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Experimental study of solar flux energy basing on measured sun covering-rate in the gulf of Tunis, Tunisia

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ABSTRACT

Knowledge of global solar radiation is required in modeling, performance investigation, and planning of solar energy projects. In this work, a new correlation is proposed to estimate the daily cumulated solar flux in the gulf of Tunis. This correlation is an adequate method to predict cumulated solar flux in this region. Furthermore, several models were applied to predict global solar radiation on horizontal planes from sun covering-rate. These models were derived from the original Angstrom linear regression and modified functions. Six kinds of regression have been adopted, namely linear, quadratic, cubic degree, fourth degree, exponential, and logarithmic. The models were tested for the gulf of Tunis (36°43′04″N latitude and 10°25′41″E longitude), using about 29,388 collected data during 2008 basing on 10 min time step. It is found that the sun covering-rate derived estimates basing on the simple linear Angstrom correlation are confined to within 6% of the measured values, giving reliability to the approval of the determined regression coefficients of the long-term desired predictions in the gulf of Tunis. Then, predicted values of global solar radiation on horizontal surfaces by the adopted models were compared to the measured values on the basis of statistical *R*-squared analysis for yearly and monthly scales. The results show that forecasting global solar radiation by the tested approaches, basing on sun covering-rate, has proved to be sufficiently reliable but the polynomial fourth degree model showed the best estimation of global solar radiation.

1. Introduction

Renewable energy resources such as wind energy and solar radiation are judged as the key for sustainable energy projects seeing that the world shift from fossil fuels to more renewable energy alternatives. Sustainable energy technologies improve diversity in energy supply markets, secure long-term sustainable energy supply, and reduce local and global atmospheric emissions (Maatallah, El Alimi, & Ben Nassrallah, 2011). One of the most reliable renewable energy is the solar energy which can be captured anywhere and harnessed in diverse applications. For this reason, several authors have carried out the global solar radiation forecasts and the solar energy resources assessments. In Europe, Zabara (1986) proposed a method to estimate the global solar radiation in 31 locations in Greece basing on the measurements data by seven meteorological stations in 1986. They used the Page formula of the global solar radiation on a horizontal surface. The regional regression coefficients of this formula were analyzed using a polynomial regression technique. The results showed that the solar radiations forecasted by this method were in good agreement with the measured ones. Soler (1990) used the Rietveld's method to estimate the global solar radiation on horizontal plane using the monthly data of 100 European stations in 1989. This method lead Soler to 12 monthly correlations and one correlation validated for all months. Using the root mean square error, the statistical comparison of monthly specific and nonspecific correlations proved for 70% of the stations monthly specific correlations gave better results than the non-specific correlations. Tiris et al. (1996) developed an empirical equation in order to correlate the monthly average daily horizontal global, diffuse, and beam radiations with the fraction of maximum possible number of sunshine hours. They used the measured data of the TUBITAK-MRC station during the years between 1988 and 1992 in Gebze, Turkey. The obtained correlation models have been tested by using statistical error tests. Menges, Ertekin, and Sonmete (2006) reviewed the global solar radiation models available in the literature. They compared the accuracy of 50 models for evaluating the monthly average daily global radiation on a horizontal plane basing on the geographical and meteorological data of Konya, Turkey in 2006. The results confirmed that the Ertekin and Yaldiz model showed the best estimation of the regional global solar radiation on a horizontal surface. Coskun, Oktay, and Dincer (2011) modified the concept of probability density frequency for predicting solar radiation distribution. They analyzed the global solar radiation for photovoltaic panel and thermal collectors basing on the

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actual global solar irradiation data of the last 15 years registered by the Turkish State Meteorological Service. This study showed that exergy efficiencies and performance of collectors depend significantly on the intensity of global solar irradiance.

In Asia, Abdul-Aziz, A-Naglt, and Zumailan (1993) examined the data of global solar radiation and sunshine duration for Yemen. They predicted global solar radiation from sunshine hours using the Angstrom's formula. The forecasted radiations showed a good agreement with the measured ones. Hussain, Rahman, and Rahman (1999) employed the Angstrom correlation to fit measurements of global solar radiation from sunshine duration in India. They obtained an improvement of fits greater than 25% in the RMS error for annual fits for half of the cases basing on data for biannual groups of months from March to August and September to February or March to September and October to February. The results showed that biannual regression parameters for a pyranometer station may be used to expect good precision global radiation for locations hundreds of kilometers away from the station if the climate, altitude, and latitude are similar. Halawa and Sugiyatno (2001) presented the monthly average daily global solar radiation correlation applicable to the Indonesian climatic region. They developed a correlation basing on the meteorological data recorded from seven meteorological stations. Their correlation was based on the Sayigh's formula and it was found that such correlation cannot be applied directly in the humid tropic climatic regions. Besides, this correlation required the availability of several meteorological parameters such as monthly average duration of bright sunshine received during the day, monthly average daily maximum air temperature and monthly average daily relative humidity. Lu, Qin, Yang, and Sun (2011) proposed a simple algorithm with artificial neural network modeling in order to investigate the non-linear physical correlation between ground daily global solar radiation data and multi-functional Transport Satellite all-channel observations in China. The assessment results showed that this algorithm can rapidly and competently build the artificial neural network model which predicts the daily global solar radiation geostationary satellite data with close accuracy in both space and time.

In America, Meza and Varas (2000) assessed the behavior of two experimental models based on the difference between maximum and minimum temperatures and compared results with a model based on sunshine hours. This survey concluded that for Chile, the models proposed by Allen and Bristow–Campbell are adequate and permit estimates of mean average global solar radiation as a function of air temperature variation. These models were calibrated for 20 locations in Chile. Besides, both the models have limitations for daily data applications. Silva et al. (2010) analyzed the long-term solar radiation for northeastern Brazil basing on data from the National Center for Environmental Prediction Center for Atmospheric Research (NCEP/NCAR) re-analysis project available for the period 1948–2009. The study showed that the modeled global solar radiation values were in close agreement with the sunshine duration in northeastern Brazil. Also, results demonstrated that there was a good agreement in trend or inter-annual variability between re-analysis and measured global solar radiation. Even though the re-analysis, surface radiation fluxes had no input from actual observations, and there was evidence to consider that the re-analysis surface radiation flux data trends have correspondence to the reality. Mathiesen and Kleissl (2011) validated the North American Model (NAM), Global Forecast System (GFS) and European Center for Medium-Range Weather Forecasts (ECMWF), global horizontal irradiance (GHI) forecasts for the continental United States (CONUS) using SURFRAD ground measurement data. Authors examined also the regional persistence and clear sky predictions. The comparison between the above mentioned numerical models was based on mean bias errors (MBE) which were obtained as a function of solar zenith angle and predicted a clear sky index in order to derive a bias correction function through model output statistics (MOS).

In Africa, Ododo, Sulaiman, Aidan, Yuguda, and Ogbu (1995) analyzed the meteorological data for nine stations located in different geographical and climatic zones in Nigeria. The authors demonstrated that maximum air temperature is a significant climatological parameter for solar radiation modeling in Nigeria, particularly if it is used in conjunction with relative sunshine duration and relative humidity variations. The maximum percentage errors varied between 2 and 5% in the prediction of global solar radiation. Elagib and Mansell (2000) examined the prospect of setting up monthly specific correlations for predicting global solar radiation across Sudan basing on data provided by stations. The investigators proposed a set of 12 equations of global solar radiation on the basis of either: (1) latitude, altitude, and relative sunshine duration, (2) relative sunshine duration, or (3) altitude and relative sunshine duration, depending on the month under question. The errors remained below 8% for the whole cases. Elminir, Areed, and Elsayed (2005) employed the Levenberg optimization function in an artificial neural network (ANN) to predict global solar radiation data in different spectral bands for Helwan (Egypt) monitoring station. The results showed that the ANN model estimated the infrared, ultraviolet, and global insolation with a good accuracy of approximately 95%, 93%, and 96%, respectively. The ANN model was tested also to evaluate the same components for Aswan over an 11-month period. The predicted values of the ANN model compared to the actual values for Aswan produced a precision of 95%, 91%, and 92%, respectively. Zawilska and Brooks (2011) presented a year-long data registered of the solar flux intensity for the Durban city in South-Africa. Global horizontal irradiance, direct normal irradiance, diffuse horizontal irradiance, and daily average clearness index were investigated. This study aimed to evaluate the solar energy resources in Durban city in order to build record for urban planning and solar energy systems.

The evaluation of solar energy capacity of a region involves that widespread radiation data information of high quality be made. Then, the fit of these measurements by the adequate model of solar radiation estimation has a great interest for the actual and the future solar energy planners and engineers. For this reason, this paper is an evaluation of several correlation models for the estimation of monthly averaged daily global solar radiation on horizontal plane basing on the sun covering-rate for the gulf of Tunis, Tunisia. Moreover, as Tunisia is a high insolation country, this work of solar energy qualification basing on empirical models has a significant role to extend the renewable energy knowledge and the sustainability of natural resources. The developed regional regression equations give very accurate solar information for the gulf of Tunis.

2. Site description and experimental design

This present work is related to the solar energy assessment in the central coast of the gulf of the capital of Tunisia (Fig. 1) which is situated on the North African coast of the Mediterranean Sea between the approximate latitudes 30–37°N and longitudes 8–12°E. Tunisia is located between Algeria and Libya and just south of Italy. The southern regions of Tunisia have a Saharan dry weather characterized by a high insolation and a low relative humidity values due to the high occurrence of hot southern winds while the northern states are endowed by a wet climatic conditions and a high relative humidity values especially near the coasts due to the hilly regions situated principally in the north-west regions.

Radiometric data were registered at the NRG weather station in the gulf of Tunis, the capital of Tunisia which lies at the southern edge of the gulf. This station is installed in 36°43′04″N latitude and