Journal of
Fundamentals of Renewable Energy and Applications

Alsadi and Nassar, J Fundam Renewable Energy Appl 2017, 7:2
DOI: 10.4172/2090-4541.1000225

Research Article | Open Access

Energy Demand Based Procedure for Tilt Angle Optimization of Solar Collectors in Developing Countries

Samer Yassin Alsadi* and Yasser Fathi Nassar

Department of Electrical Engineering, Palestine Technical University, Palestine

Abstract

For efficient performance of photovoltaic (PV) panels and flat-plate solar collectors, one of the most important factors that should be considered is tilt angle. The common approach used by researchers has been to calculate the tilt angle (S_s) which maximizes the amount of solar radiation received by the collector. Economically, solar systems must provide a maximum energy to the customer not to collect maximum solar radiation. In some situations, there is a mismatch between them. However, solar harvesters need to be tilted at the correct angle to maximize the performance of the system. In this paper, the average monthly solar fraction of the system (the fraction of energy that is supplied by solar energy) is used as an indicator to find out the optimum tilt angle (S_f) for a solar system. This manner is profitable for most developing countries where there is no law governing the exchange of energy between the main provider of electrical energy in the country (in our case the general electrical company) and investors in the solar energy (for example, house owner). Regardless, that the solar radiation in the case optimum tilt angle based upon the maximum solar radiation collection (S_s) is 4% greater than that of the offered tilt angle (S_f), but we get an improvement in the solar fraction coefficient reached to 0.31%, which is equivalent to a yearly sum of 540 MWh. The solar radiation is calculated using the clear sky ASHRAE model and then multiplied by a magnification factor to meet most of the energy demand. This factor is physically presenting the solar conversion efficiency multiplied by the area of the solar collectors. Having the total monthly energy demand, the monthly solar fraction coefficient can be calculated by dividing the total monthly energy delivered by the solar system by the total monthly energy demand.

Keywords: Solar radiation; Optimum tilt angle; Electrical load; Solar fraction coefficient

Introduction

Solar systems, like any other systems, need to be operated with the maximum possible performance. This can be achieved by proper design, construction, installation and orientation. The orientation of the collector is described by its azimuth and tilt angles. Generally, systems installed in the northern hemisphere are oriented due south and tilted at a certain angle [1]. Accordingly, it is important to determine the optimal tilt angle at which maximum solar radiation is collected. The tracking systems, that follow the direction of the sun on its daily sweep across the sky, allow the maximization of solar radiation incident on the collector's surface. A gain of 40% in solar radiation incident on the collector is achieved if a two axis tracking system is adopted instead of a fixed collector. However, tracking systems are expensive, need energy for their operation and are not always applicable especially for small scale systems [2].

Functionally, solar systems must provide a maximum energy to the customer not to collect maximum solar radiation. We mean by solar system the all system that including solar harvester (thermal solar collector or/and PV panel) and the storage (thermal or electrical). In some situation there is a mismatch between them, when we comparing the daily load curve with the available solar radiation we recognize the lack of harmony between them. This mismatch is depending on the location and the nature of the load. This paper introduces applied solar energy aspects that is optimization of tilt angle for maximum solar energy contribution in the energy-grid and presents a method for calculating it. This method takes into account the monthly energy consumption and the available solar radiation on the site of interest. It was selected two different locations with different loads behaviour for the purpose of comparison where Brack El-Shati is locating in a desert area (Sahara) which characterized by a dry and warm during the day and cold during the night in the winter season and very hot during the summer season. While Tulkarm is a city locating in a mountainous area belongs to the Mediterranean basin, characterized by moderate climate where the winter season is rainy and warm and in summer it relatively hot with high humidity. Table 1 presents the coordinates of two different sites with different electrical load distribution and different climate [3].

Theoretical Approach

The followed approach can be summarized in the following steps:

Calculation of solar radiation

There are many models for estimating solar radiation. Most of them are presented in text books of solar energy [4,5] and most recent researches [6-10], hourly total radiation ($I_{t,s/f}$) on an inclined surface using both tilt angles (S_S - The optimum tilted surface of the collector in order to collect maximum solar radiation and S_f - The optimum tilted surface of the collector in order to achieve maximum fraction coefficient or to provide a maximum solar energy) has been calculated. The model considers the anisotropy diffuse sky model formulated by Hay and Davis [4] and includes components of beam directly from the sun and diffuse irradiation from the circumsolar and the sky dome and beam and diffuse irradiation reflected from the ground. The total

***Corresponding author:** Samer Yassin Alsadi, Department of Electrical Engineering, Faculty of Engineering and Technology, Palestine Technical University-Kadoorie, Tulkarm-Palestine, 00970, Palestine, Tel: 970599410707; E-mail: samer_sadi@yahoo.com

Received December 26, 2016; **Accepted** February 01, 2017; **Published** February 03, 2017

Citation: Alsadi SY, Nassar YF (2017) Energy Demand Based Procedure for Tilt Angle Optimization of Solar Collectors in Developing Countries. J Fundam Renewable Energy Appl 7: 225. doi:10.4172/20904541.1000225

Site	Country	Latitude	Longitude	Elevation (m)
Brack El-Shati	Libya	27.53°N	14.28°E	334
Tulkarm	Palestine	32.31°N	35.03°E	125

Table 1: Geographic location of the sites.

solar radiation ($I_{t,s/f}$) - the subscript *s/f* refers to the slopes S_S and S_f respectively- for an hour as the sum of three components is given as:

$$I_{t,s/f} = (I_b + A_i I_d) R_{b,s/f} + (1 - A_i) I_d \frac{1 + cosS_{s/f}}{2} + (I_b + I_d) \varrho_g \frac{1 - cosS_{s/f}}{2}, \left[\frac{W}{m^2}\right] \quad (1)$$

Where I_b is the hourly beam radiation from the sun on a horizontal surface, I_d is the hourly diffuse radiation parts of the circumsolar and the isotropic on a horizontal surface, so the total diffuse radiation on a horizontal surface will be equal to the sum of these two components, having neglected the horizon brightening diffuse radiation component, according to Hay and Davis anisotropic sky model. A_i is the anisotropic index which is a function of the transmittance of the atmosphere for beam radiation and then $A_i = \frac{I_b}{I_o}$, where I_o is the hourly extraterrestrial radiation on a horizontal surface [9], which equal to:

$$I_o = G_{sc}\left(1 + 0.033\frac{360n}{365}\right)\cos\theta_z, \left[\frac{W}{m^2}\right] \quad (2)$$

Where G_{sc} is the solar constant 1367 W/m², n is denotes to day of the year and θ_z is the solar zenith angle at the time and day of interest.

The $R_{b,s/f}$ is a geometric factor which presents the ratio of beam radiation on the tilted surface to that on a horizontal surface at any time, $R_{b,s/f} = \frac{\cos\theta_{i,s/f}}{\cos\theta_z}$ in where $\theta_{i,s/f}$ is the solar incident angle and calculated from the following equation [9], with the corresponding azimuth surface angle ψ and tilt angle $S_{s/f}$:

$$\theta_{i,s/f} = cos^{-1}\left[sinS_{s/f}\ cos\theta_z\ cos(\phi - \psi) + cosS_{s/f}\ sin\theta_z\right] \quad (3)$$

and θ_z , is the solar zenith angle; and ϕ, is the solar azimuth angle.

$$\theta_z = cos^{-1}\left[sin\delta\ sinL + cos\delta\ cosL\ cosh\right] \quad (4)$$

$$\phi = cos^{-1}\left[\frac{sin\delta\ cosL - cos\delta\ sinL\ cosh}{\sin\theta_z}\right] \quad (5)$$

Where *L* denotes the local latitude, angle δ is the declination angle and *h* is the hour angle: h=15 (t_s-12) in where t_s presents the solar time and ϱ_g is the ground-reflectivity.

In this paper, the ASHRAE clear-sky model is adopted to estimate the hourly beam normal (I_{bn}) and diffuse (I_d) solar radiation. The ASHRAE clear-sky model appears to be general enough for the objective of the paper, furthermore, we don't need to any information about the location of interest, except the latitude angle.

The direct beam radiation and sky diffuse are calculated from the following formula [6]:

$$\begin{aligned} I_{bn} &= Ae^{\frac{-B}{cos\theta_z}} \\ I_b &= I_{bn}\cos\theta_z \\ I_d &= CI_{bn} \end{aligned} \quad (6)$$

Where A, B and C are constants for every day and are given in Table 2 for the 21st day of each month [6].

Optimum tilt angle based upon the maximum solar radiation collection

The common approach used by researchers has been to calculate the tilt angle which maximizes the amount of radiation received by the collector. Many investigations have been carried out to determine, or at least estimate, the best tilt angle was found as [3]:

Months	A: W.m⁻²	B: Dimensionless	C: Dimensionless
January 21	1,230	0.142	0.058
February 21	1,215	0.144	0.060
March 21	1,185	0.156	0.071
April 21	1,135	0.180	0.097
May 21	1,103	0.196	0.121
June 21	1,088	0.205	0.134
July 21	1,085	0.207	0.136
August 21	1,107	0.201	0.122
September 21	1,151	0.177	0.092
October 21	1,192	0.160	0.073
November 21	1,220	0.149	0.063
December 21	1,233	0.142	0.057

Table 2: Constants for ASHRAE equations for the 21st day of each month.

$$S_s = 1.5 + 1.35L - 1.069 \times 10^{-2} L^2 \quad (7)$$

Where *L* is the latitude angle.

Monthly electrical load of the site

A two-year data of daily electrical load (Q_L) in Tulkarm and Brack El-Shati is obtained from Tulkarm Municipal-Electrical department and General Electrical Company of Libya, respectively. The data has been rearranged into the form of monthly load.

Calculation of the solar fraction coefficient

The performance of a solar system is characterized by the annual solar fraction (the fraction of load supplied by the solar energy). We mean by solar system the all system that including solar harvester (thermal solar collector or/and PV panel) and the storage (thermal or electrical). Economic constrains preclude the establishment of a solar system with 100% fraction coefficient. This coefficient could be determined monthly for more accurate in analysis and it is defined as:

$$f = \frac{Q_L}{\chi H_t} \quad (8)$$

Where H_t is the total monthly solar radiation and χ is a magnification factor to meet most of the energy demand. This factor is physically presenting the solar conversion efficiency multiplied by the area of the solar collectors. Of course, the value of χ is depending on all of available solar radiation, load and the fraction coefficient. For realization of the problem we choose a value of 92% for the annual fraction coefficient, therefore magnification factor was found:

$$\chi = 61{,}000\ m^2, \text{ for Tulkarm-Palestine and}$$
$$\chi = 150{,}000\ m^2, \text{ for El-Shati-Libya} \quad (9)$$

Results and Discussion

An MS Excel-sheet has been prepared to estimate the solar radiation incident on a tilted surface using the above mentioned equations. Figure 1 presents contour plots for total monthly solar radiation in kWh/m² incident on a tilted surface as a function of the tilt angle (*S*), for both sites Tulkarm and Brack El-Shati. For stationary solar collectors, the optimum tilt angle (S_S) based upon the maximum solar radiation collection was found as:

S_S=35° for Tulkarm-Palestine and S_S=30° for Brack El-Shati-Libya

Citation: Alsadi SY, Nassar YF (2017) Energy Demand Based Procedure for Tilt Angle Optimization of Solar Collectors in Developing Countries. J Fundam Renewable Energy Appl 7: 225. doi:10.4172/20904541.1000225

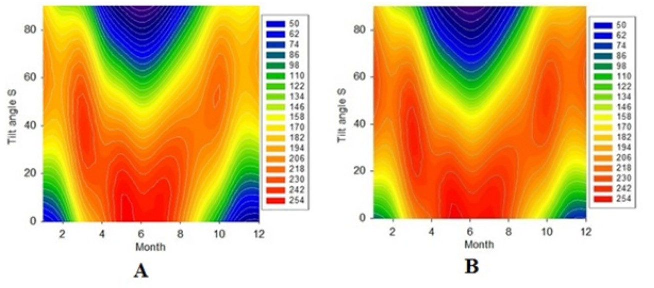

Figure 1: Contour plots of total monthly solar radiation (kWh/m²) incident on a tilted surface as a function of the tilt angle *S*; **A.** For Tulkarm-Palestine site; **B.** For Brack El-Shati-Libya site.

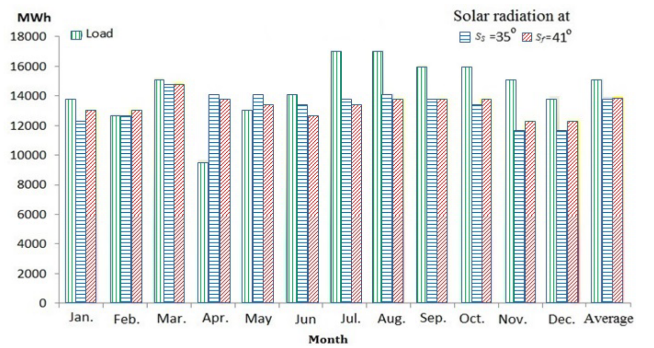

Figure 2: Monthly load distribution and the solar radiation on tilted surface, 35° and 41° for Tulkarm-Palestine.

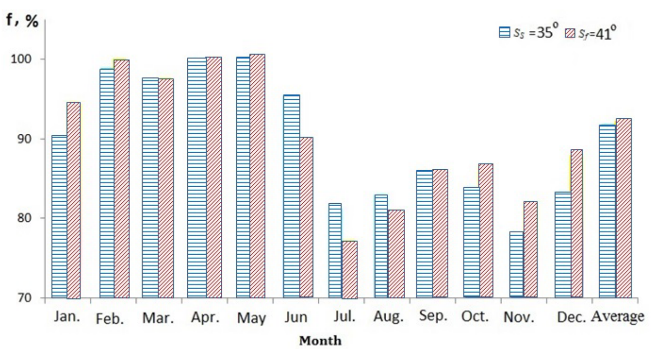

Figure 3: The monthly and annual average solar fraction coefficient for tilt angles, 35° and 41° for Tulkarm-Palestine.

Having the electrical load, the solar fraction coefficient has been determined. The optimum tilt angle (S_f) will be located according to maximum solar fraction coefficient and it was found as:

S_f=41° for Tulkarm-Palestine and

S_f=26° for Brack El-Shati-Libya

Figure 2 presents the monthly load distribution and the solar radiation incident on tilted surfaces of 35° and 41° for Tulkarm site. Figure 3 presents the monthly solar fraction and the annual solar fraction coefficient for Tulkarm site. In the same way Figure 4 presents the monthly load distribution and the solar radiation incident on tilted surfaces of 30° and 26° for Brack El-Shati site. Figure 5 presents the monthly solar fraction and the annual solar fraction coefficient for Brack El-Shati site.

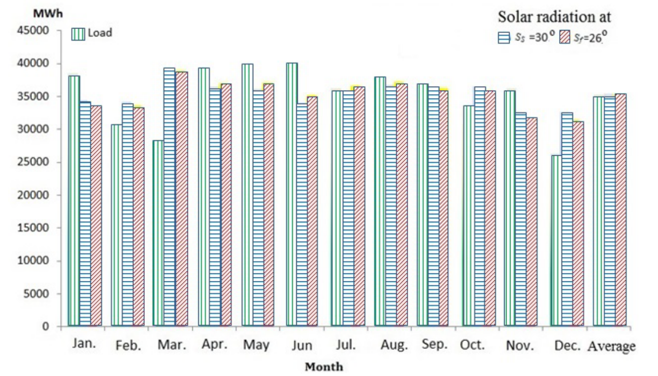

Figure 4: Monthly load distribution and the solar radiation on tilted surface, 30° and 26° for Brack El-Shati-Libya.

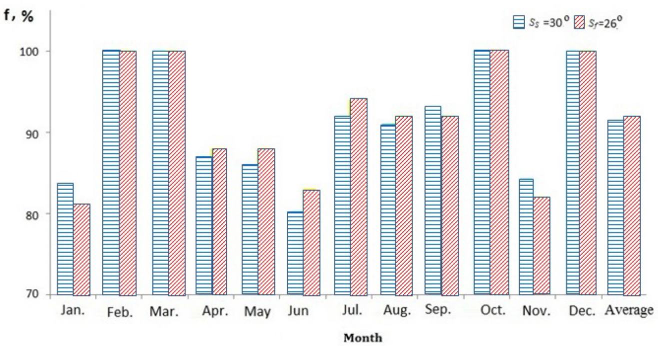

Figure 5: The monthly and annual average solar fraction coefficient for tilt angles, 30° and 26° for Brack El-Shati-Libya.

Looking at Figure 2 we find that the total energy from system with optimum tilted surface S_S=35° comes close to the load in 3 positions, June, July and August. While with the angle S_f=41° the harvested energy comes close to the load in January, February, October, November and December. However the energy from the system matches to the load in the rest of the months (March and September). When the radiation is larger than the load as it is the case in April and May the fraction coefficient is equal to 1, as it indicated in Figure 3.

As a result we find that the annual fraction coefficient for S_f=41° is larger than that for S_S=35°. From an economical point view putting solar panels at S_f =41° more economic benefit of those at S_S=35°. The situation is exactly the same for Brack El-Shati site, as it demonstrated in Figures 4 and 5.

The reason of this is that, in the developing countries where there is no law governing the energy exchange between the provider and the consumers, the losses in the collected solar energy is very high, accordingly the term "maximum" losses its meaning, because the maximum and other value may be coming equal in the case of both energy collected by the two angles will have the same solar fraction coefficient of unity.

Conclusion

Increased solar energy gain justifies changing the tilt angle of solar collectors from S_s to S_f. In our case this gain reaches up to 540 MWh yearly which is equivalent to 318 oil barrel and reduced carbon dioxide emission of (410 ton of CO_2), in addition of other pollutants reduction.

The present work has studied the optimum tilt angles for solar system by using the monthly solar fraction as an indicator and has reached the following conclusions:

1. There is no explicit function for optimizing the tilt angle of solar collectors, for a specific situation there is an optimum angle, the approach is outlined in this research.

2. The optimum tilt angle of the collector depends on the energy demand behaviour and the magnification factor.

3. In our case study, the optimum tilt angle for the maximum solar fraction for Libya is less than any of that for the maximum solar radiation at the collector by 4°. On the other hand this was found to be 6° greater for Palestine.

4. The authors recommend that further work should be conducted in countries where there is law governing the exchange of energy between the main provider and the investors in order to estimate the economic benefit of the exchange process.

References

1. Shariah A, Al-Akhras MA, Al-Omari IA (2002) Optimizing the tilt angle of solar collectors. Renew Energy 26: 587-598.
2. Darhmaoui H, Lahjouji D (2013) Latitude based model for tilt angle optimization for solar collectors in the mediterranean region. Energy Procedia 42: 426-435.
3. Asadi SY, Nassar YF, Ali KA (2016) General polynomial for optimizing the tilt angle of flat solar energy harvesters based on ASHRAE clear sky model in mid and high latitudes. Energy Power 6: 29-38.
4. Duffie JA, Beckman WA (2013) Solar engineering of thermal processes (4thedn). John Wiley & Sons, Inc.
5. Nassar YF (2006) Solar energy engineering active applications. Sebha University, Libya.
6. Alsadi S, Nassar YF (2016) Correction of the ASHRAE clear-sky model parameters based on solar radiation measurements in the Arabic countries. Int J Renew Energy Technol Res 5: 1-16.
7. Yeole SV, Awate AU, Sarode PL (2016) A review of advancements in design configurations for optimizing solar flat plate collector effectiveness. Int J Innovative Res Sci Engineering Technol 5: 4894-4902.
8. Kocer A, Yaka IF, Sardogan GT, Gungor A (2015) Effects of tilt angle on flat-plate solar thermal collector systems. Brit J Appl Sci Technol 9: 77-85.
9. Arslanglu N (2016) Optimization of tilt angle for solar collectors: A case study of Bursa, Turkey. Int J Electrical Comput Energetic Electronic Commun Engineering 10: 517-520.
10. Despotovic M, Nedic V (2015) Comparison of optimum tilt angles of solar collectors determined at yearly, seasonal and monthly levels. Energy Convers Manag 97: 121-131.