Algorithms for determining the maximum power point for photo modules at weather stations

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Abstract. The work is devoted to methods for increasing the energy efficiency of photovoltaic modules. Various algorithms for determining the maximum power points and their application to obtain the maximum possible efficiency when using solar panels are considered. The principles of the operation of algorithms are described; their advantages and disadvantages are indicated. Their comparison was carried out according to the main significant parameters. The most suitable algorithm for application at a weather station has been selected.

1. Introduction

The unified energy system of Russia has a high degree of centralization. Large power plants generate a significant part of all electricity consumed. Most consumers of this electricity are concentrated in densely populated regions of the European and partly Siberian part of Russia. At the same time, about 60% of the territories are not covered by an extensive energy network [1]. About 10 million people live on them. A characteristic feature of such areas is the very low population density in vast territories poorly developed in terms of production. Therefore, even with a developed energy system, a significant number of small and remote settlements remain beyond its borders. Such consumers include not only settlements or their groups. But also, small farms, hotels or weather stations. Such facilities are most often isolated from centralized energy supply. Therefore, in order to provide electricity, diesel generators are widely used here, the fuel for which is supplied from the central regions of Russia. However, given the fact that such places have very weak transport links with industrialized areas, this greatly affects the cost of this resource. In this regard, the cost of electricity may exceed hundreds of rubles/kW.

Therefore, the development of renewable energy is an important task. It is economically feasible and beneficial, both environmentally and socially.

In order to extract maximum power when using solar energy, the most common devices with maximum power point tracking (MPPT) are used. Their application is due to the fact that the value of the irradiance parameter of the photo modules is not constant. This parameter depends on the position of the sun, on the weather, and the ambient temperature. These factors cause changes in the load...
characteristic of the solar panel so that the power taken is no longer optimal. To maintain the extraction of maximum power from solar panels, special algorithms called MPPT algorithms are used.

There are many control algorithms. Among them are:
1. The perturb and observe algorithm;
2. Adaptive perturb and observe algorithm;
3. Incremental conductance;
4. Fractional open-circuit voltage;
5. Fuzzy logic control;
6. Neural networks control algorithm.

2. Methods and Algorithms

2.1. Observation Algorithm

In the perturb and observe (P&O) method, the device changes the input resistance of the converter by a small amount, causing changes of the voltage on the solar battery. If the power increases, the device continues to change the set parameter until the power stops growing. This method is widely used, although it has certain disadvantages. Its main advantage is simplicity. Among the disadvantages are: the inability to clearly determine the maximum power point (MPP), fluctuations of the operating point around the MPP, reduced efficiency with a small value of irradiance, erroneous results with a sharp change in the level of irradiance [2].

The main difference of the adaptive P&O is that when finding the MPP, the step by which the given parameter changes depends on the value by which the power has changed [3]. If in the previous step the power increased by a larger value than in the current one, then the increment step will decrease. This allows quick and accurate determination of MPP.

![Figure 1. The flowchart of the P&O Algorithm.](image-url)
2.2. Incremental Conductance Algorithm

In the incremental conductance method (ICM), the voltage and power increment values are measured using a converter. Based on these data, the effect of voltage changes is predicted. The complexity of the calculation increases, but also increases the speed of tracking changes in environmental conditions. This method uses increasing conductivity to calculate the sign of the voltage change with respect to power ($\Delta V/\Delta P$). If the increment $\Delta V/\Delta P$ is positive, then the voltage will increase. If negative, then, accordingly, decrease. Therefore, the displacement of the point will occur depending on the sign of the increment. When the condition $\Delta V/\Delta P = 0$ is fulfilled, this means that the output voltage of the solar panel corresponds to the maximum power value [4]. Further, the values are maintained until the level of irradiance changes.

As in the P&O method, the main disadvantage is that this method can easily make mistakes with a sharp change in the level of irradiance. Both of these methods do a good job of finding MPP in constant light. But when the irradiance changes on an inclined, the tangent, on which the algorithms are based, continuously changes along with the irradiance, as a result of changes in current and voltage occur not only due to voltage disturbances. Therefore, the algorithms can not determine what exactly the change in power is associated with [5].

Another disadvantage is that the power value fluctuates around MPP in steady mode. This is due to the fact that the control is discrete, and the current and voltage are not constantly at the point of maximum power, but fluctuate around it.

![Flowchart of the incremental conductance algorithm](image)

**Figure 2.** The flowchart of the incremental conductance algorithm.
2.3. Fractional open circuit voltage

Fractional open circuit voltage (FOCV) uses the fact that the ratio between the voltage of the maximum power point and the open circuit voltage of the solar battery is approximately linear.

\[ V_{MPP} \approx k_1 V_{OC} \]  

where \( V_{MPP} \) is the voltage corresponding to the maximum power point;

\( V_{OC} \) – open circuit voltage;

\( k_1 \) – is a constant depending on the characteristics of the photocells, and must be determined initially.

To do this, we need to compare the values of \( V_{MPP} \) and \( V_{OC} \) at different levels of irradiance and temperature. In general, the value of this constant is in the range from 0.71 to 0.78. When the constant value is determined, the MPP voltage values can be determined by measuring the open circuit voltage of the battery. In this case, it is required to momentarily turn off the power converter, which leads to power loss. The disadvantage is the fact that this algorithm is not able to track a constant change in lighting, since the voltage measurement process is not continuous. Another drawback is that the MPP selected by this method is not valid, since the constant value is approximate.

This algorithm is suitable for use in certain situations. It is cheap, simple. It does not require a microcontroller (only one voltage sensor is used).

2.4. Fuzzy control algorithm

Another algorithm that has been gaining popularity recently is the fuzzy logic algorithm. It can work with inaccurate input, does not need an exact mathematical model, and can work with non-linearity. Microcontrollers also played an important role in popularizing fuzzy logic control. Fuzzy logic consists of three stages: fuzzification, fuzzy inference and defuzzification [6]. Fuzzification involves the process of converting clear numerical input into linguistic variables based on the degree of certain sets. Membership functions are used to bind values to each linguistic term. The number of variables used depends on the accuracy of the controller, but usually it ranges from 5 to 7.

For example, PB (Positive Big), PM (Positive Medium), NS (Negative Small), PS (Positive Small), ZE (Zero), NM (Negative Medium), NB (Negative Big).

The output of the fuzzy logic of the converter is usually a change in the duty cycle of the power converter, \( \Delta D \), or a change in the reference voltage of the DC circuit, \( \Delta \). The rule base [7], also known as the fuzzy rules of the algorithm, associates the fuzzy output with fuzzy inputs based on the used power converter [8] and shown in Table 1.

| \( D_p \) | \( D_v \) | NB | NM | NS | ZE | PS | PM | PB |
|-----------|-----------|----|----|----|----|----|----|----|
| NB        | PB        | PM | PS | NS | NS | NS | NM | NB |
| NM        | PM        | PS | PS | PS | NS | NS | NS | NM |
| NS        | PS        | PS | PS | NS | NS | NS | NS | NS |
| ZE        | NS        | NS | NS | PS | ZE | ZE | NS | NS |
| PS        | NS        | NS | NS | NS | PS | PS | PS | PS |
| PM        | NM        | NM | NS | NS | PS | PS | PS | PS |
| PB        | NB        | NB | NM | PS | PS | PS | PM | PB |

The fuzzy controller input is usually an error, \( E \), and its increment \( \Delta E \). The error value can be chosen by the designer, but more often it is chosen as the ratio \( \Delta P / \Delta V \). In this way:

\[ E_k = \frac{P_k - P_{k-1}}{V_k - V_{k-1}}. \]  

(2)
\[ \Delta E_k = E_k - E_{k-1}, \]  
(3)

where \( P_k, P_{k-1} \) - power of the photoelectric converter at the current and previous cycle, respectively; \( V_k, V_{k-1} \) - the output voltage of the photoelectric converter, at the current and previous cycle, respectively; \( E_k, E_{k-1} \) - error on the current and previous cycle, respectively; \( \Delta E_k \) - error increment between cycles.

The final step in managing fuzzy logic is defuzzification. At this point, the output is converted from a linguistic variable to a clear numeric one, again using membership functions. There are various methods for converting linguistic variables into clear values. The most popular among them is the "center of gravity" method. The advantages of these controllers, in addition to working with inaccurate input data, do not require an exact mathematical model and can handle non-linearity; they also have fast convergence and minimal oscillations around the MPP. In addition, it was shown that they work well with step changes in irradiation. However, it is worth noting that no evidence was found in favor of the fact that they work well with sharp changes in irradiation. Another drawback is that their effectiveness largely depends on the skills of the designer, not only when choosing the right error calculation, but also when creating the appropriate rule base.

2.5. Neural networks control algorithm
Another method well adapted to microcontrollers is the method based on neural networks. The simplest neural network consists of three layers: input, hidden layer and output. More complex neural networks are created with the addition of hidden layers. The number of layers and the number of nodes in each layer, as well as the functions used in each layer, vary and depend on the user's knowledge. So, the input variables can be the parameters of the solar battery, its voltage and current, irradiation and temperature, or a combination thereof. The output, usually, is one or more reference signals, such as the value of the duty cycle or the voltage of the DC link. The performance of a neural network depends on the functions used by the hidden level, as well as how well the network has been trained [9]. To perform this learning process, pattern data between the inputs and outputs of the neural network are recorded over a long period of time so that the MPP can be accurately tracked [10]. The main disadvantage of this method is that the data necessary for the training process must be specially obtained for each photoelectric matrix and its location, since the characteristics of the photoelectric matrix vary depending on the model, and atmospheric conditions depend on the location. These characteristics also change over time, so the neural network needs to be trained periodically.

3. Results of Comparison
As mentioned above, each algorithm has its own advantages and disadvantages. Therefore, when choosing an algorithm, it is necessary to consider not only efficiency, but also cost complexity of implementation and complexity of operation. Consideration of these factors will make it possible to choose the best algorithm for a particular situation. The results of comparison are given in the table below.

| Type                  | Complexity of implementation | Complexity of operation | Price    | Efficiency |
|-----------------------|------------------------------|-------------------------|----------|------------|
| P&O                   | Simple                       | Simple                  | Medium   | 90.2%      |
| IC                    | Medium                       | Simple                  | Medium   | 93.1%      |
| FOCV                  | Simple                       | Simple                  | Cheap    | 92.9%      |
| Fuzzy logic control   | Complex                      | Medium                  | Expensive| 99%        |
| Neural networks       | Complex                      | Complex                 | Expensive| 99%        |
4. Conclusion
Thus, from the above algorithms, the optimal algorithm for the weather station is the fuzzy logic algorithm. It has high efficiency, while its operation is much simpler than an algorithm based on neural networks, at a comparable cost. Despite the fact that the implementation of this algorithm is a relatively difficult task, it is assumed that the implementation will be carried out by a qualified engineer. This will solve most of the problems associated with the implementation [11].

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