International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 24 (2017) pp. 15438-154446

Estimation of Solar Radiation of Clear Sky using Non- Linear Methods Case Study: Fuerteventura (Spain)

Francisco Javier Díaz Perez[1*], David Chinarro[1], Adib Guardiola Mouhaffel[2], Ricardo Díaz Martín[3], Jesús Romero Mayoral[4], Carlos Martínez Domínguez[2] and Mª Rosa Pino Otín[1]

[1]Universidad San Jorge, Zaragoza, Spain.
[2] Universidad Camilo José Cela, Madrid, Spain.
[3] Universidad a Distancia de Madrid (UDIMA), Madrid, Spain.
[4] Universidad de las Palmas de Gran Canarias, Gran Canarias, Spain.

*(*Corresponding author)*

[1]Orcid: 0000-0003-1014-3227

Abstract

The knowledge of irradiation in a geographical area is very important for multiple areas for the development of the area. Current calculation systems are based on statistical models of measurements of ground stations, or by external radiation calculations by satellite models. In this paper we show another method of calculation, based on the estimation of the incident radiation in a geographical area, through the production of electric energy generated by known photovoltaic solar installations. With the data of several years of three installations with equal inclination, model of solar panels, and in the same geographical area, the island of Fuerteventura, in the Canary Islands (Spain), we perform monthly irradiation calculations based on the total production of each month. With the calculated irradiation data, we performed a statistical study of them, using the ARIMA model with the SPSS Statistics software and we also carried out the study using a Fourier series decomposition model. With the two models, we made a comparison by measuring the forecast errors with the indicators of the root-mean-square error (RMSE) the mean absolute percentage error (MAPE) and its regression coefficient R^2. We verify the validity of the method shown for both statistical models of irradiation prediction and verify that the best results are obtained for the Fourier decomposition model.

Keywords: solar energy, irradiation, ARIMA, Fourier.

INTRODUCTION

The calculations of the global irradiation on the terrestrial surface become indispensable for multiple human activities, being the current one that more boom is taking, the one based on the applications of solar photovoltaic generation, for which the knowledge of the radiation is essential. The studies are multiple to be able to calculate the function that can represent the radiation in a geographical place. From the first expressions of regression treated by Angström in 1924 **[1]** that relates the average daily solar radiation per day for clear days and the radiation for a given place by the average of the fraction of the hours of measured solar brightness and the theoretical duration of the day, which later they were modified by multiple investigators which are summarized in the work of Bakirci **[2]**, where the different models of this type, are shown and which covers the study of the 60 different models based on the Angström original. The most widespread calculation systems are the statistics by measuring the irradiation in different areas, which have been generated Atlas of radiation for specific geographical areas **[3,4,5]**. Through statistical calculations, different irradiation studies have been carried out in the Canary Islands **[6]**, for the main irradiation databases in Turkey **[7],** Tibet **[8]**, India **[9]** and many other countries **[10,11],** the validity of their calculations has been verified. The realization of these studies has the problem of the high cost of measuring equipment and the large amount of data needed to be able to make forecasts and estimates with a certain validity, which according to the studies of Festa and Ratto **[12]** should be a minimum of 25 years for the case of hourly calculations, this is the reason why these studies become very complicated in many geographical areas.

The meteorological factors, like temperature and rainfall must also be considered in the estimates of solar radiation **[13,14].** On the way through the atmosphere, solar radiation interacts with atmospheric constituents such as molecules, ozone, water vapor, aerosols, and cloud particles, which attenuate solar radiation by absorption or dispersion **[15]**. The distribution of cloud particles and aerosols can be difficult to predict with a high degree of accuracy, and cloud particles especially can reflect a large fraction of incoming solar radiation. Different approaches have been used to predict the radiation of the solar surface, depending on the time scale of the prognosis. Used cloud motion vectors derived from consecutive satellite imagery to forecast very short-range solar radiation (30 minutes to 2 hours). At forecast intervals of more than 6 hours, numerical weather prediction models (NWP) have been found to be superior to other alternatives. Apparently, the complete coherent system of equations describing the evolution of the atmosphere is necessary for these longer forecast ranges **[16,17].**

Estimates of global irradiation estimation, considering direct and diffuse irradiation **[18,19,20]** and the other methods discussed, become very complicated to have data from all the locations that are necessary, due to their associated expenses and the amount of data needed. Complexity of the commented systems, requires a simple and efficient model that can be adapted to multiple geographical areas, and taking into account that currently photovoltaic solar installations have a large expansion in many geographical areas, taking into account the monthly generation of the same in a space of several years we can calculate a real approximation of the irradiation of the area, and whose model of easy development can be applied to any geographical area that have data of the production of the photovoltaic installation and the type of solar modules installed.

METHODOLOGY

To calculate the irradiation, it is necessary to know the angle of incidence of sunlight, due to its movement of translation around the sun of the Earth and the decline of the axis of rotation, produces a difference in the incidence of solar radiation with respect to the reference latitude, and for the calculations of this angle we use the well-known Cooper equation **[21]**, which gives the value of the approximate decline of the reference point at solar noon of the day considered

$$\boldsymbol{\delta(n) = 23,45 * sen\left[360 * \left(\frac{284+n}{365}\right)\right]}$$

"n" is the chosen day counting from January 1 to the day in question.

We can also use calculation tables to estimate the values according to the latitude and angle of the collectors or calculating the values of the three components of direct, diffuse and albedo radiation must be found, with several methods for obtaining and estimating them **[22,23,24]**. There are multiple irradiation databases **[25,26,27,28]**, for convert the values irradiation at 10º to 0º for our model of approximation, we obtain the calculation factor “k” that passes the irradiation of the 10º of the study stations to 0º , for what we use the global irradiance values of the European PVGIS - Helioclim data **[29,30]**, as starting data to 10º and 0º, where the multiplying factor of the irradiance value is obtained for flat surfaces, and will give us the approximate result for the inclined surfaces **[31],**

$$\boldsymbol{G(\beta) = k * G(0^{\circ})}$$

Where "k" is the multiplying factor for the irradiation of surface inclined to flat surface 0º is the latitude of the place, and "G (0°)" is the irradiance value for flat surfaces at 0°.

To obtain the calculations for generation, we collected the data from 3 photovoltaic generation facilities, which was provided by the management of the establishments. The sample period varies from a minimum of 3 years to a maximum of 5 years. ***Table 1*** summarises the characteristics of the facilities studied. The names of the establishments have been codified for data protection.

Table 1: List of researched facilities and their main features.

Name	Latitude	Longitude	Mark	Peak power W	Tilt angle
FEM	28º25´53"	13º52´28"	SolarWorld	88.000	10º
INP	28º31´26"	13º50´18"	SolarWorld	441.600	10º
HIE	28º31´32"	13º50´25"	SolarWorld	552.000	10º

Monthly irradiation calculation

To calculate the irradiation of the installations, we start with the monthly electric generation of the generating station, it is necessary to consider the electricity generated monthly, the peak power of the generator and the total losses, which are included in a total efficiency index known as "Performance ratio" (PR) **[32]**. With the following function we calculate the global monthly irradiation that affects the installation.

$$\boldsymbol{G(\beta,\mu) = \frac{E_{red}}{PR * P_{pp}}}$$

"G (β, μ)" is the mean irradiance according to declination and a given azimuth, "PR" is the global loss index that encompasses all losses of the system, and "Ppp" is the maximum power of photovoltaic generators. The calculation of the PR is made considering all the losses of the generating system, which are given by the function:

$$\boldsymbol{PR = (1 - (L_T + L_D + L_R + L_p)) * L_E * L_{In} * L_V}$$

Where, “L_T” are the losses by temperature that we calculate them by the method of Otherworld **[33]**, "L_D" are the losses by dispersion of parameters, “L_R” are losses by angular and spectral reflectance , "L_P" are losses due to dust on the modules, "L_E" are losses in electrical wiring, “L_{IN}” are losses due to the efficiency of the inverter, what we used the European efficiency value of the inverter **[34]** given by the manufacturer and "L_V" are other losses that were not previously considered. **Table 2** shows the data of the calculation parameters for the coefficients of the different losses.

Table 2: List of coefficients of the different losses.

Name	Description	Value
L_T	Temperature losses	Calculate
L_D	Lost by dispersion	3,00%
L_P	Lost dust and dirt	2,00%
L_R	Lost reflectance	3,00%
L_{in}	European Investor Efficiency	96%
L_E	AC and DC circuit efficiency	97%
L_V	Efficiency due to other losses	95%

Arima

The ARIMA methodology aims to extract the regularities observed in the past behaviour of the variable, and if the structural conditions that make up the series remain constant, predict its behaviour in the future. This model is known as Box - Jenkins for being its creators **[35,36]**. It is widely used for economic series analysis, as well as in hydrology, medicine, and meteorology, although the field in which the ARIMA methodology finds its main role for prediction purposes is with short-term prediction and in series with a seasonal component. The theory of stochastic processes, the ARIMA processes, provides a general methodology for the analysis of a single variable in the series that shows a clear dependence between present and past values.

The generic name ARIMA derives from its three components: Self-regressive (AR), Integrated (I), of Mobile Averages (MA). The ARIMA model presents an explicit equation that allows us to describe an observation from the series as a linear function of previous data and errors due to chance, which may also include a cyclical or seasonal component which describes each of the components that can be part of the model, as well as the notation usually used to describe them, which will be used in this study. The general function **[37,38]** represented by the ARIMA model (p,d,q) is as follows:

$$\emptyset(\boldsymbol{\beta})(\mathbf{1}-\boldsymbol{\beta})^{d}\boldsymbol{Xt}=\boldsymbol{c}+\boldsymbol{\theta}(\boldsymbol{\beta})\boldsymbol{\varepsilon t}$$

where “Xt” is the study variable, “c” a constant and “εt” is the error or residue term, which follows a normal distribution of zero mean and constant variance. The term $(1\text{-}\beta)^d$ is applied to the original series to make it stationary, and “d” corresponds to the order of part I of the ARIMA model. Ø(β) and θ(β) are polynomials of order p and q that depend on the delay operator “B”.

We have used to calculate the mathematical software of IBM SPSS Statistics **[39]**, calculating the different factors through the expert model and through the Box-Jenxisn methodology of three steps that is extended to 6 by later studies **[40]** to be able to estimate the corresponding parameters of the model. 1 Data collection of the series, 2 Analysis of the stationarity and possible transformation of the series, 3 Identification of the model, 4 Estimation of model coefficients, 5 Validation and selection of the model and 6 Prediction.

Fourier

The Fourier transform is the mathematical procedure to analyze periodic functions through the decomposition of said function in an infinite sum of much simpler sinusoidal functions, with combination of sines and cosines with whole frequencies **[41,42]**. The function initially defined at time f(t) is the transform to the domain of the frequency F(w). This new function F(w) is called the Fourier Transform **[43],** or Fourier Series, when the function is Periodic. Fourier determined that it was possible to express a function as the sum of Sines and Cosines signal of different frequencies and amplitudes until the original function was determined. This procedure was initially implemented for periodic functions, but can be extended to non-periodic. Fourier showed that virtually any periodic function can be represented as a sum of sines and cosines by assigning each a weighting coefficient.

The harmonic analysis is a type of analysis of any function, continuous within a range, can be represented by an infinite series of sine and cosine functions. This series is called the Fourier series, and the method of finding Fourier analysis functions. If there is only a finite number of points in the interval to be analysed, a finite number of sines and cosines will be able to account for all observations. This technique is adequate for investigating the harmonics of an identifiable frequency under the assumption that the time series is genuinely periodic. Each harmonic can (but need not) have a different physical meaning. Recall that if f (x) is infinitely differentiable at x = a, then the Taylor series **[44,45]** of “f” is defined as:

$$\boldsymbol{e^{x}=1+x+\frac{x^{2}}{2}+\frac{x^{3}}{6}+\frac{x}{24}^{4}}$$

we have a "representation" of the function “f”. We know from experience that representations of the Taylor series are useful in many ways. In the same way, there are other types of representations which are very useful. In this work we are concerned, specifically, with the representation of the periodic function by trigonometric series of the form:

$$\boldsymbol{Y_t=\frac{a_0}{2}-\sum_{K=1}^{k-1}\;A_n\cos(\frac{2\,\pi t}{T})-B_n sen\,(\frac{2\,\pi t}{T})}$$

Harmonic analysis means the computation of the coefficients "A_n" and "B_n". Now, with the coefficients computed according to equation is called the Fourier series of "f"; the coefficients $A_0, A_1, \ldots, A_n$, and $B_0, B_1, \ldots, B_n$ are called the Fourier coefficients off, and the individual terms are generally referred to as harmonic. Since the data are typically taken at integer times $t_j = t_0, t_1, t_{N-1}$, a discrete version of the Fourier transform must be considered. The easiest case to treat, and the only one we will consider, is the case of equal time samples N, $T_j = j_{\Delta t}$ $j = 0,1,2, .. N-1$.

Here Δt is the time between two neighbouring data points in the time series and $fs = 1/\Delta t$ is the sampling frequency - the number of samples taken per second. The discrete-time Fourier transform (DTFT) for a data set of discrete time of finite length's (0), X (Δt), X (2Δt), ..., X ((N-1) Δt).

Analogous to the series, the Fourier transform decomposes the signal into sines and cosines of different frequencies and amplitudes. Fourier showed that virtually any periodic function can be represented as a sum of sines and cosines by assigning each a weighting coefficient.

Methods

The method used to compare the real data and calculate the characteristic feature of irradiation according to the electrical energy generated by the photovoltaic generating stations is:

1. Initially the data of electric power generation of the different production plants of the study plants supplied by the facilities' managers were obtained.
2. We calculate the irradiance value of the generating plants, according to the monthly generation obtained. The calculated irradiation values are for the inclination of the solar panels of 10º.
3. We convert the irradiance value of the inclined surface from 10º to flat surface according to the calculated factor "k" of the solar DB, for all the stations.
4. With the monthly irradiation data, we calculate the characteristic function of the forecast with the ARIMA method and by the Fourier series decomposition
5. We compare the data obtained and compare it with the real values of the stations to check which system is best adjusted considering the term of RMSE, MAPE and R^2.

Figure 1 shows the flow diagram of the research carried out to obtain the actual irradiation data of the installations and their comparison with the data of the different photovoltaic generating stations.

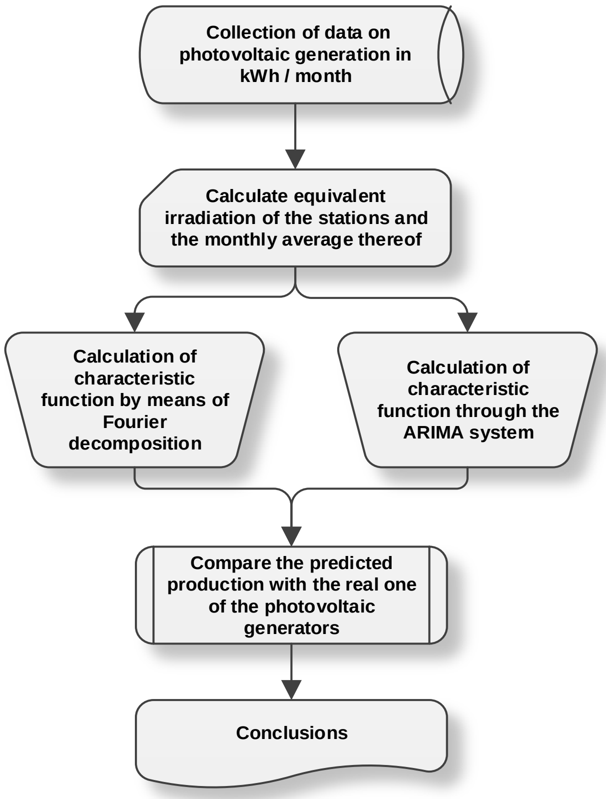

Figure 1: Research Flow Diagram.

ANALYSIS DATA

We take the values of the energy data produced from the different generating photovoltaic stations, with all the monthly production values of 3 and 5 years according to the generating station. With the obtained values, the transformation is carried out to calculate the irradiation of the different years and stations, filtering the values due to the failure of the measurements or the maintenance of the facilities. With the step coefficients "k" obtained from the PVGIS - Helioclim irradiation DB, the irradiation values for the inclined surface of the photovoltaic solar panels are calculated from 10 ° to the flat surface of 0 °. These values are shown in the following ***Figure 2***, which shows the irradiation calculated by months for flat surfaces of 0º.

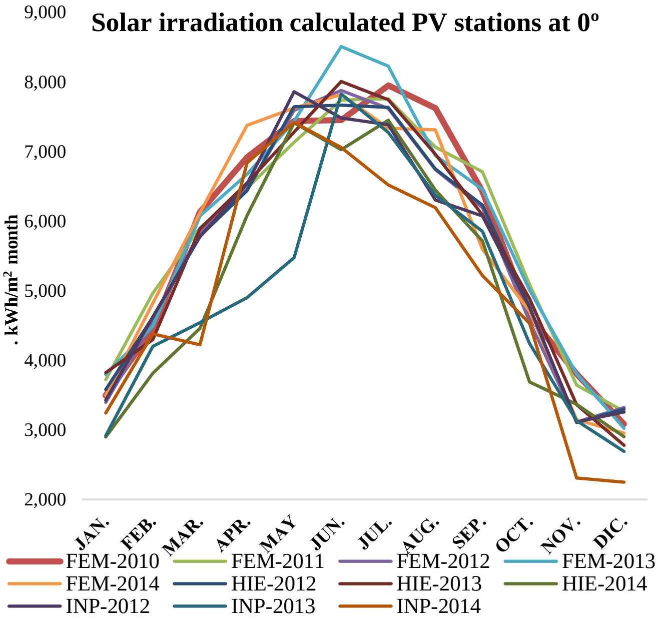

Figure 2: Solar irradiation calculated for 0º.

The monthly irradiation data depend on the solar height calculated for each geographical area and the average daily hours of insolation, that in the following ***Figure 3*** we can observe the distribution of the irradiation according to the hours of insolation and verify how it has a linear tendency with a high correlation index R2 of the irradiation with respect to the hours of insolation as expected.

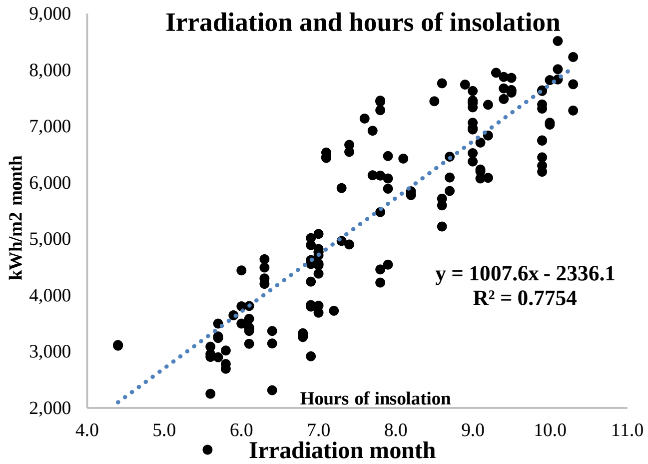

Figure 3: Distribution of the irradiation according to insolation

RESULTS

With the data obtained from monthly irradiation, we carried out the forecast calculations for the ARIMA model according to the Box-Jenkins methodology using the IBM SPSS Statistics v.23 mathematical modeling software. The modeling is done in two different ways, first the calculations are made through the SPSS expert modeling module, showing in ***Table 3*** the results obtained according to the models suggested by the software for each station. The calculations have also been made following the steps for the calculation of coefficients according to the Box-Jenkins procedure, with which another type of ARIMA modeling (p, d, q) was obtained, giving us an ARIMA model (2,0,1), which is an ARMA model (2.1), checking the results in ***Table 4***. With the obtained data, the comparison is made using the regression index R^2 of Karl Pearson **[46]** to justify their greater or lesser correlation **[47]** We compared the accuracy of the different regressions calculated by calculating the RMSE **[48,49]** and by MAPE **[50]** which is an indicator of the prognosis that measures the size of the error (absolute) in percentage terms, which gives us a relative measure of the error. The functions used are as follows:

$$RMSE = \left[\frac{1}{t}\sum_{i=1}^{t}(u_p - u_o)^2\right]^{1/2}$$

$$MAPE = \frac{100}{t}\sum_{i=1}^{t}\left|\frac{G_r - G_f}{G_r}\right|$$

Where "t" is the number of observations, "u" is the residuals of the estimates, the subscript "p" being the predicted residue and "or" the observed residue, "Gr" is the calculated real irradiation and "Gf" is the estimated irradiation according to the forecast model analysed.

Table 3: Models and forecasts for expert mode of SPSS

SPSS expert modeling - ARIMA				
Station	**Model ARIMA (p,d,q)**	**R^2**	**RMSE**	**MAPE**
FEM	(3,1,0)	0,846	672,3	10,68%
HIR	(0,2,0)	0,755	858,0	13,89%
INP	(1,1,0)	0,642	1.030,3	17,37%

Table 4: Models and forecasts for the Box-Jenkins procedure

Box-Jenkins system modeling - ARIMA				
Station	**Model ARIMA (p,d,q)**	**R^2**	**RMSE**	**MAPE**
FEM	(2,0,1)	0,918	501,2	7,24%
HIR	(2,0,1)	0,889	600,8	9,13%
INP	(2,0,1)	0,816	761,8	11,65%

It is verified with the obtained results, with the model calculated by the Box-Jenkins procedure gives better results than by the expert module of the SPSS Statistics, with very high adjustment characteristic values in the three indicators of prediction R^2, RMSE and MAPE. ***Figure 4*** shows the results for the calculations for the autocorrelation function (ACF) and partial autocorrelation (PACF) plots of the differenced series, we can tentatively identify the numbers of AR and MA terms that are needed. The plots vary within the 95% CI bounds.

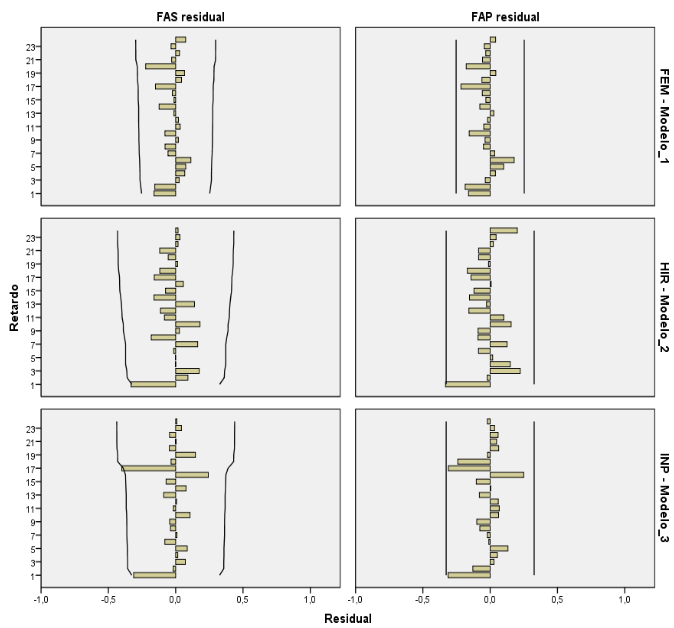

Figure 4: ACF and PACF of the residual error for the AR (2) and MA (1) models.

With the predicted values, we can observe in the following ***Figure 5*** the comparison of the irradiation of the three stations studied according to the years that we have data, with respect to the forecasts we calculate using the ARIMA model and real values calculated according to the monthly generated electricity production. We can observe the few differences that are between the real and forecasted values.

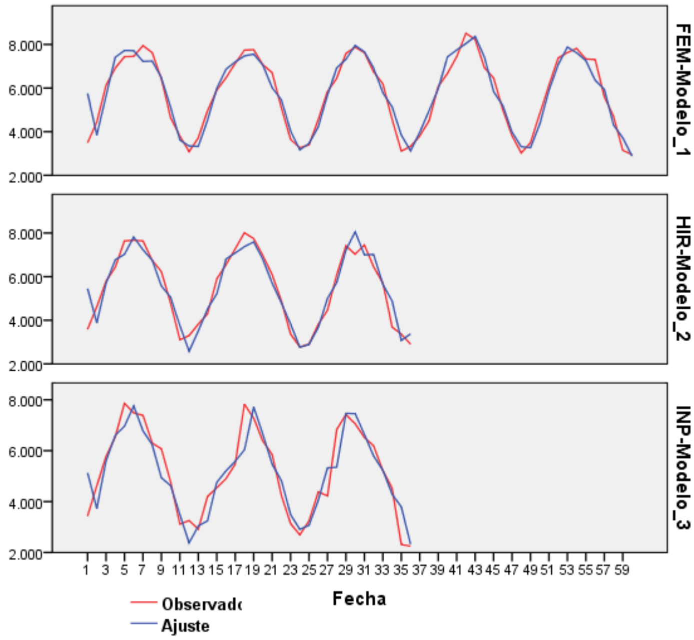

Figure 5: Real irradiation curve and predicted by ARIMA model

The characteristic function of the ARIMA model (2,0,1) calculated for the irradiation of one of the example photovoltaic stations, FEM, would be the following:

$$Y_t = 5.755,98 + 1,17Y_{t-1} - 0.979Y_{t-2} + 0.995\varepsilon_{t-1}$$

The prediction calculations according to the Fourier decomposition have given us very good values, with some indicators for the three photovoltaic stations far superior to the ARIMA model, being very close to a perfect correlation of predicted values with respect to the real ones. In the following ***Table 5*** the values of the different calculated indicators are shown.

Table 5: Models and forecasts for the Fourier decomposition

FOURIER			
Station	**R^2**	**RMSE**	**MAPE**
FEM	0,988	263,8	4,00%
HIR	0,980	338,6	5,75%
INP	0,953	505,2	8,09%

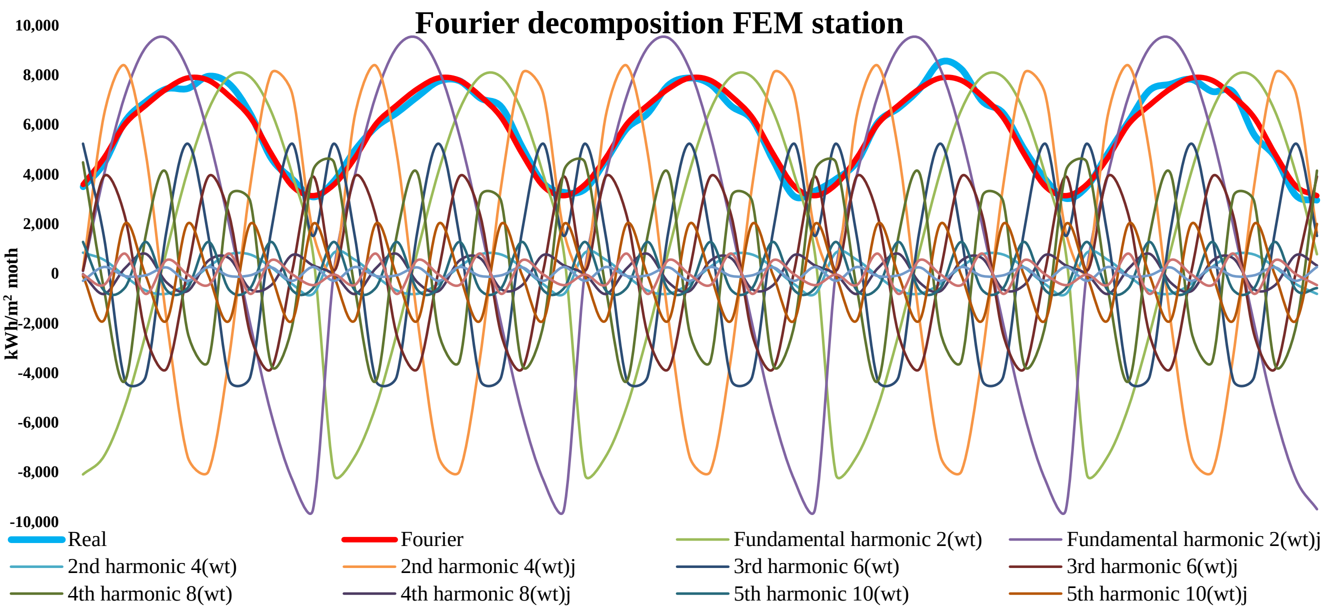

Figure 6: Fourier decomposition and characteristic harmonics together with real irradiation curve and prediction for FEM station.

The Fourier decomposition that we have done has been until the 6th harmonic, being the real function for an adjustment to the perfect formed by the harmonic infinities. ***Figure 6*** shows the decomposition of a sum of simple, sinusoidal functions whose periodic frequency. The component of the Fourier series whose frequency coincides with the fundamental (n=1) is called the fundamental component:

$$a_1 \cos(wo_t) + b_2 \sin(wo_t).$$

We can see how the adjustment of this function is superior to that of ARIMA, with a value for this station represented by $R^2 = 0.998$, and how the forecast data is almost the same as the real calculated.

The characteristic function that the irradiation represents will is composed by the harmonic components, so the harmonic of order n or nth would be that whose frequency is n times the fundamental. The values of a0/2 represent the average value of the function f (t) over a period and are called the continuous component. The sample function for the FEM station is shown below:

$$\mathbf{Y_t = 5.748,17 - 8.097,12\cos(\tfrac{2\pi t}{T}) - 9.545,59\ sen\ (\tfrac{2\pi t}{T}) + 836,86\cos(\tfrac{4\pi t}{T}) - 8.432,06\ sen\ (\tfrac{4\pi t}{T}) + 5.229,29\cos(\tfrac{6\pi t}{T}) - 4.075,64\ sen(\tfrac{6\pi t}{T}) + 4.475,47\cos(\tfrac{8\pi t}{T}) + 837,37\ sen\ (\tfrac{8\pi t}{T}) + 1.266,38\cos(\tfrac{10\pi t}{T}) + 2.251,80\ sen\ (\tfrac{10\pi t}{T}) - 302,21\cos(\tfrac{12\pi t}{T}) + 852,41\ sen\ (\tfrac{12\pi t}{T})}$$

The following ***Figure 7*** shows the comparison of the two ARIMA and FOURIER non-linear models according to the R2 and MAPE indicators, verifying how in all cases the Fourier model gives better results.

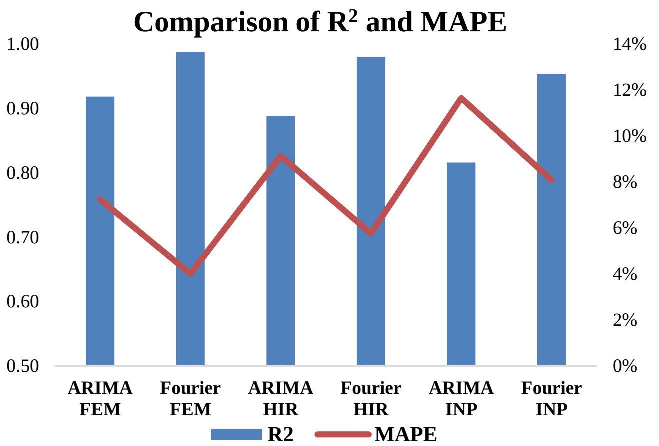

Figure 7: Comparison of ARIMA and FOURIER non-linear models according to the R2 and MAPE indicators.

DISCUSSIONS AND CONCLUSIONS

The calculation model of forecasts that we have developed for solar irradiation estimation, considering the generation of electric energy by photovoltaic solar panels (PV) is applicable to multiple destinations, provided that we have sufficient monthly data of several years and the characteristics of the PV. With the ARIMA model or the Fourier decomposition model, we obtained very good estimations and forecasts of irradiation, with R^2 values higher than 0.81 in all cases. We have also verified that using the mathematical software SPSS Statistics it is better to enhance the calculation by the Box-Jenkins procedure than by integrated expert modeling. The most recommendable model is the Fourier decomposition, with which we get better forecast indicators and a correlation index R^2 in all cases greater than 0.95.

REFERENCES

[1] Angstrom, A. (1924). Solar and terrestrial radiation. Report to the international commission for solar research on actinometric investigations of solar and atmospheric radiation. Quarterly Journal of the Royal Meteorological Society, Volume 50, pp: 121–126.

[2] Bakirci, K. (2009). Models of solar radiation with hours of bright sunshine: A review. Renewable and Sustainable Energy Reviews Volume 13, pp: 2580-2588.

[3] Scharmer, K. and Greif, J. (2000). The European Solar Radiation Atlas. Database and Exploitation Software. Les Presses de l´E´ cole des Mines, Volume 2

[4] State Meteorological Agency (AEMET). (2010). Atlas of Solar Radiation in Spain using data from the EUMETSAT Climate SAF.

[5] Commission of the European Communities (CEC) (2012). European Solar Radiation Atlas: Solar Radiation on Horizontal and Inclined Surfaces. Springer; Edition: Softcover reprint of the original 3rd ed. 1996 (June 27, 2012). ISBN: 978-3642802393

[6] Díaz, F., Montero, G., Escobar, J. M., Rodríguez, E., and Montenegro, R. (2012). An adaptive solar radiation numerical model. Computational and Applied Mathematics. Volume 236, pp: 4611–4622.

[7] Bezir, N. C., Akkurt, I., and Özek. N. (2010). Estimation of horizontal solar radiation in Isparta (Turkey). Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. Volume 32, pp: 512–517

[8] Li, H. et al. (2011). Global solar radiation estimation with sunshine duration in Tibet, China. Renewable Energy, Volume 36, pp: 3141-3145

[9] Katiyar, A.K., and Kumar, Ch. (2010). Simple correlation for estimating the global solar radiation on horizontal surfaces in India. Energy Volume 35, pp: 5043-5048.

[10] El-Sebaii, A.A., Al-Hazmi, F., Al-Ghamdi, Ahmed and Yaghmour, S. (2009). Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia. Applied Energy, Volume 87, pp: 568-576.

[11] Chegaar, M, and Chibani, A. (2001). Global solar radiation estimation in Algeria. Energy Conversion and Management, Volume 42, pp: 967–973.

[12] Festa, R., Jain, S. and Ratto, C.F. (1992). Stochastic modelling of daily global irradiation. Renewable Energy, Volume 2, pp: 23-34.

[13] Liu, D. and Scott, B. (2001). Estimation of Solar Radiation in Australia from Rainfall and Temperature Observations. Agricultural and Forest Meteorology, Volume 106, pp: 41-59.

[14] Hunt, L.A., Kuchar, L. and Swanton, C.J. (1998). Estimation of solar radiation for use in crop modelling. Agricultural and Forest Meteorology, Volume 91.

[15] Argiriou, A., Lykoudis, S., Kontoyiannidis, S., Balaras, C.A., and Asimakopoulos, D. (1999). Comparison of methodologies for TMY generation using 20 years data for Athens, Greece. Solar Energy, Volume 66, Issue 1, pp: 33-45

[16] Daubenmire, R. (1956). Climate as a Determinant of Vegetation Distribution in Eastern Washington and Northern Idaho. Ecological Monographs, Volume 26, pp: 131–154.

[17] Bergametti, G., Dutot, A.L., Buat-Menard, P., et al. (1989). Seasonal variability of the elemental composition of atmospheric aerosol particles over the NW Mediterranean. Tellus, Volume 41, Issue 3, pp: 353–361.

[18] Liu, B.Y. and Jordan, R.C. (1960). The interrelationship and characteristic distribution of direct, diffuse and total solar radiation. Solar Energy, Volume 4, Issue 3, pp: 1-19

[19] Jacovides, C, F., Tymvios, V. et al. (2006). Comparative study of various correlations in estimating hourly diffuse fraction of global solar radiation. Renewable Energy, Volume 31, pp: 2492-2504.

[20] Solanki, C.S., and Sangani, C.S. (2008). Estimation of monthly averaged direct normal solar radiation using elevation angle for any location. Solar Energy Materials and Solar Cells, Volume 92, pp: 38-44.

[21] Cooper, P.I. (1969). The Absorption of Solar Radiation in Solar Stills. Solar Energy, Volume 12, pp. 3.

[22] Aggarwal, R.K. (2013). Estimation of Total Solar Radiation on Tilted Surface. Journal of environmental engineering and technology, Volume 2, Issue 1, pp: 4-6.

[23] Nooriana, A.M., Moradib, I. and Kamalia, G.A. (2008). Evaluation of 12 models to estimate hourly diffuse irradiation on inclined surfaces. Renewable Energy, Volume 33, pp: 1406–1412.

[24] Klein, S.A. and Theilacker, J.C. (1981). An Algorithm for Calculating Monthly-Average Radiation on

Inclined Surfaces. Journal of Solar Energy Engineering, Volume 103, Issue 1, pp: 29-33.

[25] ADRASE - Ciemat. http://www.adrase.es Date accessed: 07/21/2017

[26] NASA- SSE https://eosweb.larc.nasa.go Date accessed: 07/21/2017

[27] Solar radiation data. http://www.soda-pro.com/ Date accessed: 08/24/2017

[28] AEMET. http://www.aemet.es/es/serviciosclimaticos/ Date accessed: 08/14/2017

[29] Photovoltaic Geographical Information System (PVGIS). http://re.jrc.ec.europa.eu/pvgis/ Date accessed: 07/25/2017

[30] Šúri, M., Huld, T.A., and Dunlop, E.D. (2005). PV-GIS: a web-based solar radiation database for the calculation of PV potential in Europe. International Journal of Sustainable Energy, Volume 24, Issue2, pp: 55-67.

[31] Díaz, F.J., Chinarro, D., Guardiola, A., Díaz, R., and Pino, M.R. (2017). Assement Solar Database Regarding Production Values in Fuerteventura Photovoltaic Installations. Indian Journal of Science of technology, Volume 10, Issue 13, pp: 1-16.

[32] UNE-EN 61724:2000. (2000). Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis.

[33] Osterwald, C.R. (1986). Translation of device performance measurements to reference conditions. Solar cells, Volume 18, pp: 269-279.

[34] UNE-EN 50530:2011/A1:2013. (2013). Overall efficiency of grid connected photovoltaic inverters.

[35] Box, G.E. and Jenkins, G.H. (1970). Time Series Analysis: Forecasting and Control. San Francisco: Holden Day. (Revised edition published 1976).

[36] Box, G.E. and Jenkins, G.H. (1973). Some comments on a paper by Chatfield and Prothero and on a review by Kendall. Journal of the Royal Statistical Society. Series A - General, Volume 136, Issue 3, pp: 337-352.

[37] Hillmer, S.C., and Tiao, G.C. (1979). Likelihood Function of Stationary Multiple Autoregressive Moving Average Models. Journal of the American Statistical Association, Volume 74, pp: 652-660.

[38] Liu, L.-M. (1989). Identification of Seasonal ARIMA Models Using a Filtering Method. Communication in Statistics A, Volume 18, pp: 2279-2288.

[39] SPSS Statistics v23. https://www.ibm.com/analytics/us/en/spss/spss-statistics-version/ Date accessed: 10/17/2017

[40] Makridakis, S., Wheel, S.C., and Hyndman, R.J. (1998). Forecasting: methods and applications, New York: John Wiley & Sons.

[41] Fourier, J.B. (1822). Théorie analytique de la chaleur (in French), Paris, France. Firmin Didot.

[42] Condon, E.U. (1937). Immersion of the Fourier transform in a continuous group of functional transformations. Proceedings of the National Academy of Sciences of the United States of America, Volume 23, pp: 158–164.

[43] Bochner, S., and Chandrasekharan, K. (1949) Fourier Transforms, Princeton University Press.

[44] Koch, V.H. (1903). About the analytical extension of a Taylor series. Acta Mathematica, Volume 27, Issue 1, pp: 79-104

[45] Fatou, P. (1906). Trigonometric series and Taylor series. Acta Mathematica, Volume 30, Issue 4, pp: 335-400.

[46] Pearson, K. (1900). On the Criterion that a Given System of Deviations from the Probable in the Case of the Correlated Systems of Variables Is Such That it Can be Reasonably Supposed to Have Arisen from Random Sampling. Philosophical Magazine, Volume 50, pp: 157-175.

[47] Zou, K.H., Tuncali, K. and Silverman, S.G. (2003). Correlation and Simple Linear Regression. RSNA Radiology, Volume 227, Issue 3, pp: 617-628.

[48] Murphy, A.H. and E.S. Epstein, E.S. (1989). Skill Scores and Correlation Coefficients in Model Verification. Monthly Weather Review, Volume 117, pp: 572–582

[49] Barnston, A.G. (1992). Correspondence among the Correlation, RMSE, and Heidke Forecast Verification Measures; Refinement of the Heidke Score. Weather and Forecasting, Volume 7, pp: 699–709.

[50] Goodwin, P. and Lawton, R. (1999). On the asymmetry of the symmetric MAPE, In International Journal of Forecasting, Volume 15, Issue 4, pp: 405-408.