Theory and practice of positioning a solar panel to obtain peak power points at weather stations

K O Kochmarev\(^1\), B V Malozyomov\(^1\), Svetlana Yurievna Kuznetsova \(^2\) I V Ignatev \(^3\)

\(^1\) Novosibirsk State Technical University, 20, Karla Marksa Av., Novosibirsk, 630073, Russia
\(^2\) Irkutsk National Research Technical University, 83, Lermontov str., Irkutsk, 664074, Russia
\(^3\) Bratsk State University, Makarenko St., 40, Bratsk, 665709 Russian Federation,

E-mail: Blaheart@mail.com

Abstract. This paper discusses various methods for positioning solar panels in space for autonomous power supply of weather station equipment. The principles of operation of these methods are described; their advantages and disadvantages are indicated. An effective positioning calculation was also made for one of them. The basic conditions under which one or another method is worthwhile are identified. It is determined that depending on the territorial location and environmental conditions, various positioning methods can be selected.

1. Introduction

The issues of optimizing energy consumption and power generation are quite relevant, especially for power supply of autonomous electricity consumers, which are devices of autonomous weather stations [1, 2]. One way to maximize the efficiency of solar panels is to position them relative to the Sun properly.

Sunlight travels from Sun to Earth in a straight line. When it reaches the atmosphere, part of the light is refracted, and part reaches the earth in a straight line. Another part of the light is absorbed by the atmosphere. Refracted light is what is commonly called diffuse radiation, or scattered light. The part of sunlight that reaches the surface of the earth without scattering or absorption is direct radiation. Direct radiation is the most intense [3, 4].

Solar modules generate electricity, even when there is no direct sunlight. Therefore, even in cloudy weather, the photovoltaic system will produce electricity. However, the best conditions for generating electricity will be in bright sunshine and when the panels are oriented perpendicular to sunlight. For areas of the northern hemisphere, the panels should be oriented to the South, for countries of the southern hemisphere - to the North.

2. Influence of various light conditions on the production of photovoltaic modules

The sun moves across the sky from East to West. Two coordinates determine the position of the Sun in the sky: declination and azimuth. Declination is the angle between the line connecting the observer and the Sun and the horizontal surface. Azimuth is the angle between the direction to the Sun and the direction to the south.
It should also be borne in mind that the direction to magnetic south does not always coincide with the direction to real south. There are true and magnetic poles that do not coincide. Accordingly, there are true and magnetic meridians. In addition, from that and from another, authors counted the direction to the desired item. In one case, authors deal with the true azimuth, in the other with the magnetic. True azimuth is the angle between the true (geographical) meridian and the direction to a given subject. Magnetic azimuth is the angle between the magnetic meridian and the direction to a given subject. The true and magnetic azimuths differ by the same amount by which the magnetic meridian differs from the true one. This value is called a magnetic declination. If the compass needle deviates from the true meridian to the east, the magnetic declination is called east; if the arrow deviates to the west, the declination is called western. The eastern declination is often denoted by the sign “+” (plus), the western - by the sign “-” (minus). The magnitude of the magnetic declination is not the same in different areas. So, for example, for the Moscow region in Russia, the declination is $+6.5 ... +8.2^\circ$, but generally in Russia, it varies to a greater extent [5, 6].

2.1. Solar panel orientation and solar tilt angle
In practice, solar panels should be oriented at a certain angle to a horizontal surface. Near the equator, the solar panels should be located at a very small angle (almost horizontally), so that rain would wash away dust and dirt from the photovoltaic modules.

Small deviations from this orientation do not play a significant role, because during the day the sun moves across the sky from east to west.

Solar panels work most effectively when they are directed at the sun and their surface is perpendicular to the sun's rays. Solar panels are usually located on a roof or supporting structure in a fixed position and cannot monitor the position of the sun during the day. Therefore, usually solar panels are not at an optimal angle (90 degrees) throughout the day. The angle between the horizontal plane and the solar panel is usually called the angle of inclination.

Due to the movement of the earth around the sun, seasonal variations also occur. In winter, the sun does not reach the same angle as in summer. Ideally, solar panels should be more horizontal in summer than in winter. Therefore, the tilt angle for working in the summer is chosen less than for working in the winter. If it is not possible to change the angle twice a year, then the panels should be located at the optimal angle, the value of which lies somewhere in the middle between the optimal angles for summer and winter. For each latitude there is an optimal angle of inclination of the panels. For areas near the equator only, solar panels should be horizontal.

For spring and autumn, the optimal slope angle is usually equal to the latitude of the area. For winter, 10-15 degrees are added to this value, and in summer 10-15 degrees are taken from this value. Therefore, it is usually recommended to change the angle of inclination from “summer” to “winter” twice a year. If this is not possible, then the angle of inclination is chosen approximately equal to the latitude of the terrain.

Thus, an important factor for obtaining maximum electric power from a solar battery is the calculation of the angle of inclination of the solar panels and their number necessary to cover the needs of all electric consumers.

After the approximate amount of electricity required is determined, we need to find out what is the potential for insolation in a particular area. To do this, we need to get information regarding the radiation power of the star in this or that weather [7, 8].

During the calculations, it is necessary to take into account the angle at which the panels will be located. Indeed, the system performance will directly depend on their rotation to the Sun. A mandatory minimum is the calculation of solar capabilities for two cases: with the vertical and horizontal position of the photovoltaic modules. If it is necessary to obtain the most accurate value, then the angle of inclination should be represented as the sum of the latitude at which we are and 15° [9]. This indicator should not be deliberately reduced, because the larger it is, the higher the production of panels because dust or snow will not be deposited on them.
2.2. Solar tilt angle in winter and summer
At this stage, we find out the approximate level of performance of solar panels, i.e. let’s calculate exactly how many modules will be needed to create a system with a previously set power.

If we take into account that the radiation power of sunlight is the maximum insolation, then we can understand that the panel performance refers to the insolation of an area of 1 m² in the same way as the battery power to the solar radiation power on the surface of our planet under favorable weather conditions. Thus, it is not difficult to find out the level of performance over a 30-day period. To do this, multiply the monthly insolation rate by a value that is represented by the ratio of the maximum insolation power and the panel [10].

The solar battery gives out the maximum possible power when the sun's rays perpendicularly fall on it. In this case, it is obvious that maximum efficiency can be achieved if the solar battery will always be perpendicular to the sun. This can provide a two-axis positioning system. However, it should be borne in mind that such a system has its drawbacks, which can well outweigh its advantages. Therefore, in the framework of this work, we consider the advantages and disadvantages of various positioning methods [11].

The authors managed to identify three methods for positioning solar panels in space:
1. Method of static positioning.
2. Method taking into account seasonal changes in the angle of inclination.
3. Method of single axis positioning.
4. Method of biaxial positioning.

3. Methods for positioning solar panels in space

3.1. Method of static positioning
This method is the easiest to implement. It is most widely used in the private sector, as well as in small commercial and industrial sectors. In this method, solar panels are fixed in one specific position. Most often on roofs or on special ground structures.

When using this method, it is especially important to choose the right direction for the location of the solar panel. For example, if the installation location is close to the equator, then the battery should be placed as horizontally as possible. When in the southern hemisphere, the panel should face towards the north, in the north - towards the south. To calculate the optimal angle of the panel, we can use the location information of the sun during the year. For example, the optimal angle can be calculated based on [12]. The calculation is performed for Novosibirsk and presented in the form of a graph (Figure 1).

![Figure 1. The angle of the sun during the year in Novosibirsk.](image-url)
Based on the data obtained, it is possible to determine the average value of the angle of the position of the sun. In this case, it was 27.35 degrees.

![Figure 2](image1.png) **Figure 2.** The angle of the sun during the year in Singapore.

![Figure 3](image2.png) **Figure 3.** The angle of the sun during the year in Narvik.

As it can be seen from the graphs (Figure 2 and Figure 3), depending on the geographic location, and the optimal battery angles change differently throughout the year. The advantages of static positioning are that it is a simple and cheap method. It is the most reliable and virtually maintenance-free. In addition, a large amount of space is not required, solar panels can, for example, be installed on the roof, which is almost impossible with tracking systems. In addition, in a static position, it is easy enough to take into account factors such as wind load.
3.2. Method taking into account seasonal changes in the angle of inclination

In order to reduce losses associated with the sub-optimal position of the solar battery, we can adjust the angle of inclination during the year. This method is called seasonal variation in the angle of inclination. Then, in relation to Novosibirsk, the solar panel will need to be additionally shifted by -19° in winter and +19° in summer (Table 1).

| Season     | Spring | Summer | Autumn | Winter |
|------------|--------|--------|--------|--------|
| Tiltangle, degree | 3.279  | 18.52  | -2.337 | -19.46 |

Such an adjustment will increase electricity production by 5% in winter and summer. [13] On the other hand, at low latitude, seasonal variation in the angle of inclination makes no sense (Figure 2).

3.3. Method of single axis positioning

Single-axis trackers are divided into trackers with horizontal (HSAT), inclined (TSAT) and vertical (VSAT) axes of rotation.

Horizontal axial trackers are preferably used in areas close to the equator (Figure 2). The design of such trackers allows compactly placing a large number of solar panels. For example, cascades of such batteries are placed on the pipe, which rotates along the axis, moves all the solar panels located on it at the same time. It is cost effective and more reliable. Horizontal axial trackers can also be used at higher latitudes by adjusting the slope of the panel.

Vertical trackers are mainly used at high latitudes (Figure 3). In addition, unlike horizontal trackers, they are less adapted to dense packing. In addition, when planning, it is worth considering shading in order to avoid energy losses.

Inclined trackers include all trackers in which the rotation axis is between vertical and horizontal. In certain situations, these trackers can generate more energy. However, the possibility of tight installation for these trackers is even less than for vertical ones and largely depends on the angle of inclination and latitude in which they are located.

Single-axis trackers are widespread, because they are much cheaper than dual-axis trackers, they are more reliable and easier to use.

3.4. Method of biaxial positioning

This type of tracking has maximum efficiency, allowing the solar panel to accurately follow the sun all the time. They can be placed at any latitude. In general, they are more versatile. However, they cost much more, they need more space to accommodate, and they are less reliable and more difficult to operate.

4. Conclusion

Depending on the geographical location and environmental conditions, various positioning methods can be selected. In dense urban areas, the application of the static positioning method is more justified, due to the lack of sufficient free space and the presence of shading from various objects. Despite the fact that the effectiveness of this method is significantly (from 18% or more) lower. When supplying remote facilities located in places with low population density and large territories, such as small villages, weather stations and hotels, their use is more reasonable. In addition, when choosing a positioning method, it is important to take into account the geographical location and it is advisable to perform calculations to determine the best for a given area (Figure 1, Figure 2 and Figure 3). For example, comparisons of tracking methods with respect to Bangladesh [13] did not reveal a significant difference in the operational efficiency between uniaxial and biaxial positioning. It amounted to 4.4%. Which is disproportionate to investments in a two-axis system [14, 15, 16].
References

[1] Garg A, Nayak R S, Gupta S 2015 Comparison of P&O and fuzzy logic controller in MPPT for photovoltaic (PV) applications by using MATLAB / Simulink. Retrieved from: http://www.iosrjournals.org/iosr-jee/Papers/Vol10-issue4/Version-1/H010415362.pdf

[2] Oulcaid M, Fadil H E2016 Maximum power point tracking algorithm for photovoltaic systems under partial shaded conditions. Retrieved from: https://www.sciencedirect.com/science/article/pii/S2405896316312423

[3] Banu I, Beniuă R, Istrate M 2013 Comparative analysis of the perturb and observe and incremental conductance MPPT methods. Retrieved from: https://ieeexplore.ieee.org/document/6563483

[4] Nedumgatt J J, Jayakrishnan K B 2011 Perturb and observe MPPT algorithm for solar PV systems-modeling and simulation. Retrieved from: https://ieeexplore.ieee.org/document/6139513

[5] Puchenkin A B 2011 Maximum power point regulator for solar panels. The state and prospects of the development of electrical technology: a collection of scientific papers. (IGEU) 60-63

[6] Nashwa A K, Ahmad T A 2020 PSO-Based Adaptive Perturb and Observe MPPT Technique for Photovoltaic Systems. Retrieved from: https://link.springer.com/chapter/10.1007/978-3-030-31129-2_12

[7] Dontsov O A 2015 A fuzzy logic solar controller with maximum power point tracking. Retrieved from: https://www.researchgate.net/publication/295899846_A_Fuzzy_Logic_Solar_Controller_with_Maximum_Power_Point_Tracking

[8] Chekired F, Mahrane 2017 A fuzzy logic energy management for a photovoltaic solar home. Retrieved from: https://www.sciencedirect.com/science/article/pii/S1876610217347008

[9] Suresh V 2019 Forecasting solar PV output using convolutional neural networks with a sliding window algorithm. Retrieved from: https://www.mdpi.com/1996-1073/13/3/723

[10] Abuella M, Chowdhury B 2015 Solar power forecasting using artificial neural networks. Retrieved from: https://ieeexplore.ieee.org/document/7335176

[11] Retrieved from: https://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html

[12] Retrieved from: http://uekvarma.ru/article/orientatsiya-solnechnyih-paneley

[13] Retrieved from: http://dspace.bracu.ac.bd/xmlui/bitstream/10361/9118/12221046%2C%2EE.pdf

[14] Kuziakina M, Gura D, Zverok D 2019 E3S Web of Conferences 138 02004 DOI: 10.1051/e3sconf/201913802004

[15] Shishkina V, Gura D, Gibriksa I, Bykova M 2019 IOP Conference Series: Materials Science and Engineering 698 066016 DOI: 10.1088/1757-899X/698/6/066016

[16] Brosлавский Л. И 2019 ENVIRONMENTAL SAFETY: GLOBAL WARMING AND CLIMATE CHANGE (LEGAL PROBLEMS). Business, management and law 4 15-20