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Spectral and statistical analysis of wind spectrum for Ali Al-Gharbi area in Iraq

Taghreed Ali Abbas*, Monim Hakim Khalaf , Amani I.Altmimi
Department of Atmospheric Science, College of Science, Al-Mustansiriyah University, Baghdad, Iraq

Abstract
The spectrum known represented as a relationship that's plotted between the magnitudes or energy for a specific parameter vs. its frequency, the wind spectrum is presented as the sum of wind speed created by events divided either in space, in time, or both. This paper presents a wind speed spectrum demonstration in Ali Al-Gharbi location in Iraq. The aim of the present paper is to analysis the wind speed and direction by employing the FFT (Fast Fourier Transform) therefore field measurement of wind speed and direction were collected for one year from Dec 2014 to Dec 2015 in the time interval of 10 minutes at heights of 10, 30 and 50 meters. From the performance of the FFT it was found that the values of the peak which contains the highest spectral density was (226236.282 m/sec) at the frequency of (2 Hz) on the 50 m height level throughout the night time but the lowest was (115863.7 m/sec) at the frequency of (2 Hz) at the 10 m height throughout the night time. The dominant wind direction at the area was from west-Northwest and the north-Northwest. The wind speed during morning hours was higher than that at the night time.

Keywords: Wind energy spectrum; Fourier series; Wind analysis; Weibull.

التحليل الطيفي والإحصائي لطيف الرياح لمنطقة علي الغربي في العراق

تغريد علي عباس*، منعم حكيم خلف ، اماني ابراهيم التميمي
قسم علوم الجيولوجي، كلية العلوم ، الجامعة المستنصرية، بغداد، العراق

الخلاصه
الطيف يمثل بأنه العلاقة المرسومة بين كمية او طاقة متغير معين وتردد هذا العامل المتغير , اما طيف الرياح فيمثل بأنه مجموع طاقة الرياح المستحدثة خلال احداث مقسومة اما على المكان او على الزمان او كلاهما . هذا البحث يوضح طيف سرع الرياح لمنطقة على الغربي الواقعة في العراق . تم جمع واستخدام بيانات حقلية لسرع الرياح واتجاه الرياح المأخوذة من برج انوائي لمدة سنة واحدة من كانون الاول 2014 ولغاية كانون الاول 2015 ولكل 10 دقائق يومياّ على ثلاث ارتفاعات هي 10 , 30 و 50 متر. من خلال تطبيق تحويلات فورير السريعة (FFT) لقد وجد بأن قيمة القمة والتي تحتوي على اعلى كثافة طيفية كانت (226236.282 م/ ثانية) عند التردد (2 هرتز) على الارتفاع 50 متر خلال ساعات الليل ولكن ادنى قيمة بلغت (115863.7 م/ ثانية) عند التردد (2 هرتز) على ارتفاع 10 متر وخلال ساعات الليل اما اتجاه الرياح المسيطر على المنطقة فكان من الغرب–شمال غرب و الشمال–شمال غرب .اما سرع الرياح خلال النهار فكانت اعلى منها في الليل.

* Email: taghreed_ali89@yahoo.com

1. Introduction

The wind speed is the extremely oscillating parameter. One of the most acquired methods to describe the varying nature of wind speed is the use of the energy spectrum. Information on the spectrum of the wind speed can be very useful to the researcher specially the wind power assessment studies. The spectral analysis is very important and powerful approach when it comes to wind assessment researches; the spectrum of any variable is constructed mo stly as the combination of wind speed produced by events divided either in time or in space or it could be the sum of both [1].

The Iraqi zero map project classified the area of Ali Al-Gharbi as a promising area for wind energy production and in 2017 Mohammed [2] confirmed this by conducted a study for calculating the wind power at Ali Al-Gharbi and Al-Shihabi locations in south of Iraq also the same was found by Jan [3] Resen also studied the area and conduct an analysis and mapping for it using the WAsp model for observing the wind and climate [4], The aim of the present paper is to investigate the features of the wind spectrum for the Ali Al-Gharbi area in the south of Iraq in Maysan district for the time period of Dec 2014 till Dec 2015, which would be an important contribution to the understanding of the nature of the wind speed in this area.

2. Area of study

The study of wind assessment depends mainly on the topographical of the study area. The area is located in Missan province. Ali Al-Gharbi area is about 238 Km from Baghdad (the capital of Iraq) and about 77.37 Km from the center of the province with the coordinate at about 32.27°N 46.41° E at 14 m altitude; Figure-1 shows the location of the chosen site of Ali Al-Gharbi in the south of Iraq. This area has a hot desert climate (Köppen climate classification BWh) with extremely hot and dry summers and cool with high temperatures simply extent above 40°C, moist winters with rainfall is intensified in the winter months and averages 177 mm yearly [5] .

The geographical site was once covered by marshlands which sustained different sorts of livelihoods. The landscape is currently only 25% land and over 50% desert, the Tigris River moves through Missan and nourishes the marshlands.[6] Table-1 summarize the wind characteristics in this area.

Table 1-Characteristics for the study area [2].

Height (m)	**Ū (m/s)**	**S.D.**	**Median**	**Min.(m/s)**	**Max.(m/s)**
10	3.77	3.14	3.27	0.35	**17.03**
30	5.41	3.49	4.93	0.38	**19.69**
50	6.14	3.79	5.51	0.33	**20.61**

Where Ū is the daily mean wind speed and S.D. the standard deviation

Figure 1-Location of studied site in Iraq. [7]

2. Materials and methods

Wind speed data of ten minutes interval records for one year had been studied at different heights (10,30,50 m) which was obtained from a Metrological mast (met mast) in Ali Al-Gharbi was used, data were rearranged and analyzed to detect the energy spectrum and identify the peak of the energy spectrum. The data were analysed by origin 9.0 software and the Sigma plot software. The data were obtained from the meteorological mast that's installed and maintained by the Iraqi ministry of science and technology.

3. The Weibull distribution

It's a statistical analysis that can be used to conclude the wind energy potential of a particular location and evaluate the wind energy at this place. To define the Statistical distribution of wind speed, there are numerous probability functions which can be appropriate for wind calculations. The Weibull distribution is the most accurate of the other methods, with a suitable accuracy level. This method has the advantage of making it possible to quickly determine the average wind power density at a given site [6].The wind speed probability density function can be calculated as eq.1 [8]:

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

$$(k > 0, v > 0, c > 1)$$

Where f (v) is the probability of measured wind speed v, k is the dimensionless

Weibull shape parameter and c is the Weibull scale parameter. The Weibull shape (c) and scale (k) parameters, describe the wind potential of the area of the study. Essentially, for illustrating how much wind blows at a specific site we use the scale parameter (c) for a place under consideration, whereas the shape parameter (k) the peak of the wind distribution [9].

4. The wind direction

Defining the prominent direction of wind speed is essential in wind assessment researches since it explains the impact of the geographical characteristics for the area on the wind. Employing a plot that is a cycle of (360°) that's divided into 16 sectors named the wind rose and it's a graphical instrument used in wind studies since it can represent the speed and direction of the wind at any height level and for any place selected which allow us to plot the frequency of winds over a time period by wind direction with color groups presenting the ranges of the wind speed. As it can be seen in Table -1, for wind speed at height of (10, 30, 50 m) set against the wind direction that corresponds to it [9].

5. The wind spectrum

The wind spectrum considered being complicated but there is a similarity in its shape using a different data series of wind speed. The spectral analysis of wind speed is established on the theory that the wind parameter can be modeled as a stationary and Gaussian stochastic process; the spectral analysis procedure deducts the distribution of wind power for each frequency by transforming the time series of the wind speed data into a wind spectrum, this is essentially a conversion process from the time-domain to the frequency-domain, and is performed most correctly by using a mathematical tool known as the Fast Fourier Transform (FFT) [10] .The wind spectrum is commonly represented as a continuous curve joining the discrete points create from Fourier analysis [11] .

6. Results and discussion

For any wind assessment the wind speed must be calculated and analyzed the obtained data was from a (met. Mast) at a preferred location, with devices positioned at least one year for nonstop wind measurements at the site. The data was acquired by cup anemometer at (10m) height during the year 2015. The first step in the analysis process is the arrangement of data; a ten minutes data set was rearranged in daily averaged for morning hours and night hours and at three specified height levels (10, 30, 50 m) Next a statistical analysis as well performance of the Weibull distribution and a plot of the wind rose is made, after this we began with the spectral analysis process starting by the employing of the Fast Fourier Transform (FFT).

6.1 The statistical analysis of wind speed

In order to process the data we had it averaged on a daily basis and then we divide each day into morning hour and night hours. After that, we initiated the statistical analysis for the data and presented in Table-2 that's the achieved statistical parameters. Value for the daily mean wind speed for morning hours was estimated as 5.60011 m/s at 50 m while mean daily wind speed for the night hours was

6.13485 m/s at 50 m, Its evidence from observing Table-2 that the highest wind speed was at 50 m and that's because in height levels like this the effect of the surface roughness is no longer exist, while the lowest daily wind speed was at the 10 m height levels where the roughness has a great effect on reducing the wind speed, the mean wind speed for the morning hours was 5.60011 m/s at 50 m and it was for the night time 6.13485 m/s at 50 m height it's clear that the night hours have higher values than the morning hours.

Table 2-statistical parameter for wind speed data

Height (m)	Ū (m/s)	Max (m/s)	Min (m/s)	Range	Median	Standard deviation	Skewness	Kurtosis	Confidence level (95%)
Morning hours									
10	4.26847	13.85986	0.0075	13.852	3.86	2.771	0.9985	0.583	0.284
30	5.17	16.0018	0.01	15.9	4.75	3.07	0.99	0.60	0.31
50	5.600	17.01194	0.014	16.99	5.148	3.235	0.984	0.582	0.332
Night hours									
10	3.215	10.09528	0.42	9.668	2.761	1.968	1.17	1.071	0.202
30	5.181	12.425	0.444	11.98	4.895	2.318	0.632	0.247	0.238
50	6.1348	13.945	0.351	13.593	5.840	2.7	0.451	0.108	0.277

6.2 The Weibull distribution results

For the estimation of the wind speed frequency distributions the Weibull probability function has been performed and by looking at the graphical result and the table summary it can be distinguished that the Weibull distribution fits actual distribution data well. The shape parameter (k) and the scale parameter (c) values of the Weibull function were calculated for each height and listed in Table-3. And for Ali Al-Gharbi the highest probability of recurrence of the average wind speed was found to be (4.8) m/s at 30 m for the night time, while the lowest was (2.1) m/s at 10 m for the night as shown in Figures- (2, 3, 4).

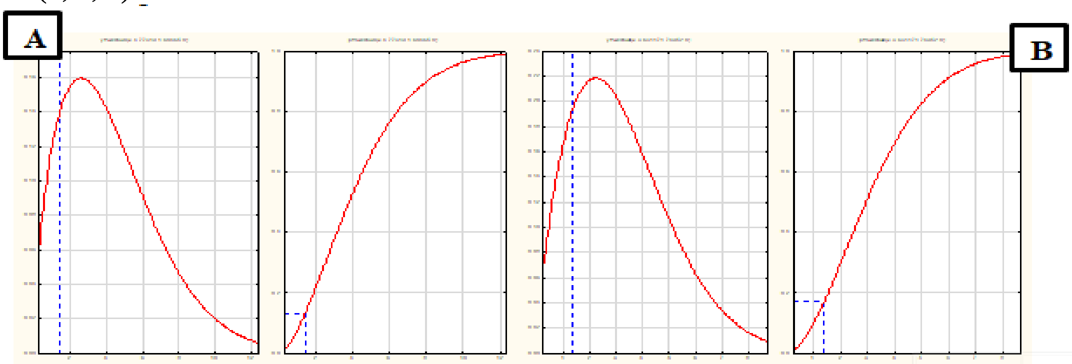

Figure 2-Weibull distribution at 10 m during (A) morning (B) night

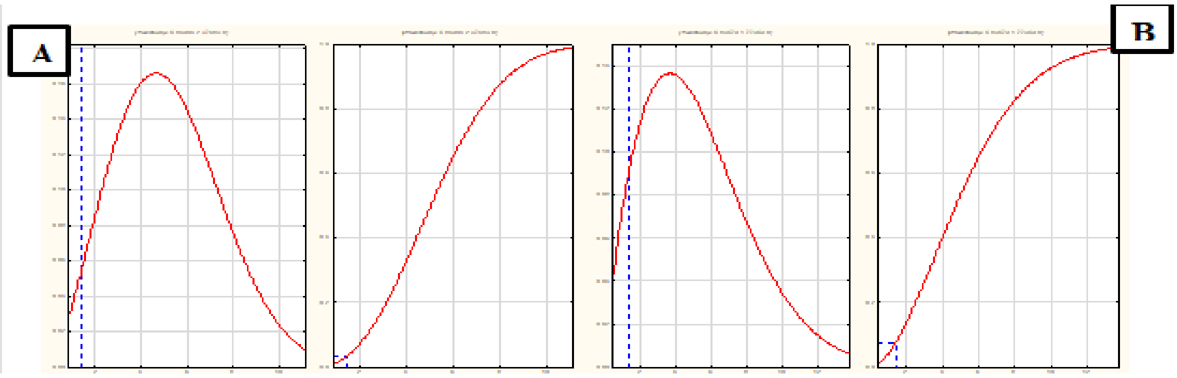

Figure 3-Weibull distribution at 30 m during (A) morning (B) night.

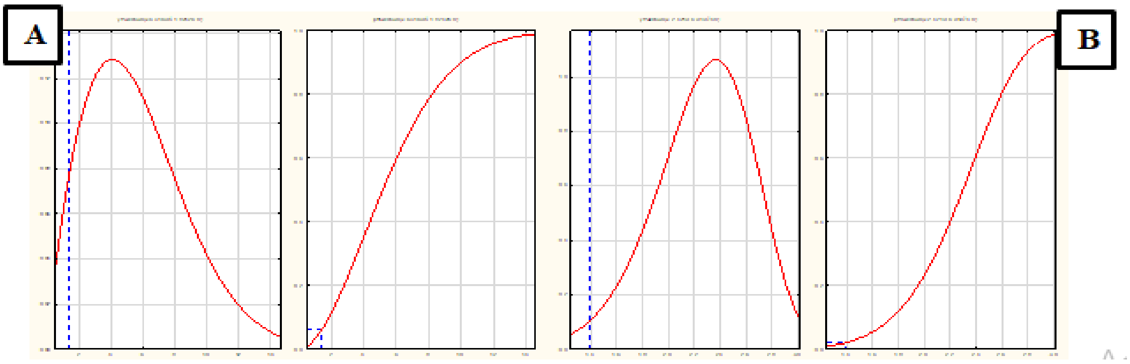

Figure 4-Weibull distribution at 50 m during (A) morning (B) night.

Table 3-the Weibull shape & scale parameters

Morning hours		
Height (M)	Scale parameter	Shape parameter
10	4.773	1.604
30	5.835	1.773
50	6.316	1.824
Night hours		
10	3.631	1.749
30	5.849	2.374
50	6.919	2.421

6.3 The wind rose

With the interval of 10 minutes data used for the wind rose graphs to present the direction of the wind speed at the three selected height levels and for both morning hours and night hours. As it can be it can be seen in Table- 4, for wind speed at height of 10 m vs. the direction that the highest wind speed was at the sector of 300° - 320° with the value of 24.68825 m/s and the lowest was at 220° - 240° with the value of 1.8609 m/s when for the 30 m the maximum wind speed was in 280° - 300° with a value of 17.37357m/s, and the lowest wind speed is in 200° -220° with a value of 1.75314 m/s. while at 50 m the highest wind speed was 25.3387 m/s at the direction of 300° - 320° and the lowest was 1.71465 m/s at 200° -220°. The dominant direction of the wind at the site was at the North West precisely at the west-Northwest and the north-north west (WNW and NNW) while the modest wind direction was at the South West and the west-Southwest (SW and WSW) ,see Figure-5.

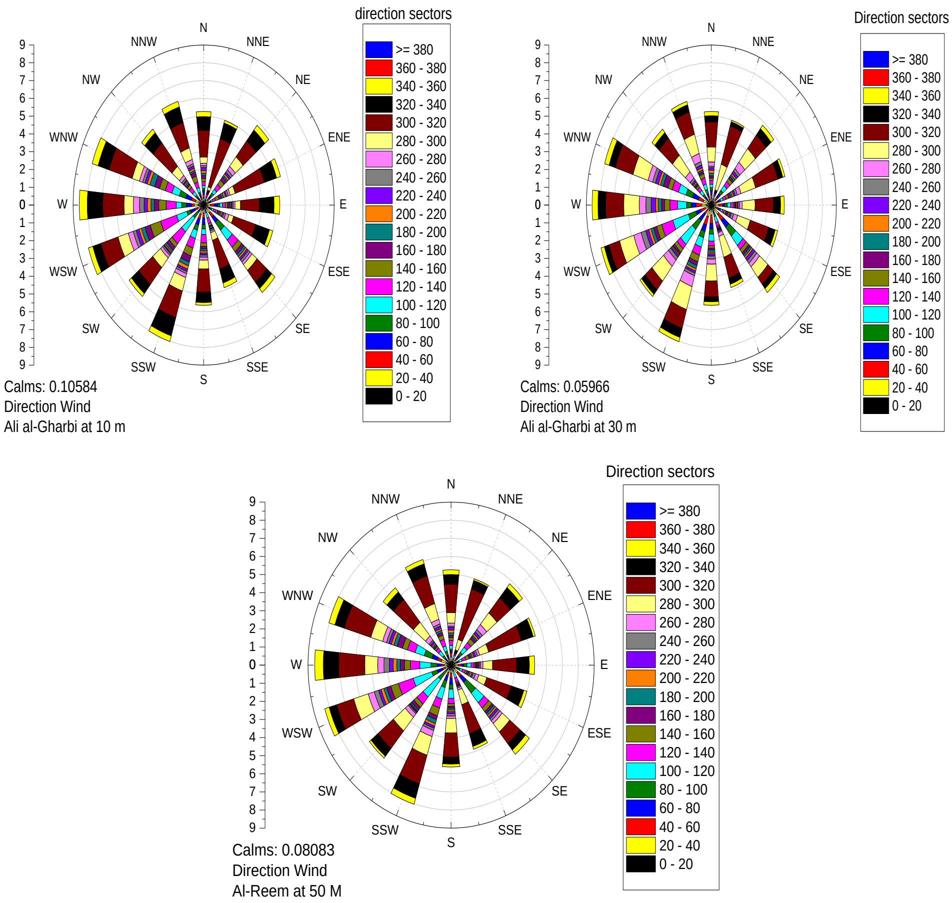

Figure 5-The Wind rose at 10, 30 and 50 m.

Table 4-Wind direction & wind speed.

Direction Sector (°)	Mean wind speed (m/s)	Calm
At 10 m height		
0 – 20	3.44854	0.10584
20 – 40	2.67685	
40 – 60	2.97321	
60 – 80	3.6506	
80 – 100	3.74682	
100 – 120	6.04072	
120 – 140	6.99523	
140 – 160	4.71673	
160 – 180	3.22531	
180 – 200	2.32469	
200 – 220	1.89362	
220 – 240	1.8609	
240 – 260	2.15534	
260 – 280	3.22916	
280 – 300	8.42699	
300 – 320	24.68825	
320 – 340	13.02248	
340 – 360	4.81872	
At 30 m height		
0 – 20	3.39466	0.05966
20 – 40	3.49858	
40 – 60	4.56277	

60 – 80	4.11631	
80 – 100	4.91302	
100 – 120	7.34932	
120 – 140	5.17859	
140 – 160	3.37926	
160 – 180	2.32276	
180 – 200	1.94173	
200 – 220	1.75314	
220 – 240	2.23424	
240 – 260	2.79617	
260 – 280	5.63082	
280 – 300	17.37357	
300 – 320	19.36725	
320 – 340	6.41598	
340 – 360	3.71219	
At 50 m height		
0 – 20	3.06943	0.08083
20 – 40	2.47671	
40 – 60	2.57871	
60 – 80	3.20414	
80 – 100	4.89762	
100 – 120	7.99207	
120 – 140	5.86752	
140 – 160	3.70064	
160 – 180	2.44592	
180 – 200	1.93018	
200 – 220	1.71465	
220 – 240	1.81857	
240 – 260	2.20345	
260 – 280	3.70834	
280 – 300	12.44131	
300 – 320	25.3387	
320 – 340	10.38026	
340 – 360	4.15095	

6.4 The time series of wind speed data

A daily time series has been created for the presentation of the general trend in wind speed and from the result it was concluded that the value (6.134852 m/sec) denotes the mean wind speed at 50 m during the night time whereas (3.215398 m/sec) denote mean wind speed value at 10 m during the night as shown in Figures-(6, 7, 8).

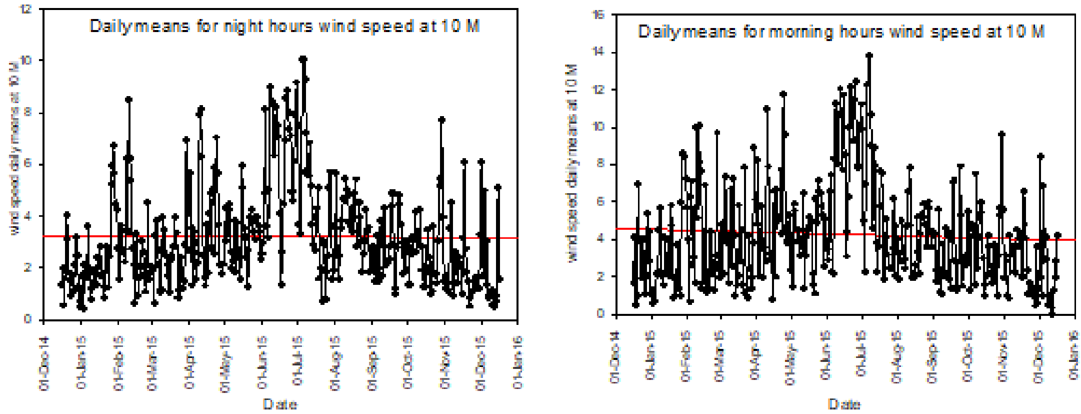

Figure-6 The time series for both morning & night at 10m,

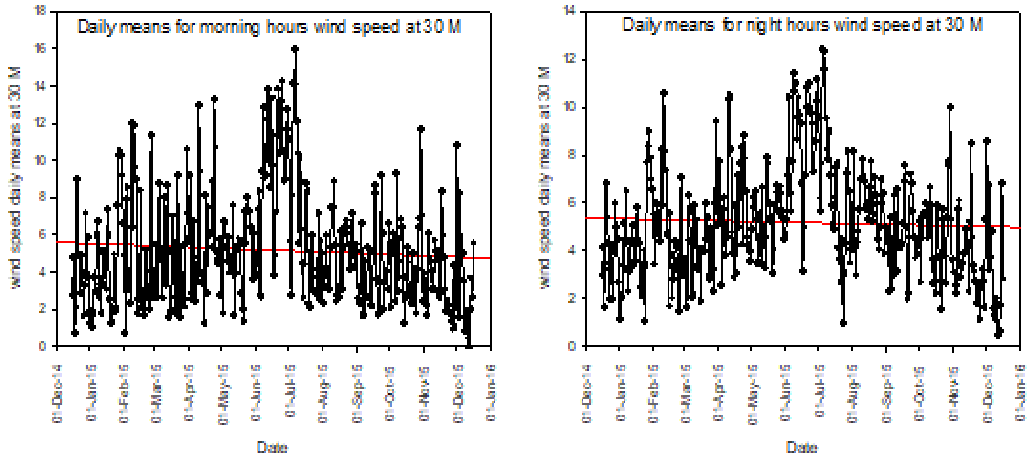

Figure 7-The time series for both morning & night at 30 m.

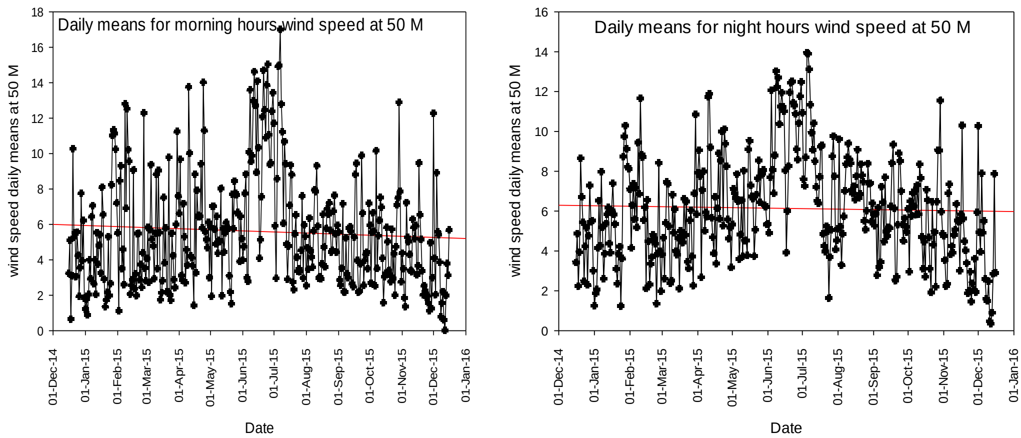

Figure 8-The time series for both morning & night at50 m

6.5 The Spectrum of wind speed

For the construction of the wind spectrum, we used a complicated but fast transform and that is the Fast Fourier Transform (FFT) for the time series for the measured data and by using some mathematical operations the power spectrum of wind speed was achieved for Ali Al-Gharbi during the day time and night time at three height levels (10, 30 and 50 m). There are a few main stages in computing the spectrum which is the completing of the time series and found the daily averaged wind speed data from the 10 minutes data and then the execution of the FFT after that a data filtering and smoothing is made. If we look at the peaks in Figure- 9 it would be clear that the highest spectral density for Ali Al-Gharbi area was (226236.282 m/sec) at the frequency of (2 Hz) on the 50 m throughout the night time but the lowest was (115863.7 m/sec) at the frequency of (2 Hz) at the 10 m

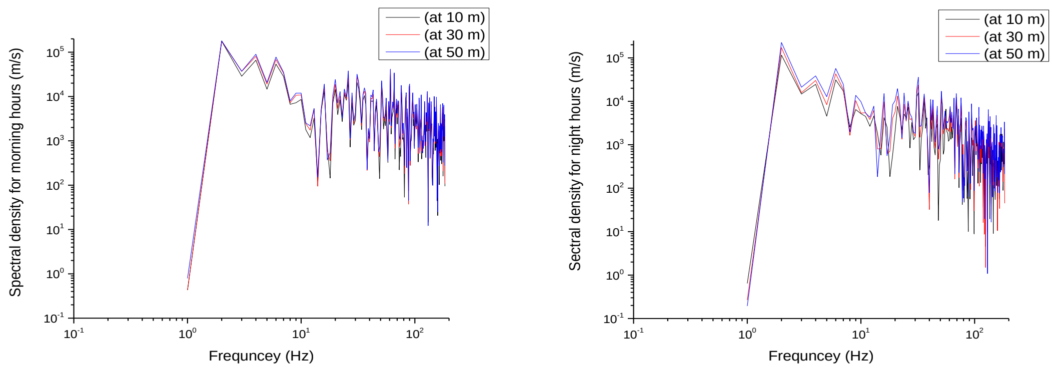

Figure 9-The wind spectrum at 10, 30 & 50 m for Night hours & morning hours respectively.

7 Conclusions

The analyzing of wind data at 10 m, 30 m and 50 m heights from the earth surface was performed in order to define the shape of wind speed spectrum in Ali Al-Gharbi site, the results can be concluded in:

1. The morning hours are the best for wind speed values than the night hours. The maximum wind speed and the mean standard deviation at 50 m height during morning hours of wind speed at the selected year of study was estimated as 5.60011 m/s and 3.235 m/s respectively.
2. The Weibull distribution function at 10 m, 30 m, and 50 m heights shows a good agreement with the data attained from the actual measurements.
3. The wind Rose revealed that he prevailing wind directions are from WNW and the NNW
4. The spectral peaks for Ali Al-Gharbi for day time show a better agreement than the night time for the heights of (10, 30 and 50 m).
5. This study of wind data at Ali Al-Gharbi site has indicated that it got the good potential for using wind power assessment.

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