Optimization of photovoltaic modules tilt angle for Oman

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3 AUTHORS:

Hussein A Kazem
Sohar University

Tamer T.N. Khatib
An-Najah National University

Ali Alwaeli
University of Baghdad

Optimization of Photovoltaic Modules Title Angle for Oman

Hussein A. Kazem[1], Tamer Khatib[1], Ali A. K. Alwaeli[2]
[1]Faculty of Engineering-Sohar University, PO Box 44, Sohar PCI 311, Oman
[2]Aben Rushid College - Baghdad University, Iraq

Abstract: This paper presents a method for optimization of photovoltaic modules tilt angle for Sohar, Oman. Numerical method for optimization of the PV module tilt angle, is implemented using MATLAB and hourly meteorological data and load demand. The results show that for Sohar zone the tilt angle of a PV array must be adjusted twice a year where the PV array must be slanted at 49 degrees in the period of 21/09-21/03 (n=255-81), while it must be horizontal (tilt angle is zero) in the period of 21/03-21/09 (n=81-255). This adjustment practice gains the energy collected by a PV array by 24.6%.This paper contains important information for those who are interested in photovoltaic system investment in Oman.

Keywords: Photovoltaic system; tilt angle; Oman

1. Introduction

Based on the fact that PV systems are clean, environment friendly and secure energy sources, PV system installation has played an important role worldwide. However, the drawback of PV systems is the high capital cost compared with conventional energy sources. Currently, many research works are carried out focusing on optimization of PV systems so that the number of PV modules, capacity of storage battery, capacity of inverter and PV array tilt angle can be optimally selected. PV system size and performance strongly depend on metrological variables such as solar energy and ambient temperature and therefore, to optimize a PV system, extensive studies related to the metrological variables have to be done [1, 2].

In the Sultanate of Oman the height electricity demand expected to increase to 5691 MW in 2014 in comparison with 2773 MW in 2007. While, in 2010 the annual growth rate, at about 17.8%, and peak demand is envisaged to continue increasing due to the population growth and accelerated industrial in Oman. The forecasted electricity generation in 2014 will be 24.0 TWh, and shortages in electricity are expected to occur in the near future if current trends continue. The natural gas production is 1,097,661 MNSCF in 2009. The government in Oman accounts for 29.16% of total gas production in 2008, while the remainder is used in oil-production and for export, and up to 92% of the natural gas is domestically used for producing electricity [3]. This situation shows that renewable energy studies must be done for Oman in order to encourage the investment in this filed. Such studies must start by assessment studies of renewable energy systems in terms of technical and economical criteria.

The Sultanate of Oman lies between latitude 16^{o}40' N and 26^{o}20' N and longitudes 51^{o}50' E and 59^{o}40' E which is in the solar belt. The climatic conditions are mainly desert in the north and subtropical in the far south. However, according to [4] the average solar radiation in Oman is 5.197 kWh/m^2/day and the daily sunshine duration is between 8.0 and 10.5 hours [5]. Based on this, Oman has a very good potential for solar energy harnessing because of the long daily duration of sunshine hours and high levels of solar radiation. In other words the use of PV system is expected to be feasible and therefore, deep technical evaluation, feasibility and size optimization studies must be done for this zone [6].

Some PV system design and evaluation work done for Oman can be found in [7-10]. In [7] solar energy averages were predicted for 17 sites in Oman namely Khasab, Majis , Buraimi, Rumais , Mina Qaboos, Seeb , Rusail , Saiq , Sur , Fahud , Masirah, Yalooni , Marmul, Thumrait , Qairoon Hairiti , Salalah , Mina Raysut. The author claimed that the average solar energy for these sites is 5.597 kWh/m^2/day. After that the authors used some intuitive method to size the PV system's components. The author claimed that the cost of energy produced by a PV system located in Oman is about 0.21 USD/kWh. However, in this research the author used simple method to design the system while more accurate methods are currently used. Moreover, they did not state the availability of the designed system which makes us unable to judge the reliability of the proposed system. In [8] data from 25 sites in Oman were used in order to investigate the feasibility of PV systems in these sites. The author claimed that the average solar energy for these sites is in the range of (4-6) kWh/m^2.day with average value equals to 5 kWh/m^2.day. After that the author assumed a 5 MWp PV plant applied to each site and discuss its feasibility by calculating the cost of energy using RETscreen software. The author reported that the cost of energy produced by such system is (0.21- 0.304) USD/kWh. In addition to that the authors used the capacity factor (the ratio of the actual annual energy output to the amount of energy the PV array would generate if it operated at full rated power for 24h per day for a year) to technically evaluate the system and it was found in the range of (0.14-0.2). In [9] the choice of applying a standalone PV/wind/ Diesel generator for rural area in Oman is assessed using HOMER. The result of this study shows that the proposed systems can displace diesel generation significantly and the economical benefits of the resulting hybrid systems depended on load and renewable energy resources. This means that the potential of the renewable energy sources (wind and solar) is not equal in Oman and thus, an optimization of the renewable energy sources share in such a system must be done. Such an optimization provides design recommendations in order to achieve the desired feasibility and reliability levels. Other utilization of HOMER for investigating renewable energy system in Oman can be found in [10]. In this study the optimum size of renewable systems is determined by HOMER in order to be able to fulfil the electrical energy requirements of remote sites located in Hajer Bani and Hameed in the North of Oman, Masirah Island and the Mothorah area in the South of Oman. As a result, the costs of energy produced by the proposed systems were found to be 0.206, 0.361 and 0.327 USD/kWh for Masirah Island, Mothorah and HB Hameed, respectively.

From the reviewed work, we can found that most of the authors did not consider the optimum tilt angle in designing the proposed photovoltaic. Based on this the main objective of this paper is to present recommendation for optimal PV module/array optimum tilt angle. This work is based on hourly meteorological data provided by Sohar

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2. Solar energy situation in Sohar, Oman

In this research data for 2 years (2011-2012) are used. These data contain hourly global solar radiation, diffuse solar radiation and hourly ambient temperature. Figure 1 shows the average daily global solar radiation, diffuse solar radiation and ambient temperature. From the figure the daily average total global solar energy is 6182 Wh/m^2, while the daily average total diffuse solar energy is 3289 Wh/m^2. In other words, Sohar zone has a very good solar energy potential and therefore, any PV system investment in this zone is expected to be very feasible. However, due to the nature of this site (desert site), the average ambient temperature is high as compared to other zones in the country. From figure 1 the daily average of ambient temperature is 32 ^{o}C. This to say, if we use a PV module with a standard test condition ambient temperature equals to 25 ^{o}C , a 3.5% reduction in the peak power occurs as the author of [11] claimed.

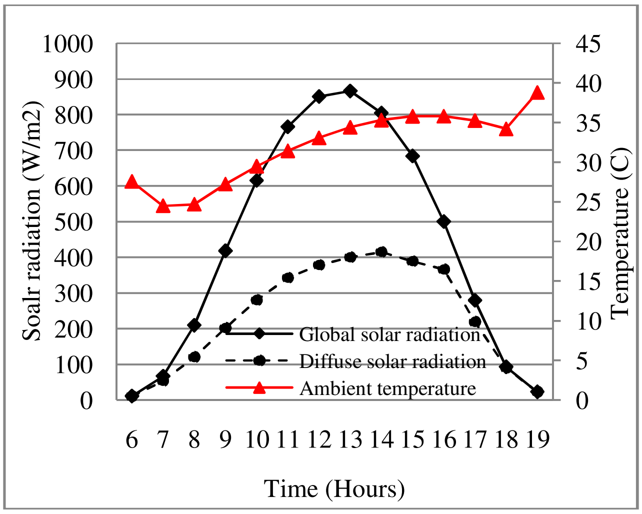

Figure 1 Solar radiation and ambient temperature profiles for Sohar

3. Modeling of solar radiation on tilt surface

The component of incident global solar radiation on a tilt surface can be expressed by,

$$G_{TLT} = B_{TLT} + D_{TLT} + R_{TLT} \quad (1)$$

where $G_{TLT}, B_{TLT}, D_{TLT}$ & R_{TLT} are global, direct (beam), diffuse and reflected solar energy on a tilt surface. However, equation (1) can be rewritten in terms of solar energy components on a horizontal surface as follows,

$$G_{TLT} = (G - D)R_B + DR_D + G\rho R_R \quad (2)$$

where G and D are the global and diffuse solar energy on a horizontal surface. Meanwhile, R_B, R_D & R_R are coefficients and ρ is ground Aledo. R_B is the ratio between global solar energy on a horizontal surface and global solar energy on a tilt surface. R_D is the ratio between diffuse solar energy on a horizontal surface and diffuse solar energy on a tilt surface and R_R is the amount of reflected solar energy on a tilt surface.

From equation (2) it is clear that the key of finding solar energy components on a tilt surface is to estimate the coefficients R_B, R_D & R_R. The most often used model for calculating R_B for the countries that located in the northern hemisphere is the Liu and Jordan model [16] which defines R_B as

$$R_B = \frac{\cos(LAT - TLT)\cos DEC \sin \omega_{ss} + \omega_{ss} \sin(LAT - TLT)\sin DEC}{\cos LAT \cos DEC \sin \omega_{ss} + \omega_{ss} \sin LAT \sin DEC} \quad (3)$$

where LAT is the latitude of the location and TLT is the tilt angle. DEC and ω_{ss} are angle of declination and sun shine hour angle, respectively. DEC is given by

$$DEC = \sin^{-1}\{0.39795 \cos[0.98563(DN - 173)]\} \quad (4)$$

while ω_{ss} is given by,

$$\omega ss = \cos^{-1}(-\tan LAT \tan DEC) \quad (5)$$

The equation for R_R is given by,

$$R_R = \frac{1 - \cos TLT}{2} \quad (6)$$

However, As for R_D, the anisotropic model have been used to estimate it. Isotropic solar models are based on the hypothesis that isotropic radiation has the same intensity regardless of the direction of measurement, and an isotropic field exerts the same action regardless of how the test particle is oriented. It radiates uniformly in all directions from a point source sometimes called an isotropic radiator. One of the most famous isotropic diffuse solar models is the Liu and Jordan model [16] with R_D being formulated as,

$$R_D = \frac{1+\cos TLT}{2} \quad (7)$$

4. Optimization of the Tilt Angle

In this part, equations (3,6 &7) are substituted in equation Figure 2 shows the algorithm for calculating the optimum tilt angle. The process can be described in steps as follows:

i) Define the specified location by its geographical coordinates (latitude and longitude) and obtain the global and diffuse solar radiations for this location.

ii) Calculate the direct solar radiation using (global solar radiation – diffuse solar radiation).

iii) Set the time span which can be monthly optimum tilt angle, seasonally tilt angle or yearly tilt angle and the tilt angle range, for example 1-90 degrees.

iv) Calculate the global solar energy using the tilt angle equation (5) at each tilt angle value for each day in the set time span.

v) Store this value in an array ([Day, G_{TLT}])

vi) Check if the maximum value of time span is reached. If no, proceed to the next time step, else, go to step (ix)

vii) The average solar energy is calculated at the end of this phase degrees and stored in an array ([G_{TLT}, *TLT*]).

viii) Check if the maximum value of *TLT* is reached. If no, proceed with next tilt angle value, else, go to step (xi)

ix) After reaching the maximum range of the tilt angle, the stored solar energy values is searched for its maximum value in order to determine the optimum tilt angle which gives the maximum global solar energy. The searching for the maximum value is done by a MATLAB function called "MAX". This function conducts a linear search in an array to find the maximum value of the array using two registers. Initially it stores the first value on a register and compares it to the second value which is stored on the second register. After that a comparison is done between the two values and the bigger value is stored while the smaller is deleted. After that it reads a new value and makes a comparison until reaching the maximum length of the array.

5. Results and Discussion

In this section, the results of the monthly and seasonal In this research four scenarios are assumed for optimum tilt angle variation namely monthly optimum tilt angle variation, seasonally tilt angle variation – assumption A (four seasons a year), seasonally tilt angle variation-assumption B (two seasons a year) and annual tilt angle variation.

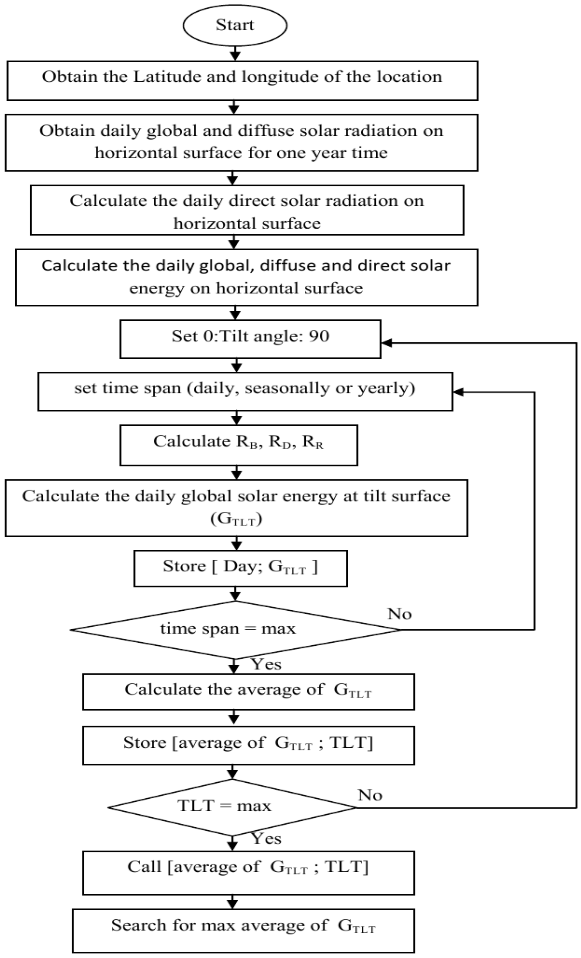

Figure 2 Optimization algorithm for PV panels tilt angle classify these regions based on these five sites.

For the first scenario, the optimum tilt angle is supposed to be changes from month to month twelve times a year. In other words, the tilt angle of a PV module/ array must be adjusted monthly in order to get the optimum solar energy yield. Meanwhile, the second and third scenarios consider that the PV module/array tilt angle must be adjusted seasonally four times a year for assumption A and two times a year for assumption B. The difference between assumption A and B that in assumption A the zone of Sohar is assumed that it has four climate cycles a year namely Climate A (21 June- 21 September), Climate B (21 September – 21 December), Climate C (21 December – 21 March) and Climate D (21 March – 21 September). On the other hand, assumption B means that it is assumed that Sohar Zone has two climate cycles namely Climate AB (21 March – 21 September) Climate CD (21 September – 21 March). Finally the annual tilt angle variation means that the system must be slanted at fixed tilt angle all the system life time. Table 1 shows the monthly tilt angle optimization results. From the table the monthly tilt angle value varies in the range of (0-60). The maximum tilt angle values are on January and December while the minimum tilt angle value occurs on May, June and July. The monthly tilt angle profile starts on by a peak value on January and it decreases dramatically until zero on May to July. On August, the tilt angle value increases until reaching it is peak again on December. The maximum Energy yield gain is achieved on January, February, September and November while the minimum energy yield gain is on May, June and July. However, as an overall result, the energy gained by 23.3% by applying the monthly tilt angle adjustment as compared to the horizontal surface.

Table 1 Monthly tilt angle optimization results

Period	β	E_{TILT}(kWh/m^2)	E_0 (kWh/m^2)	Energy Gain
JAN	57	247.1	144.3	71.2%
FEB	48	217	152.3	50%
MAR	32	234.7	203.4	15.4%
APR	10	199	196.3	1.3%
MAY	0	229.4	229.4	0
JUN	0	220.8	220.8	0
JUL	0	213.3	213.3	0
AUG	3	247	203.9	21.1
SEP	25	220.5	145.5	51.5%
OCT	44	233.3	189.2	23.3%
NOV	55	226	145.8	55%
DEC	60	257.3	181.6	41.6%
Total		2,750	2,230	23.3%

On the other hand Tables 2 and 3 show the seasonally tilt angle optimization result for assumption A and assumption B respectively. From Table 2 the optimum tilt angle is almost zero for the period 21/03 – 21/09 of the year. Meanwhile it is 47 degrees and 51 degrees for the period (21/09 -21/12) and (21/12- 21/03) respectively. The overall energy gain of the strategy of seasonally optimum tilt angle – assumption A is 20.2. However, Table 2 shows more interesting result with this regards whereas by slanting the PV module/ array at 49 degree in the period of 21-September to 21 March and zero degree for the period 21 September to 21 March, the solar energy yield is gained by 20.6% as compared to the horizontal surface. In other words, the strategy of applying the seasonally optimum tilt angle optimization assumption B is more significance than the seasonally optimum tilt angle optimization assumption B. This because the needed site visit of the second strategy is less than the first strategy, while the energy gain of the second strategy is higher than the energy gain of the first strategy.

Table 2 Results for seasonally tilt angle optimization - assumption A

Period	β	E_{TILT} (kWh/m^2)	E_0 (kWh/m^2)	Energy Gain
21/03-21/06 (n=81-163)	1	581.3	581.2	≈ 0
21/06-21/09 (n=163-255)	0	628.4	628.4	0
21/09-21/12 (n=255-346)	47	688	492.6	39.7%
21/12-21/03 (n=346- 81)	51	785	524.2	49.8
Total		2,680	2,230	20.2%

Table 3 Results for seasonally tilt angle optimization - assumption B

Period	β	E_{TILT} (kWh/m^2)	E_0 (kWh/m^2)	Energy Gain
21/03-21/09 (n=81-255)	0	1209.6	1209.6	0
21/09-21/03 (n=255-81)	49	1478.8	1016.8	45.4%
Total		2688.4	2,230	20.6%

Finally, it is concluded that the annual optimum tilt angle for a PV module/array is 27 (latitude + 3 degrees). In addition to that, it found that slanting the PV modules by 27 degrees for the whole year time increases the solar energy yield by 10.3% as compared to the solar energy yield collected by a horizontal surface.

Based on the pervious results, it is clear that the best strategy of tilt angle adjustment is the monthly adjustment, whereas the energy gain value is 23.3%. Meanwhile, the worst strategy of tilt angle adjustment is the annual (fixed) tilt angle whereas the energy gain value for this strategy is about 10.3 %. However, the third strategy which is the seasonally optimum tilt angle – assumption B seems the best strategy whereas the energy gain value of this strategy is 20.6% while only two site visits are needed. On the other hand the monthly tilt angle adjustment strategy needs twelve site visits which may be costly in terms of the transportation as we assumed that the installation site is located in a rural area. This to say, the optimum tilt angle strategy presented in Table 3 is found to be most recommended strategy for Sohar Zone.

, 7.96% and 6.13%, respectively.

6. Conclusion

In this research optimization of photovoltaic module tilt angle was done. Numerical method for optimization of the PV module tilt angle was implemented using MATLAB and hourly meteorological data and load demand. The results showed that for Sohar zone the tilt angle of a PV array must be adjusted twice a year where the PV array must be slanted at 49 degrees in the period of 21/09-21/03 (n=255-81), while it must be horizontal (tilt angle is zero) in the period of 21/03-21/09 (n=81-255). This adjustment practice gain the energy collected by a PV array by 24.6%.

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