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Determining the Number of Solar Modules of a 1kW Solar Energy System in Antalya, Turkey

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Abstract

In this paper the number of solar modules of a 1kW solar energy system was determined by using the total solar radiation and the solar module energy output energy relation. The total solar radiation was correlated with the tilt angle of solar modules. Thus the optimum yearly tilt angle of solar modules was calculated and assumed that solar modules of the system were tilted at this angle. In conclusion the monthly average daily total solar radiation, optimum yearly tilt angle and the number of solar modules of the related system were established for the city.
Key words: Total solar radiation, optimum yearly tilt angle, solar module energy output

1. Introduction

In recent years global warming has been one of the most significant issues worldwide. The rapid increase in the concentrations of the greenhouse gases due to the power generation ways has been a considerable additive of this warming [1].

Solar energy has come to the front as a clean alternative energy source with no greenhouse gas emission during the operation [2, 3]. However the emissions which occur during manufacturing, transporting and mounting of solar modules need to be regarded when evaluating the environmental profile of solar energy systems in their life cycle [4, 5]. Thus the designing stage of solar energy systems is vital to improve the greenhouse payback time and energy payback time of the systems. At this point it is important to work with accurate solar data and determine the best tilt angles to build the systems with fewer modules.

The optimum tilt angle of solar modules is defined as the angle which provides the maximum total solar radiation on the surface [6, 7]. This angle changes for different time periods: hourly, daily, weekly, monthly, seasonally, yearly and so on. The frequency in the change of solar modules improves the system efficiency. However increasing this frequency means additive cost of mechanical and/or electronic design to place the modules in the correct angles [8, 9].

In this paper the number of solar modules of a 1kW solar energy system in Antalya, Turkey was determined. The modules were assumed to be fixed at the optimum yearly tilt angle of the city. For this purpose the optimum yearly tilt angle and the monthly average daily total solar radiation at this angle were calculated. The solar data of the month with the least total solar radiation value was determined and used in further calculations. In conclusion the number of the system was established to be few and adequate to meet the energy demands all days of the year including the cloudiest ones.

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2. Materials and Method

2.1. Optimum yearly tilt angle

In this paper optimum yearly tilt angle was calculated to maximize the yearly average daily total solar radiation on the tilted surface. A MATLAB program was developed by using the following equation [10]:

$$H_t = H_b * R_b + H_d * R_d + H * \rho_g * \left(\frac{1-\cos\beta}{2} \right) \quad [1]$$

In this equation H_t, $Hb*Rb$, $Hd*Rd$, H are the yearly average daily values of total solar radiation, beam solar radiation, diffuse solar radiation and global solar radiation respectively. ρ_g is the ground reflectivity coefficient and β is the tilt angle of the surface.

2.2. Energy output of a solar module

In this paper energy output of a solar module was correlated with the total solar radiation on the optimally tilted surface by Equation 2 [11]:

$$E_p = S * n_p * H_t \quad [2]$$

In this equation S and n_p are the module area and the average module efficiency respectively. They were obtained from the technical specifications of solar modules (Table 1). H_t is the total solar radiation value of the cloudiest month of the year in the city. The calculations were made for the worst case so that the number of solar modules would be adequate to meet the energy demand at any time of the year.

The monthly average daily total solar radiation was determined by Equation 1. In this equation the monthly average daily global solar radiation data was obtained from Solar Energy Potential Atlas (GEPA). The monthly average daily diffuse solar radiation was calculated in the previous work of the authors based on the clearness index and the sunshine fraction (Table 2). Finally the monthly average daily beam radiation was calculated by subtracting the diffuse solar radiation from the global solar radiation.

Table 1. Technical specifications of the selected solar module for the system

Maximum power	100W
Tolerance	±3%
Open circuit voltage	22.95V
Short circuit current	5.85A

Table 1. (cont.)

Maximum power voltage	18.40V
Maximum power current	5.43A
Module efficiency	15.29%
Terminal box	IP65
Maximum system voltage	1000V DC
Operating temperature	-40°C- 85°C
Dimensions	1200mm x 540mm x 30mm
Weight	6.8kg

Table 2. The monthly average daily global and diffuse solar radiation values for Antalya, Turkey

H [kWh/m^2]	H_d [kWh/m^2]
2.1200	0.9942
2.5700	1.1975
4.3700	1.6432
5.4700	1.9894
6.3600	2.1506
6.9300	2.0511
6.6500	1.9528
6.1400	1.7477
5.1600	1.5183
3.9300	1.2868
2.5100	1.0336
1.9200	0.9192

3. Results

The optimum yearly tilt angle for the city was calculated to be 32° and the monthly average daily total solar radiation values on a surface tilted at this angle were given in Table 3.

Table 3. The monthly average daily total solar radiation values on a 32° tilted angle surface in Antalya, Turkey

Month	H_t [kWh/m2]
January	3.3539
February	3.5569
March	5.3588
April	5.7082
May	5.9054
June	6.0769
July	5.9841
August	6.1295
September	6.0472

Table 3. (cont.)

October	5.5251
November	3.9885
December	3.1557

Table 3 indicates that the total solar radiation received on the 32° tilted surface is minimum in December. Thus H_t for this month was used in Equation 2 and the energy output of the 100W solar module in Table 1 was calculated to be 312.868W. According to this result 4 solar modules are required to provide 1 kW power generation in December.

4. Discussion

The total solar radiation based calculations show that a 1kW solar energy system in Antalya, Turkey needs to comprise of at least 4x100W solar modules to meet the energy demand consistently. However the sunshine hour based calculations, generally used for the design of solar energy systems due to the lack of total solar radiation data, show that 3x100W solar modules are adequate. This means the system is not able to provide the required power generation in the cloudiest hours and/or days. Thus it is vital to analyse the solar radiation data of the locations and make the calculations for the worst weather conditions before building solar energy systems. In this case the total daily energy demand is met at any weather condition and the rest is stored and/or at clear sky times of the year.

Conclusions

In this study the number of solar modules of a 1kW solar energy system in Antalya, Turkey was evaluated. It was assumed that the system was a fixed one and tilted at yearly optimum tilt angle. The optimum tilt angle of the city was established to be 32° by a MATLAB program correlating the total solar radiation and optimum tilt angle. The monthly average daily total solar radiation values at this angle were estimated and it was observed that the least radiation was received in December. The energy output of a 100W solar module was calculated to be 312.868W in this month. In conclusion it was determined that the system must comprise of at least 4x100W solar module to provide the required energy generation.

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