Irradiation Analysis for Maputo

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Abstract: In the present paper was investigated the influence of the surface geometry on the amount of solar radiation arriving on that surface. The total, beam and diffuse radiation incident onto a surface was simulated using WINSUN software, which is a simulation tool developed at Lund Technical University, Sweden. The irradiation analysis are made for Maputo, latitude 25°58' South, longitude 32°36' East, Mozambique. The climate data was derived from Meteoronorm files. Such study has practical value since the output of solar systems is depending upon the amount of solar radiation reaching to the surface of the collector.

Key words: Solar radiation, surface geometry, WINSUN, Meteoronorm.

1. Introduction

For solar-based renewable energy technologies such as solar thermal and photovoltaic conversion systems, the basic resource or fuel available is solar radiation. Assessment on the solar resource for these technologies is based upon measured data, where available. However, the sparse distribution in space, and particularly over time, of measured solar data leads to the use of modelled solar radiation as the basis for many engineering and economic decisions [1].

From the earth's perspective, the sun travels from the east to west every day and also moves from the north to south as the seasons change. And solar panels and solar collectors produce, respectively, more electricity or heat when they are positioned at 90° from incoming light. Solar tracker tends to solve this problem. They follow the sun, so that the panel mounted on them catch more rays and produce more energy. Trackers fall into basic categories, they have either a single-axis, meaning they move east and west/north-south, or a double-axis, meaning they move in all four directions [2].

Understanding the sun's motion is essential for a proper solar system design and the choice of a proper

location for solar collectors or photovoltaic modules. The most important geometrical parameters, which describe earth-sun relations, include declination (δ), solar height (α_s), and the solar azimuth (γ_s). They are defined as following:

$$\delta = 23.45^\circ \sin \left[\frac{360(284 + n)}{365} \right] \quad (1)$$

$$\sin(\alpha_s) = \sin(\phi) \sin \delta + \cos(\phi) \cos(\delta) \cos(\omega) \quad (2)$$

$$\gamma_s = \arcsin \left[\frac{\cos(\delta) \cdot \sin(\omega)}{\cos(\alpha_s)} \right] \quad (3)$$

where, n is the day of the year, ϕ is the latitude angle and ω is the hour angle. The time involved is the solar time, based on the apparent motion of the sun across the sky. Solar time is related to the standard time by

$$\text{Solar time} = \text{standard time} + EOT + (L_{st} - L_{loc}) \cdot 4 \text{ min/degree} \quad (4)$$

where, L_{st} is the standard meridian for the local time zone, L_{loc} is the longitude of the location in question and EOT is the equation of time (in minutes). It is given by:

$$EOT = 229.2(0.000075 + 0.001868 \cos(B)) - 0.032077 \sin(B) - 0.014615 \cos(2B) - 0.04089 \sin(2B) \quad (5)$$

where, $B = 360(n - 81)/364$ in degrees. EOT is essentially a correction factor that accounts for the ellipticity of the earth's motion around the sun [3, 4].

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1.1 The Tilt and Azimuth Angles of Photovoltaic Modules

The proper tilt and azimuth angle choice is by far more important for photovoltaic systems design than solar thermal system design. Manual or automatic tilt angle adjustment can increase the total light-electricity conversion up to 30% and more in locations with high values of solar radiation. Incidence angle should be as close to 90° as possible. Photovoltaic module tilt angle and location choice in general require more care than solar collectors tilt angle and location choice. Shaded locations, including partially shaded, are not suitable for photovoltaic module fixation. Modules should be south oriented in the northern hemisphere and north oriented in the southern hemisphere [4].

1.2 The Solar Radiation on Earth

The total irradiation is the amount of energy that is contained in the sunlight that strikes a unit surface over a specific period of time. The irradiance is the power of the sunlight that is incident on the surface. The total irradiance on the surface can be divided into direct or beam radiation, which has traveled in a straight path directly from the sun, and the diffuse radiation, which is received indirectly as result of scattering due to clouds, fog, dust and other substances in the atmosphere, as well as from the ground buildings and other surrounding objects, according to [3, 5, 6]

$$I_{tot} = I_b + I_{diff} \quad (6)$$

The distinction of the two components is important because the amount of diffuse radiation affects the performance of most of the solar energy technologies. For example, PV (photovoltaic) systems (like flat-plate systems) can use both forms of radiation, while solar concentrator systems can only use direct radiation.

For calculating the incidence radiation on fixed inclined surface, it is important to determine the angle of incidence, θ_i , of the surface, which is the angle between the solar position vector and the surface normal. This angle can be calculated using

$$\cos(\theta_i) = \cos(\theta_z)\cos(\beta) + \sin(\theta_z)\sin(\beta)\cos(\gamma_s - \gamma) \quad (7)$$

where, β is the tilt angle with respect to the horizontal, γ is the surface azimuth and θ_z is the zenith angle. The zenith angle is related to the solar altitude by

$$\alpha_s = 90^\circ - \theta_z \quad (8)$$

where, θ_z is the zenith angle of the sun. The beam irradiance is expressed in terms of the solar radiation normal to the surface, and the angle of incidence using a cosine factor:

$$I_b = I_{b,n} \cos(\theta_i) \quad (9)$$

2. The Data Source and Method

2.1 Data Source

Two different data sources were used in this work:

- Measured data by the INAM (National Institute of Meteorology), covering the period of 1977 to 2006. Global and diffuse radiations were measured by pyranometer CM6B, from Kipp and Zonen and monitored for long term measurements through the data logger C22;
- Synthetic METEONORM data derived from METEONORM climate files. The data represent an average year for a certain location over a period of at list 30 years. The derived data correspond to the period of 1961 to 1990, and the site is Maputo (Latitude $25^\circ 58'$, Longitude $32^\circ 36'$).

2.2 Method

The measured, along 30 years, radiation data, were averaged and compared with the results from METEONORM files. Then, METEONORM data files were used in the simulation software WINSUN.

WINSUN is a simulation program based on TRNSED/TRNSYS that calculates the theoretical monthly and annual output from solar collectors or PV systems using a dynamic model. The Software was developed at Lund Technical University, Sweden. The use of long term average data, normal 30 years, ensures to minimize the effect of extreme climate variations. The collector performance parameters, the orientation of the collector, are used as input data. The monthly average operating temperatures of the collector

throughout the year can also be incorporated. The energy output for the period is returned as monthly and annual values.

For irradiation analysis the needed data input parameters in the simulation program are (time span, system location and system orientation):

- The month of simulation (January to December);
- Day of the month for starting simulation (1st to 30/31 or 1st to 28/29 for February);
- Length of simulation (day, week, 2 weeks, 4 weeks, 8 weeks or year around);
- Location of system (choose climate);
- System orientation.

Additional, other parameters that take in to account the reflected radiation from surrounding, the fact that the collecting surface is fixed or moving, if it is inclined and its orientation relative to the cardinal coordinates. These parameters appear as follows:

- Albedo or of ground reflectance, which varies from 0.2–0.3 for grass, 0.1 for asphalt and 0.9 for snow. The ground reflectance was set to 0.2;
- The tracking mode of the system (fixed, one axis-tracking and full tracking);
- Slope of the surface or tracking axis from horizontal;
- Azimuth of the surface or tracking axis.

3. Results and Discussions

3.1 Measured and Derived Global and Diffuse Radiation

Global and diffuse radiations, both measured and delivered from METEONORM files, are represented in Figs. 1 and 2, respectively.

The two sources of data are related to the same physical site (Maputo). This figure shows good agreement between the global radiations of the two data sources, despite the fact that they represent different periods of time. Fig. 1b shows that the correlation between the two sources of data is almost one by one ($m = 1.0202$, $R^2 = 0.9971$). Meanwhile, the correlation between the diffuse components of solar

radiation on horizontal surface, given in Fig. 2, is not as good as in the global radiation ($m = 1.364$, $R^2 = 0.937$). In this case, Fig. 2b indicates that diffuse radiation measured by INAM is 36% lower than the derived by METEONORM. Two main reasons should be pointed out: (1) the diffuse radiation was measured by using a shade-ring to block out the direct irradiance coming from the sun's disc on the pyranometer, which needs regular adjustment to correct the shadow band; (2) The diffuse radiation provided by METEONORM might be corrected taking into account that the shadow band provided by a shade-ring gives an error between 10 to 15% compared to the measurements performed by a rotating shadow band (rotating disc) as reported in [5]. Other researchers [6, 7] have pointed out that the most accurate method for measuring the diffuse component of solar radiation is the indirect one, that is the measurement of global and beam radiation simultaneously, and calculate the difference between the two measurements. The disadvantage of this being the relatively expensive tracking system required for measuring the beam radiation.

3.2 Simulations from WINSUN

(1) Horizontal surface

For simulating irradiation on horizontal surface, the tracking mode is set to 1 (fixed mode), the slope of the surface is set to zero and the azimuth of the surface is set to zero, i.e., the surface is flat and oriented towards North. The annual global irradiation is $1,916 \text{ kWh/m}^2$, being $1,123 \text{ kWh/m}^2$ — the beam and 793 kWh/m^2 — the diffuse component of solar radiation;

(2) Fixed surface tilted towards North

For this simulating mode, the tracking mode remains the same as the horizontal one, but the slope of the surface is set to 26° (latitude tilt- this is the optimal tilt for year around simulation) and the surface azimuth is kept zero;

(3) One axis-tracking with surface tilted around an East-West axis

(a) Global radiation on horizontal surface_ Maputo

(b) Correlation between Meteonorm and INAM data

Fig. 1 The global radiation: (a) Global radiation on horizontal surface in Maputo, blue — measured data, red — delivered from METEONORM files; (b) Correlation between global radiations from the two data sources.

(a) Diffuse radiation on horizontal surface in Maputo

(b) Correlation between Meteonorm and INAM data

Fig. 2 The diffuse radiation: (a) Diffuse radiation on horizontal surface in Maputo, blue — measured data, red — delivered from METEONORM files; (b) Correlation between diffuse radiations from the two data sources.

In this case the tracking mode is set to 3, the slope of the surface zero and the azimuth of the tracking axis is set 90°;

(4) One axis-tracking with surface tilted around a north-south axis tilted zero;

This is the case of geometry in tracking mode 3, but now the azimuth of the tracking axis is set to zero;

(5) One-axis tracking with surface tilted around a north-south axis tilted 26°;

In this case the plan (surface) is rotating around a North-South axis tilted 26°;

(6) Two axes tracking

In this configuration the tracking mode is set to 4.

The overall output in terms of annual irradiation for the different simulated modes are represented in Figs. 3–8 and the values summarized in Table 1. Table 2

gives the relative gain of incident irradiation relative to latitude tilt (left) and horizontal surface (right).

Observing Figs. 3–8 and Table 1, can be seen that the annual collectable irradiation for solar system, increase relative to the fixed system in all cases. Mainly the direct component of solar radiation is the most incremented compared to the diffuse component. When the horizontal surface is tilted towards equator at latitude tilt the beam component of solar radiation increases because the rays reach the surface at incidence angles less than that in horizontal surface, while the diffuse component decreases because the view factor of the surface is decreased, i.e., the surface can see part of the sky compared to horizontal surface. Thus the global irradiance for latitude tilt increases by 7.5%, as illustrated in Table 2.

Fig. 3 Irradiation on horizontal surface.

Fig. 4 Irradiation on a fixed surface tilted 26° towards North.

Fig. 5 Irradiation on a surface tilted around an East-West axis.

Fig. 6 Irradiation on a surface tilted around a North-South axis tilted 0°.

Fig. 7 Irradiation on a surface tilted around a North-South axis tilted 26°.

Fig. 8 Irradiation on a surface with two-axes tracking.

Table 1 Summary of annual irradiation on different surface geometries.

Geometry	Global kWh/m ²	Beam kWh/m ²	Diffuse kWh/m ²
Horizontal	1,916	1,123	793
Latitude tilt	2,060	1,253	787
East-west	2,199	1,367	805
North-south	2,447	1,585	822
North-south_26	2,570	1,695	821
Two_axes	2,667	1,770	842

Table 2 Relative gain of incident irradiation relative to latitude tilt and horizontal surface.

Geometry	Global Relative lat tilt	Beam Relative lat tilt	Diffuse Relative lat tilt	Global Relative horiz.	Beam Relative horiz.	Diffuse Relative horiz.
Horizontal	0.93	0.90	1.01	1	1	1
Lat tilt	1	1	1	1.08	1.12	0.99
East-west	1.07	1.09	1.02	1.15	1.22	1.02
North-south	1.19	1.27	1.04	1.28	1.41	1.04
North-south_26	1.25	1.35	1.04	1.34	1.51	1.04
Two_axes	1.29	1.41	1.07	1.35	1.58	1.06

For the tracking modes, starting with east-west tracking, the beam irradiation increases 9% relative to the one with latitude tilt and 21% relative to the horizontal, while the global irradiation increases by 6.7% and 14.7%, respectively.

For a surface rotating around a horizontal north-south axis, the beam irradiation increases 26.5% relative to latitude tilt and 41% relative to horizontal, while the gain in global irradiance becomes 18.8% relative to latitude tilt and 27.7% relative to the

horizontal surface. If the rotating axis is tilted 26°, then the direct incidence rays will strike the surface with less incidence angle compared to the previous tracking mode, and as before the view angle for the diffuse radiation will decrease as seen in Table 2. In this mode beam irradiation increases 35% relative to latitude tilt and 50.9% relative to the horizontal surface, while the global irradiation increases 24.8% and 34%, respectively.

For two-axes tracking, the beam irradiation increases 41% compared to the latitude tilt and 57.6% relative to horizontal surface, while the global irradiation increases 29.5% and 39%, respectively.

4. Conclusions

This paper presents the results of solar radiation data measured in Mozambique and delivered from METEONORM files. The paper also presents the results of simulated irradiations incident on different geometries.

The main conclusions emerging out from this study are as follows:

METEONORM weather files are viable for using as input data for different simulating tools.

By using appropriate surface geometry, the received global irradiance can be increased from 7% to 29 % relative to fixed surface latitude and the beam irradiance can be boosted from 9% to 41% relative to the same configuring.

The results of the present simulations can be used to make decision about what the surface geometry to implement known that the increase in the amount of available solar radiation, potential means the increase in the solar system output (PV module or solar

collector). For instance, if concentrators are to be used, the suitable geometry for Maputo should be the one with highest gain in the beam component of solar radiation.

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