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Analysis of Solar Radiation in Jordan

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Abstract

This paper analyzes global radiation, diffused radiation, and other meteorological data needed to give a comprehensive study on the solar radiation in The Hashemite University in Jordan (32.05_N, 36.06_E). Measured and simulated daily, monthly, and annually global radiation averages are presented and analyzed. The measured data is collected by the Dhleel Metrological Center while the simulated data is generated by the METEONORM software (a comprehensive meteorological software). The inclination angle θ is also optimized in this work for every month of the year and for the whole year in order to maximize solar energy production.

Keywords: Water Management Global radiation, Diffused radiation, Surface temperature, Solar Energy, Jordan.

1. Introduction

The sun is the largest regenerative source of energy in the world. It is estimated that the annual sun exposure amounts to $3.9\times10^{24} J = 1.08\times10^{18} kWh$. This corresponds to more than 10,000 times of the present world energy needs [1]. Furthermore, the constant fluctuation in oil prices, as shown in figure 1 [2], has pushed people and institutions to think more seriously about renewable energy resources and somehow reduce their dependence on oil.

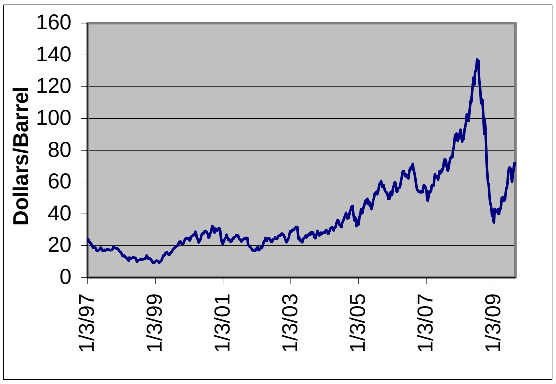

Figure 1: Weekly oil prices from 1997 to 2009

Another urgent reason to seriously consider renewable energy resources is that studies show that the oil depletion point has been reached in 2006 [3]. This is a direct result of consuming oil much faster than it is naturally produced. Since formation of new petroleum is a complicated geological process takes millions of years. In addition, energy demands are increasing at alarming rate as shown for example for the electrical energy in Jordan in figure 2 [4-11].

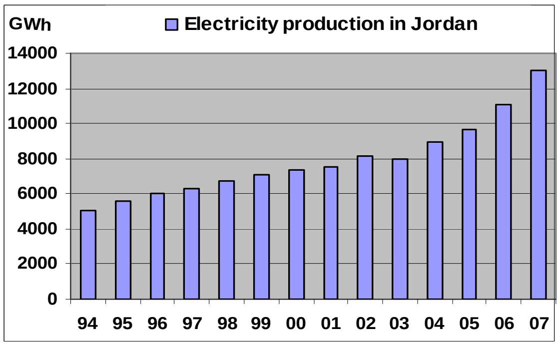

Figure 2: Electricity production in Jordan

We believe that the time is coming soon where world governments are required to offer alternative energy sources to keep their economies running or practice programmed blackouts. One of the solution measures surfacing is the wide spread of national energy centers worldwide to tackle this urgent energy problem. Jordan is no exception, The National Energy Research Center has been established in Amman – Jordan [12] for the purposes of research, development and training in the fields of new and renewable energy; In addition, to raise the efficiency of using energy in the different economic sectors.

In the literature, solar radiation was measured and analyzed in Abu Dhabi area, where hourly, daily and monthly global horizontal radiation were collected and processed [13], the paper showed that PV application in Abu Dhabi is a promising solution to energy expansion in the country. Furthermore, diffused radiation were collected in different locations in China for few years, the data is handled to fit suitable models for radiation

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estimation in the country [14]. Moreover, a new method, called elevation angle constant (EAC) method, is developed to determine the solar radiation for any location in the world [15]. The EAC method showed great accuracy compared with other methods. However, this paper analyzes the global and diffused radiation and meteorological data to explore the potential of solar energy generation in Jordan (32.05_N, 36.06_E). It also investigates the solar tracking and the optimal inclination angle.

The rest of this paper is divided as follows: Section 2 discusses the global radiation and yearly air temperatures; also it compares measured and simulated metrological data. Section 3 investigates the tracking and optimal inclination angle and studies average global radiation versus monthly inclination angles. Section 4 discusses the main outcomes of this work. Finally, section 5 presents conclusions and future work.

2. Global Radiations and Temperatures

Global radiation is the most important solar characteristics to be investigated to explore the potential of solar-energy generation in a particular location. In order to study this potential in the area of The Hashemite University, we have obtained measured monthly global radiation data from Dhleel Metrological Center for ten years [16-25]. The center is located 10 Km to the north of The Hashemite University. In addition, the METEONORM 5.0 software is applied to simulate the radiation data. This software is a comprehensive meteorological reference, incorporating a catalogue of meteorological data and calculation procedures for solar applications and system design at any desired location in the world [26]. Measured and simulated monthly radiation data are depicted in figure 3 for comparison purposes.

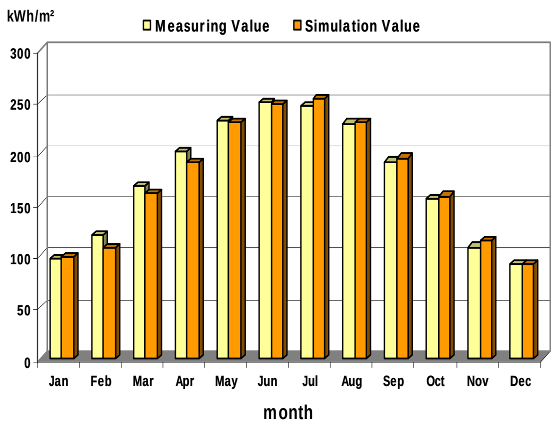

Figure 3: Measured and simulated monthly radiation data.

Furthermore, the simulated and measured data are shown in figure 4 in the x-y coordinates to determine how close the two sets of data to each other, and to decide if this software is reliable to be used for further analyses.

Fortunately, the plotted points are very close to the unity-sloped line and the standard deviation is very small and equal to 2.48%. That means, the simulated data are very close to the measured ones and therefore, the software can be used with a high confidence from now on though out the paper.

Global radiation in a specific location is defined as the sum of direct and diffused radiation reaching that location throughout the day from sunrise to sunset as well as it depends on the day of the year. In addition, diffused radiation in a location depends on the amount of scattered incoming radiation.

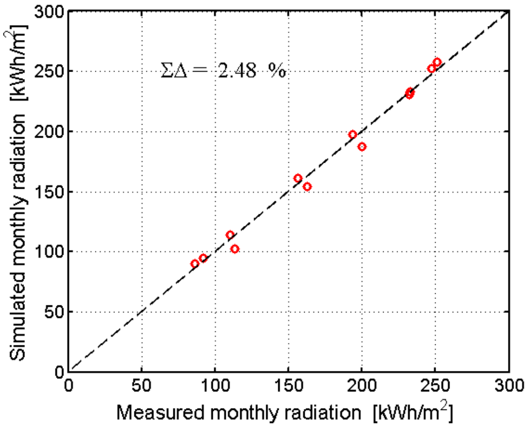

Figure 4: Simulated monthly radiation versus measured monthly radiation.

Daily global, direct and diffused radiations are depicted in figure 5 for the 365 days of the year. The average daily global radiation is 5.7 kWh/m² [27], while the average daily diffused radiation is 1.58 kWh/m²; in addition, the maximum daily global radiation is 8.72 kWh/m² and occurred in 26th June with daily diffused radiation is 1.3 kWh/m² for that day.

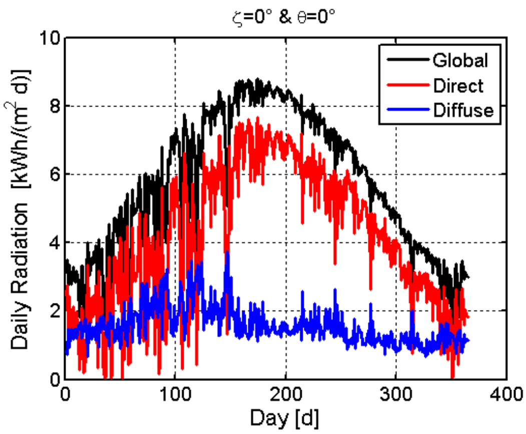

Figure 5: Daily Global, direct and diffused radiation

Furthermore, It is considered that the yearly global radiation is analyzed as a function of inclination and azimuth angles as illustrated in figure 6. High radiation occurs for inclination angles between 10 degrees and 35 degrees and azimuth angle around 0 degree. The radiation range is between 100 W/m^2 and 280 W/m^2. Note that the surface is color coded where the dark red indicates high radiation and blue color indicates low radiation, also the global radiation is projected on the lower plane in colored curves to better illustrate the changes in the global radiation.

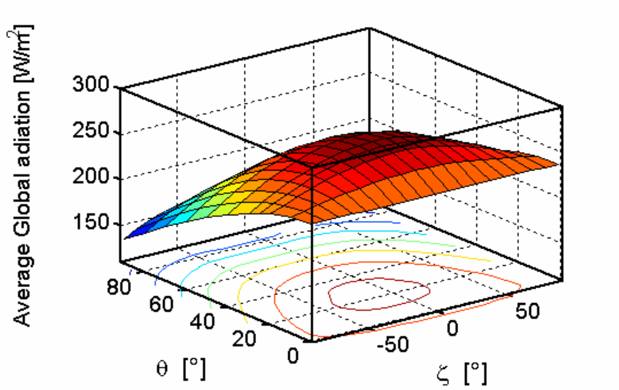

Figure 6:Average global radiation

In addition, this paper studies the yearly-diffused radiation as a function of inclination and azimuth angles as shown in figure 7. The diffused radiation changes between 65 W/m^2 and 75 W/m^2, and this represents almost one third of the global radiation. Note the high diffused radiation occurs for inclination angles between 40 degrees and 60 degrees and azimuth angle around 0 degree.

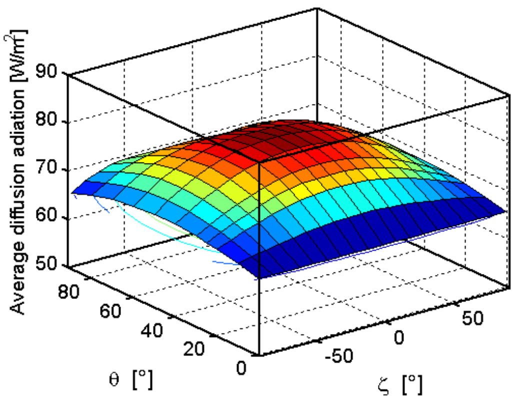

Figure 7: Yearly diffused radiation

It is important to examine the air temperature changes in the location since extreme temperatures might negatively affect the performance of photovoltaic systems. Fortunately, the air temperature in Jordan is appropriate as shown in figure 8. The hourly temperature is depicted in the figure and it varies in a small range of 39˚C and -2˚C throughout the year. In addition, the daily changes are around few degrees only.

Table 1 lists the global radiation in different locations of the world to better understand the situation here in Jordan [26].

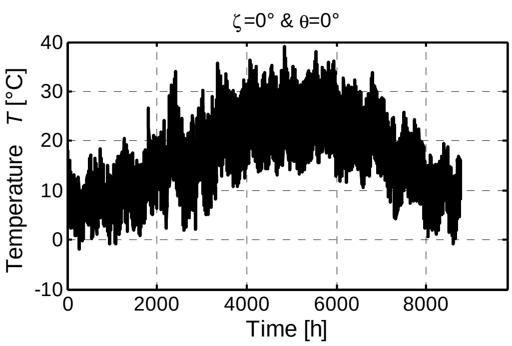

Figure 8: Yearly hourly Temperature

Table 1: Yearly Global radiation for different locations in the world

City	Yearly global radiation (kWh/m²)
Hashemite University, Jordan	2080
Berlin, Germany	1000
Paris, France	1038
London, UK	944
Cairo, Egypt	2074
Dubai	1929
NY, USA	1427
Hong Kong	1371

Table 1 clearly shows that global radiation in Jordan is one of the highest values worldwide, therefore, with this high global radiation and more than 300 sunny days annually, Jordan has an excellent and promising potential of power generation from solar energy, which basically constitute a national resource waiting to be invested to the full extent.

3. 3. Solar Tracking

The generated solar energy is given, in general, as a global radiation on a horizontal PV-panel surface. However, fixed panels receive solar radiation at angle that reduces the amount of energy considerably [28, 29]. Therefore, it is important to determine the optimal angle that generates maximum energy if tracking is not available.

In general, relative sun position with respect to the earth depends on rotation of the earth around the sun and rotation of the earth around itself. The first rotation generates the inclination angle and the second rotation generates the azimuth angle. Moreover, the tracking with respect to inclination angle is called one-axis tracking and the tracking with both inclination and azimuth angles is called two-axis tracking.

Figure 9 considers the one-axis tracking and has shown the average global radiation for all months of the year, the radiation is changing for different months and different inclination angles. December and January months show the lowest global radiation, and June and July months showed the highest global radiation.

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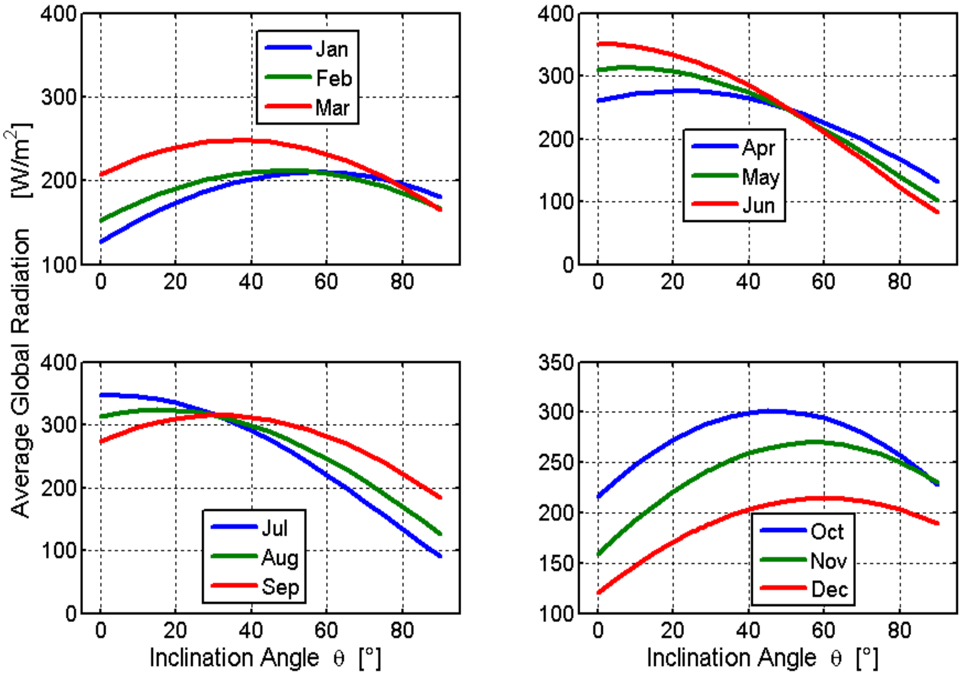

Figure 9: Monthly global radiations

In addition, figure 10 shows the yearly global radiation as a function of inclination angle. The maximum global radiation occurs at 30 degrees, therefore, for fixed panels used in The Hashemite University location and to obtain the maximum solar-energy generation, the PV panels have to be fixed at 30 degrees.

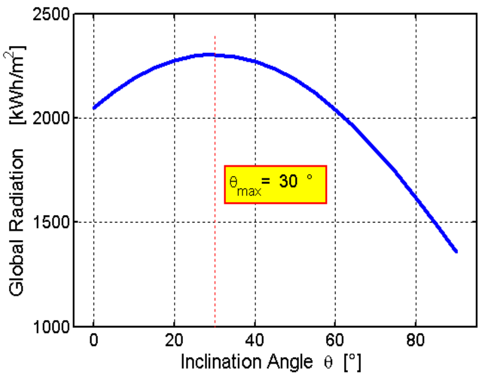

Figure 10: Optimal inclination angle

4. Results and Discussion

The comparison between the simulated and measured monthly radiation with a standard deviation of 2.48% proves the accuracy of applying the METEONORM software throughout this work. Therefore, one can rely on this software in calculating the global radiation for different inclination angles at different times in the year.

Optimizing the inclination angles is accomplished by maximizing the energy yield depending on the sun position. This motivates us to design a solar tracking system relying on the results of this work.

5. Conclusions

Global and diffused radiation and meteorological data were investigated to explore the potential of solar energy generation in the area of The Hashemite University in Jordan (32.05_N, 36.06_E). A comparison was conducted between ten-years-data of measured monthly global radiation from Dhleel Metrological Center and simulated data from METEONORM comprehensive meteorological software. This comparison revealed close match between both sets of data.

Hourly temperature data for the whole year demonstrated changes in a comfortable range for PV systems, the maximum temperature reached was 39˚C and minimum temperature reached was -2˚C. Furthermore, optimal inclination angle was investigated and monthly inclination angle versus average global radiation was plotted as shown in figure 9, the figure shown different optimal angles for different months; however, figure 10 demonstrated a fixed inclination angle of 30 degree gives the maximum global radiation (2330 kWh/m²) for the whole year.

Finally, it is important to state that Jordan, with global radiation of 2080 kWh/m² and more than 300 sunny days a year, has excellent potential for solar energy generation. Future work is to consider the tracking in two axes versus one axes tracking and investigate its feasibility.

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