FORECASTING OF SOLAR RADIATION USING STOCHASTIC MODELS

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Abstract

The large-scale use of renewable energy technologies would greatly mitigate or eliminate a wide range of environmental and human health impacts of energy use. Renewable energy technologies include solar heating and cooling, hydroelectric power, solar power, and wind power. In this paper, an Autoregressive Integrated Moving Average (ARIMA) model will be developed for forecasting solar radiation. The solar radiation time-series data obtained from previous records of 29 years period from 1984 to 2012 for Benghazi are used for forecasting solar radiation intensity based on a developed (ARIMA) model. The model's validation was based on the mean absolute percentage error (MAPE) between the actual and predicted values. The MAPE was found to be 6% indicating that the model could be used effectively to predict solar radiation.

Key word: Forecasting, Solar Radiation, ARIMA, MAPE.

الملخص :

من شأن الاستخدام الواسع النطاق لتقنيات الطاقة المتجددة أن يخفف إلى حد كبير أو يزيل مجموعة واسعة من الآثار البيئية وصحة الإنسان لاستخدام الطاقة. تشمل تقنيات الطاقة المتجددة التدفئة والتبريد بالطاقة الشمسية ، والطاقة الكهرومائية ، والطاقة الشمسية ، وطاقة الرياح. في هذه الورقة ، سيتم تطوير نموذج متوسط متحرك متكامل ذاتي الانحدار (ARIMA) للتنبؤ بالإشعاع الشمسي. تُستخدم بيانات السلاسل الزمنية للإشعاع الشمسي التي تم الحصول عليها من السجلات السابقة لمدة 29 عامًا من 1984 إلى 2012 لبنغازي للتنبؤ بكثافة الإشعاع الشمسي بناءً على نموذج (ARIMA) المطور. استند التحقق من صحة النموذج إلى متوسط النسبة المئوية للخطأ المطلق (MAPE) بين القيم الفعلية والمتوقعة. تم العثور على MAPE بنسبة 6 ٪ مما يشير إلى أنه يمكن استخدام النموذج بشكل فعال للتنبؤ بالإشعاع الشمسي.

1. Introduction

The sun is the source of thermonuclear processes and generates enormous amounts of energy [GATE, 1986]. Solar energy or solar radiation refers to the energy emitted by the sun. Despite the large distance between the sun and the earth, a significant amount of solar energy reaches the earth. By far the most important natural source of energy on the planet. Other sources include geothermal heat flux from the earth's interior, natural terrestrial radioactivity, and cosmic radiation, all of which are insignificant in comparison to solar radiation. The earth intercepts approximately 180 x106 GW at any given time. The energy contained in daylight, called sunlight based energy, can be changed over into power also. On the off chance that this energy is changed over into power straightforwardly utilizing gadgets dependent on semiconductor materials, called photovoltaic (PV). The term photovoltaic comprises of the Greek word (phos), which means light, and volt, which alludes to power and is a veneration to the Italian physicist Alessandro Volta (1745-1827) who designed the battery. run of the mill efficiencies of the most business sun based modules are in the scope of 15-20% [Wind, 2019]

By connecting a group of solar cells together, a surface called the Solar Panel can be formed, which connects from both negative and positive sides in order to carry an electric current and thus it is possible to recharge a battery in which the electricity is stored and used when needed for various purposes and according to the amount of electrical energy stored in the electric battery. In the event that a larger amount of electrical energy is needed, a group of solar panels can be connected to form the so-called solar array and connected directly to an electrical system such as lamps, water pump, refrigerator.....etc.

Energy from fusion reactions in the Sun’s interior is transported through successive convection, radiation, absorption, emission and re-radiation to the Sun’s equivalent of a surface, the photosphere, which absorbs and emits a continuous spectrum of radiation [Klaus, 2014].

Figure 1 shows different energy sources and the ways of their being utilized. Usually the chemical energy stored in fossil fuels is converted to usable forms of energy via heat by burning, with an efficiency of about 90%. Using heat engines, thermal energy can be converted in to mechanical energy. Heat engines have a conversion efficiency of up to 60%.

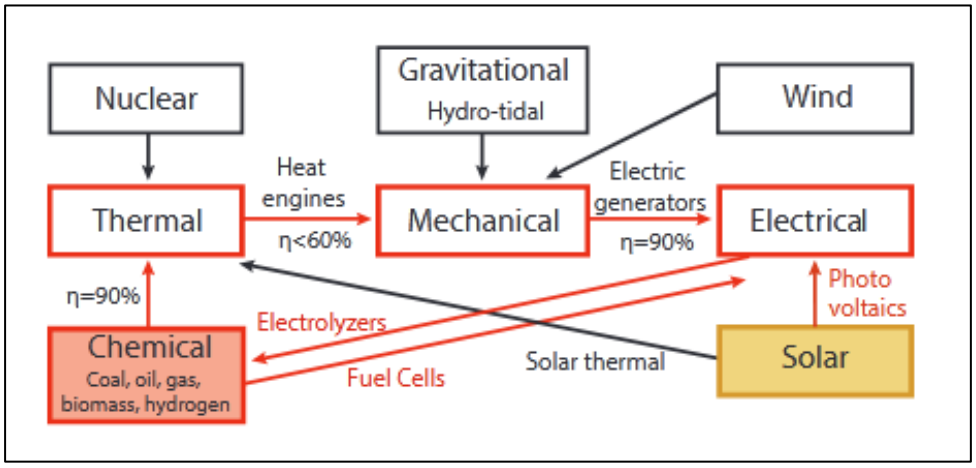

Figure 1 The different energy carriers and how being utilized them [2].

2. Literature Review

Masoud et al.[Masoud, 2015] applied an Artificial Neural Networks (ANN) approach for prediction of global solar radiation and other parameters such as maximum and minimum daily temperature, relative humidity and wind speed in Tehran. This ANN modeling strategy is used for estimating the amount of daily absorption of global solar radiation (both beam and diffuse radiation) on the land surface of Tehran during a year. Furthermore, indexes of root mean square error (RMSE), absolute fraction of variance (R^2) and mean absolute percentage error (MAPE) are used for accuracy evaluation of modeling results.

Predicting solar radiation at high resolutions with comparison of time series forecasts, was presented by Reikard **[**Reikard, 2009**].** Forecasting experiments are run using six data sets, at resolutions of 5, 15, 30, and 60 min, using the global horizontal component. The data exhibit nonlinear variability, due to variations in weather and cloud cover. Nevertheless, the dominance of the 24-h cycle makes it straightforward to build predictive models. Forecasting tests are run using regressions in logs, autoregressive integrated moving average (ARIMA), and unobserved components models

Farhath. Arputhamary. And, Arockiam [Farhath, 2016] published a paper on forecasting with the use of ARIMA version. They gave a concise description of some famous time series forecasting models used in practice, with their salient functions. Whilst fitting a model to a dataset, special care is taken to pick the maximum parsimonious one to evaluate forecast accuracy as well as to evaluate among distinct fashions suited to a time series models

In an other study Miao[Junwei, 2015] mentioned that it is necessary to forecast China's energy consumption to formulate energy and economic policy. An ARIMA model was developed in the study for forecasting energy consumption. It is also observed that China's energy consumption is likely to increase during the period 2012-2020. Energy consumption in 2020 is projected to be 4450Mtce in 2020, lower than target value.

3. The time series

3.1 Definition of a Time Series

A time series is a consecutive arrangement of information focuses, estimated normally over progressive times [Ratnadip, 2013]. It is numerically characterized as a bunch of vectors x(t), t = 0,1,2,... where t addresses the time slipped by. The variable x(t) is treated as an arbitrary variable. The estimations taken during an occasion in a period series are organized in an appropriate sequential request. A period series containing records of a solitary variable is named as univariate. Yet, on the off chance that records of more than one variable are thought of, it is named as multivariate. A period series can be nonstop or discrete.

3.2 Components of a Time Series

A period series overall should be influenced by four principle parts, which can be isolated from the noticed information. These parts are: *Trend*, *Cyclical*, *Seasonal* and *Irregular* components. The overall propensity of a period series to expand, diminish or deteriorate throughout an extensive stretch of time is named as Mainstream Pattern or basically Pattern. Consequently, one might say that pattern is a drawn out development in a period series. For instance, series identifying with populace development, number of houses in a city and so on show up pattern, while descending pattern can be seen in series identifying with death rates, scourges, etc[6].

3.3 Time Series and Stochastic Process

In general models for time series data can have many forms and represent different stochastic processes. There are two broadly used linear time series models. Autoregressive (AR) and Moving Average (MA) models. Consolidating these two, the Autoregressive Moving Average (ARMA) and Autoregressive Integrated Moving Average (ARIMA) models.

3.4 Autoregressive Integrated Moving Average (ARIMA) Models

The ARMA models, described above can only be used for stationary time series data. However in practice many time series such as those related to socio-economic and - 22 – business show non-stationary behavior. Time series, which contain trend and seasonal patterns, are also non-stationary in nature. Thus from application view point ARMA models are inadequate to properly describe non-stationary time series, which are frequently encountered in practice. For this reason the ARIMA model is proposed, which is a generalization of an ARMA model to include the case of non-stationary as well. In ARIMA models a non-stationary time series is made stationary by applying finite differencing of the data points. The mathematical formulation of the ARIMA (p,d,q) model using lag polynomials is given below:

$$\phi(L)(1-L)^d y_t = \theta(\mathrm{L}) \in_i, i.e.$$

$$\left(1-\sum_{i=1}^{P}\phi L^i\right)(1-L)^d y_t = \left(1+\sum_{j=1}^{a}\theta L^j\right)\in_i$$

Here, p, d and q are integers greater than or equal to zero and refer to the order of the autoregressive, integrated, and moving average parts of the model respectively. The integer d controls the level of differencing. Generally d=1 is enough in most cases When d=0, then it reduces to an ARMA (p,q) model. An ARIMA (p, 0, 0) is nothing but the AR (p) model and ARIMA (0, 0, q) is the MA (q) model. ARIMA (0, 1, 0), i.e. $Y_t = Y_{t-1} + \varepsilon$ is a special one and known as the Random Walk model. It is widely used for non-stationary data, like economic and stock price series.

4. Data preparation and analysis

4.1 Development of ARIMA Model

For using the ARIMA model of Minitab 17 statistical software for forecasting of solar radiation in Benghazi, the first step is drawn the time series plot , It was found that the data do not exhibit saturation as shown in Figure 2.

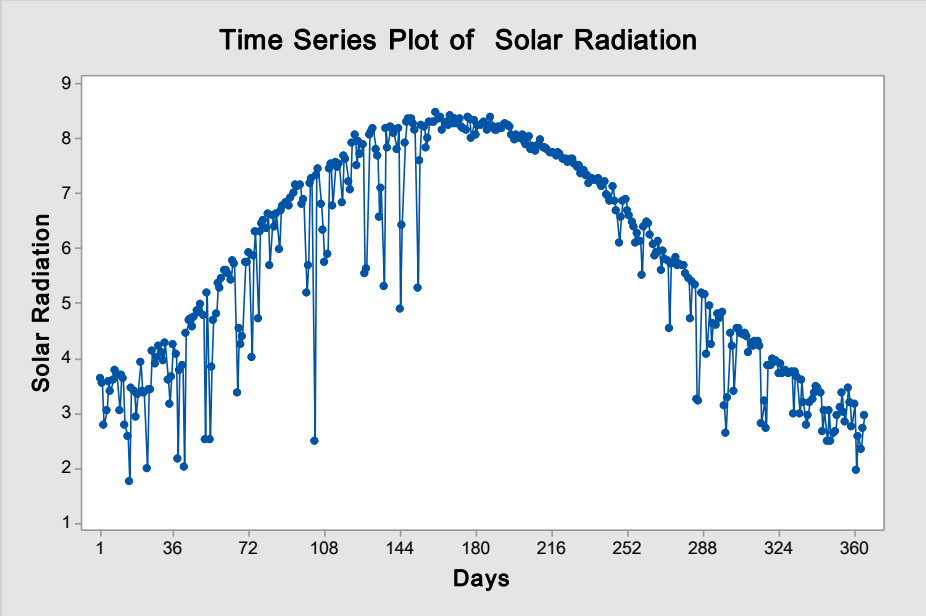

Figure 2 Data collected for solar radiation intensity in Benghazi

The next step is to be plotting the log base 10 for the data. If data are in saturation, one can apply ARIMA model. However, as shown in Figure 2, the data do not have this characteristic. Thus, the final step is, calculating the differences of log base 10 data solar radiation intensity time series. Data are plotted, as given in Figure 3.The figure indicates that ARIMA model for forecasting can be applied where (d = 1) in ARIMA parameters forecasting (p d q).

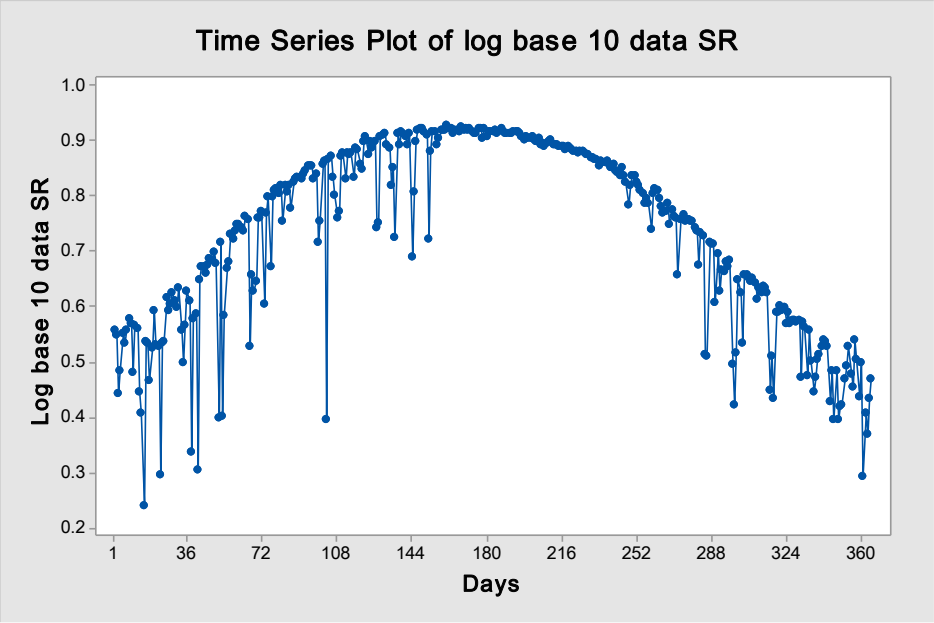

Figure 3 Log base 10 data solar radiation in Benghazi

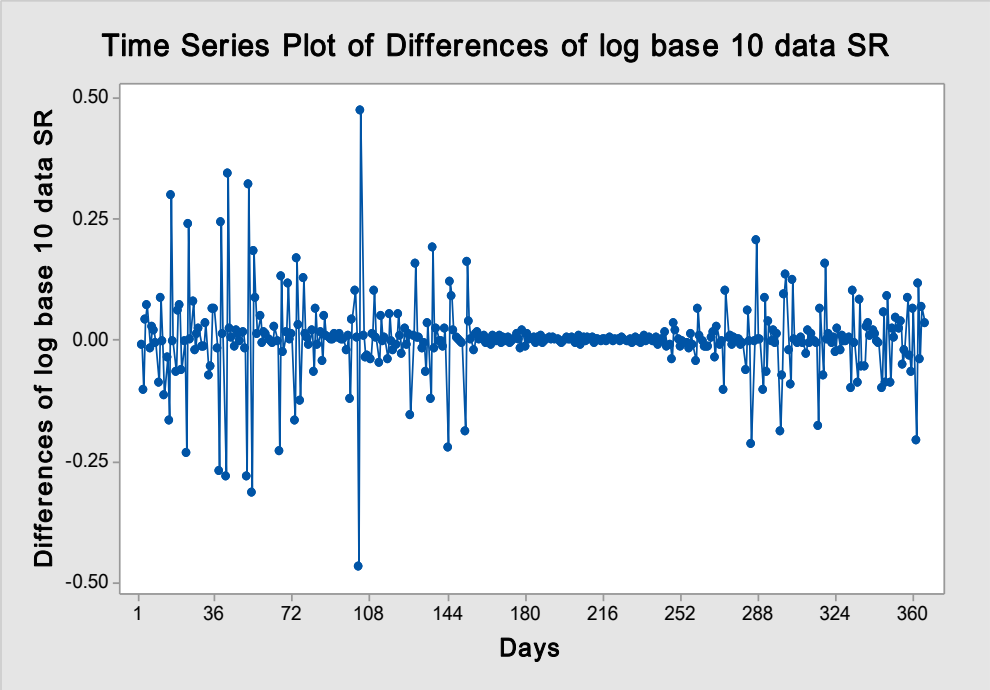

Figure 4 Differences data solar radiation in Benghazi

The parameters of ARIMA (p, q) were determined by Autocorrelation Function (ACF), Partial Autocorrelation Function (PACF). From Figures 5 and 6, p and q were found to be 2 and 2 respectively.

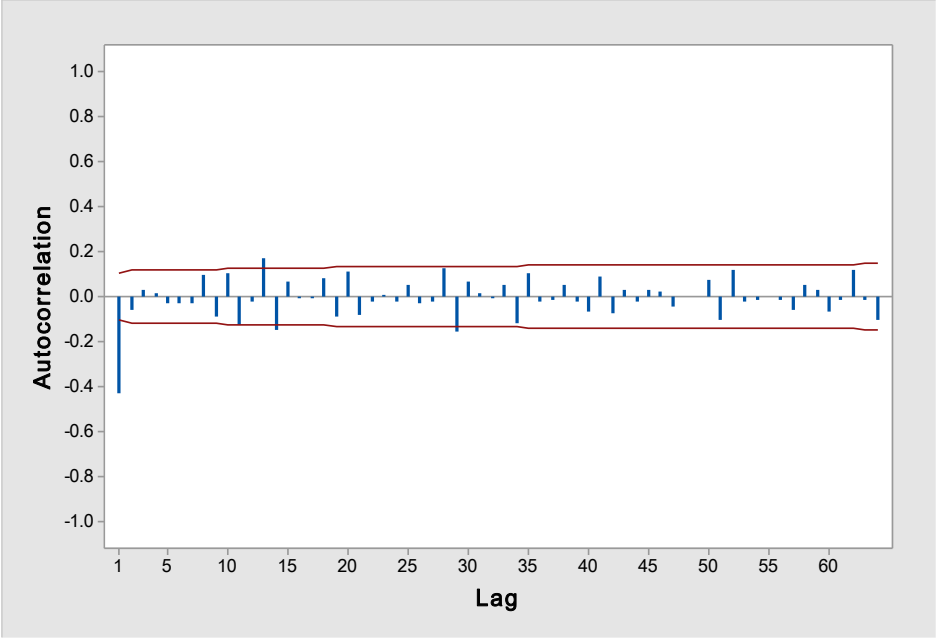

Figure 5 Autocorrelation Function (ACF)

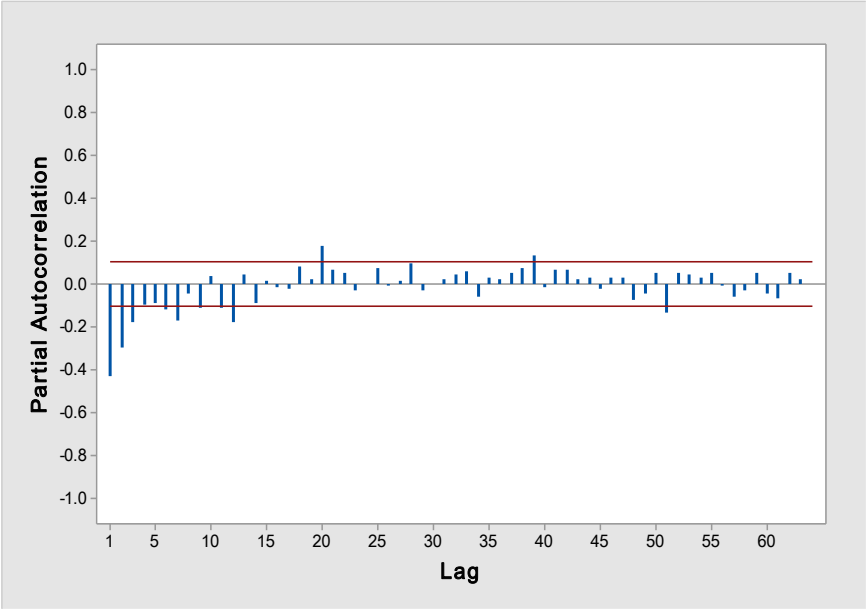

Figure 6. Partial Autocorrelation Function (PACF)

4.2 Validating Model

The actual data of years 24 through 29 are used for purpose of validation, the forecasted data for mean solar radiation are given in Table 1.

Table 1 The forecasting data for mean solar radiation

Years	2008	2009	2010	2011	2012
Forecasting (SR)	5.52	5.44	5.37	5.36	5.42

The validation model for solar radiation is made by comparing the actual with the predicted value of solar radiation intensity, as given in Table 2. Absolute value of error and percentage error are given. The mean absolute percentage error was found to be 6 %.

Table 2: Validation of the Model

Actual Data(At)	Forecasted Data (Ft)	Absolute Data	Error %
5.55	5.52	0.03	1
5.74	5.44	0.30	5
5.75	5.37	0.38	7
6.224	5.36	0.87	14
5.69	5.42	0.27	5
		MAPE	**6**

4.3 Analysis of ARIMA Model

The parameters in the model are in Table 3. Based on the above analysis, we established the function of energy consumption is established as follows:

$$\mathbf{SR}_t = -0001723 + 06965SR_{t-1} + 00793SR_{t-2} + 00521\ \varepsilon_{t-1} - 0.0332\ \varepsilon_{t-2} \quad (1)$$

Note, however, that ARIMA is a fairly sophisticated model for accurate forecasting. Comparing6 the observation, together with the forecasts, show that the ARIMA (2, 1, 2) results fit the actual time-series data considerably. The ARIMA model selects the parameters using a significant level 5%. As a result, the parameters found to be significant are AR (1), AR (2), MA (1), and MA (2) as obtained in Table 4. Where the P value were 97, 89, 61, 94 %.

Table 3 ARIMA Model for SR

Type	Coef	SE coef	T	P
AR 1	0.0521	1.3676	0.04	0.970
AR 2	-0.0332	0.2600	-0.13	0.899
MA 1	0.6965	1.3642	0.51	0.610
MA 2	0.0793	1.1362	0.07	0.944
Constant	-0.001723	0.007837	-0.22	0.826

Also, the results of the modified Box Pierce Chi Square Statistic, as given in Table 5 showed independence of the errors, thus indicating that the model is dependable.

Table 4 Evaluation of Box Pierce

Lag	12	24	36	48
Chi-Square	13.7	48.4	77.7	88.3
DF	7	19	31	43
P-Value	0.056	0	0	0

Based on the P-value as obtained in Table 4 that are higher than 5%., it is found that ARIMA (2, 1, 2) will fit the model with respect to the Solar Radiation data.

5. Conclusions

After applying the ARIMA model for predicting mean solar radiation for 5 years in Benghazi, and comparing the actual data with the predicted, ones the mean absolute percentage error was found to be 6 %. Performing analysis of the model showed that it significantly predicts the solar

radiation value. This is a valuable tool to determine requirements of solar panels for different applications of use of solar energy.

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