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An Analysis of Wind Speed Distribution at Benina, Benghazi, Libya

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Abstract. The statistical wind data obtained from measurements for the 12 month period of January to December 2008 at Benina, Benghazi, Libya. The site coordinates are: latitude 32,05’N and longitude 20,13’E. The elevation of the site is 136 m above mean sea level (AMSL). The wind speed has been measured at height of 10 m above the ground level using 3 cup anemometers. Moreover wind speed has been estimated at height of 40 m. The statistical wind data set was analyzed using weibull distributions in order to investigate the weibull shape and scale parameters at 10 m and 40 m height. Finally, the yearly power density has been estimated at both heights. The results showed that strong and sufficient winds for power generation are available at most of months in Benina region.

Introduction

Energy need of the world increases 4-5% every year whereas fossil fuel reserves covering that need decrease much faster than the need. Because of the negative environmental impact of fossil fuel use, it is necessary to find ways to economically utilize non-polluting sources of energy. Since wind energy is a clean and renewable energy, systems transforming wind power to electrical energy has been developing quite fast (Aras, et al. 2003). Libya is a rapidly growing energy consumer and its domestic energy production increase each year between 10% to 15 %. In addition energy is essential to the economic and social development, and will improve the quality of life in Libya as in other countries.

A proper analysis of statistical wind data is a very important step when performing a wind resource assessment campaign which supports a wind energy feasibility initiative. Its therefore necessary to have detailed knowledge of wind to select the suitable wind turbine for a certain zone and also to estimate its performance accurately. The performance of wind turbine generators (WTG) on a particularly site can be determined by the site’s probability distribution of wind speeds and the corresponding WTG power curve. Consequently, since the WTG power curves are known, the probability distribution of wind speeds is the key information needed to estimate wind energy output at a given site for a particular WTG model.

There are several works that deal with the use of probability density functions to describe wind speed frequency distribution [1]. In general, the Weibull probability density function can be used to estimate a site’s probability distribution of wind speeds. The Weibull distribution technique is widely accepted and used in the wind energy industry as the preferred method for describing wind speed variations at a given site; some claim the Weibull distribution as the best fit for describing wind speed variations at a given site [2]. However, some researchers report that for sites having very low mean wind speeds, the Weibull distribution does not represent well the site’s wind speed distribution [3]. Apart from the Weibull distribution, there are some distributions such as Gaussian distributions, exponential distributions, gamma distributions and logistics distributions that can be used to model a site’s wind speed variation [4].The aim of this paper is to analyze the measured wind data at Benina, Benghazi in eastern Libya using the Weibull distribution technique.

The Weibull probability density function is given by Eq. 1.

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

where f(u) is the probability of the measured wind speed, u, k is the Weibull shape parameter (dimensionless), 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 [5]. Wind speed distributions where the Weibull shape parameter is in the range of 1.5-3 are shown in Fig. 1. [6]

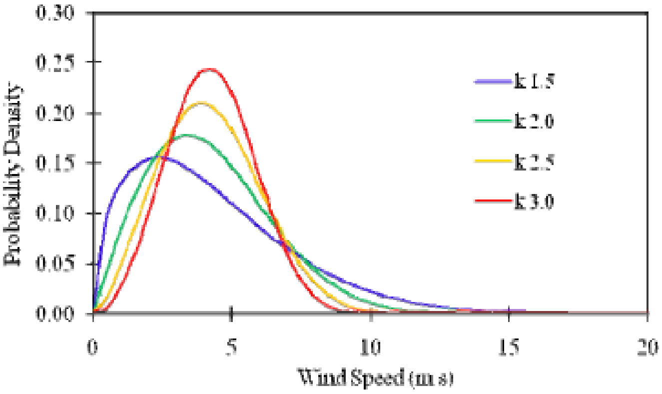

Figure 1. Weibull distribution of wind speeds k = 1.5-3 and c= 4.8 m/s [6]

The cumulative frequency distribution is the integral of the Weibull probability density function, and is given by Eq. 2.

$$f(u) = 1 - \exp\left(\left(-\frac{u}{c}\right)^{k}\right) \tag{2}$$

There are many numerical methods were used for estimating the parameters of the weibull distribution, such as graphical method, maximum likelihood method, energy pattern factor method, moment method, empirical method, and others [7].In this study the weibull distribution parameters was determined using the graphical method.

The vertical variation of wind speed can be expressed by power exponent function

$$U_{(z)} = U_r\left(\frac{z}{z_r}\right)^{1/7} \tag{3}$$

Where, $U_{(z)}$ is the wind speed at the selected height z, and U_r is the wind speed at the reference height (z_r) a bove the ground level.

Graphical Method:

In the graphical method, the cumulative distribution function is transformed into a linear form , Eq.2 can be rewritten as:

$$\text{In}[-\text{In}(1-F(u))] = k\,Inu - k\,Inc \tag{4}$$

In order to find the Weibull shape and scale parameters, a graphical method is introduced and used by plotting ln u against ln[-ln(1-F(u))] in which a straight line will be obtained as shown in Fig. 2. The Weibull shape parameter, k, will be the slope of the line and the y-intercept will be the value of the term –k ln c [8].

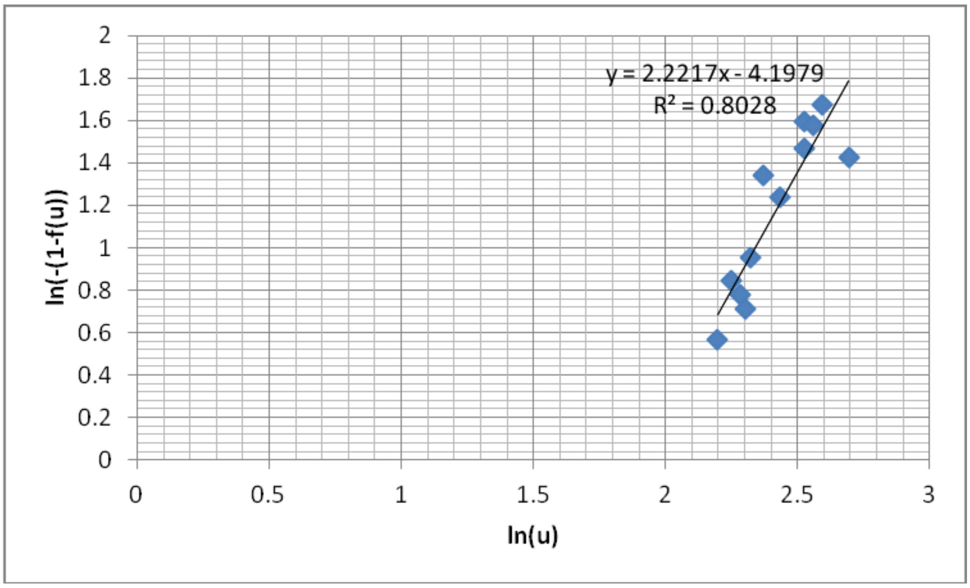

Figure 2. Graphical method used to obtain Weibull shape and scale parameters, *k* and *c*.

Wind speed distribution analysis

The Weibull shape and scale parameters, k and c, corresponding to the wind speed distributions measured at 10 m AGL and obtained from the graphical method were used in mean wind speed analysis by using the correlations expressed in Eq. 4

$$\bar{u} = c\Gamma\left(1 - \frac{1}{k}\right) \tag{5}$$

Where $\bar{u}$ is the mean wind speed and Γ is the Gamma function which is obtained from Eq. 5.

$$\Gamma(t) = \int_{0}^{\infty} e^{-x} x^{t-1} dx \tag{6}$$

Gamma function can be obtained using the Stirling approximation as is given by Eq. 6 [8].

$$\Gamma(x) = \sqrt{2\pi x}\, x^{x-1} e^{x}\left[1 + \frac{1}{12x} + \frac{1}{288x^{2}} + ...\right] \tag{7}$$

By using the Weibull shape and scale parameters, *k* and *c*, the standard deviation of the wind speed, *σ*, can be expressed by Eq. 7 [9].

$$\sigma = \bar{v}\frac{\sqrt{\Gamma\left(1+\frac{2}{k}\right) - \Gamma^{2}\left(1+\frac{1}{k}\right)}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{8}$$

Furthermore, the most frequent wind speed, u_{mp}, and the maximum energetic wind speed, $u_{\max E}$, can be expressed in terms of the Weibull shape and scale parameters, *k* and *c*, as shown by Eq. 8 and Eq. 9 respectively [9].

$$u_{mp} = c\left(\frac{k-1}{k}\right)^{1/k} \tag{9}$$

$$u_{\max E} = c\left(\frac{k+2}{k}\right)^{1/k} \tag{10}$$

Finally, the wind power density, *E*, (W/m^2) can also be expressed in terms of the Weibull shape and scale parameters, *k* and *c*, using the correlation shown by Eq. 11

$$E = \frac{1}{2}\rho c^{3}\left(1 + \frac{3}{k}\right) \tag{11}$$

where *ρ* is the air density (kg/m^3) which is correlated to the air temperature [10].

According to the table 2 the wind power potential can be classified.

Table 1. Wind power classification at 50 m [11].

Wind Power Class		Wind Power Density (W/m^2)	Mean Wind Speed (m/s)*	Resource Potential
1	1-	0-100	0-4.381	Very Poor
	1+	100-200	4.381-5.588	
2	2-	200-250	5.588-6.035	Poor
	2+	250-300	6.035-6.393	
3	3-	300-350	6.393-6.706	Marginal
	3+	350-400	6.706-7.018	
4	4-	400-450	7.018-7.287	Good
	4+	450-500	7.287-7.510	
5	5-	500-550	7.510-7.778	Very Good
	5+	550-600	7.778-8.002	
6	6-	600-700	8.002-8.404	Excellent
	6+	700-800	8.404-8.807	

3. Results and Discussion

The yearly probability density functions and the yearly cumulative frequency functions calculated from the measured wind speeds at 10 m AGL at Benina, Benghazi are shown in Fig.3 and Fig 4 It was found that the yearly Weibull shape parameter, *k*, at 10 m AGL was 2.22. The yearly Weibull scale parameters, *c*, at 10 m AGL was 6.61 m/s, thus corresponding to monthly mean wind speeds in the range of 9-14.8 m/s. Furthermore the wind speed at high 40 m has been calculated using equation 3, also the shape and scale parameters k, c has been obtained for this case, the shape parameter k was 2.33 and scale parameter c was 7.3 m/s. Table.2 shows a summary of monthly mean speed for year 2008.

Table 2. A summary of monthly mean speed for year 2008 for Benina, Benghazi, Libya at 10 m height

Month	Mean Speed (m/s)
Jan	9
Feb	9.5
Mar	10.8
Apr	10.4
May	12.5
Jun	12.9
Jul	12.5
Aug	11.4
Sep	10.2
Oct	9.8
Nov	10
Dec	14.8

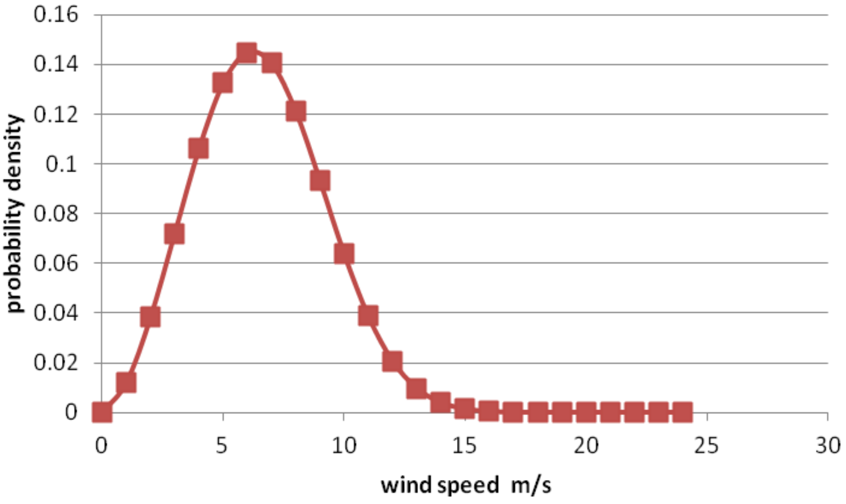

Figure 3. Yearly Weibull distributions at 10 m AGL at Benina, Benghazi, Libya

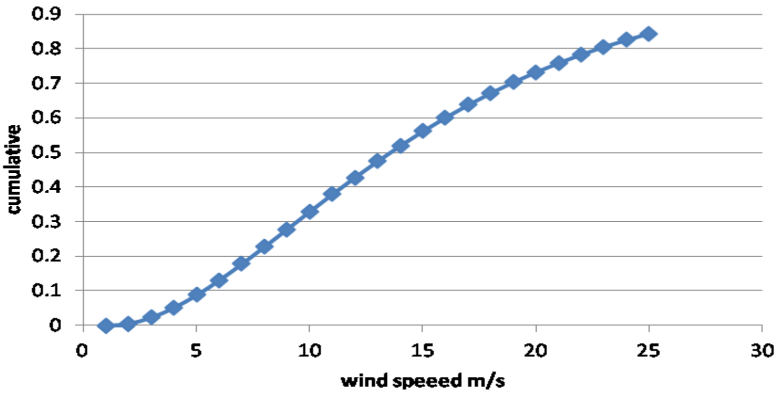

Figure 4 Cumulative probability 10 m AGL at Benina, Benghazi, Libya

Yearly mean wind power densities at 10 m and 40 at Benina, Benghazi calculated based on constant air density method at 1.225 kg/m^3 using equation 11. It is found that the yearly wind power density at 10 m and 40 m height is 415.83 W/m^2 and 545 W/m^2 respectively. The constant air density method can be used to overestimate the monthly mean wind power densities by up to 5.5% [11]. This overestimation is acceptable for resource assessment unless the variable air density is available.

4. Conclusions and recommendations

It is concluded that the Weibull distribution using the graphical method is a useful technique to conduct wind speed analysis from observed wind speed data at Benina, Benghazi in eastern Libya. From the observed wind speed data during January to December 2008, the yearly Weibull shape parameters were 2.221 and 2.33 at 10 m and 40 m height respectively and the yearly Weibull scale parameters were 6.61 and 7.3 m/s at 10 and 40 m height respectively. The yearly mean wind power density was 415.82 W/m^2 at 10 m height corresponding to the wind power classes 4-and 545 w/m^2 at 40 m height which classified at wind power class 5-. Because of the limitation of the available measured wind speed (the data were available as a monthly recorded), therefore , it is recommended that the wind data should be measured for long period which include daily wind speeds, as a result the use of these data will enhance the obtained results. Also it is recommended that, for future research the variation of air density due to change temperature and pressure should be taken in account in order to improve the accuracy of the obtained results. In addition, the obtained results could be verified by comparing them with results obtained by using advanced soft ware such as WASP.

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