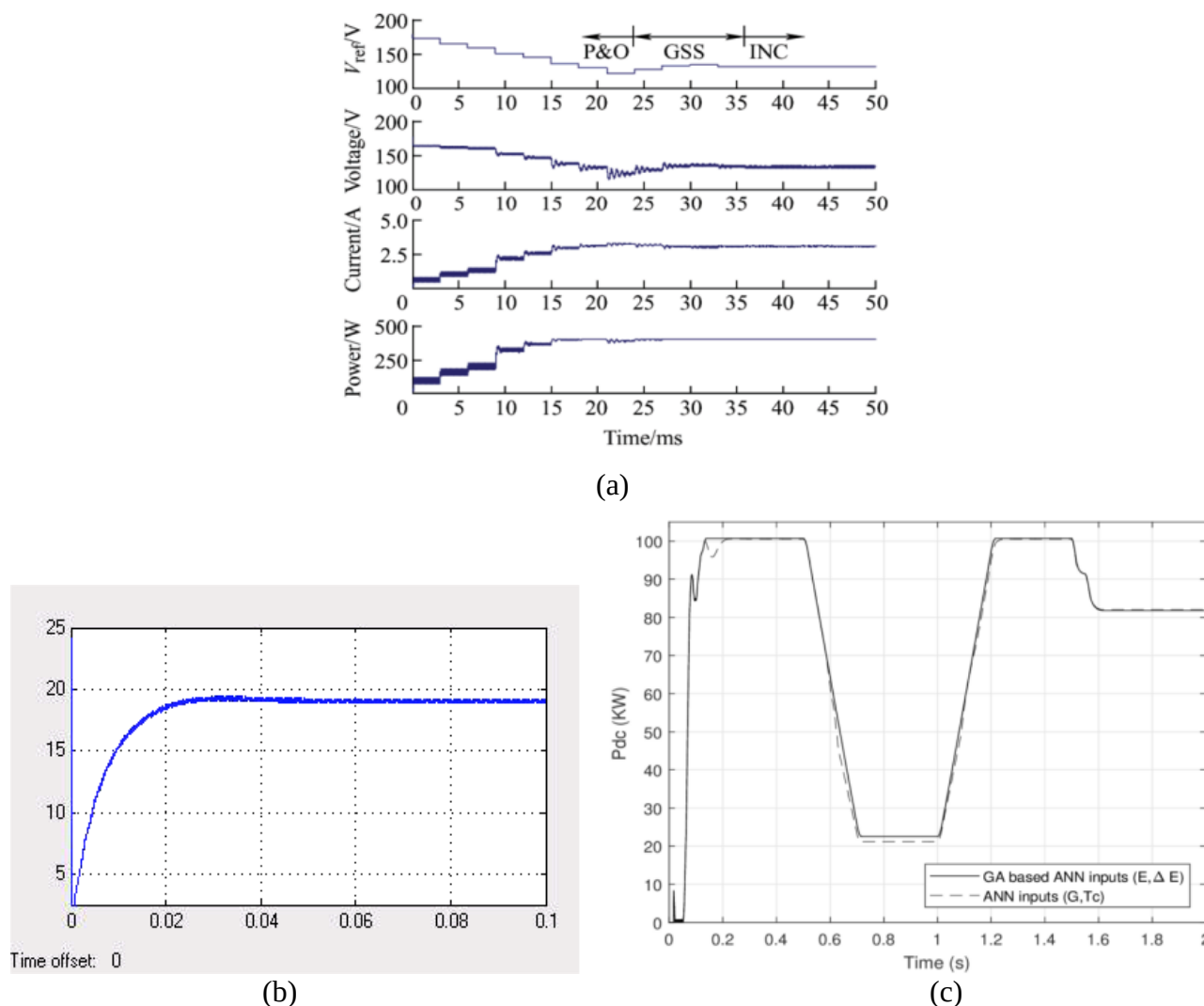


**Figure 4.** The output waveform of three improved methods. (a)GSS, (b)AFSA, (c) Improved ANN

It can be found that the three methods all achieve a stable output in a short time. In table 2, more details are provided.

**Table 1.** Major Characteristics of MPPT Algorithms

| Method name  | Tracking Time          | Implementation | Accuracy                            |
|--------------|------------------------|----------------|-------------------------------------|
| P&O          | Medium (28 500 ms)[12] | Simple         | 98.28 %[12]                         |
| GSS          | Very short (36 ms)[12] | Complex        | Very high (99.94%)[12]              |
| AFSA         | Short (1023 ms)[6]     | Simple         | Higher than P&O[6]                  |
| Improved ANN |                        | Medium         | Higher than manual designed ANN[14] |

As table 1 shows, in the comparison of tracking time, the Golden Section Search-based MPPT method takes a very short tracking time, the second is AFSA. The tracking time of improved ANN is

not included in the research, but it is at least shorter than P&O. The tracking time of AFSA is very short compared to P&O, but it still takes 25 times more time than GSS.

The complexity of implementation is highly related to the structure of the methods. So, P&O and AFSA are considered simple for implementation. GSS, due to the multi-stage design, is complex for implementation. The improved ANN is more complex than AFSA, but simpler than GSS.

The accuracy of GSS is tested to be very high (99.94%), the precise number of accuracies about AFSA and improved ANN are not mentioned. However, they are compared to other methods, and the results indicate that AFSA has higher accuracy than P&O and improved ANN has higher accuracy than manual designed ANN.

These methods all improve the tracking speed and accuracy, especially GSS. GSS takes advantage of both P&O and INC and overcome the flows of these conventional methods. AFSA provide the idea to use generally applicable artificial methods for MPPT control and is proved to have better performance than conventional P&O method. The improved ANN goes deeper in the Artificial Neural Network area and make the improvement, which follows the future trend in industry. However, some drawbacks still exist. Besides the complexity of implementation, GSS can only be applied to MPPT of unimodal function till now. Under the condition of partial shading, this algorithm needs to consider more points to locate the MPP [12]. The efficiency of Artificial Fish Swarm algorithm is high-related to the fish scale and maximum number of iterations. So, it requires high performance processor when applying to systems with large scale or complex environment. The improved ANN still faces with the common challenges of AI algorithms, such as the long training time and low adaptability to different environments.

## 5. Conclusion

In this paper, an overview of PV system and typical conventional MPPT control methods are provided. This paper chooses three promising MTTP control methods for comparison. The basic concept and performance index are summarized. The main advantages and disadvantages of these methods are covered. According to the research, GSS-based MPPT algorithm have the best performance. However, this method combines GSS, P&O and INC to build a multi-stage MPPT algorithm, which is complex. The biggest flaw of GSS is that it cannot be applied to multimodal functions. The Artificial Fish Swarm algorithm and improved ANN have fewer complex structures and have better performance than conventional MPPT control methods. These are promising techniques with the rapid development in the AI area. For AI algorithms, the main challenge is to improve the adaptability and shorten the training cycle. For the future research, this paper suggests that a more efficient and less complex MPPT algorithm can be realized with AI technology. The complexity can be reduced by using artificial neural networks. The future research can focus on shortening the training cycle of AI to make the MPPT control method more effecient and more adaptable. Also, the parameters chosen to detect the PV system may have better choices which can further improve the accuracy and promptness. These promising improved MPPT control methods are valuable for further research in the future.

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