Analyses of Variations in Solar Irradiation based on Wavelet Technique

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Abstract

Solar irradiance is characterized by fluctuations due to the moving clouds. These fluctuations may lead to variations in power flow in the grids and may affect the stability of the grid system. Therefore it is important to predict the characteristics of the fluctuations for network planning in distribution grids. Predicting the characteristics of the fluctuations requires a mathematical approach, such as wavelet analysis. Wavelet decomposition is an analyzing method of time-frequency localization with fixed area window size and with changeable time-windows and frequency-windows. In this study, an analysis for extraction temporal structural changes of seasonal oscillation in global solar irradiance data measured at 10 meteorological stations distributed in two different (Marmara and Southeastern) regions of Turkey is presented based on wavelet transform. The data sequence of solar irradiance is mapped into several time-frequency domains by using wavelet decomposition methods. In addition to global solar irradiation data, clearness index have also been analyzed and evaluated for the years of 2011 and 2012. Some results of wavelet analyses of solar radiations properties are presented. In general, combined effects of small and large scale events have a great importance on global solar irradiance in spring, autumn and winter except summer at the study area.

Keywords: Global Solar Radiation, Fluctuations, Clearness index, Wavelet

1 Introduction

Wavelet Packet Program covers Morlet, Mexican Hat and Meyer wavelets. These wavelets have generally applied on analyses of atmospheric variables in different scales. Walker used Daubechies, Coifman, Haar, Gabore Sine, Gabore Cosine and Gabore Complex wavelets by using FAVA software. Wavelet means, small waves. At the initial stage, this method was used analyses of seismic signals by Morlet and Grossmann. Wavelet methodologies, has been used in different fields like; turbulence, ocean waves, seismic data, batimetry, environment, biology, electro cardio data, temperature, global warming.

Fourier spectrum does not detect some details of high frequency variations. Wavelet methods have more advantages than Fourier spectrum. They have been applied non stationary time series. They detect the details at frequency and time domain simultaneously. In recent years Wavelet methods have been applied on diagnostic fluctuations, as SST and climatic systems.

An adaptive wavelet – network model for forecasting daily total solar-radiation was applied on classification, identification and control problems. Mellit et al. (2006) use adaptive wavelet-network architecture in finding a suitable forecasting model for predicting the daily total solar-radiation. [5] Total solar-radiation is considered as the most important parameter in the performance prediction of renewable energy systems, particularly in sizing photovoltaic (PV) power systems. For this purpose, daily total solar-radiation data have been recorded during the period extending from 1981 to 2001, by a meteorological station in Algeria. The wavelet-network model has been trained by using either the 19 years of data or one year of the data. Results indicate that the model predicts daily total solar-radiation values with a good accuracy of approximately 97% and the mean absolute percentage error is not more than 6%.

The instantaneous clearness index is a parameter on which the Wavelet analysis is applied, and which is decomposed into components of different scales; corresponding to their persistence.[7] These components are examined to evaluate the magnitude and the persistence of the various fluctuations of the solar radiation. The method presents a valuable tool for the estimation of power flow as induced by solar radiation fluctuations.

On the basis of the principle of combination of artificial neural networks and wavelet analysis, a model is completed for forecasting solar irradiance.[3] Based on the historical day-by-day records of solar irradiance in Shanghai an example of forecasting total irradiance is presented in this paper. The results of the example indicate that the method makes the forecasts much more accurate than the forecasts using the artificial neural networks without combination with wavelet analysis.

A time series of global irradiance on the inclined plane can be simulated with the wave strapping procedure applied over a signal previously detrended by a partial reconstruction with a wavelet multi-resolution analysis, and, once again, the fluctuation behavior of this simulated time series is correct.[8] This procedure is a suitable tool for the simulation of irradiance incident over a group of distant PV plants. A wavelet variance analysis and the long memory spectral exponent show that a PV plant behaves as a low-pass filter.

1.1 Study Area

Descriptive explanations of study area are shown in Table 1 and Fig. 1. Ground data recorded at 10 different stations (Kırklareli, Tekirdağ, Samandıra, Çanak-kale, Bursa, Kilis, Ceylanpınar, Bozova, Şırnak and Mardin) at two regions (Marmara and Southern Anatolia) of Turkey have been analyzed. Marmara Region is mostly urbanized area and under the effect of air mass systems between eastern Europe, Black Sea, Agean Sea, Marmara Sea and Mediterranean Sea. Southern Anatolia is less urban-ized part of Turkey and mostly under the effect of Basra Air Systems and circulations.

Table 1. Geographic Descriptive of Study Area

Station	Latitude (degree min)	Longitude (degree min)	Height (m)
Kırklareli	41 74	27 22	232
Tekirdağ	40 96	27 50	4
Samandıra	40 99	29 21	123
Çanakkale	40 14	26 40	6
Bursa	40 23	29 01	100
Kilis	36 71	37 11	640
Ceylanpınar	36 84	40 03	360
Bozova	37 37	38 51	622
Şırnak	37 52	42 45	1350
Mardin	37 31	40 73	1040

Fig. 1. Study area

1.2 Data and method

Daily global solar radiation and sunshine duration for 10 stations between 1st January 2011 and 31st December 2011are archive data of the Turkish State Meteorological Service.

Two study areas selected for this paper have different solar radiation climatological conditions. Marmara Region is under the northerly and westerly frontal sys-tems. But in general, southerly and southeasterly systems effect in Southern Anatolia. Additionally, dust transportation is another factor observed in Southern Anatolia. Annu-al mean solar energy in Turkey is 3.6 kWh/m^2 day, mean insulation is 7.2 hours/day.[11] Solar energy values calculated in Marmara Region and Southern Anatolia in the year of 2011 are 1.96 kWh/m^2 year and 2.4 kWh/m^2 year respectively. Annual mean insulations in Marmara and Southern Anatolia Regions are 5.4 hours and 8.5 hours respectively.

In this paper temporal variation of Clearness index (H/H_o) is defined the ratio of global radiation measurements to radiation at top of the atmosphere. H_o is computed by considering astronomical parameters. Similarly, insulation ratio (S/S_o) is the ratio of measurements to theoretical insulation value.[2,6,9]
Mathematical equations for of wavelet packets of a f(t) function are given as below:[1,4]

$$\int_{-\infty}^{\infty} | f(t) |^2 \, dt < \infty \qquad (1)$$

$\psi(t)$ is a continuous wavelet function:

$$\int_{-\infty}^{\infty} |\psi(t)|^2 \, dt = 1 \tag{2}$$

$$\int_{-\infty}^{\infty} |\psi(t)| \, dt = 0 \tag{3}$$

Continuous wavelet analysis of the Total Solar Irradiance (TSI) time series accurately describes its non-stationary, multi-scale variations over a wide time-scale domain.[10] This paper presents some results of clearness index (H/H_o) variations by f(t) based on 1D Wavelet Packets and Continuous Wavelet Transforms.

2 Analyses

2.1 Statistical Analyses

Table 2 and 3 show some descriptive statistics of clearness index and insulations at different stations in two study areas. Highest standard deviations and lower averages have been recorded in Marmara Region than observations recorded in Southern Anatolia.

Table 2. Descriptive statistics of H/Ho at study area

H/Ho	Maximum	Minimum	Average	Stand. Dev.
Kırklareli	0,760	0,047	0,484	0,189
Tekirdağ	0,749	0,026	0,486	0,211
Samandra	0,746	0,035	0,457	0,212
Kilis	0,796	0,074	0,582	0,170
Ceylanpnar	0,751	0,085	0,585	0,150
Bozova	0,805	0,002	0,601	0,171
Şırnak	0,791	0,040	0,533	0,177
Mardin	0,812	0,007	0,586	0,171

Table 3 show monthly and annual averages of S/So insulation in all stations. The lowest value (32%) is defined in Samandra and the maximum value (72%) is observed in Bozova.

Table 3. Monthly variation of average S/S_o

No	Station	January	February	March	April	May	June	July	August	September	October	November	December	Average
							Marmara Region							
17052	**Kırklareli**	0,32	0,35	0,35	0,38	0,57	0,57	0,73	0,75	0,67	0,31	0,39	0,27	0,47
17056	**Tekirdağ**	0,37	0,42	0,38	0,33	0,48	0,59	0,72	0,72	0,74	0,36	0,38	0,41	0,49
17065	**Samandıra**	0,3	0,37	0,4	0,23	X	X	X	X	X	X	X	X	0,33
17112	**Çanakkale**	0,27	0,25	0,24	0,24	0,35	0,62	0,78	0,85	0,81	0,51	0,45	0,36	0,48
17116	**Bursa**	0,05	0	0,17	0,27	0,39	0,6	0,75	0,69	0,72	0,44	0,55	0,35	0,42
							Southern Anatolia							
17052	**Kilis**	0,49	0,53	0,7	0,53	0,7	0,81	0,87	0,88	0,82	0,76	0,56	0,58	0,69
17056	**Mardin**	0,65	0,52	0,7	0,45	0,73	0,87	0,85	0,9	0,88	0,76	0,67	0,71	0,72
17065	**Şırnak**	0,5	0,43	0,65	0,43	0,67	0,76	0,78	0,9	0,85	0,69	0,49	0,47	0,64
17112	**Bozova**	0,55	0,56	0,7	0,51	0,7	0,89	0,91	0,91	0,84	0,76	0,64	0,71	0,72
17116	**Ceylanpınar**	0,49	0,51	0,7	0,47	0,69	0,89	0,84	0,9	0,83	0,75	0,57	0,57	0,68

2.2 Analyses of clearness index by wavelets

Temporal analyses of signal are based on “MATLAB program/wave-menu”. Variations of clearness index, global solar radiation and insulations and role of events at different scales are discussed as below. Because of the page limitations, only two cases (Tekirdağ; in Marmara Region and Bozova; in Southern Anatolia) have been selected to discuss the results of wavelet analyses at this part of the paper.

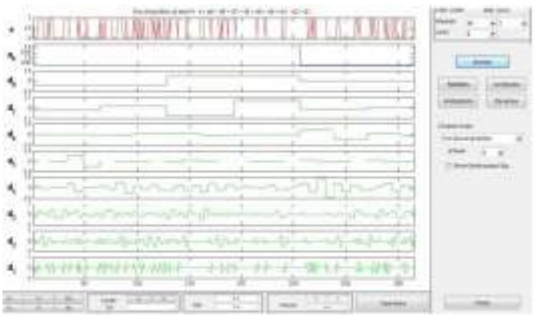

Fig. 2. 1D Wavelet Analyses (db, Level8), Tekirdağ (2011)

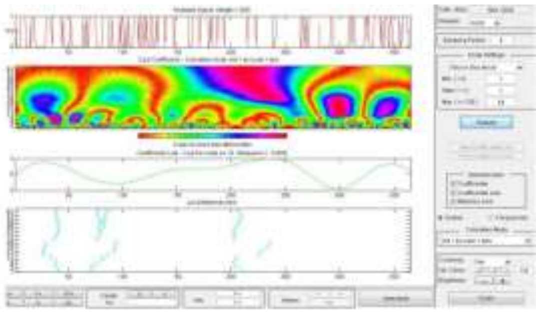

Fig. 3. 1D Continuous wavelet, Sampling Period: 1, Mexh.,Tekirdağ (2011)

Fig. 2 shows 1DWavelet analyses of clearness index in Tekirdağ. High frequency fluctuations have observed in winter and early spring. 1D Continuous wavelet analyses explain the role of small, meso and large scale events and their periodicity on temporal data (Fig.3). The study area is under the effect of large scale events with 2-3 weeks periodicity in the second part of January and all February. In July, only small scale factors are effective and, except July, there are more influences at all scales. Beginning from September, combined effects of small, meso and large scale fluctuations play an important role on temporal variations of clearness index in Tekirdağ.

Fig. 4 presents 1DWavelet analyses of clearness index in Bozova. There are no any fluctuations in summer in small scale. Periodicity of large scale events are traditionally decreasing from winter to spring and slightly increasing from September to January, (Fig. 5). Because of the influence of more stationary conditions in summer, frequency of small and large scale events are changing up to four and eight weeks respectively.

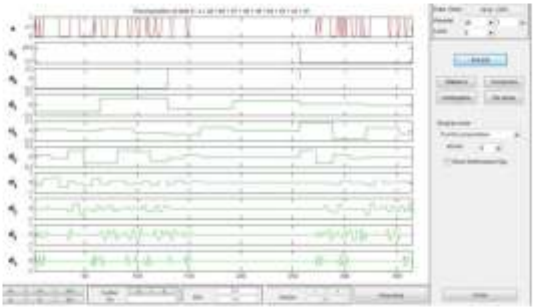

Fig. 4. 1D Wavelet Analyses (db, Level8), Bozova (2011)

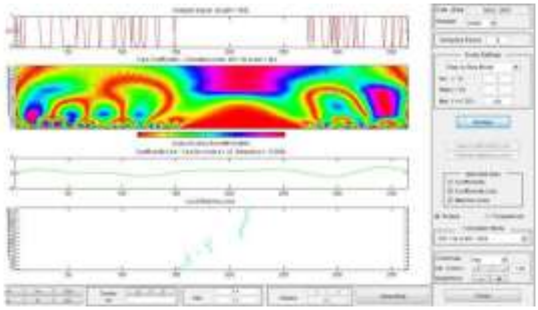

Fig. 5. 1D Continuous wavelet, Mexh., Sampling Period: 1, Bozova (2011)

3 Results and conclusion

The general behaviour of a PV plan would be determined by its physical properties (size etc.) and the regional meteorological conditions. The wavelet analysis of both global solar radiation and clearness index would be helpful to define power fluctuation levels. Statistical and wavelet time series analysis may explain the importance of local, meso and large scale fluctuations on energy analyses.

Stations in Marmara Region are generally under the combined effects of large and small scale events. But for other stations in Southern Anatolia, small scale influences on global solar radiation variations and clearness index are mostly observed in summer.

The daily average clearness indices with Wavelet analysis explains occurrence period of small, meso and large scale fluctuations at two different geographical regions. Definition of roles of pollution and climate changing on temporal variation of incoming solar radiation is essential to estimate power capacity. For this reason, it is also important to have a valid solar energy estimation model at study areas. The main results of this paper underlined that imbedded local parameters (urbanization, industrial pollutions etc.) by considering regional factors in large scale simulations would be useful in increasing the level of accuracy of large scale simulations in Marmara Region.

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References

[1] Aslan. Z., S. Topçu. M.C. Barla. G. Özdemir, Atmospheric Physics, Papatya Yayıncılık, ISBN-975-6797-56-8, pp. 120, İstanbul, Türkiye, 2004.

[2] Aslan, Z., D. Okçu and A. S. Soğut, Wavelet Based Analysis of Rainfall Rate and Erosivitiy, International Conference on Climate Change and the Middle East Past, Present and Future, 20-23 November 2006, Editors: Y. Ünal, C. Kahya, D. Demirhan Bari, İTÜ, Istanbul, (p. 107-113), 2006.

[3] Cao, J. C. and S.H. Cao,Study of forecasting solar irradiance using neural networks with preprocessing sample data by wavelet analysis, Energy, Vol. 31, p. 3435–3445, 2006.

[4] Çağlar N. Z., Tokgözlü A., Aslan Z., Application of Wavelet in Analysis of Solar Radiation and Solar Energy Potential, IWW2009, 2009.

[5] Mellit A., M. Benghanem and S. A. Kalogirou An adaptive wavelet – network model for forecasting daily total solar-radiation, Applied Energy , Vol. 83, p. 705–722, 2006.

[6] Okçu, D., Aslan, Z., Maktav, D., Söğüt, A.S., Oğuzhan, B., Çağlar, N. Z., Tek, A., Yeniçeri, N., Giden, F., Kalafat, A., Koyuncu, H., Şengül, A., Ertürk A.G., Solum, Ş.,Sel ve Taşkın Tahmini, Şehirleşmenin Sel Olayına Etkisinin Zaman Serileri ile Analizi, BÜ, BAP Proje No: 5572, İstanbul, 2012.

[7] Peled, A. and , J. Appelbaum, Evaluation of solar radiation properties by statistical tools and wavelet analysis, Renewable Energy, Vol. 59, p. 30-38, 2013.

[8] Perpinan O. and E. Lorenzo, Analysis and synthesis of the variability of irradiance and PV power time series with the wavelet transform, Solar Energy, Vol. 85, p. 188-197, 2011.

[9] Topcu S. and S.Öney, The Estimation of Hourly Total Irradiation for Cloudy Sky in İstanbul, Renewable Energy, Pergamon, 4, 2, 223-226, 1994.

[10] Willson R. C. and A. V. Mordvinov, Time-Frequency Analysis of Total Solar Irradiance Variations, Geophysical Research Letters, Vol. 26, No. 24, p.3613-3616, 1994.

[11] http://www.sanayi.gov.tr/Files/Documents/bilim-sanayi-ve-teknoloji-31122012154058.pdf (Energy Ministry, 11.07.2013).