OPTIMIZATION OF THE TILT ANGLE OF SOLAR COLLECTORS

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ABSTRACTThe optimum tilt angle greatly affects the performance of solar collectors. Maximum power can be obtained by solar collectors if they are installed at an optimal slope. This study uses a mathematical model to determine the solar radiation incident on an inclined surface and calculates the optimal angles of inclination for each month, season and year for solar collectors in the Arnasay Province of Jizzax region. Calculations are based on measured monthly average daily global radiation and estimated diffuse solar radiation on a horizontal surface. It is established that the optimal slope is different for each month of the year. For this, a computer program was developed in the MATLAB environment. The collected energy on an inclined collector is modeled by changing the angle of inclination.

Keywords: *Optimum tilt angle, solar collector, declination, latitude, solar radiation.*

INTRODUCTION

A photovoltaic (PV) cell is used to convert solar energy falling on the earth's surface into electrical energy, while it is converted into heat energy through a solar collector. The intensity of the beam incident on the solar panel depends on the day of the year, latitude, azimuth angle, inclination or inclination and angle of incidence. This intensity can be measured using devices called pyranometers and pyrheliometers, which are placed near the solar device. For locations in the northern hemisphere, the solar device should be oriented facing the equator (or due south) [1]. To estimate global solar radiation for a given location, various empirical models have been created that use such parameters as: number of hours of sunshine, declination and latitude, daylight hours, relative humidity, most extreme temperatures, altitude and latitude [2]. The solar device will have maximum efficiency if it is facing the sun during the day. The slope of a surface plays a key role in affecting the solar radiation it receives [3]. Thus, in order to increase the power output of solar devices, we need a sun-oriented structure that follows the directions driven by the sun to improve the incident radiation on that surface.

Solar energy can be used directly with various devices such as a solar collector or a photovoltaic (PV) cell. Proper installation of the collector can improve the efficiency of its application, since the magnitude of the radiation flux incident on the collector is mainly affected by the azimuth and angles of inclination. Since solar radiation is not always available in the desired amount and at the right time, the challenge is how to maximize the available solar energy. It has been established that the intensity of solar radiation incident on a horizontal flat surface at a given time and in a given place increases with an increase in the angle of inclination of the surface when the hemisphere of the Sun is tilted. As is known [1], the angle of inclination depends on many external factors, such as geographic latitude, climatic conditions of the area and the period of use of collectors. The tracking system is the best way to collect the maximum electrical energy from the solar panel. In this case, it is advisable to orient the solar collector at a fixed optimal angle of inclination β for the season/year-round, which will provide enough maximum performance. The purpose of this work is to predict the optimal tilt angles for the maximum collection of solar energy for each month, season and year in the Arnasay region of the Jizzakh region.

1. Basic equations

Given the monthly horizontal radiation, H the average monthly clarity index can be calculated using the formula [2]:

$$K_T = \frac{H}{H_0}, \qquad (1)$$

H_0 - monthly average daily external radiation to a horizontal surface, calculated by the following expression:

$$H_0 = \frac{24 \cdot 3600}{\pi} \cdot I_0 \cdot \left(1 + 0.033 \cdot \cos\frac{360 n}{365}\right)\left(\cos\varphi \cos\delta \cos\omega_c + \frac{\pi\omega_c}{180}\sin\varphi \sin\delta\right) \qquad (2)$$

where I_0 is the solar constant (1367 W/m^2), φ location latitude, δ is the angle of declination, and ω_s is the hourly angle of sunset in degrees. declination δ is given by the following expression [3]:

$$\delta = 23.45 \sin\left[\frac{2\pi}{365}(284+n)\right] \qquad (3)$$

n is the average monthly daytime hours of bright sunlight, and the hour angle ω_s is defined as

$$\omega_s = \cos^{-1}(-\tan\varphi \tan\delta). \qquad (4)$$

Theoretically, the monthly collected radiation on an inclined surface for any month of the year can be calculated by the formula [4]

$$H_T = H_B R_B + H_D R_D + rH\left(\frac{1-\cos\beta}{2}\right). \qquad (5)$$

where β is the angle of inclination of the collector, r is the albedo of the earth, H_B is the average daily beam radiation received on the inclined surface can be simply expressed as

$$H_B = H - H_D. \qquad (6)$$

H_D is the monthly scattered radiation, R_b is the ratio of the average monthly and daily beam radiation on an inclined surface to that on a horizontal surface. R_b for surfaces with a fixed slope, inverted to the equation of the equator in the northern hemisphere, described in [5], is

$$R_B = \frac{\cos(\varphi-\beta) \cdot \cos\delta \cdot \sin\omega_s + (\pi/180)\omega_s \cdot \sin(\varphi-\beta)\sin\delta}{\cos\varphi \cdot \cos\delta \cdot \sin\omega_s + (\pi/180)\omega_s \cdot \sin\varphi \sin\delta}, \qquad (7)$$

where ω_s is the hourly angle of sunset for an inclined surface for the average day of the month, which is determined by the expression

$$\omega_s = \min\begin{cases}\cos^{-1}(-\tan\varphi\tan\delta), \\ \cos^{-1}(-\tan(\varphi-\beta)\tan\delta).\end{cases} \qquad (8)$$

where " min " means the smaller of the two values in brackets [6]. The quantity R_D in equation (5) is the ratio of the monthly diffuse radiation collected per unit area of an inclined surface to the monthly diffuse radiation collected per unit surface area in a horizontal position, and is determined by the hemispheric distribution of diffuse sky radiation. If the distribution of diffuse sky radiation is isotropic, then R_D it is given as

$$R_D = \left(\frac{2+\cos\beta}{3}\right). \qquad (9)$$

It can be seen from the above that the average monthly radiation, H_T, collected by a unit area of the inclined surface, will depend on many factors, and in particular on the angle of inclination. β. The optimal angle of inclination of the collector ensures that the collector receives maximum radiation in a given period of time.

2. RESULTS AND DISCUSSION

The available monthly average daily global solar radiation and hours of sunshine duration were taken from the website of the weather station of the Jizzakh region for the period 2022. Extraterrestrial radiation on a horizontal surface during monthly periods was calculated numerically using declination, latitude, and hour angle of sunset from the estimation methods. Then counted average clarity index K_T, from which monthly scattered radiation was obtained using evaluation methods H_D. Monthly average daily values of solar radiation for extraterrestrial, global and diffuse solar radiation on horizontal surface for Jizzax shown in Table

Table 1. Global, diffuse and ray average monthly radiation on a horizontal surface.

Months	H	H_0	ω_s	K_T	δ	H_d	H_b
Jan	19.65	31.99	86.13	0.61	-20.92	6.40	13.25
Feb	20.01	34.60	87.67	0.58	-12.95	7.15	12.86
Mar	21.95	36.91	89.57	0.59	-2.42	7.53	14.42
Apr	22.35	37.94	91.68	0.59	9.41	7.77	14.58
May	21.83	37.57	93.44	0.58	18.79	7.75	14.08
June	19.76	37.01	94.31	0.53	23.09	7.85	11.91
Jul	18.42	37.11	93.92	0.50	21.18	7.97	10.45
Aug	16.37	37.55	92.42	0.44	13.45	8.09	8.29
Sep	17.43	37.08	90.39	0.47	2.22	7.99	9.44
Oct	21.36	35.11	88.29	0.61	-9.60	7.07	14.29
Nov	17.95	32.50	86.53	0.55	-18.91	6.83	11.12
Dec	18.77	31.09	85.69	0.60	-23.05	6.29	12.48

The Fig. 1 shows the global, diffuse and ray average monthly radiation to a horizontal surface. It can be seen that the ray component prevails over the diffuse component throughout the year, so the main contribution of solar radiation falls on the ray component.

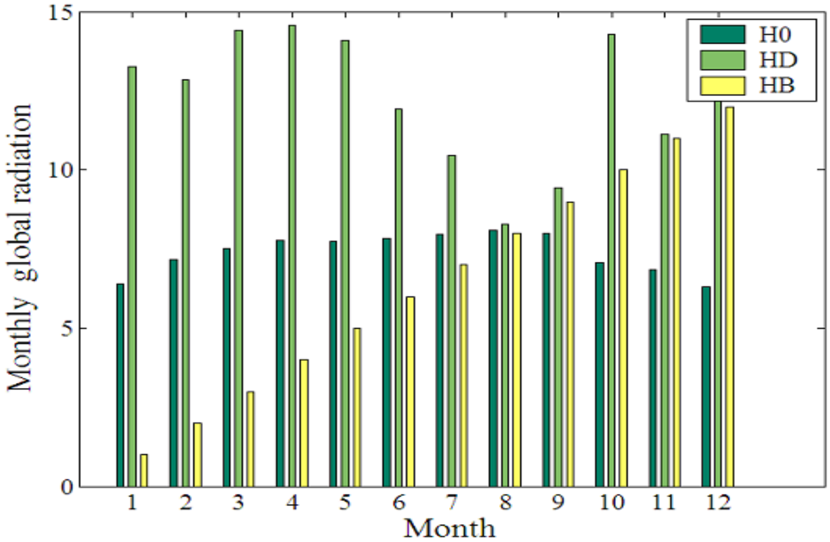

Figure 1. Monthly average daily global radiation, diffuse radiation and ray radiation on a horizontal surface in Jizzakh.

Calculations show that the optimal angle of inclination varies from 0° (June) to 59° (December) throughout the year. The average annual optimal slope angles for 2022 were 28°. From the annual analysis of the collected data, it was clearly seen that for each month of the year there is a unique β, for which the solar radiation is maximum for this month. Fig. 2 shows the tilt angles for each month of the year when the collector panel is tilted at the optimum angle at the Arnasay site.

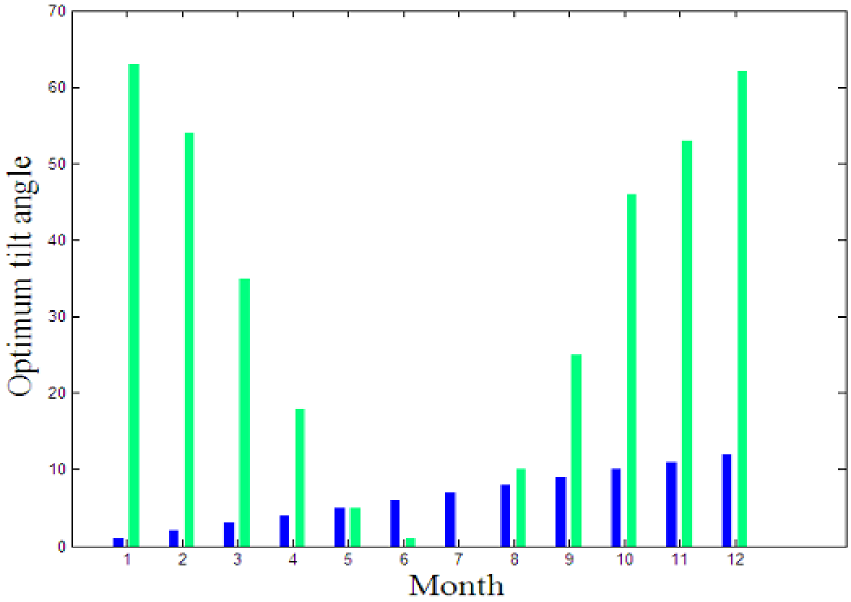

Fig.2. The optimal average angle of inclination for each month of the year at the terrain site.

It can be seen that the optimal angle of inclination reaches values very close to the Arnasai latitude (28.20). It reaches a maximum value of 28° in January, decreases to a minimum of 20° in July and rises again to 28° in December. Thus, β it reaches higher values in winter and lower values in summer. The average annual value of monthly optimal tilt angles is 24°. In addition, monthly angle optimization achieves an annual gain of 6.169% compared to a horizontally aligned panel. In addition, by optimizing the tilt angle every year, an annual gain of 6.093% is achieved compared to a horizontally aligned panel. Thus, optimizing the angle of inclination greatly improves efficiency and gives better performance than a conventionally placed horizontal collector. Moreover, when the angle of inclination is optimized annually instead of monthly, there is an average annual loss of 0.0314% in the output. Annual optimization is only possible for places where people are rarely reached, for example, in rural areas.

The values of slope angles optimal for this period also tend to increase by June. This is because the sun has just crossed the observer's latitude and is moving north until it reaches its maximum declination in June (i.e. $d = 23.09°$).

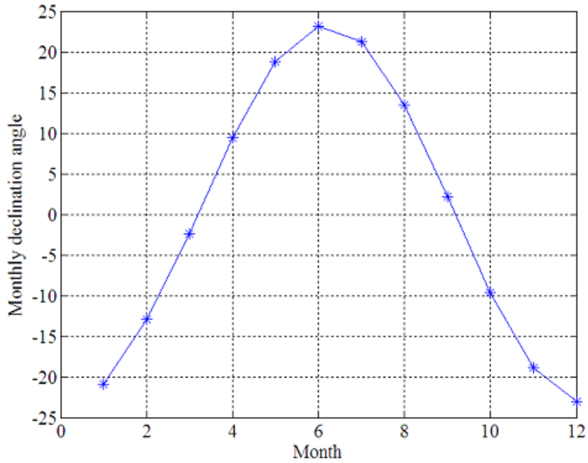

Fig.3. Monthly declination angle

At the latitude of the observer (i.e. when the sun is directly above the observer) the angle of incidence is zero, and this occurs on a certain day in March and September. The values of optimal tilt angles tend to increase from September to December. This is because the sun once again crossed the observer's latitude and moved south until it reached its maximum declination in December ($d = -23.09°$). The average values of the optimal slope angle were found for three periods: January-March, April-August and September-December. Figure 2 requires changing the slope of the reservoir three times a year: January-March (27°), April-August (22°) and September-

December (25°). These values clearly show that the optimal tilt angles for the periods January-March and September-December should be equal to latitude plus 18°. The optimal angle of inclination in the period from April to August should be equal to the latitude of the place plus 20

Conclusion

The aim of this study was to evaluate the optimal solar collector tilt angle based on monthly horizontal radiation. It turned out that the optimal slope is different for each month of the year. We also found that the average annual optimal slope is latitude plus 28°. The results show that the optimal tilt angles for the periods January-March and September-December are latitude plus 16°, and the optimal tilt angle for the period April-August is latitude plus 27°. The energy loss when using both the annual average fixed angle and the average seasonal tilt angle is about 1%. However, it can be concluded that the average annual fixed slope can be used in many applications (e.g. domestic heating) to keep the manufacturing and installation costs of collectors low. The 1% loss also shows that the models used in the present study give satisfactory results.

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