Int. J. of Thermal & Environmental Engineering
Volume 14, No. 2 (2017) 163-173

Effect Weibull Distribution Parameters Calculating Methods on Energy Output of a Wind Turbine: A Study Case

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Abstract

Wind energy is an important renewable energy source. It is considered as one of the most significant, freely available and alternative source of energy distributed throughout the world. The estimation of the potential of wind energy in a site plays a vital role in estimating the energy output of the wind turbines and, therefore, affects economics and decision making. Site characterization can be expressed mathematically in different methods. Weibull distribution is one of the most common methods used to represent wind energy potential in a site. In this study, wind speed data was collected for year 2013, from Jan 2013 to Dec 2013. The data collected for three different heights (20 m, 40 m and 60 m) from measurement station installed at Jordan University of science and technology campus area (Irbid, Jordan). The data recorded based on ten minutes averages using a data logger. Yearly shape factor (k) and scale factor (c), of Weibull distribution for the wind speed are calculated for each height using graphical and standard deviation methods. Both arithmetic and cubic mean wind speeds were used to estimate Weibull parameters. Then, the energy outputs of Vestas V80-2.0 wind turbine installed at the site were estimated using calculated Weibull parameters and actual estimation. The results are compared to check the accuracy of methods of estimating Weibull parameters. A new method of characterizing the site is proposed and tested. The method is based on Weibull distribution but the specific power density is the main variable of the distribution function. The results showed that this method is the most accurate method among all tested methods.

Keywords: *Wind power, Weibull distribution, Irbid-Jordan.*

1. Introduction

The global energy use has been growing over 45 years and in 2008; the total worldwide energy consumption was 5×10^{20} J of which 80-90% originates from combustion of fossil foil [1]. As the world energy consumption growing especially in the developing countries, the fossil foil consumption increase causing the global warming, by increasing carbon emission to the environment [2]. Uncertainty in oil price and environmental problems has led to energizing of research in renewable energy. At present, renewable energy availability supply 13.3% of the world primary energy needs and their future potential observed [3].

Renewable energy technologies resources such as the sun, wind, earth geothermal and biomass have good benefits compared to non-renewable sources. Renewable energy came from continuous source of energy and it is asymmetrically distributed through over the world. So, every region has some renewable sources [4]. Wind energy is one of the most renewable energy used today and it is one of the fastest growing source of energy by zero emission. The total installed production capacity of wind energy in the whole world was 432,419 MW at the end of 2015 [5]. Wind energy is mainly used in two purposes; to generate electricity and water pumping.

Average wind speed and the wind speed variation affect how the use of wind power. Many ways are discussed by numerous researchers to find the potential wind site. The two factors in Weibull distribution c & k are used to estimate the prospective wind site by estimating the wind energy at certain site, and there are several methods to

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DOI: 10.5383/ijtee.14.02.010

calculate these parameters such as, graphical method, standard deviation method, moment method, maximum likelihood method and energy pattern factor method [6]. Many researchers developed several methods to analyze wind data from using Weibull distribution. Azad et al. [7] developed three methods to predict wind energy generation in Bangladesh. Pishgar-Komleh et al. [8] analyzed wind speed and power density based on Weibull and Rayleigh distributions in Fairouzkooh region of Iran. Benatiallah and Sellam [6] use Weibull distribution to discuss the wind potential in Sahara site of Algeria and perform a research on the wind power potential of desert of Algeria. Another case study was done in Ankara, Turkey by Levent Bilir et al. [9] using Weibull distribution function to predict seasonal and yearly wind speed distribution and power density at three different height (20, 30, 50 m) for data collected for a one year between June 2013 to June 2013, which they conclude that the highest wind power at winter and the lowest one at autumn.

Furthermore, it is important to analyze the behavior of wind speed because rough wind is not suitable to install wind turbine for electricity generation. Also, it is important to analyze wind shear for wind data. After select the potential windy sites and based on the selected site data, a proper wind turbine design needed. In this study, two numerical methods in several techniques have been used for determining the value of Weibull parameters. These parameters are used to identify the characteristics of wind and the potential of wind energy. This statistical study involves identifying the most accurate way to apply Weibull distribution to predict the potential of energy in a certain site with a selective wind turbine [8].

This work considers the wind data records which was collected for year 2013, from Jan 2013 to Dec 2013. The data collected for three different heights (20 m, 40 m and 60 m) from measurement station installed at Jordan University of Science and Technology campus area (Irbid, Jordan). The data recorded by a data logger based on ten minutes averages using NRG#40 cup-anemometers. Two anemometers were installed at each height. Namely; 20 m, 40 m and 60 m.

Methodology

One of the most widely statistical methods used in wind data analysis is Weibull distribution. The Weibull shape factor (k) and scale factor (c) are the main parameters to predict Weibull probability density function and cumulative distribution function as shown in (equation 1) respectively [10].

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-(V/c)^k} \quad (1a)$$

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \quad (1b)$$

Where v is the wind speed in m/s, k is the shape factor which is dimensionless parameter and c is the scale factor in m/s. Two methods for calculating Weibull distribution parameters are used in this study; graphical method and standard deviation method. Standard deviation method used several techniques to estimate the two Weibull distribution factors. Wind data recorded based on ten minutes average was divided into two data sheet; the first one has intervals of wind speed and the probability density function of Weibull distribution and the second one analyze the data for each average speed of data recorded.

2.1 Standard deviation method

The arithmetic mean wind speed (Vm) and the root mean cube wind speed (Vmc) were calculated for the two data sheet of wind data, and the variance (σv) for each average speed also was calculated. Then for each average speed and variance the Weibull distribution factors c & k calculated using GAMMA function or a simpler approach to estimate them as is discussed below.

The average wind speed calculated for each data sheet by different equations. , For interval data the arithmetic mean wind speed and the root mean cube wind speed is calculated as in equation 2a and equation 2b, respectively. The standard deviation is calculated for mean wind speed and root mean cube wind speed according to equation 3a and equation 3b, respectively.

$$\text{Vm (arithmetic)} = \frac{\sum \text{fi x vi}}{\sum \text{fi}} \quad (2a)$$

$$\text{Vmc (root mean cube)} = \left[\frac{\sum \text{fi x } Vi^3}{\sum \text{fi}}\right]^{1/3} \quad (2b)$$

$$\sigma_v\ (\text{Vm}) = \sqrt{\frac{\sum \text{fi (Vi}-\text{Vm)}^2}{\sum \text{fi}}} \quad (3a)$$

$$\sigma_v\ (\text{Vmw}) = \sqrt{\frac{\sum \text{fi (Vi}-\text{Vmw)}^2}{\sum \text{fi}}} \quad (3b)$$

The arithmetic mean wind speed and the root mean cube wind are calculated according to equation 4a and equation 4b, respectively. And then the standard deviation is calculated for mean wind speed and root mean cube wind speed:

$$\text{Vm (arithmetic)} = \frac{1}{n}\sum \text{Vi} \quad (4a)$$

$$\text{Vmc (root mean cube)} = \left[\frac{1}{n}\sum \text{Vi}^3\right]^{1/3} \quad (4b)$$

The standard deviations are calculated using:

$$\sigma_v\ (\text{Vm}) = \sqrt{\frac{\sum (Vi - Vm)^2}{n}} \quad (5a)$$

$$\sigma_v\ (Vmw) = \sqrt{\frac{\sum fi\ (Vi - Vmw)^2}{n}} \quad (5b)$$

After the mean wind speed Vm or Vmc and the variance σv (Vm) or σv (Vmw) of data are known, then the value of the two factors of Weibull distribution c & k can be calculated. Mainly, the scale parameter c referenced to characteristics of the wind distribution and the shape factor k referenced to how peak the wind distribution. These two parameters are estimated by two techniques; (1) using GAMMA function and (2) a simpler approach (as it will be discussed later). These parameters (c and k) will be calculated twice; first time using the arithmetic mean wind speed and the second time using the root mean cubic wind speed.

The value of average wind velocity and variance of wind speed can be calculated using GAMMA (г) using:

$$Vm = c\ \Gamma\ (1+\frac{1}{k}) \quad (6a)$$

$$\sigma v = c\ [\Gamma\ (1+\frac{2}{k}) - \Gamma^2\ (1+\frac{1}{k})]^{1/2} \quad (6b)$$

Once the values of average wind speed and the variance of wind speed data are known then GAMMA function (г) is used to estimate the value of shape factor as in equation 7, and find the value of K by solving the following expression numerically. The value of scale factor c is estimated according to:

$$(\frac{\sigma v}{Vm})^2 = \frac{\Gamma\ (1+\frac{2}{k})}{\Gamma^2\ (1+\frac{1}{k})} - 1 \quad (7)$$

$$C = \frac{Vm}{\Gamma\ (1+\frac{1}{k})} \quad (8)$$

Then after estimating these factors, a simpler approach of GAMMA function is used to estimate the values of the shape and scale factors c & k using [11]:

$$K = (\frac{\sigma v}{Vm})^{-1.090} \quad (9a)$$

$$c = \frac{Vm\ k^{2.6674}}{0.184+0.816\ k^{2.73855}} \quad (9b)$$

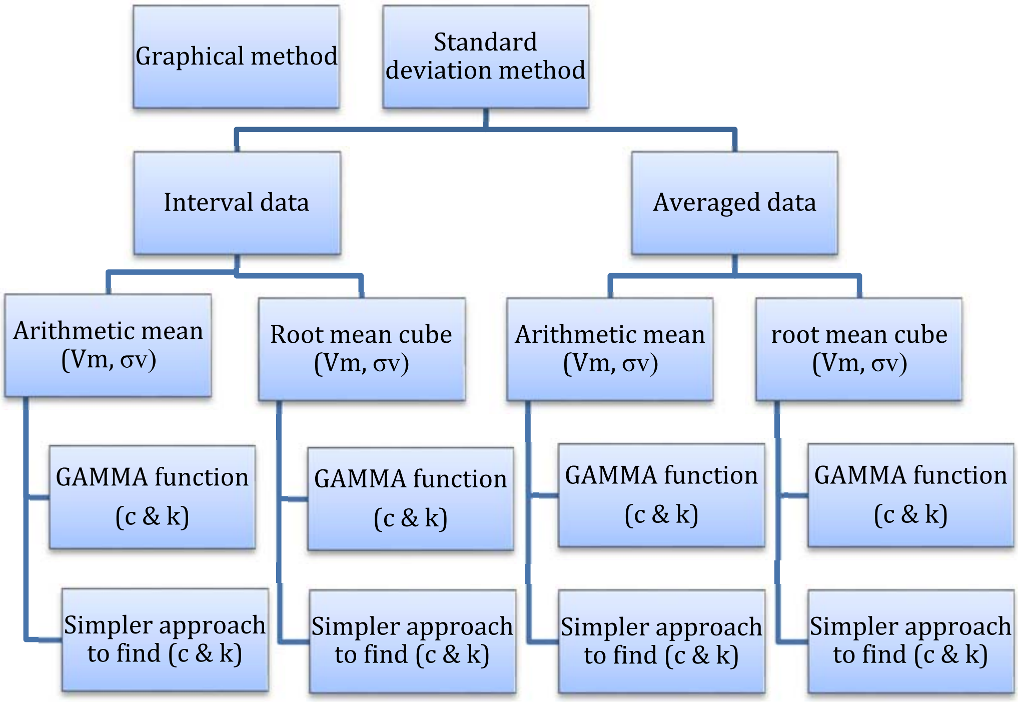
2.2 Graphical method

The following expressions can be developed from Equation (1b) [11]:

$$P\ (V < Vi) = P\ (V \geq 0)\ \{1-\exp\ [-\ (\frac{Vi}{c})^{k}]\} \quad (10)$$

$$Ln\ \{-\ln\ [1-F\ (v)]\} = k \ln (vi) - k \ln c \quad (11)$$

A plot of Ln {- ln [1- F (v)]} vs. ln (Vi) presents a straight line with a slope of k and a y-intercept of – k ln c. This logarithmic transformation is the basis of graphical method. Graphical method requires that the wind speed data be in cumulative distribution format. Best fit line can be drawn using a least square regression. The following chart summarizes all methods of solution-techniques used at this study.



In summary, there are eight techniques to find (c & k) and eight value of (c) and eight values of (k) at each height in the site, then the potential wind power and energy predicted of the site of a selective turbine can be calculated as the values of c & k are known.

A new method of estimating the energy output of a certain wind turbine installed in a specific site is proposed and tested. This method relies on the fact that care is always needed in estimating wind speeds in a site is because of their energy content. Since the wind power varies with the cube of the wind speed, then design/selection of a wind turbine based on mathematical average wind speed may lead to an improper utilization of wind potential at the site [12]. The proposed method still rely on Weibull distribution to describe the wind characteristics of the site but it uses the specific power density (cube of wind speed) rather than the wind speed.

The potential wind power at a given speed is given as:

$$P = \frac{1}{2}\rho A V^3 \qquad (12)$$

Specific power density is given as:

$$\frac{P}{\rho A} = \frac{1}{2}V^3 \qquad (13)$$

Or for simplicity use of specific power density according to:

$$\frac{P}{0.5\rho A} = V^3 = \xi \qquad (14)$$

The measured data for V is used to calculate the values of ζ according to Equation (14). The Weibull distribution function is used to model the distribution of ξ as follows:

$$f(\zeta) = \frac{k_\zeta}{c_\zeta}\left(\frac{\xi}{c_\zeta}\right)^{k_\zeta - 1} e^{\left(\frac{\zeta}{c_\zeta}\right)^{k_\zeta}} \qquad (15)$$

The methods used for calculating the values of c and k for v-based Weibull distribution function can be used to calculate c and k for ζ-based Weibull distribution function. To calculate the energy produced from a certain wind turbine located in a site described by c and k the following equation is used:

$$E = \int_0^\infty P(V) f(V) dV \qquad (16)$$

Where $P(V)$ is the variation of the power output of a specific wind turbine with the variation of the wind speed. Similarly, the energy output is calculated using the ζ-based Weibull distribution function according to:

$$E_\zeta = \int_0^\infty PP(\zeta) f(\zeta) d\zeta \qquad (17)$$

Where $PP(\zeta)$ is the power output of a specific wind turbine with the variation of the specific power density of the site, i.e. with V^3.

To check the accurcy of the used methods to describe the characteristics of the site, a wind turbine is selected. Then, the energy output is estimated using the values of k and c calculated earlier for the site and compared with the actual energy output based on instantenous measured wind speeds.

For this purpose, the power curve of a 2 MW Vestas V80-2.0 wind turbine is used to represent an actual wind turbine. It has the following specifications [13]: cut in, rated and cut-out velocities 4 m/s, 16 m/s and 25 m/s, respectively. Its power curve expressed in kW is given accordng to Equation (18) as:

$$P(V) = \begin{pmatrix} 0 & V < 4 \\ aV^3 + bV^2 + cV + d & 4 \le V < 16 \\ 2000 & 16 \le V \le 25 \\ 0 & 25 < V \end{pmatrix}$$

(18)

Where a, b, c and d are constats evaluated using best curve fit. Their associated values are a=2.9626, b=83.583, c=523.96 and d=1001.9.

Energy produced from the wind turbine is estimated based on site specifications using Weibull based approach and EES (Engineering Equation Solver) [14] by solving equations (16) and (17).

1. Results and Discussion

In this study, ten minutes time series wind speed data have been collected at different heights in Irbid, Jordan. The data has been sorted out according to annually mean wind speed for the selected site. Figure 1(a, b and c) shows the wind speed probability distribution based on 1m/s bin width at heights of 60, 40 and 20 m in the site, respectively.

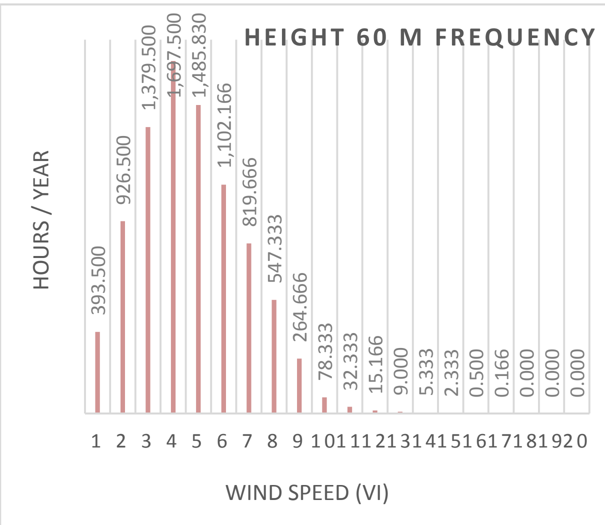


Fig. 1(a): Wind speed probability at 60m height

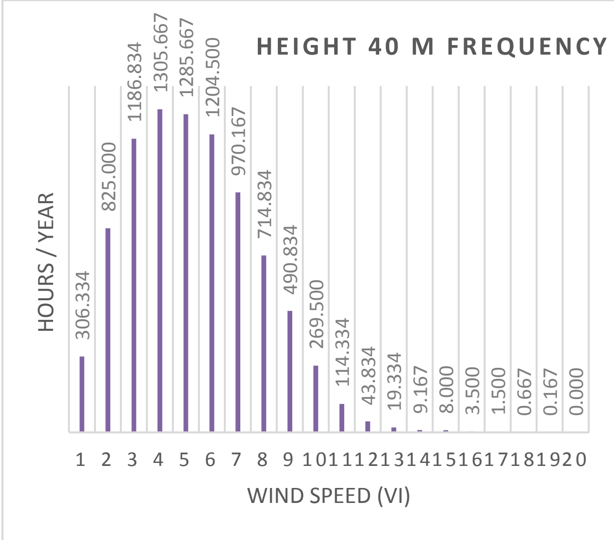


Fig. 1(b): Wind speed probability at 40 m height

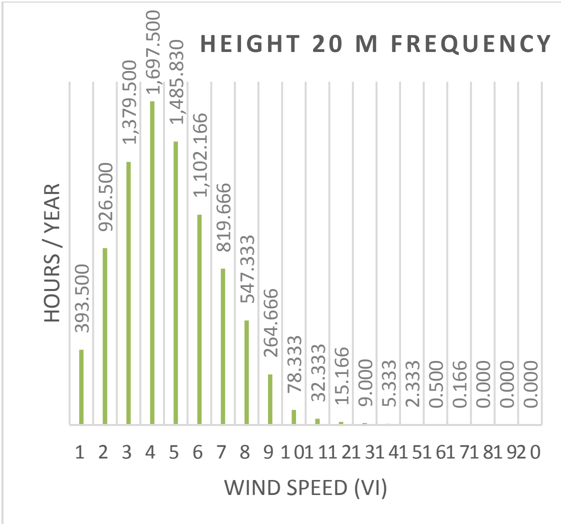


Fig. 1(c): Wind speed probability at 20 m height

Based on frequency distribution and cumulative distribution the values of the wind speed average (Equation (2a)), root mean cube (Equation (4b)) and standard deviations (Equations (3)) are calculated using the center of the interval as a pivot. Equations (7-8) are then used to calculate a set of values of c and k labeled as “Gamma function” in Table 2. Another set of c and k are obtained by using Equations (9). This set is labeled as “Simpler Approach” in Table 1. Thus, four pairs of (c, k) at each height are obtained. The results are shown in Table 1. It is clear from the results obtained that the values based on root mean cube are higher than those values obtained based on arithmetic mean.

The two sets are re-calculated but based on the mean average and cube mean average and standard deviations obtained from the measured data directly. The results obtained are shown in Table 2. One can also notice that the values of c and k based on Vrmc are higher than those obtained based on the arithmetic mean. One can also notice that the sets of c and k obtained for the same height using both methods are close to each other.

The sets of c and k are obtained using the graphical method as follows: Equation (11) for each height is plotted as shown in Figure 2. A best curve fit equation is obtained. Then value of c & k are obtained as described earlier. Table 3 shows the values of c & k at each height that estimated using graphical method.

The total actual energy output from Vestas V80-2.0 generated by the turbine over a period can be computed by adding up the energy corresponding to all possible wind speeds in the regime, at which the system is operational as shown in Figure 3.

Vestas V80-2.0 wind turbine constant parameters from 3rd order relation between wind speed and power output are shown in Figure 4. The energy generated from the turbine is calculated using the actual measured velocities. The results are shown in Table 4. This data is labeled as actual energy output. It should be mentioned that even though the diameter of the selected wind turbine is 80 m, which is higher than the hub height, the actual energy is calculated. The results should be read as the energy output if the wind turbine is erected at heights having the values of c and k same as those at 20 m or 40m heights. It should be noted that in reality the actual energy output will be less than this value. The reason is that the calculations do not take into consideration the variation of the wind direction. The calculations of the energy produced by the wind turbine assumes that the wind speed is always normal to the blade. This in reality is impossible.

Table 1: Weibull distribution constants using frequency distribution and standard deviation method

60 m				40 m				20 m			
Arithmetic mean		Root mean cube		Arithmetic mean		Root mean cube		Arithmetic mean		Root mean cube	
Vm = 4.856 σv = 2.614		Vmw = 6.054 σv = 2.875		Vm = 4.797 σv = 2.472		Vmw = 5.905 σv = 2.709		Vm = 4.212 σv = 2.133		Vmw = 5.159 σv = 2.334	
GAMMA function	Simpler approach	GAMMA function	Simpler approach	GAMMA function	Simpler approach	GAMMA function	Simpler approach	GAMMA function	Simpler approach	GAMMA function	Simpler approach
C = 5.476 K = 1.936	5.478 1.965	6.836 2.225	6.836 2.252	5.414 2.032	5.415 2.059	6.665 2.313	6.665 2.338	4.755 2.072	4.755 2.099	5.822 2.35	5.822 2.374

Table 2: Weibull distribution constants using actual measured wind and standard deviation method

60 m				**40 m**				**20 m**			
Arithmetic mean		Root mean cube		Arithmetic mean		Root mean cube		Arithmetic mean		Root mean cube	
Vm = 4.818 σv = 2.593		Vmw = 6.002 σv = 2.854		Vm = 4.747 σv = 2.454		Vmw = 5.852 σv = 2.691		Vm = 4.163 σv = 2.111		Vmw = 5.104 σv = 2.311	
GAMMA function	Simpler approach	GAMMA function	Simpler approach	GAMMA function	Simpler approach	GAMMA function	Simpler approach	GAMMA function	Simpler approach	GAMMA function	Simpler approach
c = 5.423 k = 1.933	5.426 1.961	6.777 2.222	6.777 2.249	5.358 2.025	5.359 2.053	6.605 2.307	6.605 2.332	4.700 2.069	4.701 2.097	5.759 2.347	5.760 2.372

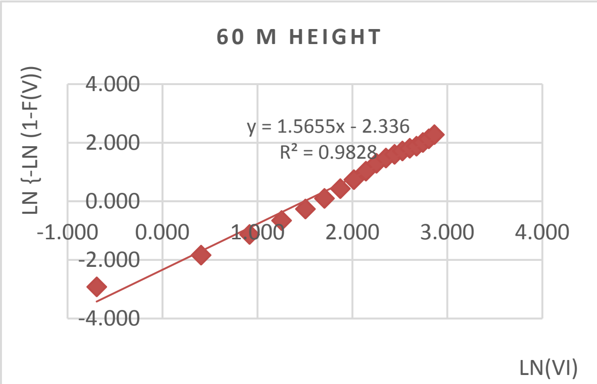


Fig. 2(a) Graphical method to estimate c & k at 60 m

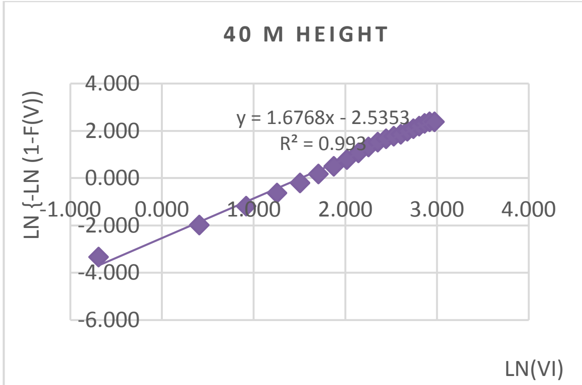


Fig. 2(c) Graphical method to estimate c & k at 40 m height

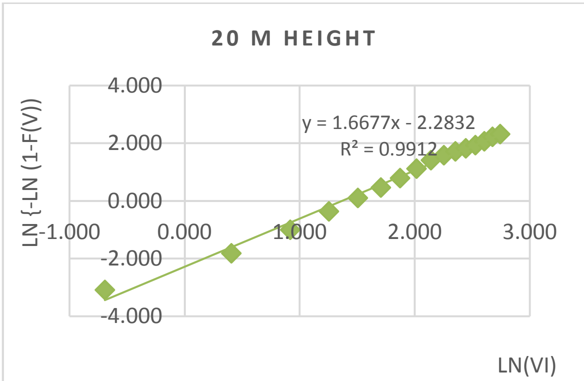


Fig. 2(b) Graphical method to estimate c & k at 20 m heights

Table 3: Weibull parameters using graphical method

60 m		40 m		20 m	
c	k	c	k	c	k
4.447	1.5655	4.536	1.677	3.930	1.668

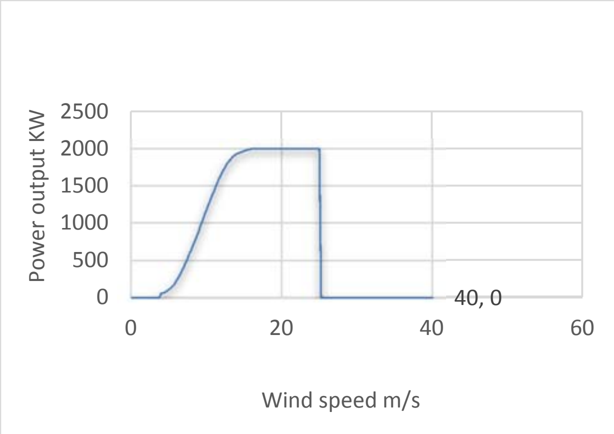


Fig. 3 Power curve for Vestas V80-2.0

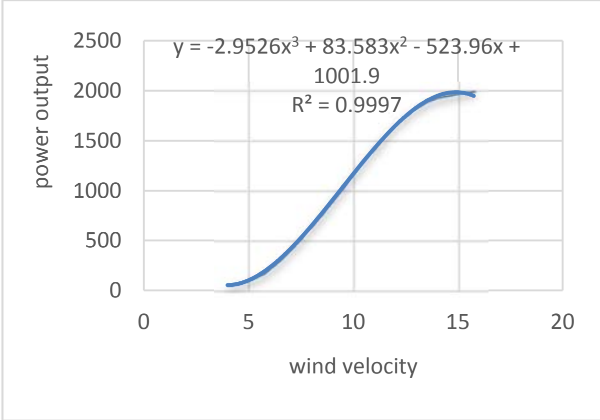


Fig. 4 The relationship between wind speed and power output between cut-in and rated speeds for V80-2.0 wind turbine

Table 4: The actual energy output for all heights

60 m Height		40 m Height		20 m Height	
Actual energy (Mwh)/year	2021.46	Actual energy (Mwh)/year	1863.09	Actual energy (Mwh)/year	1164.1

EES software is used to calculate the energy output from the selected wind turbine located in the site using several relation and expressions including integral expression to estimate the energy of the turbine for nonlinear relation and using c & k as entered values to calculate the energy as shown in Figure (4).

Table 5 shows the energy output from the selected wind turbine using graphical method (Table 6) and standard deviation method for the four techniques used; interval wind speed (Table 5a) and the average wind speed (Table 5b) data collected at each height of 60, 40, 20 m which compared with the actual energy about for each height The error in predicting the actual energy output for each technique using is calculated and tabulated. It is clear from the table that the techniques based on the average wind speed are very accurate (error less than 5%) in predicting the energy output.

Table 5a: Standard deviation method used interval wind speed technique

SD-Interval wind speed			Energy output Mwh/year	Actual energy Mwh/year	Error %
60 m	Arithmetic mean	GAMMA function	2106	2021.46	4%
		Simpler approach	2081		2.86%
	Root mean cube	GAMMA function	3550		43%
		Simpler approach	3552		43%
40 m	Arithmetic mean	GAMMA function	1952	1863.09	4.5%
		Simpler approach	1931		3.5%
	Root mean cube	GAMMA function	3264		42.9%
		Simpler approach	3249		42.6%
20 m	Arithmetic mean	GAMMA function	1263	1164.1	7.8%
		Simpler approach	1245		6.5%
	Root mean cube	GAMMA function	2184		47%
		Simpler approach	2169		46.3%

Table 5b: Standard deviation method used averaged wind speed technique.

SD-Average wind speed			Energy output Mwh/year	Actual energy Mwh/year	Error %
60 m	Arithmetic mean	GAMMA function	2050	2021.46	1.4%
		Simpler approach	2027		0.20%
	Root mean cube	GAMMA function	3473		41.8%
		Simpler approach	3455		41.5%
40 m	Arithmetic mean	GAMMA function	1897	1863.09	1.78%
		Simpler approach	1875		0.6%
	Root mean cube	GAMMA function	3189		41.5%
		Simpler approach	3173		41.3%
20 m	Arithmetic mean	GAMMA function	1216	1164.1	4.2%
		Simpler approach	1199		2.9%
	Root mean cube	GAMMA function	2113		44.9%
		Simpler approach	2099		44.5%

Table 6: Energy output using the graphical method

Graphical method	Energy output Mwh/year	Actual energy Mwh/year	Error %
60 m	1456	2021.46	27.9%
40 m	1406	1863.09	24.5%
20 m	895.879	1164.1	23%

For the ζ-based Weibull distribution method, the characteristics of the site are calculated based on ζ and listed in Table 7. The power curve for the wind turbine Vestas V80-2.0 is reproduced in terms of ζ.

Fig. 5 shows the variation of the power output in the region between cut-in and rated wind speeds for Vestas V80-2.0 turbine. ,

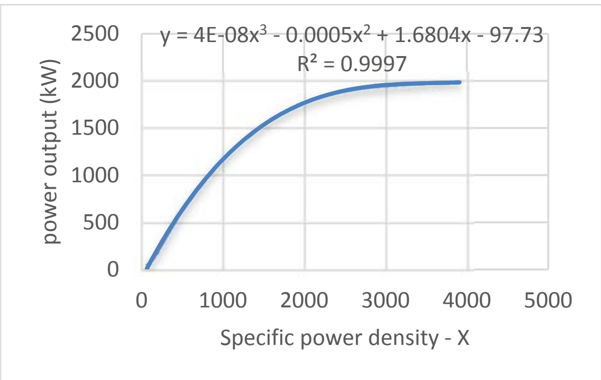


Fig. 5: 3rd order relation between power and cubic wind speed

Table 7: Wind data analysis for cubic wind speed using standard deviation method.

60 m		40 m		20 m	
Average cubic wind speed		Average cubic wind speed		Average cubic wind speed	
Vm = 216.188 σv = 330.465		Vm = 200.369 σv =299.818		Vm =132.939 σv =201.318	
GAMMA function	Simpler approach	GAMMA function	Simpler approach	GAMMA function	Simpler approach
C = 193.2	152.087	180	144.7	119.2	94.611
K = 0.8145	0.63	0.823	0.6445	0.8181	0.63613

Table 8: Comparison between ζ-based analysis and actual energy output for Vestas V80-2.0 wind turbine

SD-Average cubic wind speed		Energy output Mwh/year	Actual energy Mwh/year	Error %
60 m	GAMMA function	2003	2021.46	0.9%
	Simpler approach	1894		6.7%
40 m	GAMMA function	1843	1863.09	1%
	Simpler approach	1767		5.4%
20 m	GAMMA function	1134	1164.1	2.6%
	Simpler approach	1133		2.7%

Close inspection of Table 8, one can see that the ζ-based analysis methods have the highest accuracy among other methods.

2. Conclusion

The potential of wind energy output from Vestas V80-2.0 wind turbine at three different heights (60, 40, 20 m) of the certain site have been studied in this research using v-based and ζ-based Weibull distribution functions. Different methods are used to calculate Weibull parameters (c & k). The graphical and standard deviation methods are used based on the arithmetic mean and root mean cube. Relative percentage of error in estimating energy output using selected wind turbine has been analyzed and compared. Obtained results indicated that all methods based on Vrmc are 50% away from the actual results. While results based on arithmetic averages, in general, are accurate. It is also found that among the techniques of estimating the Weibull parameters, the graphical technique is less accurate than the standard deviation method. A new method of characterizing the site is proposed and tested. The method is based on Weibull distribution but the specific power density is the main variable of the distribution function. The results showed that this method is the most accurate method among all tested methods.

References

[1] Energy – Consumption "Consumption by fuel, 1965–2008" (XLS), Statistical Review of World Energy 2009, BP. July 31, 2006 (accessed 24.10.09).

[2] Zhang, X., Zhao, X., Smith, S., Xu, J., & Yu, X. (2012). Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies. Renewable and Sustainable Energy Reviews, 16(1), 599-617.

[3] Hasan, M. A., & Sumathy, K. (2010). Photovoltaic thermal module concepts and their performance analysis: A review. Renewable and Sustainable Energy Reviews, 14(7), 1845-1859.

[4] Bull, S. R. (2001). Renewable energy today and tomorrow. Proceedings of the IEEE, 89(8), 1216-1226.

[5] http://www.gwec.net/global-figures/graphs/; date: 11 Feb. 2016.

[6] Dahbi, M., Benatiallah, A., and Sellam, M. (2013). The analysis of wind power potential in Sahara site of Algeria-an estimation using the 'Weibull'density function. Energy Procedia, 36, 179-188.

[7] Azad, A. K., Rasul, M. G., Islam, R., & Shishir, I. R. (2015). Analysis of wind energy prospect for power generation by three Weibull distribution methods. Energy Procedia, 75, 722-727.Chicago

[8] Ohunakin, O. S. and Akinnawonu, O. O. (2012) Assessment of wind energy potential and the economics of wind power generation in Jos, Plateau State, Nigeria, and Energy for Sustainable Development. 16, 78-83.

[9] Bilir, L., İmir, M., Devrim, Y., and Albostan, A. (2015). Seasonal and yearly wind speed distribution and wind power density analysis based on Weibull distribution function. International Journal of Hydrogen Energy, 40(44), 15301-15310.

[10] Azad, K. (2012), Statistical Weibull's Distribution Analysis for Wind Power of The Two 1.668Dimensional Ridge Areas, International Journal of Advanced Renewable Energy Research (IJARER). 1, 8-14.

[11] Mathew, S. (2006), Wind Energy: Fundamentals, Resource Analysis and Economics, Springer-Verlag Berlin Heidelberg, p 84.

[12] Wagner, · H-J. and Mathur J. (2009), Introduction to Wind Energy Systems: Basics, Technology and Operation, Springer-Verlag Berlin Heidelberg, p.38

[13] System Advisor Model Software, Version 2015.6.30, free software

[14] Engineering Equation Solver (EES) Software,