

Key technologies for photovoltaic power generation

Wenrui Liu *

Leicester International College, Dalian University of Technology, Panjin, Liaoning, 124000, China

* Corresponding Author Email: 20203291020@mail.dlut.edu.cn

Abstract. In the face of the increasingly serious energy and environmental problems in the world, it is imperative to develop renewable energy, including photovoltaic power generation. The fact that photovoltaics is still in their infancy suggests that they have a lot of potential. Wide-ranging potential for solar power generation opens up a lot of room for the advancement of photovoltaic technology and industrial growth. Solar energy is mainly used for photovoltaic power generation system (PV system). Its main components are solar cells, batteries, controllers and inverters. Solar cells and MPPT technology are the two main structure in PV system. The development of solar photovoltaic power generation is the premise of the development of photovoltaic technology, because he is an important element of photoelectric conversion, which is related to the energy conversion of the entire system. MPPT voltage is a very critical parameter in the design of photovoltaic power plants. In this article, advantages and disadvantages of four different types of solar cells and their improvement methods will be expounded, while the MPPT technology starts from the traditional algorithm and the intelligent algorithm, with the introduction of several different algorithms. The final prospect of the two key technologies is given at the end of this paper.

Keywords: photovoltaic power generation, renewable energy, Solar cells, MPPT technology.

1. Introduction

New energy refers to the energy that has just been developed and utilized or is under active research and needs to be promoted, such as biomass energy, solar energy, wind energy, etc. Due to the finite nature of conventional energy and the rising importance of environmental issues, all nations are paying greater attention to new energy sources that are defined by environmental protection and renewable energy. Solar energy as a renewable energy source is inexhaustible, inexhaustible, and at the same time it is a clean energy source, without environmental pollution. Comparing solar energy to traditional energy, there are three key benefits to consider: It can be argued that it is endless and inexhaustible because it is the most plentiful energy that is available to mankind. Second, there is no transportation issue on earth because solar energy is present everywhere and can be generated and used locally. Thirdly, solar energy is a clean energy source that, when produced and used, won't create waste materials, waste water, waste gas, noise, or disrupt the natural equilibrium.

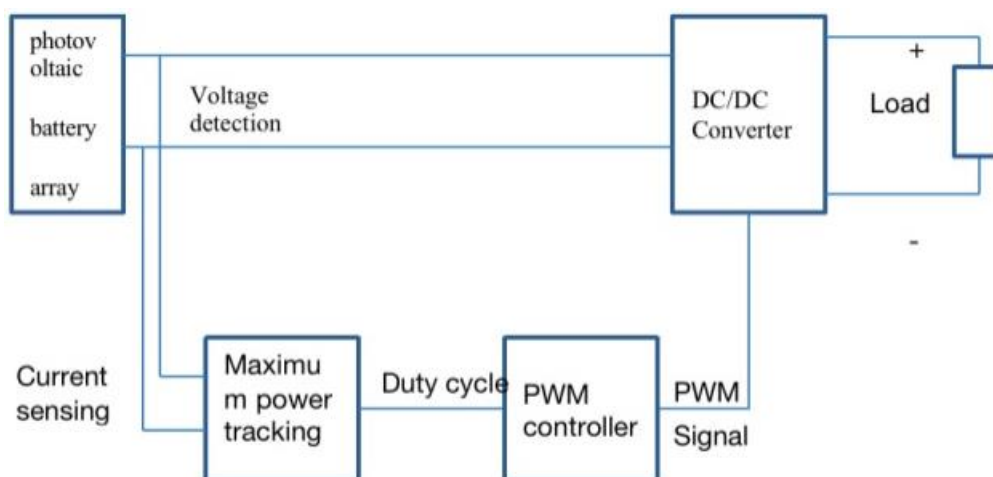


Figure 1. Block diagram of the pv system

Figure 1 demonstrated the system diagram of a PV systems. Generally, oone of the key

technologies for photovoltaic power generation is solar cells. The basis of the working principle of solar cells is the photogenerated volt effect of the semiconductor PN junction. There are many advantages of solar cells, including but not limited resources, no pollution to the environment, wide range of applications, low noise, solar cells have different kinds of materials, according to the material can be divided into several commonly used cells: silicon solar cells, inorganic salts Examples include functional polymer materials made of huge dol energy cells, nanocrystalline solar cells, gallium arsenide III-V compounds, cadmium sulfide, copper indium selenium, and other multi-compounds as components of the battery. According to statistics, 136 nations worldwide have contributed to the growth in solar cell adoption, of which 95 nations are actively researching and developing solar cells on a big scale and generating a range of associated new goods that save energy. Another crucial technical method for photovoltaic power generation is Maximum Power Point Tracking (MPPT). The operating voltage of the MPPT controller affects the output power of the photovoltaic cell, and only when it operates at the best voltage will it reach a specific maximum in terms of output power. When choosing different inverters for a photovoltaic system, the total power generation of the system can vary by 5% to 10%, with the inverter being the primary cause of this difference. The cost of the inverter in a photovoltaic system is less than 5%, but it is one of the key factors in the efficiency of power generation. The MPPT efficiency is the primary determinant of the photovoltaic inverter's ability to generate power, and it even outweighs the inverter's own efficiency in terms of significance. The hardware efficiency, which is mostly decided by the sampling circuit's accuracy, the MPPT voltage range, and the number of MPPT channels, is equal to the software efficiency multiplied by the hardware efficiency, and the software efficiency, which is primarily determined by the program. The advantages and enhancement techniques of several solar cell types are reviewed in this study, along with the introduction of a few MPPT-related algorithms.

2. Different types of solar cells

2.1. Silicon solar cells

2.1.1. Structure, Principle and Advantages

The structure of silicon solar cell is shown in the figure 2. And the silicon solar cell is made of semiconductor materials, and uses the photovoltaic effect of PN junction to directly convert light energy into electrical energy. Crystalline silicon solar cells and thin-film silicon solar cells can be distinguished by the silicon wafer's various thicknesses. Amorphous silicon (a-Si), microcrystalline silicon (c-Si), and polycrystalline silicon (p-Si) are the three types of thin-film silicon solar cells [1]. However, it is challenging to considerably lower the price of monocrystalline silicon due to its high cost. In order to conserve silicon materials, monocrystalline silicon solar cells have been replaced with multi-product silicon thin films and amorphous silicon films [1].

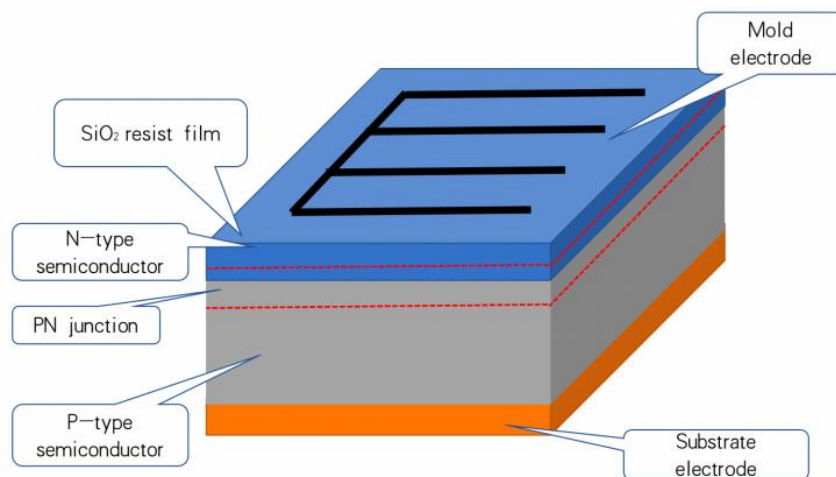


Figure 2. Structure of Silicon solar cells

Polycrystalline silicon solar cells often make use of cast polysilicon, low-grade semiconductor polysilicon, and other materials created specifically for solar cell application. In comparison to monocrystalline silicon solar cells, which are one of the main solar cell products, polycrystalline silicon solar cells are less expensive and have conversion efficiencies that are nearly as high. Polycrystalline silicon solar cells have low manufacturing costs and high module efficiency, and the efficiency of large-scale production has reached about 18%. Polycrystalline silicon solar cells occupy the mainstream, in addition to depending on the excellent performance of such cells, but also in its sufficient, cheap, non-toxic, non-polluting silicon raw materials source, and in recent years, the reduction of polysilicon costs will make polycrystalline silicon solar cells more popular [1].

Thin-film solar cells made of amorphous silicon have a lot of potential because they are lightweight and inexpensive, making them ideal for mass production. Amorphous silicon is a semiconductor with an amorphous crystal structure, meaning that its atomic structure is not consistently ordered like crystalline silicon's. Being a direct band material, amorphous silicon has a high solar absorption coefficient; a film merely 1 μm thick may absorb 80% of the sun's energy. The development of amorphous silicon thin-film solar cells was aided by the emergence of these devices in 1976, which came about as a result of a shortage of silicon raw materials and an increase in their price. Amorphous silicon thin-film batteries' inexpensive price makes up for their inefficient photoelectric conversion. The constructed solar cells, however, are ineffective and prone to the photoelectric efficiency reduction effect brought on by their materials. Additionally, the stability of the amorphous silicon in the sun is low, which has a negative impact on its practical applicability.

2.1.2. Promotion Methods

(1) TEXTURE: The surface of the bare silicon wafer reflects more than 30% of the light. In order to reduce the reflectivity of the silicon wafer surface to light, a bumpy suede structure is usually prepared on the surface of the silicon wafer. At present, the typical process is: using alkali corrosion method, a pyramid-like structure of 1–2-micron size is prepared on the surface of a single crystal silicon wafer; The acid corrosion method is used to prepare a black silicon structure on the surface of the polycrystalline silicon wafer. In this way, the reflectivity of the surface of monocrystalline and polycrystalline silicon wafers can be initially reduced to less than 10% [2].

(2) Aluminum backfield (BSF, Backside Field): Like the anterior surface, the presence of the dorsal surface also causes a compound loss of photogenerated carriers. In order to reduce the composite loss of photogenerated carriers in the back surface area, the industry first uses a layer of aluminum paste printed on the back surface of the silicon wafer, and then forms a silicon aluminum alloy layer by sintering, the alloy layer forms an electric field with the silicon body (called aluminum back field BSF), and its role is to drive back the small number of carriers (electrons) that move to the back surface area back into the silicon body material, thereby reducing the composite loss of the photogenerated carrier on the back surface, so as to improve the conversion efficiency[3].

2.2. Dye-sensitized solar cells

2.2.1. Structure, Principle and Advantages

Nanoporous semiconductor films, dye sensitizers, redox electrolytes, counter electrodes, and conductive substrates make up dye-sensitized solar cells (Figure 3). The dye molecules adsorbing on the titanium dioxide photoanode's surface are excited from the ground state S to the excited state S^* when sunlight strikes the battery's surface. Subsequently, an electron is injected into the titanium dioxide conduction band, causing the dye molecule to change to the oxidized state S^+ . An electric current is created when the electrons that are injected into the titanium dioxide layer are enhanced into the conductive substrate and travel through the external circuit to the counter electrode. The dye molecules in the oxidized state obtain electrons from the electron donor in the electrolyte solution and return to the reducing state themselves, so that the dye molecules regenerate. The oxidized electron donor diffuses to the counter electrode, obtains electrons on the surface of the counter electrode, and is reduced, thereby completing a photochemical reaction cycle. Due to the advantages

of low cost, simple production process and good stability, this battery has gradually entered people's field of vision [3].

Dye-sensitized solar cells use nanocrystalline semiconductor porous membranes as photoanodes, and the roughness of their surface makes the entire semiconductor film spongy, with a large surface area, which can adsorb more dye monolayers. This not only overcomes the shortcomings of the original solar cell that can only adsorb a single molecular layer and absorb a small amount of sunlight, but also enhances the absorption of sunlight by dyes, resulting in a larger photocurrent [4].

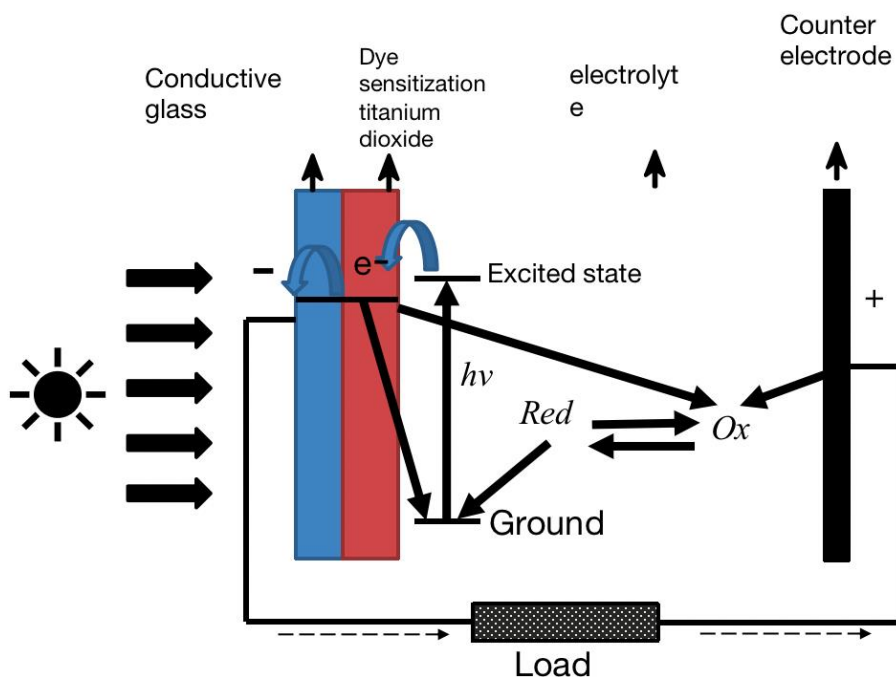


Figure 3. The structure of Dye-sensitized solar cells

2.2.2. Promotion Methods

In the dye synthesis technology, nano-semiconductor thin film analyses, battery sealing and electrode development to implement certain results, design and synthesis of a variety of new dye photosensitizers and study the impact of their adsorption properties and spatial effects on sensitization performance, the synthesis of key technologies to prepare $15 \times 20 \text{ cm}^2$ solar cell modules. The Changchun Institute of Applied Chemistry of the Chinese Academy of Sciences realized a breakthrough in the study of new dyes and ionic liquid electrolytes, and they studied dye C101 based on mixed ionic liquid electrolyte batteries, resulting in higher conversion efficiency [5].

2.3. Perovskite solar cells

2.3.1. Structure, Principle and Advantages

Since 2009, new solar cells based on organic-inorganic perovskite materials have received widespread attention, and in just a few years, their energy conversion efficiency has rapidly increased from 3% at the beginning to more than 15% and set off a analyse boom internationally. With the further development and maturity of the battery process, perovskite solar cells are expected to obtain energy conversion efficiency of more than 20%, and have a wide range of application prospects [6].

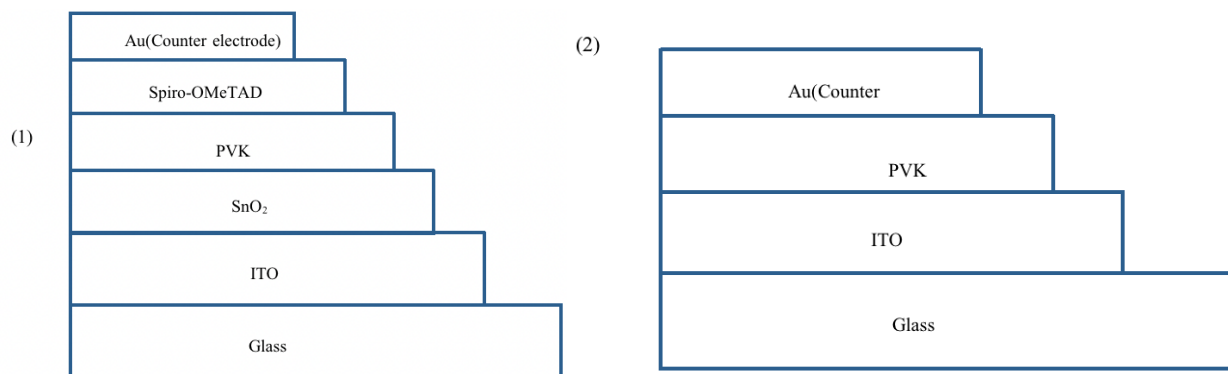


Figure 4. Structure of perovskite solar cells

The typical structure is shown in the figure 4. Depending on how the five essential functional layers are arranged, it can be divided into nip-type structures and pin-type structures. And the photogenerated volt effect serves as the fundamental tenet of perovskite solar cells, and the mechanism by which they function can be broadly classified into five processes: photon absorption process, the diffusion of excitons, exciton dissociation process, then exciton dissociates, free carriers are produced, free electrons and free holes are collected by the cathode layer and the anode layer. Closed loop is created between the battery and the applied load, and a current is created there.

The most basic component of calcium battery performance is the light absorption layer. High-efficiency solar cells require the light absorbing layer to be able to fully absorb photons in the near-ultraviolet-visible-near-infrared region to generate a light excited state, which is the key process that determines whether the next step of charge separation can be accomplished. In perovskite solar cells, the photo resorption layer with high crystallinity and good uniformity is more conducive to the generation and separation of photoelectric loads, resulting in higher efficiency.

2.3.2. Promotion Methods

The preparation process of the dense layer of perovskite batteries is changed by optimizing the morphology of perovskite-type materials, the performance of perovskite solar cells can be effectively improved. By using CH, NH, and Cl as morphological control agents, the researchers obtained a dense and smooth perovskite layer, in which the requirements for temperature, humidity, and preparation time of perovskite thin film crystallization were significantly reduced, and the photoelectric conversion efficiency of perovskite solar cells prepared by applying this material was significantly improved [7]. At present, the effect of nanoscale pores in dense layers on thin film resistance and battery properties was studied by high-resolution topography analysis of TiO₂ films with different morphologies prepared by spin coating, spraying and atomic layer deposition method. The findings indicate that the hole barrier layer's high compactness is crucial. Additionally, by successfully preventing physical contact between the conductive electrode and the light-absorbing layer, the energy and charge loss brought on by interface charge recombination can be significantly reduced, increasing the device's parallel resistance and overall energy conversion efficiency [6].

2.4. Organic solar cells

2.4.1. Structure, Principle and Advantages

The idea behind organic solar cells is to create voltage to create a current with a photovoltaic effect by using organic matter with photosensitive qualities as a semiconductor material. The primary organic compounds that are photosensitive have a conjugated structure and conductivity, such as cyanine (cyanine), porphyrins, and phthalocyanine compounds.

Depending on the semiconductor materials used, organic solar cells can be classified as having an elemental junction structure or a P-N heterojunction structure.

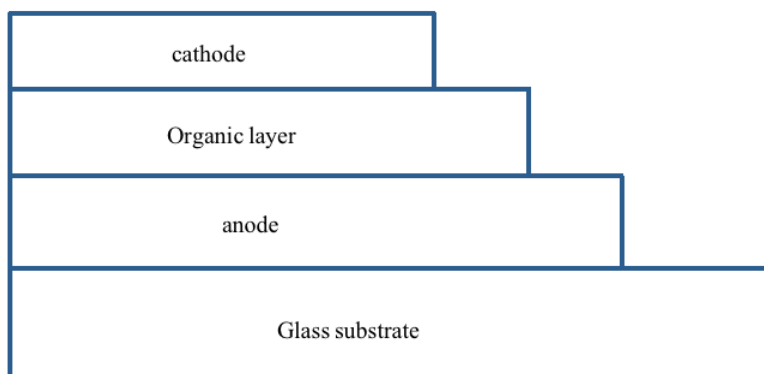


Figure 5. Elemental junction organic solar cells

The components junction structure is an organic solar cell. The device's components are made of glass, metal electrode, dye, and metal electrode. It creates an electric field by moving electrons from the metal electrode with low work function to the electrode with high work function, which results in photocurrent. They all receive their electron-holes from the same substance; hence their photoelectric conversion rate isn't very high.

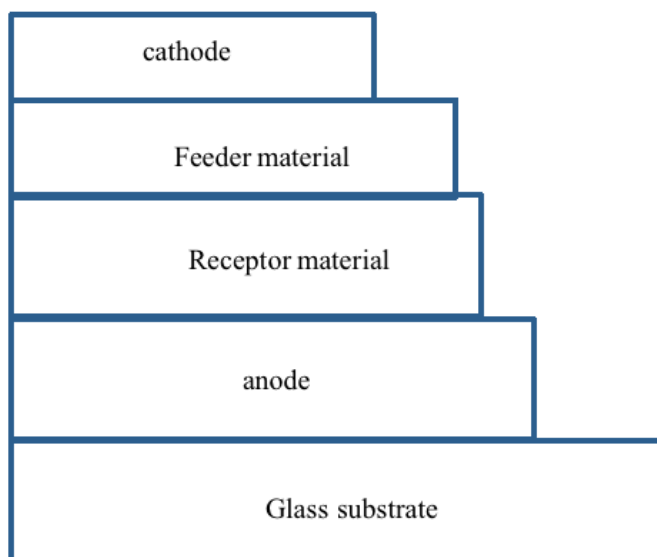


Figure 6. p-n hetero junction organic solar cells

The term P-N heterojunction structure refers to this structure, which is seen in Figure 5 and 6, and features a heterojunction structure of the donor-acceptor. Most of them are dyes, such as phthalocyanine compounds and paraphthalaldehyde imide compounds, which use the D/A interface between semiconductor layers (Donor, Acceptor) and electron-hole locations in various materials, respectively, to increase the separation efficiency. The advantages of inorganic and organic molecules were combined by Elias Stathatos et al. to achieve a photovoltaic conversion rate of 5% to 6%.

Organic solar cells are the use of organic materials "photogenerated volt effect", organic materials absorb incident light to generate excitons, excitons under the action of built-in electric field at the interface of the receptor charge separation to generate carriers (that is, free holes and free electrons), free holes and free electrons are transmitted to the two electrodes to generate current. The advantage of organic solar cells is that the raw materials used are polymer molecules, which are inexpensive, simple in process, and easy to realize flexible foldable preparation [8].

2.4.2. Promotion Methods

Organic solar cell cathodic modification layer process changes. Organic solar cells are mainly composed of an active layer, anode modification layer and cathodic modification layer. The anodized layer material is available with PEDOT: PSS, a commercially available conductive polymer with excellent performance (figure 7). In contrast, cathode modification layer materials currently have

large problems, they either contain ammonium salt groups, which accelerate device attenuation of ion diffusion, or are amine compounds, whose amino decomposition cyanoindone non-fullerene receptors, or low conductivity, film thickness dependence.

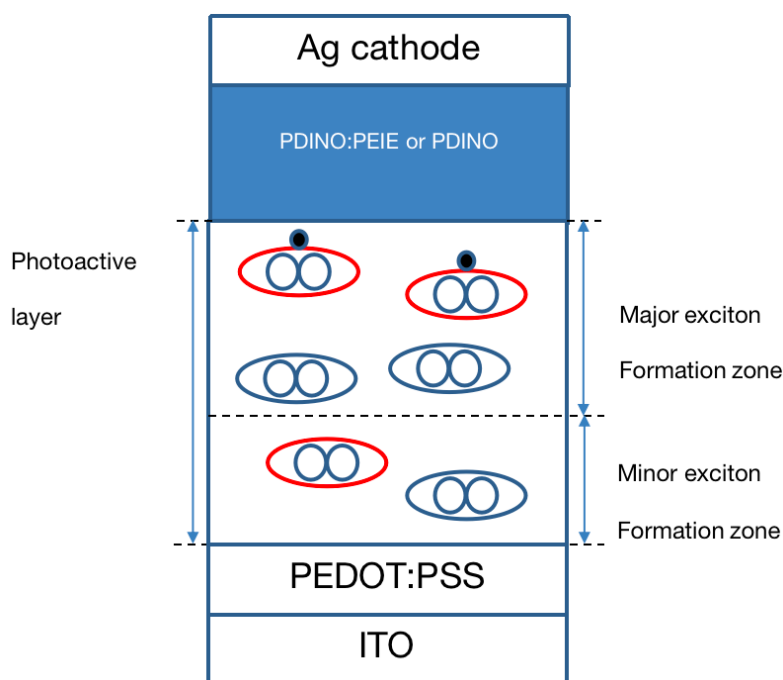


Figure 7. Organic solar cells (the yellow part of the figure is a cathodic modification layer)

The organic photovoltaic device prepared with ZnO as the cathode modification layer, with the new high-efficiency organic material PM6:Y7 as the active layer system, increased the efficiency of the device by 10.87% by changing the proportion of the recipient, the thickness of the active layer, the annealing temperature, and the annealing time. When the concentration is 2%, the JSC of the device is increased by 5%, and the efficiency is further increased from 14.58% to 15.16%, which verifies that a certain concentration of additives will affect the morphology of the active layer, which can make the surface of the film smoother and the interface contact between the electrode and the semiconductor is better [9].

3. Maximum Power Point Tracking (MPPT)

In the solar photovoltaic power generation system, photovoltaic cell module is the most basic component. To improve the efficiency of the entire photovoltaic system, it is necessary to improve the conversion efficiency of photovoltaic cells. Therefore, it is hoped that photovoltaic cells will work at the maximum power point to maximize the conversion of light energy into electrical energy.

3.1. Classification of algorithms

In the process of photovoltaic MPPT control, the algorithm is usually divided into traditional algorithms and intelligent algorithms, of which the traditional algorithms mainly include curve quasi-legal, table lookup method, fixed voltage method, fixed current method, open circuit voltage proportional method, open current proportional method limited cycle disturbance method, disturbance observation method, conductivity increment method, intermittent variable step search method, power stepping method, intelligent algorithm can generally be divided into fuzzy control method, expert system control, swarm intelligence algorithm (including more classic genetic algorithm, ant colony algorithm, Particle swarm algorithms, etc.), neural network control, etc. Several of the algorithms are going to be introduced are shown in the figure 8 below.

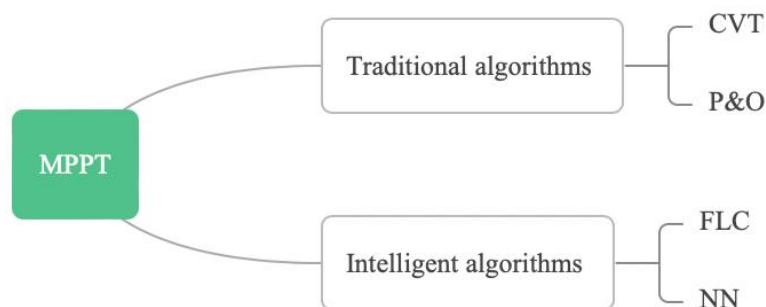


Figure 8. Classification of MPPT algorithms

3.1.1. Traditional Algorithms

(a) Constant voltage tracking method: One of the simplest maximum power tracking techniques is the constant voltage method, sometimes known as CVT (Constant Voltage Tracking).

The goal of the constant voltage tracking approach is to regulate the solar cells' output voltage at their maximum power point voltage so that they operate close to their maximum power point [10].

The operating voltage stability of the system is enhanced with CVT control, and the control is also straightforward and simple to use. The method also has some obvious drawbacks, including poor maximum power point tracking accuracy, a lack of adaptability to changes in the system's external environment when the maximum power point changes, and a significant negative impact on system performance when the system working voltage is set incorrectly.

(b) Interference observation method: The interference observation method, or P&O method for short, is the Perturbation and Observation Method. It is based on the P-U output of the photovoltaic cell array, the introduction of small variables, observation after the comparison of the results of the comparison of the results of the photovoltaic cell adjustment.

By adjusting the output voltage of the photovoltaic cell array and real-time sampling of the output voltage and current, the output power is determined. The output power is then compared to the power acquired the first time; if it is higher, it means that the disturbance is coming from the right direction and hasn't altered from the first direction. If it is lower than the initial power, the output power should be reduced and the output voltage of the solar cell should be reduced, causing the disturbance, observation, and comparison to be repeated until the photovoltaic cell array is operating at its peak power. To achieve the tracking control of the maximum power point, the output voltage of the photovoltaic cell array must be changed by changing the duty cycle of the switch such that it realizes $P/U = 0$ at the maximum power output point [11].

The interference observation method's main benefits are its straightforward structure, manageable measurement requirements, and straightforward implementation. The interference observation approach has drawbacks. First, a significant amount of power is lost as a result of the solar cell array oscillating close to its maximum power point. Second, the tracking step cannot be considered for both tracking accuracy and tracking speed at the same time. If the tracking step is too large and causes oscillation near the maximum power point, the tracking accuracy is decreased. However, it is frequently too small and causes the tracking speed to be relatively slow, allowing the photovoltaic cell array to work in the low power output area for an extended period of time. Third, poor judgment happens when the outside environment abruptly changes.

3.2. Intelligent Algorithms

In the standard environment, the output characteristic curve of the photovoltaic array presents a single peak, however, it is difficult for us to establish the photovoltaic array in a place that will not be affected by the external environment at all in actual life, in the process of photovoltaic array work, it will often be obscured by clouds and trees, forming a local shadow, in order to avoid causing the output characteristic curve of the photovoltaic array to present multiple peaks, in order to solve this problem, the maximum power tracking control method based on intelligent algorithms has been widely proposed and successfully applied; These methods include fuzzy logic controller (FLC),

sliding mode control (SMC), etc. Several common smart maximum power tracking control methods are analyzed below.

A popular artificial intelligence system known as MPPT based on fuzzy logic controller is built using a collection of fuzzy rules. Three steps can be used to implement a control rule: fuzzy, control rule assessment, and defuscation. The primary function of FLC is system control using linguistic rules that reflect the expertise and experience of experts. Furthermore, FLC has good dynamic and steady-state performance because it can track MPP quickly and maintain MPP in steady-state situations without fluctuation. However, the fundamental drawback of FLC is that drift and implementation complexity can be brought on by variations in irradiance. The definition of fuzzy sets, choosing the shape of membership functions, and creating rule tables all need additional knowledge and intuition from designers, which has a direct impact on tracking's speed and precision [12].

It is suggested that the sliding mode control exploit control discontinuities by forcing the closed-loop system to move to and stay on the sliding surface of the design via high-frequency transformations. The switching device modulation depth step that is chosen will have an impact on the dynamic and steady-state features of the system tracking, however this technique can greatly increase the tracking speed of solar systems. The tracking speed can be quickened when the AU rises, but this also causes the solar array's output power and voltage to fluctuate more [12].

4. Summary and Outlook

Table 1. Summary of solar cells

Types of solar cells		Advantages	Ways to improve
Silicon solar cells	Monocrystalline silicon solar cells	The highest efficiency and the most mature technology	Innovation in surface processing technology
	Polycrystalline silicon solar cells	Low manufacturing costs and high component efficiency	
	Amorphous silicon solar cells	Low cost and low weight, easy to mass production	
Dye-sensitized solar cells		Low cost, simple production process, good stability	Dye synthesis technology, nano-semiconductor thin film research, battery sealing and electrode development
Perovskite solar cells		High photoelectric conversion efficiency, flexible preparation, low cost	The dense layer preparation process changes
Organic solar cells		Low cost, simple process, flexible folding preparation	Cathodic modification layer process changes

Table 2. Summary of MPPT

MPPT algorithm		Advantages	Disadvantages
Traditional algorithms	Constant voltage tracking method	Good stability, simple control, easy to implement	The maximum power point tracking accuracy is poor
	Interference observation method	Simple sturcrue, easy parameters under test	Power loss, loss of accuracy
Intelligent algorithms		Solve the situation where there are multiple peaks in the traditional algorithm, such as FLC and SMC.	

References

- [1] Huang Q, Lin J and Wei C, et al. Application research and progress of silicon solar cells. *Materials Development and Application*, 2009, 24 (6): 4.
- [2] Zhang J. Exploration of monocrystalline silicon fleece making process. Zhejiang Normal University, 2021.DOI: 10.27464/d.cnki.gzsfu.2021.000180.
- [3] Chen Y. Study on the characteristics of aluminum backfield of monocrystalline silicon solar cells. Central South University, 2010.
- [4] Qin G, Yuan X and Li X. Research Progress on Dye Sensitizers for Dye-Sensitized Solar Cells [J]. *Journal of Chaohu University*, 2009 (3): 9.
- [5] Zhao Y, Dai S and Sun Y, et al. Research status and development trend of thin-film solar cells. *Nature Journal*, 2010, 32 (3): 6.
- [6] Yang X, Chen H and Bi E, et al. Key problems in the development of high-efficiency perovskite solar cells. *Acta Physica Sinica*, 2015(3):10.
- [7] Xi M. Research Progress of Perovskite Solar Cells. *Chemical Management*, 2021(26):43 44.DOI: 10.19900/j.cnki.ISSN1008 - 4800.2021.26.022.
- [8] He Y, Zhang W, Yang J and Chen C. Research Progress of Organic Solar Cells. *Special Equipment for Electronics Industry*, 2022, 51 (02): 5 - 9.
- [9] Zhou Y. Exploring ways to improve the photoelectric conversion efficiency of organic solar cells through comparative research on cathodic modifier layers and new materials. Beijing Jiao tong University, 2020.
- [10] Zhao C. Research on maximum power tracking control system of photovoltaic power generation system. Chang'an University, 2018.
- [11] Cui Y, Cai B and Li D, et al. Comparative study on MPPT control algorithm of solar photovoltaic system. *Journal of Solar Energy*, 2006, 27 (6): 5.
- [12] Mao M, Cui L, Zhang Q, Guo K, Zhou L and Huang H. Classification and summarization of solar photovoltaic MPPT techniques: A review based on traditional and intelligent control strategies. *Energy Reports*, 2020 (6): 1312 – 1327.