Forecasting of Solar Radiation using an Empirical Model

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ABSTRACT

Global demand for energy is increasing rapidly and natural energy resources such as oil, gas and uranium are declining due to the widespread diffusion and development of the industry in recent years. To cover energy needs, research is being conducted on renewable energy. One of the renewable energies that can meet the world's demand so far is solar energy, which is free and inexhaustible in most parts of the world, and it has become an economic source. In this article we will make a forecast of the empirical Campbell model which will allow us to estimate the daily global irradiation on a horizontal plane and to compare it with the results measured at the Adrar site. The results show that the mean absolute percentage error (MAPE) less than 7%, the mean bias error does not exceed 3% in absolute value, relative RMSE does not exceed 7% and the correlation coefficient greater than 0.99 for the annual global radiation. It was concluded that this model could be used to predict the global solar radiation for Adrar site and for other sites with similar climatic conditions.

I. Introduction

Consumption and use of conventional fossil fuels such as coal and oil have created significant pollution problems and these energy supplies are expected to run out in the face of increased demand and rapid industrialisation [1]. Knowledge of solar irradiation is important for the design of energy systems and for applications where solar radiation is concentrated, either to raise the temperature of the system, as in thermal solar energy, or to produce current electric in solar cells, as in solar photovoltaic systems [2]. Measuring stations are rare in all countries; other running costs were incurred through monitoring and maintenance photovoltaic solar station. From this we use several models of solar radiation built in literature to estimate different components of solar radiation [3-13]. These models are constructed in the form of correlation. To be applicable to the sites considered, they must be compared with the actual measured values on the site considered over a period covering the different seasons [14]. Globally, there are many studies conducted to estimate global solar radiation using data available which include solar radiation parameters, they are meteorological models best suited to other measuring networks, Lacis and Hansen [15], Ashrae [16], Machler [17], and Lui and Jordon [18]. Among currently available models in the literature, the empiricals models of Bird & Hulstrom model [19], Huashan et al. [20], Davies model [21]. Liu et al. [22] developed several models in China using data on global solar radiation and sunshine duration; statistical index analysis showed that cubic models provided the best performance in radiation region.
The main objective of this study is to determine and compare an empirical model for estimating the horizontal solar radiation based on the solar elevation and the optical air mass. To do this, several days were selected to compare the values calculated by the Campbell model and those given by the radiometric station

in the city of Adrar. We chose the Adrar site for the study, because of the availability of the radiometric data sought, and this region is one of the most favorable sites for solar energy. This area has enormous solar energy potential, with an intensity of global solar radiation.

II. Data

Experimental data for 2016 are collected at the Adrar observation station (URER-MS), which is the only station available in the far south that provides long-term data. Adrar is located in the southwest of the Algerian territory; it is bounded between 20° 13'-31 ° 40'N latitude and 5° 46′W-2 ° 15′E longitude, but it should be mentioned that Adrar is located in the region of the solar belt [23], which benefits from abundant light for more than 3000 hours of sunshine per year with a daily solar radiation of more than 6 kWh /m^2/ day and a duration of sunshine ranging from 9 to 11 hours per day [24], Adrar is a Saharan city in the middle of the Sahara [27], a station representative of the climate of the great Algerian south (Fig. 1), routine measurements of global, diffuse and direct radiation on a horizontal and inclined surface are carried out by the research unit of renewable energy in the Saharan environment (URERMS) in the Adrar region [28] equipped with the SOLYS 2 system (Fig. 2).

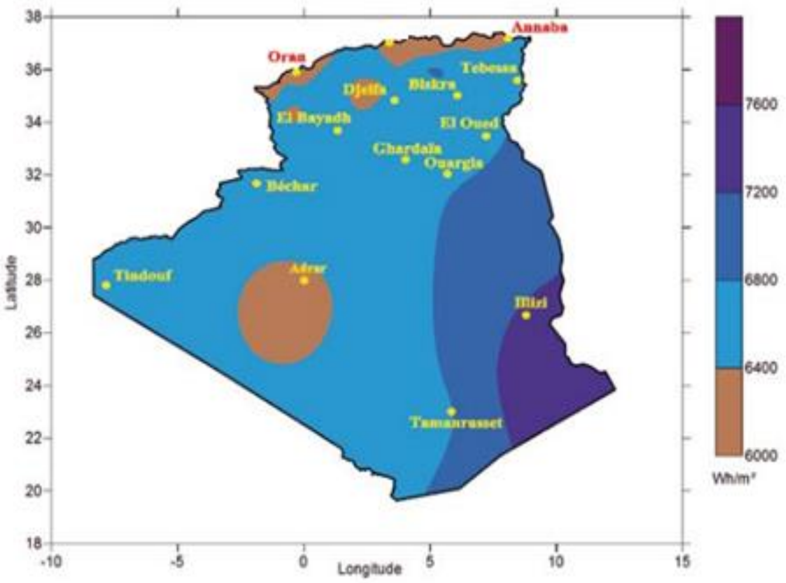


Figure 1. Monthly average solar irradiation in Algeria

Figure 2. Neal URER-MS-Adrar Meteorological Station

III. Description of the model

The solar radiation passed through the Earth's atmosphere and arriving at its surface has three components: the direct component I (W/m^2), the diffuse component D (W/m^2) and the reflected component R (W/m^2) all form the global solar radiation G (W/m^2). The direct component is the part of radiation which arrives directly on the ground. It does not take into account the elements absorbed and reflected by atmospheric components (water vapor, aerosols, ozone ...etc); it only depends on the direction of the sun. The diffuse component is the part of radiation scattered by atmospheric constituents. It comes from all the space and it has no privileged orientation. The part of reflecting solar radiation is called reflected radiation and is assumed to be zero for horizontal surfaces of the earth [24].

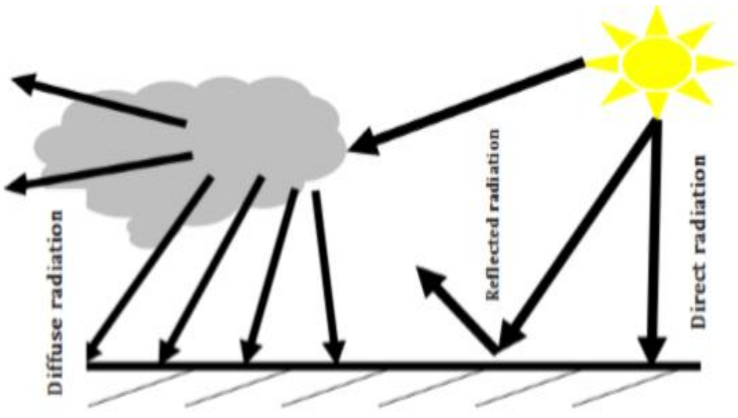


Figure 3. The three components of global solar radiation

It is difficult to know the value of solar irradiation for a specific site, with a well-defined orientation and inclination. There are approximate models for calculating whether at least one has the global horizontal radiation measured or estimated.
The following equations are used to measure global solar radiation G (W /m^2), beam solar radiation in the direction of rays I_n (W/m^2) and diffuse solar radiation D (W/m^2) on the horizontal surface under a clear day, as suggested by Campbell [25]:

$$I_N = G_0 T_0^{m_a} \quad (1)$$

$$I = I_N . \sin(h) \quad (2)$$

$$D = 0.3\, G_0 \left(1 - T_0^{m_a}\right) \sin(h) \quad (3)$$

$$G = I + D \quad (4)$$

The parameter T_0 is the atmospheric transmittance, and according to this model, it is between 0.65 - 0.75; h (deg.) is the solar elevation, m_a is the optical air mass and G_0 is the solar constant (W/m^2).

IV. Results and interpretations

To analyze the efficiency of the studied solar radiation model, we will confront some instantaneous solar radiation flux values measured by this model with those given by the local meteorological station in different months of the year for some clear days.
We present the following figures; comparative graphs relating to the global radiation Cambpell model with the 2016 experimental data on the Adrar site. The time relative error graph (TSV) is also given to the global radiation.
The expression for the mean relative error (%) is given by the following equation:

$$E_r = \frac{|G_{measured} - G_{calculated}|}{G_{measured}} .100 \quad (5)$$

G: Global solar illumination (W/m^2)

The experimental data on the components of global solar radiation on a horizontal plane, thus during a clear sky and days of four seasons on the city of Adrar are presented in the form of graphs in the figures below, and compared with the data of the model studied.

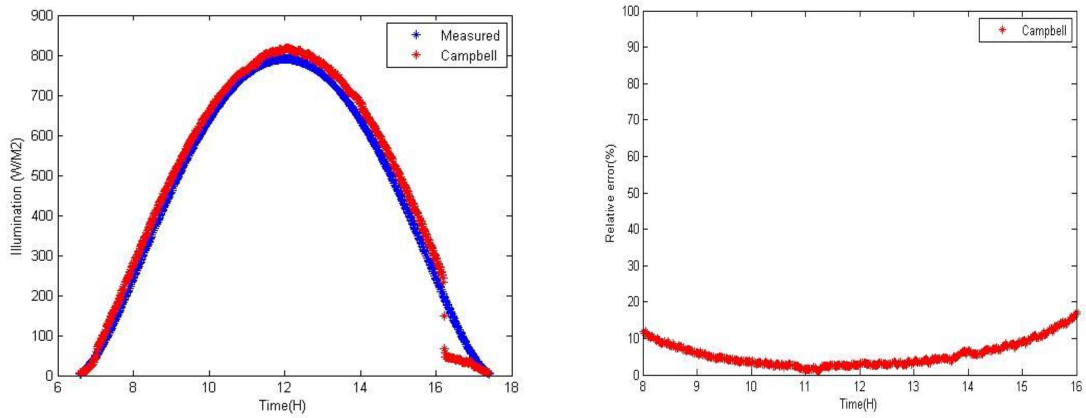


Figure 4. Global solar radiation fluxes and relative error on February 07

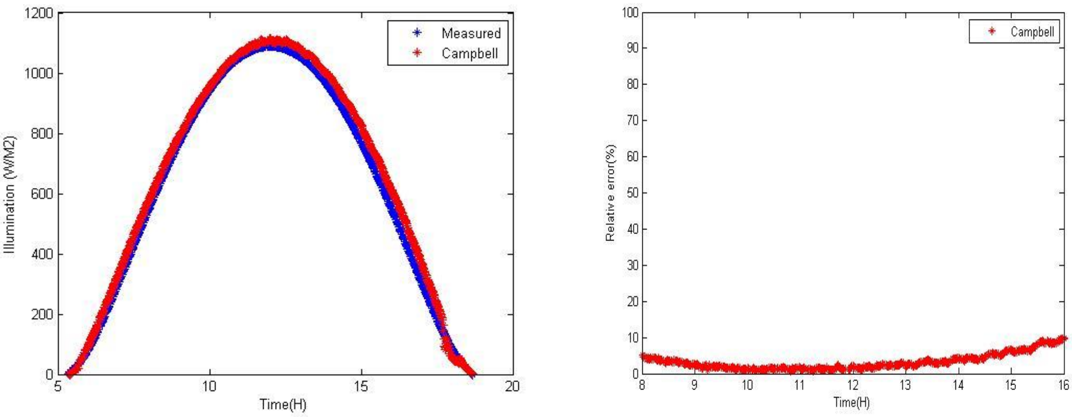


Figure 5. Global solar radiation fluxes and relative error on May 13

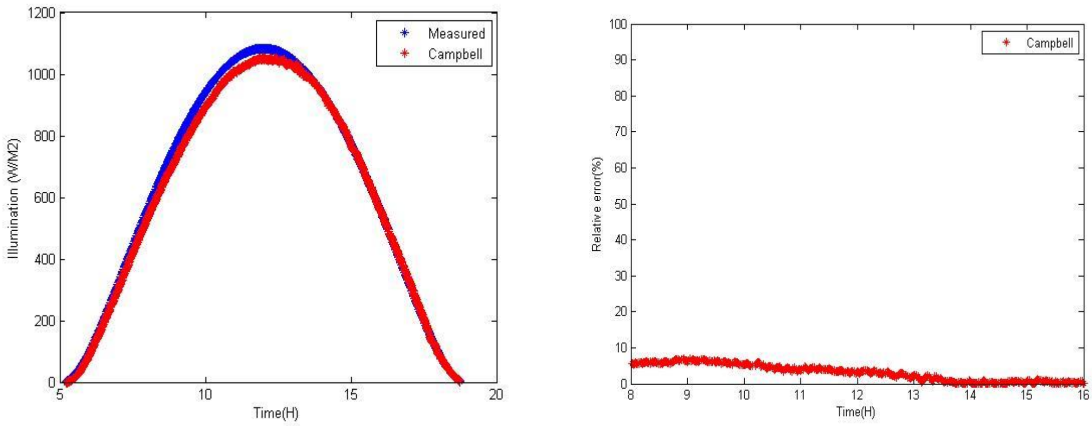
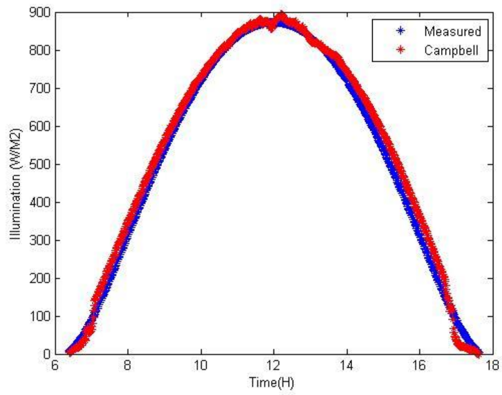


Figure 6. Global solar radiation fluxes and relative error on July 19



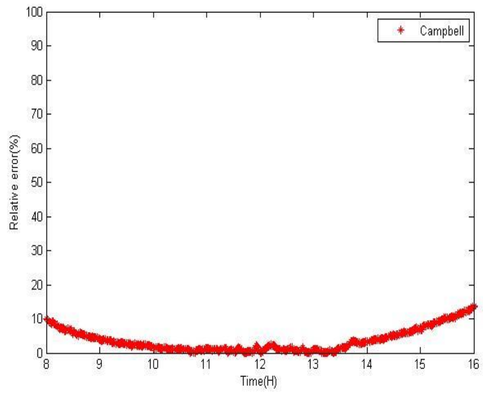


Figure 7. Global solar radiation fluxes and relative error on October 16

IV.1. Statistics and evaluation

The performance of the solar radiation model studied is also evaluated on the basis of the statistical scores and correlation coefficient proposed by [26] such as the mean bias error (MBE), the root mean square error (RMSE) , the correlation coefficient (R) and mean of the absolute pecentage errors (MAPE). The expressions for the aforementioned statistical parameters are the most popular and most used which are:

• RMSE (Root Mean Square Error), RMSE provides information on short-term performance which is a measure of the variation of predictive values around the measured data. The lower of the RMSE, the more precise the estimate is, and is always positive:

$$RMSE = \sqrt{\sum_{i=1}^{N}(G_c^i - G_m^i)^2/N} \quad (6)$$

• MBE (Mean Bias Error), MBE is an indication of the average deviation of the predicted values from the corresponding measured data and can provide information on the long-term performance of the models, the lower of the MBE represent the better prediction of the long-term model. A positive MBE value indicates the amount of overestimation in predicted direct solar irradiation and vice versa.

$$MBE = \sum_{i=1}^{N}(G_c^i - G_m^i)/N \quad (7)$$

• MAPE (Mean Absolute Pecentage Error), MAPE is generally a measure of the accuracy of the forecast. MAPE value of less than 10% is considered acceptable.

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{(G_c^i - G_m^i)}{G_m^i}\right) \times 100 \quad (8)$$

• R (correlations coefficient): The correlation coefficient measures how close the values are to the values. Clearly, a value of the correlation coefficient closer to one implies a better estimate.

$$R = \left[\frac{\sum_{i=1}^{N}(G_m^i - \overline{G_m^i})(G_c^i - \overline{G_m^i})}{\sqrt{\sum_{i=1}^{N}(G_m^i - \overline{G_m^i})^2 \sum_{i=1}^{N}(G_c^i - \overline{G_c^i})^2}}\right] \quad (9)$$

with:
G_m^i: Measured value
G_c^i: Calculated value
$\overline{G_m^i}$: The average value of the solar irradiation measured
$\overline{G_c^i}$: The average value of the estimated solar irradiation
N: Number of observations value

IV.2. Analysis and discution

Figs.4-7 illustrate a comparison of the estimated values of global solar radiation fluxes with those determined by local station for each clear day selected during all season of the year. It is clear from these figures that the model estimation provides a better approximation to measured data. By analyzing and evaluating the results presented in Figures (4 to 7) and Table 1, we deduce that:
- The global solar radiation increases over time to a maximum value of around 12 noon, then begins to decrease until it reaches zero (layer of the sun).
- We found that the solar flux varied around 1000 (W/m^2), with an increase for the summer months, a slight decrease during the spring and autumn months and a considerable decrease for the winter months. This variation is mainly due to the declination angle and the temperature change.
- The global solar fluxes estimated by this model, as seen from the figures, are almost superimposed on those measured by the Adrar station. The mean relative error is small. A typical example appears on July 19 and August 15 where the curve simulated by this model is in very good agreement with the curves of measured values, the relative error is therefore very small (MAPE error does not exceed 4%).
- The Cambpell model is generally give high accuracy for the estimation of solar irradiation on a horizontal plane, especially between April and October.

The results of the statistical scoress of the values of rMBE, rRMSE and R for this model are presented in Table 1; we can see that for the model studied, the rMBE (relative mean bias error) is between -6 and +11 percent for all months of this year, the relative mean square error does not exceed 14%. The correlation between the estimated and measured values throughout the year is greater than 0.99, which is good. We also found that this model was the most beneficial during most seasons of the year (the MAPE and rRMSE averages error did not exceed 7%).

Table 1. Statistical scores for all days in this study

Day	MAPE (%)	MBE (Wh/m^2)	rMBE (%)	RMSE (Wh/m^2)	rRMSE (%)	R
January 15	9.72	35.45	7.95	45.53	10.21	0.9950
February 07	6.51	19.57	4.01	37.34	7.65	0.9942
March 15	7.18	37.47	6.17	45.87	7.55	0.9974
April 07	4.34	-4.51	-0.74	32.91	5.39	0.9963
May 13	4.39	27.55	4.10	34.36	5.11	0.9984
June 05	4.38	28.19	4.25	34.19	5.15	0.9986
July 19	3.26	-17.73	-2.89	26.24	4.27	0.9989
August 15	3.76	-22.73	-3.76	25.48	4.22	0.9997
September 21	5.21	-28.66	-5.21	32.93	5.99	0.9997
October 16	4.32	17.29	3.22	27.78	5.17	0.9972
November 28	7.76	27.26	6.22	36.13	8.24	0.9957
Décember 31	12.70	48.24	10.97	59.86	13.61	0.9911
Average	**6.13**	**13.95**	**2.86**	**36.55**	**6.88**	**0.9969**

In addition, Figure 7 shows the scatter plot of daily values of global solar radiation in 2016 for simulated and experimental data. We can see that the data are distributed as a set of points closer to the perfectly adjusted linear line (in red), indicating the relationship between the measured and simulated values (W/m^2) during the study period.

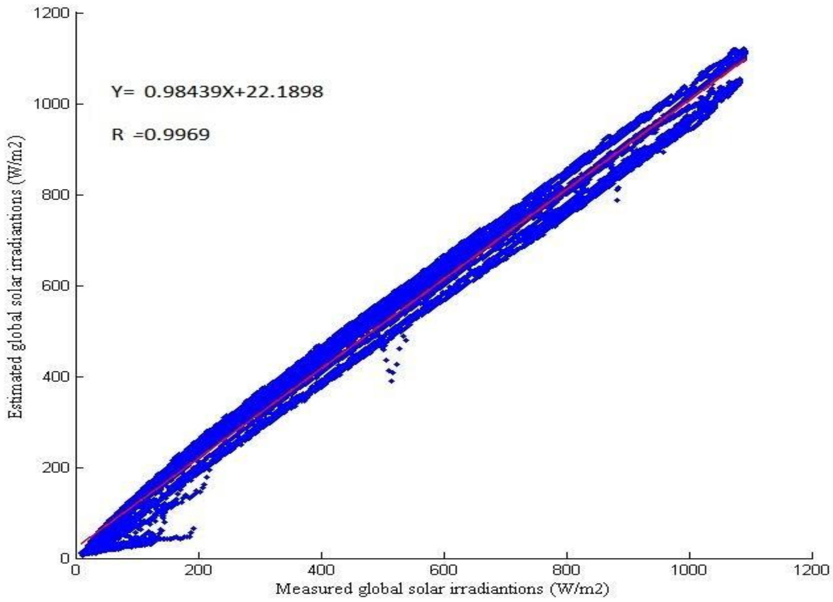


Figure 7. Scatter plot over the whole period of study

III. Conclusion

In this article, a modeling of solar radiation by the Campell model is presented and performed. This model used its own equations to calculate the parameters of direct, diffus and global illumination. This work allowed us to compare measured values and those estimated by this parametric model. We have found that the Cambpell model gives an estimate of solar radiation which has a considerable influence on the design of solar energy systems. For this site, this model turns out to give estimated values close than those measured, where the average annual values are (MAPE=6.13%, MBE=13.95 Wh/m^2, RMSE=36.55 Wh/m^2, R=0.9969). We can conclude that this model makes it possible to accurately predict the fluxes of global solar radiation in the position studied.The Cambpell model is essential for estimating horizontal solar radiation, which is interesting for dimensioning thermal systems (hot water), solar heating and sizing solar system for photovoltaic installations, especially in Algeria.

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