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ANALYSIS OF CALCULATING THE POSITION OF THE SUN OVER CITIES OF THE REPUBLIC OF UZBEKISTAN

***Ergashev Sirojiddin Fayazovich* [1], *Oshepkova Elvira Axtemovna* [1]**

[1] Fergana polytechnic institute, Uzbekistan

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Abstract

An effective way to increase the productivity of photovoltaic installations is to use solar tracking systems. The pronounced dependence of the amount of solar radiation entering the receiving surface of solar panels on the geographical location of the power plant causes significant differences in the characteristics of solar radiation for different regions of Uzbekistan. The smaller the angle of the Sun's position above the horizon, the greater the path of solar radiation through the Earth's atmosphere, therefore, the loss of intensity of solar radiation in the atmosphere increases. Considering the above, this article is aimed at determining the position of the sun over the cities of the Republic of Uzbekistan located in different coordinates to justify the provision of photovoltaic installations with a tracking system.

Keywords: *Solar declination, geographical locations, azimuthal and altitude angles, optimal positioning*

Introduction

Of all the known renewable energy sources, one of the most popular and dynamically developing at present is photovoltaic technologies, the advantages of which include a long service life of the main energy components, minimal operating costs, and the ability to assemble solar installations that generate power as close as possible to the objects of electrical consumption (Ergashev, S.F., Tokhirov, M.K., Oshchepkova, E.A., 2021; Reda, I. and Andreas, A., 2004).

However, despite the obvious advantages, the limiting factors for the introduction of photovoltaic stations remain the high cost of purchased equipment and the low efficiency of energy conversion. The use of a solar tracking system makes it possible to achieve an increase in the productivity of photovoltaic installations on average from 15 to 60%, depending on the type of tracker, the geographical location of the solar power plant and the time of year (Mousazadeh, H., Keyhani, A., Javadi, A., Mobli, H., Abrinia, K. and Sharifi, A. 2009; Saheli, R., 2012).

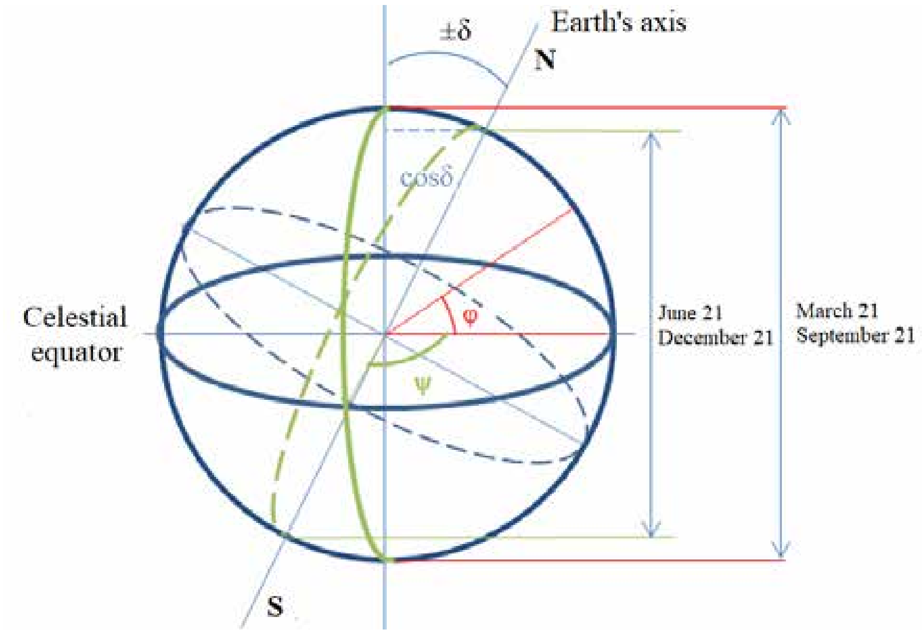
It is necessary to conduct a full analysis of the technical characteristics of the tracking system in the design of a photovoltaic station in accordance with the operating conditions: the range of movement of photovoltaic modules in azimuthal and altitude angles, the method and algorithm used for tracking the position of the Sun and the maximum wind speed, etc.

Research method

One of the most important technical characteristics of solar photovoltaic power plants is the operating ranges of movement of the solar tracker in the azimuth and altitude angles of the sun, which should cover the maximum possible angle values in the planned location of the photovoltaic installations.

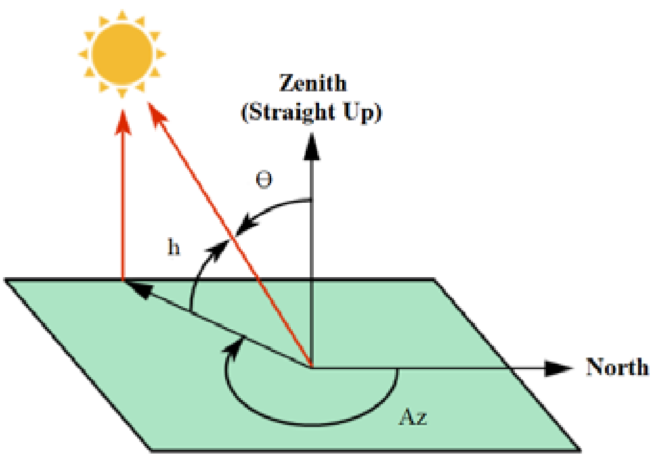
Fig. 1 shows the Earth with its axis around which it rotates every 24 hours. The Earth's axis is perpendicular to the Earth's equatorial plane. The Earth's surface is characterized by two main quantities: geographic latitude φ – the angle formed by a plumb line passing through a given point on the Earth's surface and the plane of the equator; geographic longitude ψ – the dihedral angle between the planes of the prime meridian and the meridian of a given point (Mahmood, O.T., 2013).

Figure 1. *Movement of the Earth around its axis in space: δ – declination of the Sun, N – north pole, S – south pole, φ – geographic latitude, ψ – geographic longitude*



The angle between the sun's rays and the Earth's equatorial plane is the declination of the sun δ and is a measure of seasonal changes. Solar declination changes throughout the year due to the tilt of the Earth's axis. On the day of the summer solstice, the Sun reaches its greatest positive declination, that is, it is located north of the celestial equator.

Figure 2. *Diagram showing: θ – Solar Zenith Angle, h – Solar Altitude Angle, Az – Solar Azimuth angle*



On the contrary, on the day of the winter solstice, the Sun reaches its greatest negative declination, being located south of the celestial equator (Francisco, D., Pedro, D.G., Luis, C.G., 2010; Nayak, S.R. and Pradhan, C.R., 2012). On the days of the spring and autumn equinoxes, the declination of the Sun is zero, since the Sun is at the celestial equator. The declination of the Sun can be calculated using equation of Cooper:

$$\delta = 23.45 \cdot \sin\left[\frac{360}{365}(N+284)\right], \text{ degrees}, \quad (1)$$

where N is the number of the calendar day from the beginning of the year.

Solar Zenith Angle is determined by the formula:

$$\theta = \arccos(\sin(\varphi) * \sin(\delta) + \cos(\delta) * \cos(\varphi) * \cos(\omega)), \text{ degrees}, \quad (2)$$

where φ – is the latitude of the area at the installation point of photovoltaic modules; δ – is the declination angle of the Sun, ω – Hour Angle, the difference between noon and the current time of day in terms of a 360° rotation in 24 hours.

The altitude angle of the Sun above the horizon h is determined by the expression:

$$h = 90 - \theta \quad (3)$$

The azimuthal position angle of the Sun Az is found from the equation:

$$Az = 180 - \arcsin((-\sin(\omega) * \cos(\delta)) / (\cos(h))) \quad (4)$$

Results analysis

We compared the azimuthal and altitude angles of the sun hourly on the day of the summer solstice in four cities of Uzbekistan: Muynak (43.7683 N59.0214 E), Uchkuduk (42,1535 N63.5617 E), Termez (37.2242 N67.2783 E), Fergana (40.3842 N71.7843 E). The results are shown in the Table 1 and Figure 3. Cities were selected from extremely different geographical locations to compare the solar trajectory at different longitudes and latitudes. It is clear from the diagrams that in the middle northern latitudes the value of the sun's altitude angle during daylight hours varies within relatively large limits, especially in the summer months of the year, in particular the considered day of the summer solstice. Accordingly, for optimal positioning of the surfaces of photovoltaic modules on the Sun, it is necessary to change their inclination in a fairly wide range of angles. The city of Muynak has the lowest values of the solar trajectory for altitude and azimuth angles. Slightly higher on the graph is the solar trajectory of the cities of Uchkuduk, Termez and Fergana.

Table 1. *Azimuthal and altitude angles of the sun by hour in the cities of Uzbekistan*

Time of day (hours) June 21	Muynak 43.7683 deg N. 59.0214 deg E.	Uchkuduk 42.1535 deg N. 63.5617 deg E.	Termez 37.2242 deg N. 67.2783 deg E.	Fergana 40.3842 deg N. 71.7843 deg E.
	Sun altitude angle above the horizon, h (degrees)			
6:00	5.0311	7.2821	7.8568	12.2957
9:00	36.291	39.671	42.7192	45.9853
12:00	65.5869	68.8256	74.523	72.7719
15:00	58.9997	56.8076	55.649	51.5067
18:00	27.5739	24.0443	20.1742	17.6253
20:00	6.8968	3.2048	–1.7533	–2.9758
	Azimuthal angle of the sun. Az (degrees)			
6:00	62.0258	64.8351	66.4574	69.57
9:00	91.1491	93.0807	91.2371	97.4024
12:00	141.0561	148.3904	150.6667	168.5139
15:00	238.3457	246.1865	256.92	256.6642
18:00	276.9574	280.5793	284.6564	286.1198
20:00	296.0349	299.1208	301.5326	304.5468

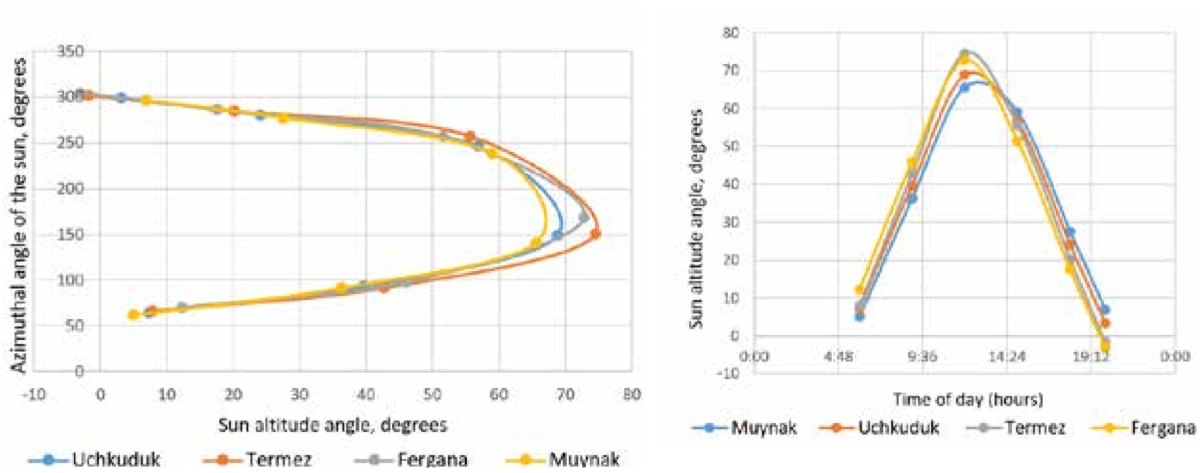


Figure 3. *Diagram of azimuthal and altitude angles of the sun in the cities of Uzbekistan (a) and Diagram of the altitude angle of the sun by hour in the cities of Uzbekistan (b)*

Table 2 and Figure 4 compare the azimuthal and altitude angles of the sun hourly in cities of Uzbekistan with similar latitudes. Obviously, the value of the altitude angle differs between cities mainly by hour. The city of Namangan is located in the east of Uzbekistan, which causes a significant increase in its value before noon in comparison with the Kungrad region, located in the west of Uzbekistan, and at the same time, a decrease in the afternoon as sunset approaches. At noon we record the greatest difference in degrees of the azimuthal angle in the cities of Uzbekistan, which amounts to a maximum difference of 36 degrees between the Kungrad region and Namangan.

Table 2. *Azimuthal and altitude angles of the sun by hour in cities of Uzbekistan with similar latitudes*

Time of day (hours) June 21	Kungrad d-ct 41.6203 deg N. 56.4280 deg E.	Urgench 41.5345 deg N. 60.6248 deg E.	Chirchik 41.4689 deg N. 69.5822 deg E.	Namangan 40.9983 deg N. 71.6726 deg E.
	Sun altitude angle above the horizon, h (degrees)			
6:00	2.3255	5.0453	11.1306	12.4304
9:00	34.3664	37.504	44.1998	45.8193
12:00	65.8584	68.0654	71.3094	72.1533
15:00	61.7518	59.0515	52.8331	51.4429
18:00	29.2162	26.0943	19.5163	17.8759
20:00	7.7009	4.8407	–0.9899	–2.5581
	Azimuthal angle of the sun, Az (degrees)			
6:00	60.235	62.9196	68.4608	69.6298
9:00	87.8791	90.5719	96.8325	97.9459
12:00	132.9547	141.0027	162.9209	168.5645
15:00	238.0294	243.641	253.3173	255.8169
18:00	276.4721	279.0798	284.473	285.8655
20:00	294.6291	297.2724	303.1031	304.4961

Figure 4. *Diagram of the azimuthal and altitude angles of the sun for cities of Uzbekistan with similar latitudes (a) and Diagram of the altitude angle of the sun by hour for cities of Uzbekistan with similar latitudes (b)*

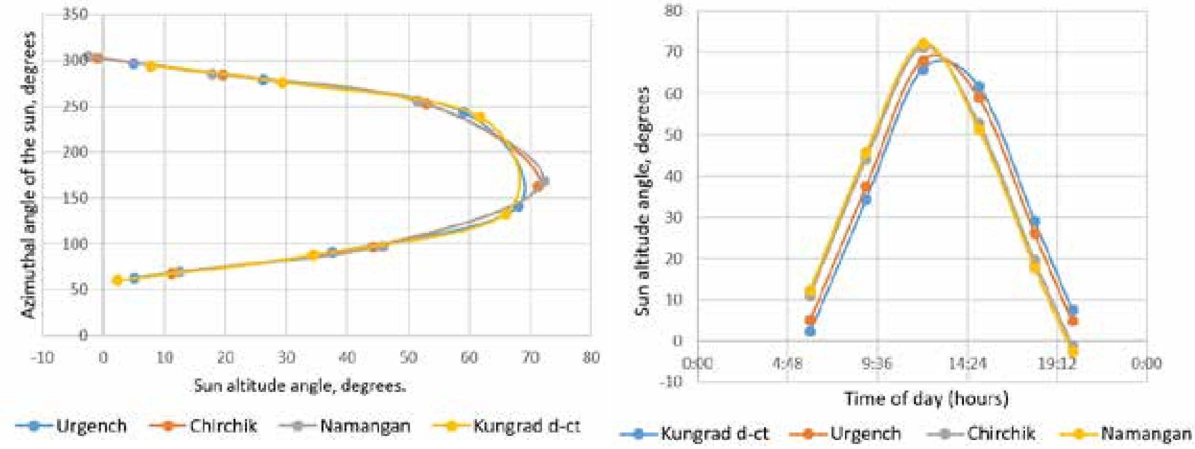


Table 3 presents the values of the azimuthal and altitude angles of the sun on characteristic days of the summer and winter solstices in Fergana. Figure 5 shows the solar altitude angle charts and the maximum and minimum azimuthal angle ranges on June 21 and December 21 for use in the control algorithm of a dual-axis continuous tracking system.

Table 3. *Azimuthal and altitude angles of the sun on the days of the summer and winter solstice in Fergana city*

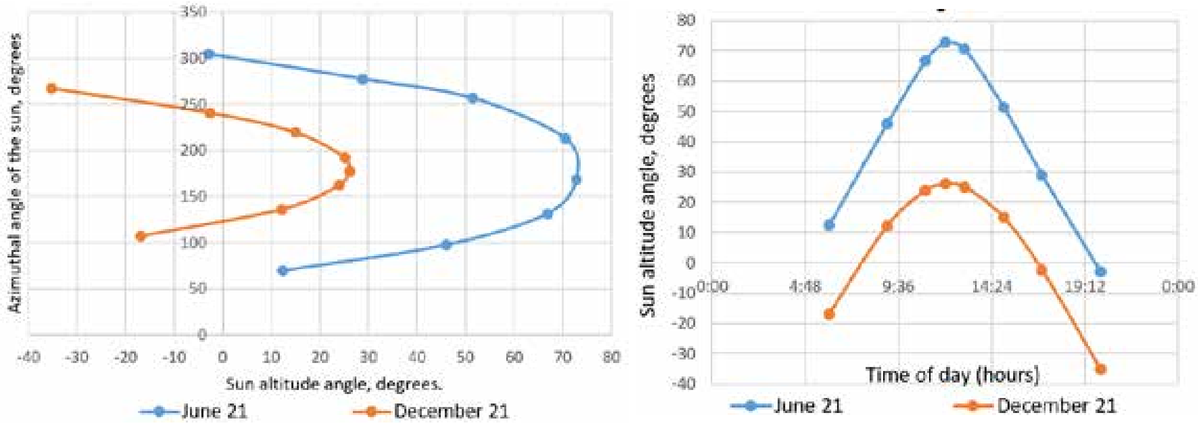
Fergana city, 40.3842 deg N. 71.7843 deg E.				
Time of day (hours)	Sun altitude angle above the horizon, h (degrees)		Azimuthal angle of the sun, Az (degrees)	
	June 21	December 21	June 21	December 21
6:00	12.2957	–16.9246	69.57	106.6784
9:00	45.9853	12.2475	97.4024	135.9718
11:00	66.8898	24.0682	131.5131	162.1458
12:00	72.7719	26.1251	168.5139	177.1689
13:00	70.5619	25.1698	212.7376	192.3951
15:00	51.5067	15.0636	256.6642	219.6725
17:00	28.7987	–2.5287	277.3699	240.9784
20:00	–2.9758	–35.2425	304.5468	267.7988

From the graphical dependencies presented in Fig. 5, it is clearly seen that at noon on June 21, the value of the altitude angle reaches a maximum value of 72.77°, while on December 21, the value of the altitude angle reaches a maximum value of 26.12°. The difference in degrees is 46.65.

On the day of the winter solstice, the duration of daylight at a latitude of 40.3842° is 9 hours at a maximum solar altitude angle of 26.1768°, while on the day of the summer solstice the duration of daylight is more than 14 hours at a maximum solar altitude angle of 73.0439°. This proves the effectiveness of the use of tracking systems.

Discussions. A comparative analysis of the azimuthal and altitude angles is provided for cities in Uzbekistan located in radically different geographical coordinates, as well as in approximately the same northern latitudes, but at different eastern longitudes. In addition, a comparative characteristic of the angle parameters and an assessment of the effectiveness of the use of solar tracking systems for a photovoltaic station for the city of Fergana on the most characteristic days of the winter and summer solstice were carried out.

Figure 5. *Diagram of the azimuthal and altitude angles of the sun on the days of the summer and winter solstice in Fergana (a) and Diagram of the altitude angle of the sun by hour on the days of the summer and winter solstice in Fergana (b)*



Conclusion. Carrying out an analysis of the change in the azimuthal angle on characteristic days of the year, we can conclude that the smallest difference is at noon and is 8.66°, but reaches a maximum in the hours of the day close to dawn and sunset and is 37.11° and 36.75° respectively. A dual-axis solar tracker allows to capture a wide range of angles of solar rays, which will provide a significant increase in the values of direct solar radiation arriving at the surface of photovoltaic modules.

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Contact: Oshchepkova.elvira@gmail.com