Energy Reports 4 (2018) 536–546

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Research paper

Extracting the maximum energy from solar panels

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HIGHLIGHTS

- Using programs through MATLAB to estimate the totality of the solar radiation on any inclined surface, we could determine the optimum tile angle for daily, monthly and yearly solar radiation relative to the site of Khouribga city in Morocco. The method could be extrapolated to other cities.
- How to extract the appropriate angle under which the maximum energy could be captured and absorbed by the solar cells.

ARTICLE INFO

Article history:
Received 7 July 2017
Received in revised form 12 May 2018
Accepted 15 May 2018

Keywords:
Solar radiation
Energy
Inclination
Optimum tilt angle

ABSTRACT

The performance of solar systems to convert solar radiation depends on its inclination angle to the horizontal plane, independently from meteorological conditions. Sunlight should fall with steep angle to extract maximum power from solar panels. Therefore, optimum fixed tilt angles of solar panels should be changed monthly and seasonally. In our study, MATLAB program is used to estimate the total solar radiation on a tilted panel surface with any inclination. The implementation developed to allow us to extract the correct angle at which the maximum energy could be absorbed by the solar cells. We could determine the optimum tile angle for monthly, seasonal, and yearly solar radiation relative to the site of Khouribga city (latitude 32°52′ North and longitude −6°54′ West), and we used the same method to draw the table of solar gains depending on the optimum tilt angle of the solar panels to the main Moroccan cities.

1. Introduction

The design of solar systems requires knowledge of the useful solar radiation received on the surface of the installation, it is one of the essential parameters of the preliminary study. For a given energy need, more energy received means fewer panels to install and vice versa, so in order to study the solar field available on an inclined surface at Khouribga city, a series of insolation and irradiation data compute according to the inclination and orientation of the solar panel, and then we apply the same strategy of this work in 20 Moroccan cities.

In a given city, the annual production of solar energy depends on various factors. Especially:

- Incidental solar radiation at the installation site.
- Tilt and orientation of panels.
- Presence where there is no shading.
- Technical performance of system components (mainly modules and inverters).

In this work, we precede some fundamental notions of astronomy that give information on the radiation received by the ground (diffuse, direct and global).

We have developed a code by using Matlab, and we can give the different coordinate systems used to calculate the solar irradiation, according to time in our city (Khouribga) of latitude 32°52′ North and Longitude −6°54′ West.

2. Experimental data of solar irradiation in Khouribga city

Currently, in Morocco, measurements of solar radiation data are performed in an instantaneous and continuous manner, this study is carried in the Khouribga city of latitude 32°52.86′ North and longitude −6°54.37′ West.

This section deals with the daily solar radiation reaching the surface of the earth over a large area, taking full account of seasonal variations in day length, the height of the sun above the horizon, and absorption by clouds and other atmospheric components. Solar radiation includes visible light and ultraviolet radiation.

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https://doi.org/10.1016/j.egyr.2018.05.002

Nomenclature

θ	Latitude
α	Tilt angle.
α_{opt}	Optimum tilt angle.
δ	The declination
AH	The hour angle
TSV	The local solar time
H	The elevation
Z	The zenith angle
φ	The Azimuth angle
Z'	This is the angle between the vector normal to the panel and the vertical of the place.
φ'	It is the angle between the projection of the vector to the normal panel on the horizontal plane and the north.
ω	Angle of Incidence
I_0	Extraterrestrial solar radiation (solar constant).
I_{dir}	Direct Irradiation
I_{dif}	Diffused Irradiation
R_{dif}	Correction factor of the diffuse radiation

Daily solar radiation incident on the earth's surface know the extreme seasonal variation during the year (see Fig. 1).

The most radiant period of the year lasts 3, 6 months, from the first May to 22 August, with incident solar radiation greater than 7.2 kWh/m^2. The bright day of the year is 21 June, with an average of 8, 3 kWh/m^2 (Weather Spark, 0000).

The least radiated period of the year lasts 3, 4 months, from 30th October to 10th February, with incident solar radiation below 4,1 kWh/m^2. The darkest day of the year is 17 December, with an average of 3.0 kWh/m^2.

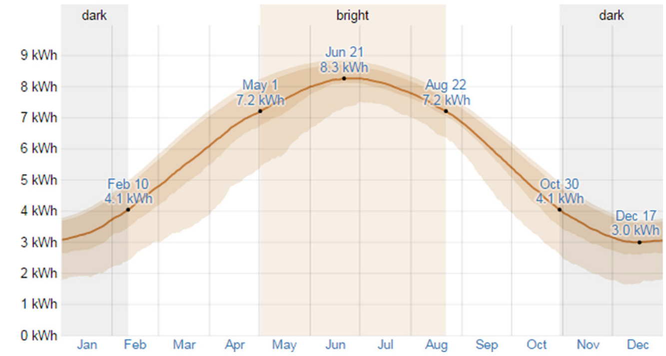

Fig. 1. The daily solar radiation received on a surface of 1 m^2 at Khouribga city (Weather Spark, 0000).

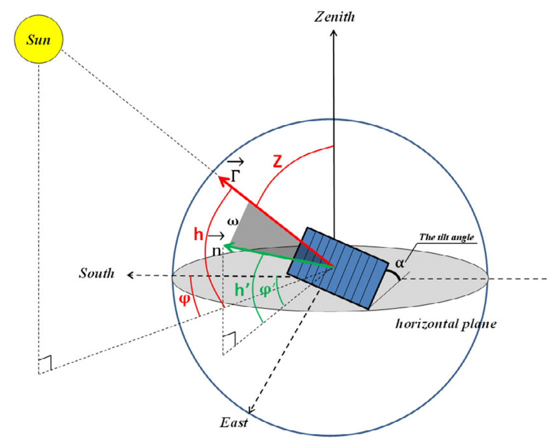

Fig. 2. The solar horizontal coordinates and the angle of incidence.

The typical day of the month:

For a given magnitude, the typical day is the day of the month approximating the monthly average of that magnitude (Klein, 1977).

The list of the typical days proposed by Klein is shown in Table 1.

We summarize in Table 2, the data of the experimental results of solar irradiation obtained for each typical day in the year (Weather Spark, 0000).

3. Study of global solar radiation at Khouribga city

The study or applications of the solar energy in a given site are depending on more complete and detailed data on the geometric parameters and solar radiation of this site.

3.1. Modeling of geometric parameters — angle of incidence (ω)

The angle of incidence of the solar beam with any surface of inclination and orientation is the angle formed by the direction vector of the solar beam and the normal leaving the surface (Won et al., 1994; Sera et al., 2007) (see Fig. 2).

Where:

h: The angle of the solar height — Elevation

The angle of the sun's height (h), or the altitude is the angle between the direction of the sun and the horizontal surface; the elevation h from 0° to 90° towards the zenith (Oudrane et al., 2017).

$$\sin(h) = \sin(\theta)\sin(\delta) + \cos(\theta)\cos(\delta)\cos(Ah). \tag{1}$$

Z: The zenith angle

It is the angle between the direction of the sun and the vertical of the place (zenith). The angle Z is complementary to h (Oudrane et al., 2017).

$$\cos(Z) = \sin(\delta)\cdot\sin(\theta) + \cos(\delta)\cdot\cos(\theta)\cdot\cos(Ah). \tag{2}$$

φ : The Azimuth angle

This is the angle between meridian and the location of the vertical surface passing through the sun (Oudrane et al., 2017).

$$\sin(\varphi) = \frac{\cos(\delta) * \sin(Ah)}{\cos(h)}. \tag{3}$$

Every day, the sun describes a trajectory whose two main coordinates, φ and h, are represented on a graph (see Fig. 3).

Each geographical point potentially has its own graph of the race of the sun, whose graphs depend on the longitude, latitude and altitude of the place.

The graph above presented the race of the sun at Khouribga city, with the hours of the day (Ennaoui, 2014).

AH: The hour angle

The hour angle AH is calculated by the daily rotation of the earth around its axis.

$$AH = 15(TSV - 12) \tag{4}$$

TSV is the local solar time.

δ: The Declination

Declination (δ) is the angle between the vector "center of the earth–sun" and the equatorial surface of the earth (Oudrane et al.,