Bispectrum and Energy Analysis of Wind Speed Data

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***Abstract*—The bispectrum has a different analysis functions compared to the power spectrum analysis. The bispectrum provides additional information for nonlinear or non-Gaussian data, and also the method gives detailed information on the phase information signal. In this study, bispectrum and energy analysis was performed for wind speed data for the regions of Turkey Kırklareli. Hourly wind speed data of Kırklareli Region belonging to the year 2011 is used. Data were obtained from The General Director of Meteorology, Ankara, Turkey. As well as time-amplitude graph, energy graph obtained and monthly analysis is made of this diagram. Subsequently, sufficiency level of speed zones has been tested frequency from time and frequency information by obtaining spectrograms of velocity information. Random processes which are described more accurately than statistically and high grade statistics for processing phase information (more than two) and studies on spectrum can provide useful results. In this context, bispectrum of annual velocity information was obtained. In addition to the bispectrum analysis, methodology of the diagonal slices spectrum is used for data which do not show mark in the non-linear structure or Gaussian distribution researches. Also, after obtaining bispectrum surfaces, monthly results through these charts were found and evaluated by removing diagonal slices analysis. Peaks in the bispectrum indicates the frequency component and phase overlap in the signal. By means of these analyses, the frequency component and phase conflict are determined in the wind speed data. The results of the analysis determined by the energy level was consistent with the wind speed. Wind speed phase-coupling and diagonal slices are calculated. As a result of the calculations, it is determined low and high frequency groups.**

***Index Terms*—wind speed, bispectrum, energy analysis, spectral analysis**

Manuscript received November 25, 2016; revised May 30, 2017.

I. Introduction

According to 2015 data, the installed power of the total wind energy plant around the world nearly reached 430000 MW level. The wind energy capacity of European Union countries rose to the level of 141.578 MW in 2015 [1]. The cumulative capacity of wind plants all around the world is shown in Fig. 1 [2].

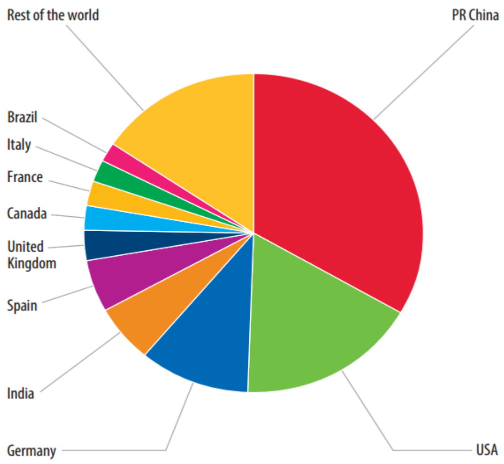

Figure 1. Cumulative capacity of the world [2].

The wind energy potential, wind measurements and other meteorological measurements are conducted by General Directorate of Meteorology (GDM) in Turkey. Wind observation stations were founded and data are collected and analysed [3]. Turkey's wind energy potential atlas was prepared by Turkish Electrical Power Resources Survey and Development Administration in order to ascertain the characteristics and distribution of wind energy resources. The installed wind power potential of Turkey is given in Fig. 2 [4] and [5].

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doi: 10.18178/ijoee.5.1.87-91

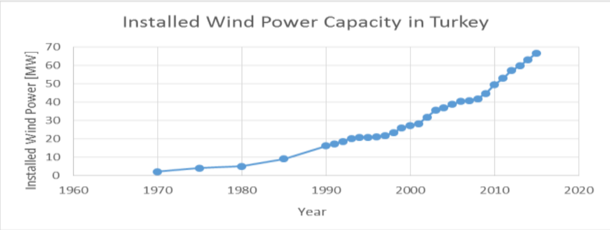

Figure 2. Installed wind power capacity in Turkey [4].

The distribution of wind energy plants by provinces under operation and Kirklareli region analysed within this study are shown in the graphic of Fig. 3 [6].

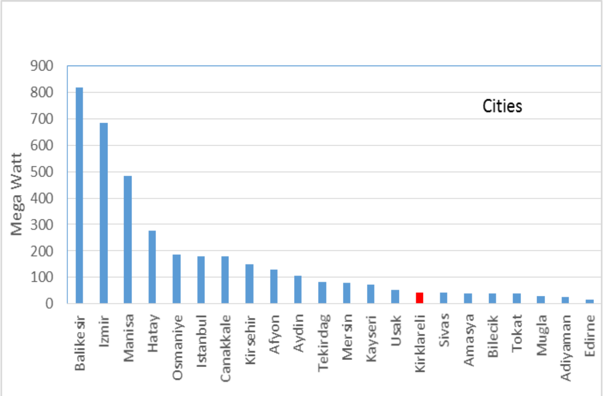

Figure 3. Cities according to installed capacity for operational wind power plants [5].

Statistical analysis of gale force plays an important role both in the determination of the place where wind turbines will be installed and in the choice of wind turbines [7]-[9]. While analysing the wind characteristic of a region, such data of information as hourly average, daily average, monthly average, seasonal average and upwind are required. [7]-[10]. Thanks to these data, it can be possible to carry out statistical analyses [9]-[11]. Second-order spectra hold a considerable place in many signal processing applications and linear and Gaussian time series analyses [12]. When the process in the analyses becomes Gauss, second-order spectra analyses include the whole necessary information about data [13]. With this method, analysis would be performed by ignoring high order spectrums. In order to study non-linear and non-Gaussian processes, one needs to consider higher order spectra. Theoretically it is possible to compute the spectrum of any order, but computationally it is very costly. Hence, in this study it considers only the bispectrum, the simplest higher order spectrum.

II. Mathematical Methods

Many different methods are used in literature in the determination of measurement parameters of wind speed. However, Weibull distribution method is usually the most preferred one in the analysis of wind speed data analysis. Weibull probability distribution is an effective method calculated with statistic approach in the calculation of randomly obtained data [14]-[16]. In this study, the Weibull probability distribution, Bi-spectrum and Energy analyses of the wind speed data belonging to Kırklareli district have been made.

A. Weibull Distribution

Weibull distribution method is a sort of calculation used in the statistical analysis of random signs. This function is one of the most used statistical distributions used in the determination of wind energy potential. Average wind speed, average wind power density and wind energy estimation are achieved based on Weibull probability density function. The Weibull probability density function is shown by (1).

$$f(v)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}\exp\left(\left(-\frac{v}{c}\right)^{k}\right) \tag{1}$$

where $f(v)$ is the probability of the measured wind speed and v, k are also the Weibull shape parameter, and c is the Weibull scale parameter (m/s). The Weibull shape parameter, k, generally ranges from 1.5 to 3 for most wind conditions. The cumulative frequency distribution is the integral of the Weibull probability density function, and it is given by (2) [7] and [8].

$$F(v)=1-\exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

B. Bispectrum and Energy

The measure of the phase relationship between three spectral components is called bispectrum. The bi-coherence spectrum may be particularly used to determine nonlinearly coupled waves and spontaneously excited waves, and to measure the fraction of power emerging as a result of quadratic wave coupling. If approached from this perspective; bispectrum, is quite influential in revealing the signs resulting from nonlinear process [12]. The power spectrum of random sings is given in (3).

$$P_2^x(f)=DFT(C_2^x(m).e^{-j2\pi mf}) \tag{3}$$

The 3rd degree mass spectrum is, however, called bispectrum and this equity is shown in (4). The stable random definition of data that has reel value is given in (5). Cross bispectrum connection is given in (6).

$$B^x(f_1,f_2)=\sum_{m=-\infty}^{\infty}\sum_{n=-\infty}^{\infty}C_3^x(m,n).e^{-j2\pi(mf_1+nf_2)} \tag{4}$$

$$B(w_1,w_2)=X(w_1).X(w_2).X^*(w_1+w_2) \tag{5}$$

$$B_{XYZ}(f_1,f_2)=\sum_{m=-\infty}^{\infty}\sum_{n=-\infty}^{\infty}C_{XYZ}(m,n).e^{-j2\pi(mf_1+nf_2)} \tag{6}$$

for the special situation where w_1 and w_2 frequencies are equal, the diagonal slice (DS) of single univariate bispectrum can be given as:

$$B(w)=X^2(w).X^*(2w) \tag{7}$$

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In the bi-spectrum, there are 6 zones which are reciprocally symmetrical and a symmetrical spectrum in each zone. Namely, 12 spectrums in total which are similar to each other come into being in bispectrum. The zones where symmetrical spectrums are formed are given in Fig. 4 [12]-[14].

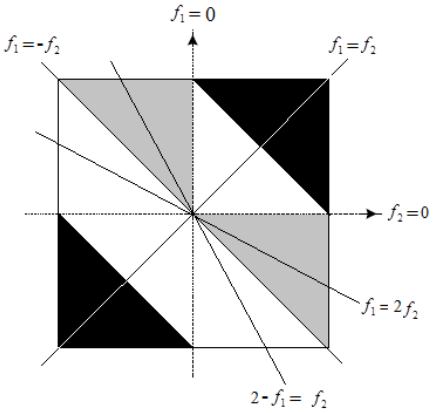

Figure 4. Bispectrum symmetry and overlapping zones [14].

These zones are the zones which are restricted according to certain values in f_1 and f_2 frequency axes. The grey and white zones seen in the figure are reciprocally symmetrical according to f_1 and f_2 frequencies. In the shaded areas, there is not any sign information under normal condition. When sampling frequency is low, if there is aliasing in spectrum, there exists a component in this zone. When a zone becomes the symmetry of a spectrum in another zone, it will be enough to analyse one of them. For this reason, as a general approach, a zone analysis where both frequencies are positive is performed. Unlike power spectrum, bispectrum also offers the phase information of sign as a significant characteristic of it except from providing information for the data which are nonlinear or do not display Gauss distribution. The top in bispectrum indicates frequency components within sign and phase overlap. While the tops where two frequencies are the same are indicating the frequency components within the sign, the hills with different frequencies indicate that there is a phase overlap in these frequencies [12]-[16].

The energy expression of a numerical sign is given in (8) [12].

$$E_x = \sum_{n=-\infty}^{\infty} |x(n)|^2 \tag{8}$$

III. Application

In this study, one-year wind data of Kırklareli district of Turkey which is placed in the European continent were examined. Data were obtained from General Directorate of State Meteorology as one year and an hour period. In Fig. 5 is plotted one year and hourly wind data. It is given Weibull Probability Distribution of Kırklareli district in Fig. 6.

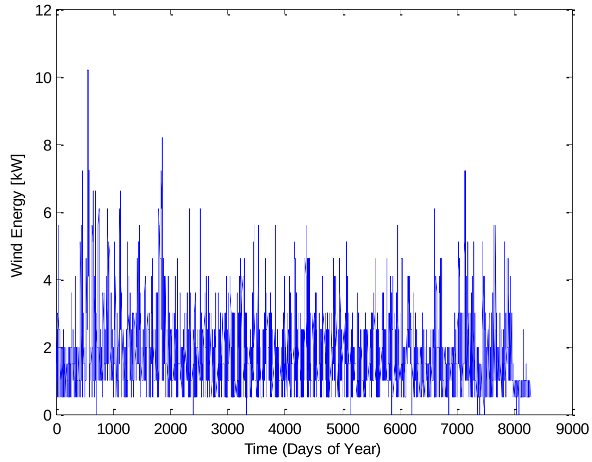

Figure 5. Kirklareli district annual wind speed information.

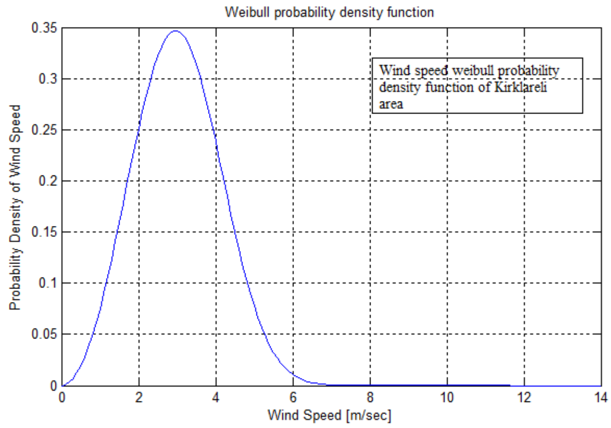

Figure 6. Weibull probability density of wind speed.

The equiphase surface and the highest group in diagonal slice at low frequencies shown in Fig. 7 are around 427 level and it reaches the height of 275 units in the next 2nd highest group. In Fig. 8, it is given the diagonal slice graphic of wind speed information. Here, following the heights whose highest top is 104 unit comes the third highest top of 130 units. The peak height that attracts attention at high frequencies is however around 57. The first 1/5 slice of frequency is the part where activity is most intensive. Later, there is a general stable flow. Only in the middle of 4/5 slice is found a high amplitude activity.

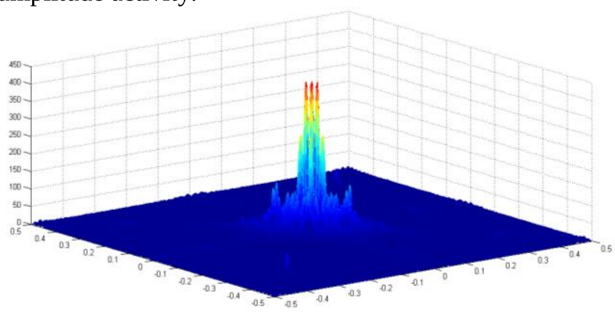

Figure 7. Bispectral equiphase surface of Kirklareli district wind speed information.

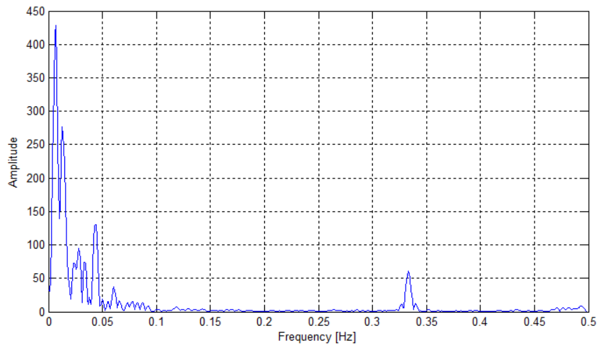

Figure 8. Diagonal slice of Kırklareli district wind speed information.

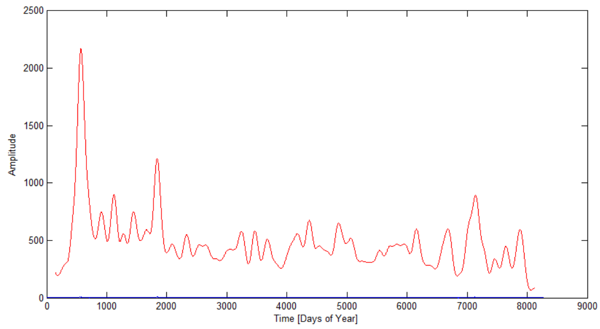

Figure 9. Energy graphic of Kirklareli district wind speed information.

The energy graphic of annual wind activity is shown in Fig. 9. Here, it shows high energy value in the first month of year (2146), then, around March a high energy is ascertained again (1190). While the coming months are going with lower energy levels, the 3rd highest energy draws attention in November (886).

IV. Conclusion

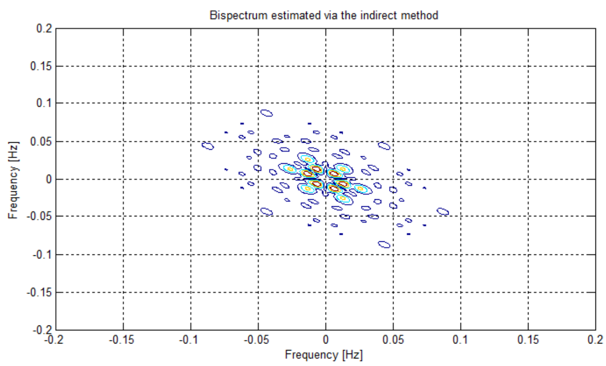

Figure 10. Bispectrum equiphase surface of wind data.

Today, the rise of energy demand has canalised energy producers towards renewable and clean energy resources. Of all these energy resources, the most economic to use and popular one is wind energy. In this study, the wind characteristic of wind speed in Kırklareli District was analysed using 12 months, hourly average gale force data of State Meteorological Service belonging to 2011. In the study, firstly the wind speed data were examined if they were suitable with Weibull probability distribution. Then, Bispectral analysis of wind speed data was achieved. According to this analysis, the analysis of bi-spectral equiphase surfaces is given in Fig. 10 above. Bispectral analysis method is a technique of a higher order spectral analysis. In this analysis, phase relations of two spectral components with each other were researched.

In this study, bi-spectral and energy analyses of wind speed data of Kirklareli district were performed. When the equiphase surface and diagonal slices were calculated with the performed analysis, low frequencies were clustered in three groups and high frequency zone in one group. These took the unit amplitude values of 427, 275 and 130 at low frequencies. In high frequency values, however, 57 unit reached the highest amplitude value. It can be derived from here that the busiest time of wind activity throughout the year coincides with the zone at low frequencies, namely, winter season. In addition, through wind speed energy analysis, it was observed that the highest energy activity of the year (2146) realizes in January and the second highest energy level (1190) realizes around March. In future work, 10 years of using wind speed data analysis is planned.

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