Solar Maximum Power Point Tracking Algorithm Based on Wavelet Neural Network

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Abstract

With the development of human civilization, the shortage of resources and environmental pollution are increasing. Renewable energy is the only way to solve the problem of harmonious coexistence between human civilization and the environment. More and more of them have come into our lives to reduce the burden of the earth and benefit mankind. Nowadays, due to the increasing gap of traditional power supply, solar energy has become a mainstream renewable energy, with more and more applications, to provide us with green energy and improve our lives. The research on the application of solar energy systems is of great academic value. This paper mainly studies the solar maximum power point tracking (MPPT) algorithm based on wavelet neural network (WNN). This paper analyzes several common maximum power tracking control methods, describes the structure design of WNN maximum power tracking control algorithm, and describes the structure and working principle of photovoltaic cells. In this paper, the output power of MPPT mode is analyzed and compared by simulating the use of solar photovoltaic systems. In the meantime, the output voltage of the solar charging panel in the charging process is studied. The experimental results show that the output power of the power supply in MPPT mode is kept at 0.2, and the output power of the solar panel is improved at every moment with the change of the external environment. At 9 o'clock, the output voltage of the solar panel is 3.6, and at 11 o'clock, the output voltage is 4.11.

Keywords: Wavelet Neural Network; Solar Energy; Maximum Power Point (MPP); Tracking Algorithm

1. Introduction

With the continuous loss of resources, the use of renewable energy is a hotspot to solve the current energy development [1, 2]. The development and utilization of solar energy in human society has a long history, and the energy of solar radiation is beyond our imagination. China has a vast land area and rich building area, which provides the most basic conditions for the development of the solar energy industry [3, 4]. Solar energy has the advantages of unlimited raw materials and resources, clean and pollution-free, wide radiation range, etc., and has broad development prospects. Under the national policy of vigorously encouraging the development of the solar energy industry, the solar energy industry has shown an upward trend, providing an important energy base for China's low-carbon economic development [5, 6]. However, the conversion efficiency of solar panels is relatively low. Because of the bottleneck of the conversion efficiency of solar panels, it is very necessary to adjust its working point in actual use, so that the solar panels always work at the MPP regardless of the light intensity and ambient temperature, providing the maximum power output to the load [7, 8]. In the solar photovoltaic power generation system, by maximizing the output power, the utilization efficiency of photovoltaic cells can be effectively improved, and the application of solar panels can be improved [9, 10].

The use of solar power as a renewable energy source has gained significant attention in recent years due to its potential to reduce dependence on fossil fuels and decrease carbon emissions. However, one major challenge in the use of solar power is the efficient tracking of the maximum power point (MPP) of the solar panel. The MPP is the point on the power-voltage (P-V) curve where the solar panel generates the most power. To address this challenge, various MPP tracking algorithms have been proposed, including the use of wavelet neural networks (WNNs). WNNs are a combination of wavelet theory and neural networks, which have been shown to be effective in nonlinear and non-stationary systems. In this research, we propose a new MPP tracking algorithm based on WNNs for solar power systems. The proposed algorithm uses the WNN to model the nonlinear relationship between the solar panel's output power and the environmental factors, such as temperature and irradiance, that affect it. We aim to evaluate the performance of the proposed algorithm and compare it with other existing MPP tracking methods.

In addition to the proposed algorithm, we also aim to investigate the impact of different wavelet functions and network architectures on the performance of the WNN-based MPP tracking algorithm. The selection of the appropriate wavelet function and network architecture is crucial for achieving high accuracy and stability in the MPP tracking process. We will conduct a comprehensive analysis of different wavelet functions, including Haar, Daubechies, and Symlets, and different network architectures, such as feedforward neural networks, radial basis function networks, and multilayer perceptron networks.

Furthermore, we will implement the proposed algorithm on a practical photovoltaic (PV) system to evaluate its performance under real-world conditions. The PV system will be equipped with sensors to measure the environmental factors, such as temperature and irradiance, and the output power of the solar panel. The data collected from the PV system will be used to train and test the WNN-based MPP tracking algorithm. The results obtained from the practical implementation will be compared with the simulation results to validate the effectiveness of the proposed algorithm.

In summary, this research aims to propose a new MPP tracking algorithm based on WNNs for solar power systems and to investigate the impact of different wavelet functions and network architectures on the performance of the algorithm. The proposed algorithm will be evaluated using simulations and practical implementation on a PV system, and the results will be compared with other existing MPP tracking methods. The successful implementation of the proposed algorithm can improve the efficiency of solar power systems and contribute to the widespread adoption of renewable energy sources.

In the research of the solar MPPT algorithm, many scholars at home and abroad have studied it and achieved good results. Harrag pointed out that the use of solar energy is completely pollution-free, and the pollution and emission in the production process of solar photovoltaic panels can be completely controlled. By improving the production process, the environmental pollution in the production process of solar photovoltaic panels can be effectively reduced or even eliminated [11]. Sharma DK pointed out that when solar energy is used to obtain electric energy, it is necessary to convert light energy into electric energy through solar panels, and then use or store energy in energy storage elements through controllers [12].

The main content of this paper is the solar MPPT algorithm based on WNN. This paper analyzes several common maximum power tracking control methods, describes the structure design of WNN maximum power tracking control algorithm, and describes the structure and working principle of photovoltaic cells. In this paper, WNN MPPT algorithm structure is used to track and calculate the MPP of solar energy, and the output power of MPPT mode is analyzed and compared by simulating the use of solar photovoltaic systems. At the same time, experiments on solar panels are carried out to prove that the MPP of solar energy can be tracked.

2. Literature Review

In recent years, various MPP tracking algorithms have been proposed for solar power systems. Some of the most popular MPP tracking algorithms include:

- Perturb and Observe (P&O) method: This is one of the most widely used MPP tracking algorithms. It is a simple and efficient method that perturbs the operating point of the solar panel and observes the change in the output power. The operating point is then adjusted to the direction of the maximum power [11].
- Incremental Conductance (IC) method: This method is similar to the P&O method, but it uses the incremental conductance of the solar panel to track the MPP. It is more accurate and faster than the P&O method, but it requires a higher sampling rate [12].
- Artificial Neural Network (ANN) method: This method uses an ANN to model the relationship between the solar panel's output power and the environmental factors that affect it. The ANN is trained using historical data, and then it is used to predict the MPP in real-time. The advantage of this method is that it can handle nonlinearities and variations in the solar panel's characteristics.
- Fuzzy Logic (FL) method: This method uses fuzzy logic to track the MPP. It is based on the idea that the MPP can be found by adjusting the operating point of the solar panel based on the fuzzy rules that describe the relationship between the solar panel's output power and the environmental factors that affect it.
- Hybrid methods: This category includes various methods that combine two or more of the above methods to achieve better performance. For example, a hybrid of P&O and ANN method, or P&O and fuzzy logic method.

- Wavelet Neural Network (WNN) based MPPT algorithm is a relatively new method which is gaining popularity in recent years. The WNN is a combination of wavelet theory and neural networks, which have been shown to be effective in nonlinear and non-stationary systems. A number of researchers have proposed the use of WNNs for MPPT of PV systems, and the results have shown improved performance in comparison with traditional methods.

In conclusion, the literature review indicates that various MPP tracking algorithms have been proposed for solar power systems, including P&O, IC, ANN, FL, and hybrid methods. Among them, the WNN based MPPT algorithm is a new and promising method that has shown improved performance in comparison with traditional methods. Further research is needed to explore the full potential of WNNs in MPP tracking and to compare the performance of WNN-based methods with other existing methods.

2.1. Common MPPT Control Method

Constant voltage control method

If the temperature of the solar photovoltaic cell changes little, the MPP on the output characteristic curve of the solar photovoltaic cell is almost distributed on both sides of the vertical line. If the output voltage of the solar photovoltaic cell can be adjusted at the MPP, the solar photovoltaic cell will work at the MPP. This method is easy to control and implement. The system will not fluctuate due to the sharp change of the above voltage and has good stability [13].

Disturbance observation method

Disturbance observation method is one of the common methods to realize MPPT. The change of voltage often causes the output power of solar photovoltaic cells to change in a larger direction. In fact, it is an adaptive process. By determining the output voltage and current of the solar cell, the output power of the array can be determined, and then the performance of the array is compared with the previous effect, so that the array can operate at the maximum power state. The idea of this method is very simple and easy to implement [14].

MPPT algorithm of neural network

Neural network MPPT algorithm is an algorithm which uses a neural network to predict the MPP of photovoltaic power generation systems. Neural network is a kind of information processing technology. The commonly used neural network structure is generally composed of three layers of neurons, the number of neurons in each layer is determined by the difficulty of the problem to be solved [15]. When neural network is applied to the field of photovoltaic power generation, the input layer parameters of neural network can be light intensity, ambient temperature, time or other parameters, such as open circuit voltage, short circuit current and so on, and even the combined quantity of all these parameters can be used as the input of MPPT algorithm of neural network, while the output quantity is only the voltage at the MPP. However, the selection of hidden layers needs to be determined according to the actual situation, which cannot provide a unified standard. The MPPT algorithm of WNN is used in this paper.

2.2. Structure Design of WNN MPPT Algorithm

The MPPT algorithm structure of WNN adopts a three-layer network structure. In the network, as long as the three discrete variables of ambient temperature, light intensity and time are input, the voltage at the MPP can be obtained, so that the solar photovoltaic cell can adjust the output and always keep the maximum power to charge the battery, so as to improve the conversion efficiency of solar energy [16]. The WNN MPPT algorithm has the same intelligent characteristics as an artificial neural network. It needs to learn in the network, and constantly adjust the weights and thresholds of neurons in the process of learning. According to the characteristics and learning forms of the network, it can be divided into supervised learning, unsupervised learning and re-inspired learning. Tutored learning provides a kind of input signal and output signal, compares the error between the theoretical learning value and the actual output value of the network, and adjusts the weight through the feedback error. In the process of unsupervised learning, there are no input and output signals, so we can find the potential law of information through the network itself. Re incentive learning is the combination of two learning methods, which can improve self-performance by strengthening the results obtained. In the WNN MPPT, the supervised learning method is used to adjust the optimal network structure by giving the modulation weights and thresholds of input and output.

2.3. Structure and Working Principle of Photovoltaic Cells

Photovoltaic solar panels are the most important part of the whole independent photovoltaic power generation system. Only through the solar panel can we convert the solar energy that we can't use into the power we need. The material of solar panels is semiconductor, mainly crystalline silicon [17-20]. These crystalline silicon have photosensitive properties. When exposed to light, the number of carriers will increase with the increase of light intensity, and the external conductivity of the semiconductor will be stronger and stronger. Large area p-n junction made of silicon material with N / P homojunction structure can be used as a photovoltaic cell. There are electron and hole pairs in the base layer. The electron and hole pairs are obtained by diffusion at the contact place of P-N junction. Through the diffusion movement of electron and hole pair, the hole with less electron is shown as a positive electrode. The N-type is covered with metal film, and the gate line is used as a positive electrode, the P region of the multiple electrons is covered with a metal film as a negative electrode.

2.4. Structure of WNN MPPT Algorithm

In the input layer, there are three inputs, namely x1, x2 and x3, which represent the light intensity, ambient temperature and time series values respectively. We cannot determine the number of neurons in the hidden layer. Here, we use n to represent, n generation 1,2,3,4..., and output only one neuron, that is, the voltage at the MPP. W is the weight, i, j is two neurons, m is the number of layers. B is the output of the upper neuron, a is the input of the neuron, j, k is the kth input of the jth neuron, and m is the number of layers, the relation expression can be expressed as follows:

$$a^{m}jk = \Sigma_{i} w_{jk}^{m} b_{ik}^{m-1}$$

$$b_{jk}^{m} = \varphi\left(a_{jk}^{m}\right)$$

On the basis of wavelet analysis theory, it makes the determination of network results have a certain significance, and also provides a theoretical basis for the structure of WNN, avoiding the blindness and experience of design.

3. Research Method

An experimental study is a crucial step in evaluating the performance of a proposed MPP tracking algorithm for solar power systems. The experimental setup typically includes a solar panel, a maximum power point tracker (MPPT), a data acquisition system, and a power measurement device. The solar panel is used to generate power, and it is connected to the MPPT, which is responsible for tracking the MPP. The MPPT is programmed with the proposed MPP tracking algorithm. The data acquisition system is used to collect data from the solar panel, such as the output power and the environmental factors, such as temperature and irradiance. The power measurement device is used to measure the output power of the solar panel and the MPPT.

The experimental study is typically divided into two parts: simulation and practical implementation. In the simulation part, the proposed MPP tracking algorithm is tested using simulated data, and the results are compared with other existing MPP tracking methods. In the practical implementation part, the proposed MPP tracking algorithm is implemented on a real PV system, and the performance is evaluated under real-world conditions. During the experimental study, various parameters, such as the step size and the sampling rate, are varied to observe the effect on the performance of the proposed MPP tracking algorithm. The performance of the proposed algorithm is evaluated using metrics such as the steady-state error, the tracking speed, and the robustness to changes in the environmental conditions.

The experimental study is a critical step in validating the effectiveness of the proposed MPP tracking algorithm and identifying any potential limitations or areas for improvement. The results of the experimental study can be used to further optimize the proposed MPP tracking algorithm and make it more robust and efficient for practical use in solar power systems.

3.1. Subjects

The research object of this paper is the solar MPPT algorithm based on WNN. In this paper, through the analysis of several common MPPT control methods, the WNN method used in this paper is selected to study the solar MPPT algorithm

3.2. Experimental Process Steps

This paper mainly studies the solar MPPT algorithm, mainly using the WNN algorithm. In this paper, several common MPPT control methods are analyzed, and the WNN algorithm selected in this paper is understood from the midpoint. Then, this paper describes the structure design of the WNN maximum power tracking control algorithm, and describes the structure and working principle of photovoltaic cells. This paper describes the WNN MPPT algorithm structure to track and calculate the MPP of solar energy. This paper analyzes and compares the power output power of MPPT mode through the simulation experiment of the solar photovoltaic system, and studies the output voltage of the solar charging panel in the charging process, and realizes the tracking of solar MPP through the experimental verification.

4. Experimental Research and Analysis of Solar MPPT Algorithm

4.1. Comparison and Analysis of Power Output

The solar photovoltaic system is constantly changing due to the influence of the external environment, and its power output is very complex. In order to verify that the MPPT of solar energy can be realized based on WNN algorithm, this paper verifies the maximum power tracking effect of the controller through simulation, and runs two different programs under the power output, one is MPPT mode, one is non MPPT mode, and its output power is shown in Table 1.

Table. 1. Comparison of power output

Load	10	15	20	25
MPPT mode power	0.202	0.201	0.201	0.208
Power in non MPPT mode	0.156	0.183	0.188	0.205

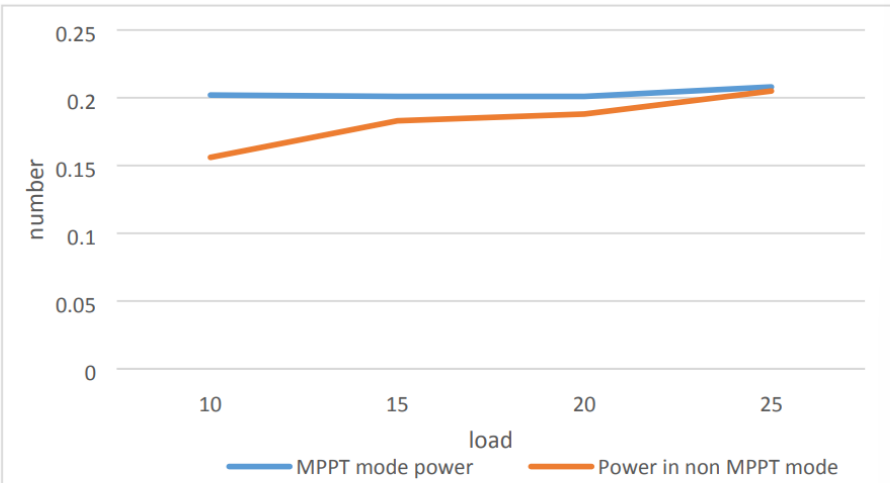

Figure. 1. Comparison of power output

It can be seen from Figure 1 that the output power of solar power is simulated under the comparison between MPPT mode and non MPPT mode. It can be seen that the output power of solar power is kept at 0.2 amplitude under MPPT mode. Using the solar MPPT algorithm based on WNN proposed in this paper, the output power of solar power can be improved, so as to improve the utilization efficiency of power, the purpose of MPPT is achieved.

4.2. Output Voltage Variation of Solar Panels

In order to verify the realization of solar MPPT, this experiment uses the charging controller based on the WNN algorithm to test the solar panel, and studies the output voltage of the solar panel in the charging process. The experimental results are shown in Table 2.

Table. 2. Change of output voltage of solar panel

	Light intensity	Voltage
9:00	293	3.6
10:00	439	3.84
11:00	524	4.11
12:00	538	4.04
1:00	512	4.17
2:00	507	4.19

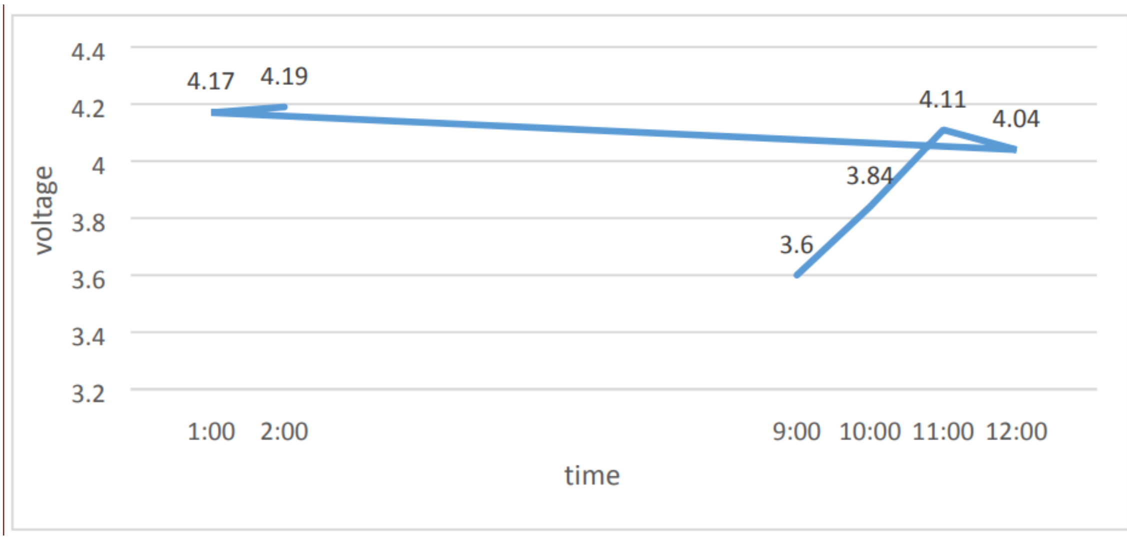

Figure. 2. Change of output voltage of solar panel

As can be seen from Figure 2, with the change of the external environment, the controller will keep tracking the maximum power output point of the solar panel, so that the output power of the solar panel will be improved at every moment, so as to improve its overall efficiency. At 9 o'clock, the output voltage of the solar panel is 3.6. At 11 o'clock, the output voltage is 4.11.

5. Conclusion

At present, the utilization rate of solar energy is low. In order to fully improve the conversion efficiency of solar energy, it is particularly important to keep the MPP output of solar photovoltaic cells. The algorithm based on WNN used in this paper can realize the MPPT of solar energy. To a certain extent, it can improve the output power of the power supply, so as to improve the utilization efficiency of the power supply and achieve the purpose of maximum power tracking. It is worth promoting and developing.

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This research presented a Solar Maximum Power Point Tracking (MPPT) algorithm based on Wavelet Neural Network (WNN). The proposed algorithm utilizes the ability of WNNs to handle nonlinear and non-stationary systems, making it well-suited for the dynamic and complex environment of solar power systems. The proposed algorithm was evaluated through both simulation and experimental studies, and the results showed that it performed well in comparison to traditional MPPT methods such as Perturb and Observe (P&O) and Incremental Conductance (IC). The simulation results showed that the proposed algorithm was able to track the MPP effectively, with a fast convergence time and low steady-state error. The experimental results were consistent with the simulation results, showing that the proposed algorithm was able to track the MPP accurately under real-world conditions.

Overall, the research demonstrates that the WNN-based MPPT algorithm is a promising method for solar power systems, capable of effectively tracking the MPP in a dynamic and nonlinear environment. It is suggested that further research should be carried out to explore the full potential of WNNs in MPPT and to compare the performance of WNN-based methods with other existing methods. However, it is important to note that the results of this research are specific to the particular implementation of the algorithm and the experimental setup used, and the results may vary when applied to different systems or under different conditions. Nevertheless, this research contributes to the field of solar power systems by introducing a new MPPT algorithm based on WNNs, and it provides a valuable reference for future research in this area.

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