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Determination of the optimal angle for high efficiency of solar panels in Uzbekistan

Dilshod Kodirov[1*], *Valijon* Makhmudov[2], *Jakhongir* Normuminov[3], *Abror* Shukuraliev[4], *Nodira* Begmatova[5], Yusupov Abdurashid[4]

[1]Department of Power Supply and Renewable Energy Sources, National Research University TIIAME, Tashkent 100000, Uzbekistan
[2]"Yashil Energiya" LLC Tashkent, Uzbekistan
[3]Tashkent State Technical University, Tashkent, Uzbekistan
[4]Andijan Machine Building Institute, Andijan 170119, Uzbekistan
[5]Department of Algorithms and Programming Technologies, Karshi State University, Karshi, Uzbekistan

Abstract. This article examines the potential utilization of solar energy in Uzbekistan, a country blessed with abundant sunshine throughout much of the year, making solar radiation an attractive resource. It discusses various approaches for determining the most effective angle for installing solar panels, drawing upon research conducted by several international scholars. Additionally, it presents findings from the application of one of these methodologies in Andijan, a mountainous region in Uzbekistan, offering insights into its feasibility and performance in the local context.

1. Introduction

One of the cleanest renewable energy sources, solar energy never runs out. If utilized effectively, the irradiance of solar electricity trapped by the earth is approximately 1.8 x 1011 MW, sufficient to address the current global energy issue. In recent years, solar photovoltaic (PV) electricity generation has progressively increased globally.The use of solar energy is expanding quickly worldwide since it is a clean energy source. One option to use solar energy is to generate solar power, however installing a solar power system is still very expensive. The cost of solar cell modules is roughly 60–70% of the total cost of solar power generation today.

Installing solar panels at the ideal tilt angle is one of several strategies for efficiently utilizing photovoltaic energy, and it can significantly increase the generating efficiency of PV-based generating units [1]. The amount of solar radiation incident on PV panels has a major impact on the generation efficiency of PV-based generating units. The direction and tilt angle of the panels are two crucial elements that affect the amount of solar energy impacting on them [2, 3, 4]. The ideal tilt angle of the panel changes in accordance with the sun's position in relation to the earth. It changes every day, every month, and every year. Furthermore, the position determines the ideal angle. To achieve maximum energy output, it is crucial to maintain the panel at its ideal tilt angle throughout the year.

Uzbekistan has set an ambitious goal - to produce 30% of electricity from renewable sources by 2030. Solar energy is expected to play a main role in this mission. Today, large projects on the use of solar energy are being carried out. Considering that there are an average of 330 sunny days per year, the potential of solar energy is greater and it is necessary to use it effectively. In this case, the efficiency of using solar energy is evaluated by the intensity and duration of radiation. The Global Solar Atlas Network was used to monitor solar radiation throughout the year (Fig. 1) [5].

When determining the energy value of solar radiation, the average monthly, daily and hourly value of at least three years of data from the solar atlas is analyzed [6]. In this, a comparative analysis of the energy values of total solar radiation (GHI), normal surface direct solar radiation (DNI) and horizontal surface diffuse solar radiation (DHI) is presented. According to observations of the duration of sunlight, necessary calculations were made according to the recommended calculation formula at all meteorological stations located in the Republic. The maximum arrival of solar radiation is 720 W·h/m ^{2} between 12-13 o'clock in June, and the minimum arrival is 300 W·h/m ^{2} between 11-14 o'clock in winter (November-February). During the year (March, April, September, October) the sunshine time is 10 hours on average. The average energy value for months is 450-550 W·h/m ^{2}.

[*]Corresponding author: kodirov.dilshod@gmail.com

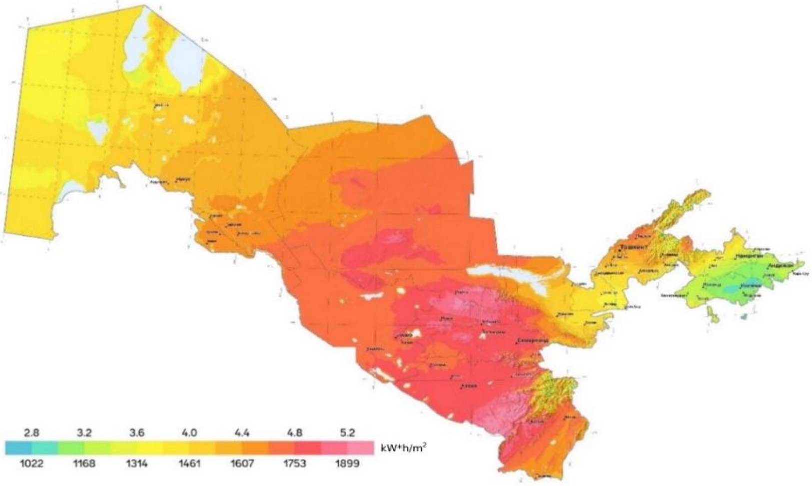

Fig. 1. Solar radiation indicators in Uzbekistan [5]

2. Research methods

The researchers of Orenburg State University and Aerospace Institute V. Jabayeva, A. Belyakova, I. Besedina in their article which is named "Comparison of methods for calculating the tilt angle of solar panels" proposed to calculate the required angle for optimal use of solar panels in 4 different ways. The proposed methods are as follows (Table 1) [7] :

1. The most common way to install solar panels on the roof of the building is to install them at an angle of 45 degrees;
2. Installation at an angle close to the width of the area;
3. Installation at an angle whose value is between the optimal angles for summer and winter;
4. Installation at a calculated angle.

Table 1. The following values were achieved for the city of Orenburg

Methods	Result, ° (degrees)
1	45
2	51.8
3	51.6
4	42.5

However, seasonal changes also occur as a result of the earth's movement around the sun such as in winter, the sun does not reach the same angle as in summer, which means that solar panels must be placed more horizontally in summer than in winter. Therefore, it is recommended to change the angle of the solar panels twice a year to get high efficiency. In this case, it is shown that the correct selection of the "winter" and "summer" tilt angles of the solar panels has a significant impact on the efficiency of the solar power plant (Fig. 2).

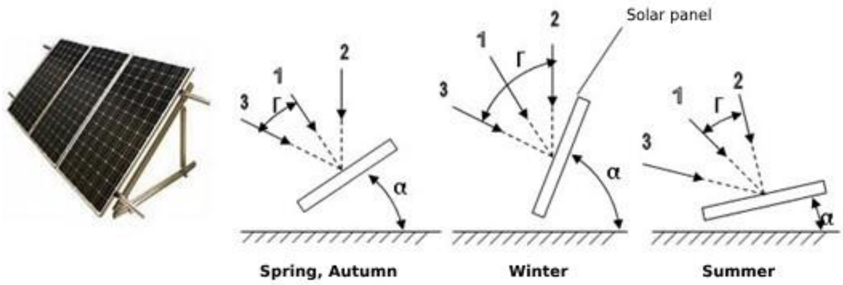

Fig. 2. Installation angle of solar panels depending on the seasons

The following parameters affecting the output of solar energy, such as incidence angle, temperature and solar radiation have been analyzed [8]. As a result, it was possible to design more efficient PV systems and to experimentally study the solar radiation monitoring system in two axes and in a fixed system [9]. Azimuth, zenith, and hour angles for estimating solar radiation, as well as recommended installation angles for solar panels are defined (Fig. 3).

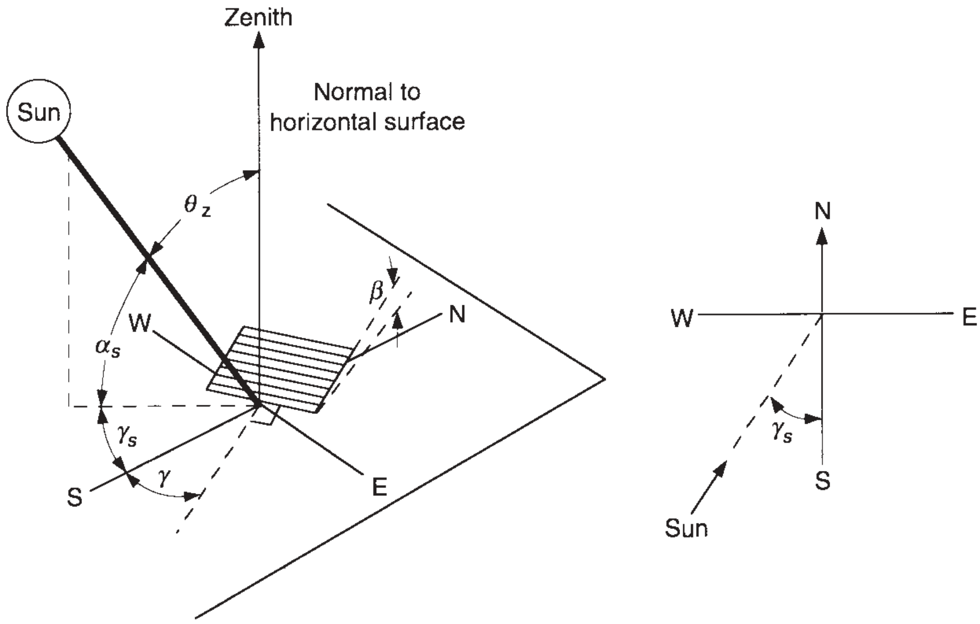

Fig. 3. Zenith angle, slope, surface azimuth angle and inclined surface for solar azimuth angle [9]

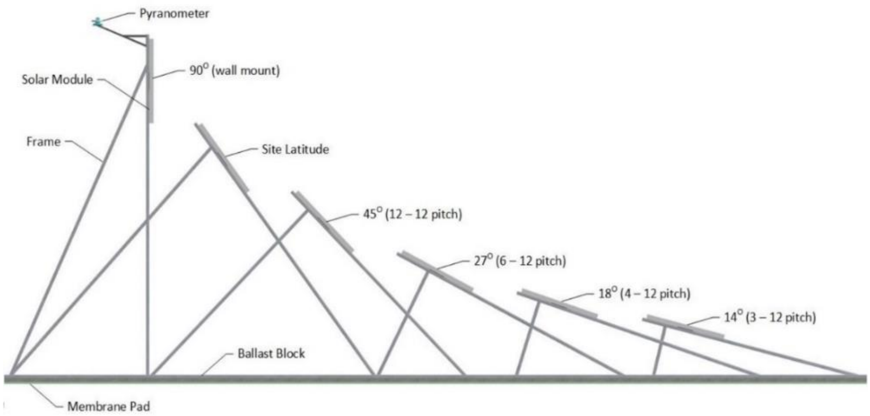

Fig. 4. The most common mounting angles [9]

The angle between the solar radiation and the horizon called the elevation angle (α_s), while the solar azimuth angle (γ_s) is the angle that shows the sun's rays tilting clockwise to the north. Surface azimuth angle (γ) is an angle indicating the deviation of the vertical surface to local longitude takes positive values for an east-facing for facing surfaces. It has negative values for the western surface. Whereas the declination angle δ is the angle between the equatorial plane and the sun's rays at 12 o'clock.
The deviation angle δ can be found using Cooper's equation from:

$$\delta = 23{,}45\,\sin(360\,\frac{284-n}{365}) \tag{1}$$

where *n* is the recommended average day values for months.
Proper installation and operation of solar panels is one of the main factors in achieving high efficiency of the work being done [10, 11, 12]. A solar panel is made of photovoltaic cells. The more sunlight hits the solar cells, the more electricity is generated in the solar panel. From this point of view, the geographical location of the solar panels in the area can be difficult to determine the optimal angle that provides high efficiency. Monitor individual module performance in the

most common mounting angles possible. Ground structures based on 14˚, 18˚, 27˚ and 45˚ roof peaks, as well as the width of the site and installation at 90˚ to the wall were selected (Fig. 4).

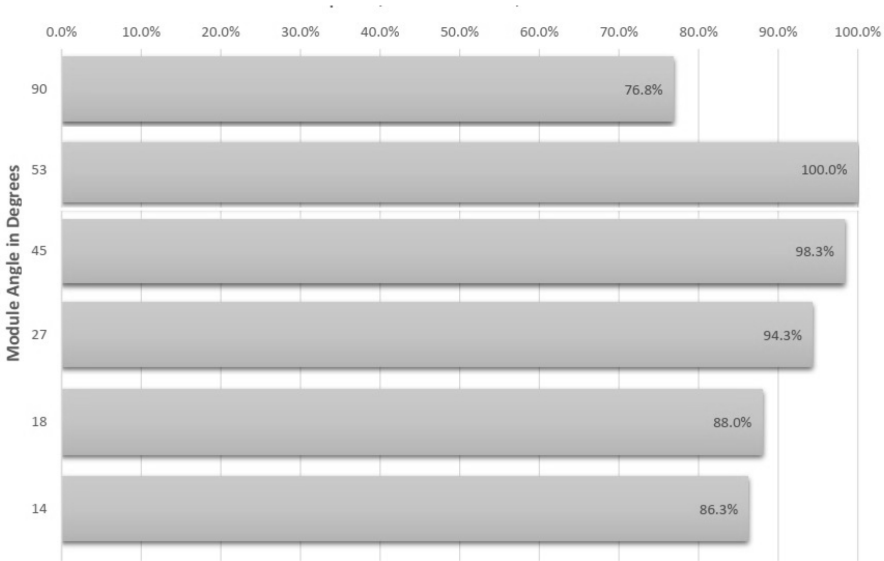

Fig. 5. The efficiency of electricity production compared to the installation of solar panels at different angles

To increase the efficiency of solar panels, it is necessary to correctly choose the angle of the bridge along the horizon, azimuth and other parameters. Of course, it is necessary to produce maximum electricity from solar panels. For this, it is necessary to determine the optimal angle of the solar panel that produces maximum electricity for the same area. The determined optimal angle directly affects the increase of the useful work coefficient of the device. Since the planned panels are installed directly on the roof, the electric chargers must take into account the angle of installation of the solar modules. To determine the daylighting of a sloped area, divide the monthly average solar radiation in kW/month by the number of lunar days in an area with the same slope angle as the solar panels.

Fig. 5 shows the power generation relationship between different tilt angles using the peak generation angle as the baseline. Data from each set of left and right modules were combined for this report. According to modeling calculations of the optimal tilt angle for solar panels , the optimal angle of solar panels for a PV power plant is found to be 53˚. It can be seen that the efficiency is 100 % depending on the width.

3. Results and Discussions

Based on research carried out in the scientific work, if the deviation angle of the solar panels installed in Andijan region (Fig. 6) is 30-35^{O}, it is expected that the EF (Efficiency Factor) of these solar panels will be brought closer to ideal values. But this situation is a privately calculated value observed for solar panels over a certain period of time, and external factors are not taken into account. The EF of a photocell mounted on a solar tracker is significantly different from a photocell mounted on a fixed base due to the automatic detection of the deviation angle. If the maximum power that can be obtained from a sample photovoltaic cell is assumed to be equal to 100%, according to calculations, the maximum efficiency of the installed photovoltaic cell is 63%, and the average efficiency is 20-23%. The maximum and average efficiency of the solar elements installed on the solar tracker are 97.5-62%, respectively.

One of the main disadvantages of photocells installed in the solar tracker is the temperature increase in this cell. Therefore, in the areas where the photovoltaic cells are installed in the solar tracker, the external temperature moderation can ensure the high efficiency of the station. Solar radiation, temperature, wind speed, relative humidity, etc. can be analyzed based on the data obtained from the Meteonorm 8.0 database (Fig. 7).

After receiving meteorological data , the angle and azimuth of the solar panels are selected (Fig. 8). When simulated with the help of the program, when installed at 0 ^{o} azimuth and at an angle of 35 ^{o} , the electricity produced during the year was equal to 35.62 MW. If it is choosen 0 ^{o} azimuth and 0 ^{o} angle, the electricity produced during the year was equal to 11 , 79 MW . Similarly, the maximum value can be achieved by choosing different angles and azimuths [13, 14].

After choosing the azimuth and installation angle, the next step is to choose the solar panels and inverter. In this case, the program can choose a panel and an inverter based on the capacity planned or the available space. Then, models close to solar panels and inverters are selected, their parameters are selected according to the characteristics of inverters and solar panels. On the other hand, the use of a solar tracker can have a positive effect on efficiency, as well as the cost of purchasing and operating additional equipment [14].

Fig. 6. The process of measuring solar panels horizontally in degrees

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/mth	kWh/m²/mth	°C	m/s	[-]	%
January	55.0	28.9	2.6	2.10	3.702	71.1
February	62.4	36.5	4.3	2.40	4.500	66.2
March	112.5	58.1	11.3	2.70	5.475	56.8
April	138.1	71.0	16.6	2.70	5.530	55.9
May	193.3	85.6	23.0	2.79	5.120	43.1
June	214.3	79.8	27.6	3.00	4.949	34.9
July	227.1	70.7	30.0	2.89	4.515	29.3
August	201.6	66.5	28.2	2.79	4.218	32.2
September	154.8	49.8	22.1	2.50	4.284	37.2
October	104.3	46.7	15.2	2.20	5.383	51.7
November	69.7	30.5	8.2	1.89	4.827	65.7
December	46.0	25.7	3.1	2.00	3.852	72.8
Year	**1579.1**	**649.9**	**16.0**	**2.5**	**4.696**	**51.4**

Fig. 7. Data from Meteonorm 8.0 database

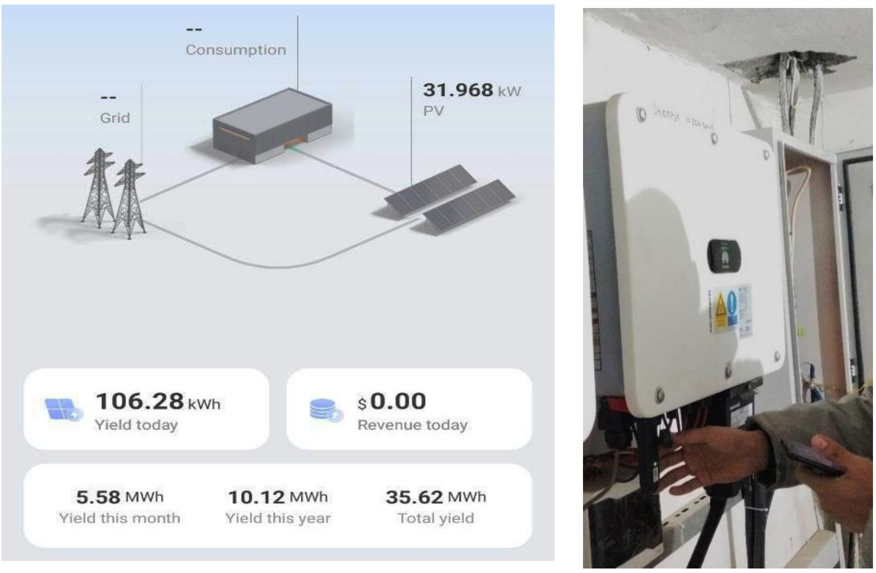

Fig. 8. Monitoring of solar panels installed in Andijan region

4. Conclusions

Due to the fact that the work carried out in order to obtain the maximum efficiency from solar panels is based on the conditions of Andijan region, the application of these calculation books in the conditions of the whole of Uzbekistan may cause errors. Therefore, it is necessary to develop methods for determining the angles suitable for the conditions of Uzbekistan with the help of computer programs (Pvsyst, RETScreen Expert, etc.).

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