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Analysis of Wind Speed Data for Energy Production at Central Ethiopia, Adama

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ABSTRACT: Analysis of wind speed data is one of the tremendous jobs now a day's to have knowledge about the velocity of wind at a region. In this study, wind speed characteristics were analyzed using Weibull approach. The basic mean wind speed data were collected from Adama meteorological agency at a span between 2009 and 2012. These data was measured at a height of 2m using cup type of anemometer then extrapolated to 10 m height. The probability density function and cumulative density functions were also evaluated. The cut-in wind speed essential for design of wind turbine is one of the viable options for small scale energy production in this location also suggested.

KEYWORDS: Weibull approach, probability density function (PDF), cumulative density function (CDF).

I. INTRODUCTION

In recent days, most of the developing countries are concentrating to generate energy from the natural resources. Moreover, wind is a potential renewable energy sources on the earth. It is essential to have a comprehensive knowledge about the wind characteristics for efficient planning and implementation of power generation units. Due to increase in demand on utilizing natural energy resources, it becomes very important to speculate the fluctuations of wind from time to time. The judgment of wind speed velocity is more intricate than the wind flow regime; consequently its evaluation becomes more unwieldy. Wind actions are determined from the basic values of wind velocity and the response of structures should be calculated from the peak velocity pressures. These can be mainly depends on the climate, terrain roughness, orography and reference height.

Wind characteristics such as speed, probability of blowing and its direction plays a vital role in establishing the wind power generation plant and understanding the level of power generation and economic feasibility. There are uncertainties for prediction of wind by both graphically and temporally. Assessment of wind speed in a region can be rigorously carried out by using simple mathematical tools such as probabilistic models and by using standard procedures given in the regional codes on wind speed calculations. Out of all, Gumbel's distribution is one of the easy and simple methods to analyse the wind speed data and the estimators. Mainly we have probability weighted moments (PWM), method of moment (MOM) and the maximum likelihood methods (MLM) are available at Smail Mahdi and Myrtene Cenac, 2004 [1]. Predicted values of different return periods considered in the study was following logarithmic variation and in all the years the minimum and maximum value of wind speed velocity noticed are varying in the range of 1.3 to 3.1. The mean value is almost same for all the years and its value noticed is varying in the range 2.2 m/s to 2.3 m/s. This analysis helps very much for the engineers to take appropriate decision about the design of foundation for wind turbine as well future power generation [2]. The probability weighted moments method is more comfortable compared to other methods for the estimation of both α and ε parameters. The Weibull parameters also can be derived using MLM, modified MLM and the graphical method [3]. Out of three methods, root mean square error values showed the modified maximum likelihood method performed better than the graphical method infrequency distribution format. Goodness-of-Fit (GoF) tests involving Anderson-Darling (AD) and Kolmogorov-Smirnov (KS), and diagnostic test using Root Mean Square Error (RMSE) are adopted for selection of a suitable method for

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determination of parameters of Gumbel distribution for modelling WSD [4]. The order statistics approach was suited well for estimation of design wind speed for the regions. The estimation of wind speed potential at a region is a pre-requisite while designing tall structures such as cooling towers, stacks, transmission line towers, etc. it is very important to assess the wind speed in a region can expediently be carried out by probabilistic modelling of historic Wind Speed Data (WSD) using an appropriate extreme value distribution, or by using standard procedures available under BIS code of practices for building and structures.

We have several computational approaches from the last few decades but they are still at a level that faltering prevails when their results are suggested for use in practical applications. The meteorological variables plays key role in analysis of wind speeds in a specific period time. Since good olden days, it is believed that the solar and wind are main sources of non-conventional energy that allows farmers to have potential for transferring kinetic energy captured by the wind mill for pumping water, drying crops, heating systems of green houses, rural electrification's or cooking [5]. In the present study, the basic mean wind speed velocity (m/s) over past 4 years was collected from Adama Meteorological Agency (AMA), Nazareth, Oromia region, Ethiopia. The geographical coordinates of the meteorological station where the wind speed data were captured at a height of 2 m by a cup-anemometer are given in Table 1.

Fig. 1 Data collected from cup - anemometer

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Table 1. The geographical location of Adama Meteorological Agency

Station Name	Latitude (N)	Longitude (E)	Altitude (m)	Measurement Period
Adama Meteorological Agency	8° 32' 29"	39° 16' 08"	1712	2009-2012

The available wind data are measured at a height different from the wind turbine hub height. It is noted that, wind speed at the hub height that is of interest for wind power application; therefore, the available wind speeds are adjusted to the wind turbine hub height using the following power law expression, [6]

$$\frac{V}{V_o} = \left(\frac{h}{h_o}\right)^{\alpha} \quad (1)$$

Where V is the wind speed at the hub height h, V_o is wind speed at the original height ho and α is the surface roughness coefficient and is assumed to be 0.143 (or 1/7) in most cases. The surface roughness coefficient α can be determined from the following expression [7]:

$$\alpha = [0.37 - 0.088 \ln(V_o)] / \left[1 - 0.088 \ln\left(\frac{h_o}{10}\right)\right] \quad (2)$$

II. METHODOLOGY USED IN THE STUDY

In Weibull distribution, the variation in wind velocity is characterized by two parameter functions: the probability density function and the cumulative distribution. The probability density function f(V) indicates the probability of the wind at a given velocity V, while the corresponding cumulative distribution function of the velocity V gives the probability that the wind velocity is equal to or lower than V, or within a given wind speed range. The Weibull probability density function is given as,

$$f(V) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^{k}\right] \quad (3)$$

Where f (V) is the probability of observed wind speed (V), k is dimensionless Weibull parameter and c is the Weibull scale parameter (m/s). The scale factor can be related to the mean wind speed (WS_m) through the shape factor, which determines the consistency of the wind speed in a given place. The cumulative distribution function F (V) is the integral part of the probability density function, and it can be written as,

$$F(V) = 1 - e^{-\left(\frac{V}{c}\right)^{k}} \quad (4)$$

This method is useful when only the mean wind speed and standard deviation is available. The monthly and annual values of Weibull parameters were calculated using standard deviation method. It can be relates with the mean of the entire month. Moreover, it is unlike most of the other methods that may require more detailed wind data for the determination of the Weibull distribution shape and scale parameters. The shape and scale factors are accordingly computed from Equations 5 and 6 given by

$$k = \left(\frac{\sigma}{WS_m}\right)^{-1.086} \quad (5)$$

$$c = \frac{WS_m}{\Gamma\left(1 + \frac{1}{k}\right)} \quad (6)$$

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Where σ is the standard deviation, WS_m is the mean wind speed (m/s) and Γ(x) is the gamma function, which can be defined as

$$\Gamma(x) = \int_0^{\infty} t^{x-1} e^{-t}\, dt \tag{7}$$

Alternatively, scale factor can be determined mathematically from the following expression given in Eqn (8).

$$c = \frac{WS_m}{0.568 + 0.434/k^{2.148}} \tag{8}$$

In addition to the mean wind speed, the other two major wind speeds parameters for wind energy estimation are the most probable wind speed (V_F) and the wind speed carrying maximum energy (V_E). The expressions can be written as respectively

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

$$V_E = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \tag{10}$$

The rated wind speed can be used for wind turbine design. Most of the earlier studies have attributed that the wind turbine system runs most efficiently at rated wind speed. It is important that, the rated wind speed and the wind speed carrying maximum energy should be as close as each other.

III. RESULTS AND DISCUSSIONS

The annual probability density and cumulative distributions functions of wind speed over the period of 2009 to 2012 obtained using the Weibull distribution function are furnished in Figs. 1 and 2 respectively. The probability distribution function (PDF) is used to explain the amount of time at which the maximum wind speed prevailed at particular location. The probability density frequencies of all years skewed the higher values of maximum mean wind speed. From the distribution it can be stated that the peak value of the probability density function curve indicates the most frequent velocity in worst case. Based on this we can assume the basic minimal wind speed at particular location.

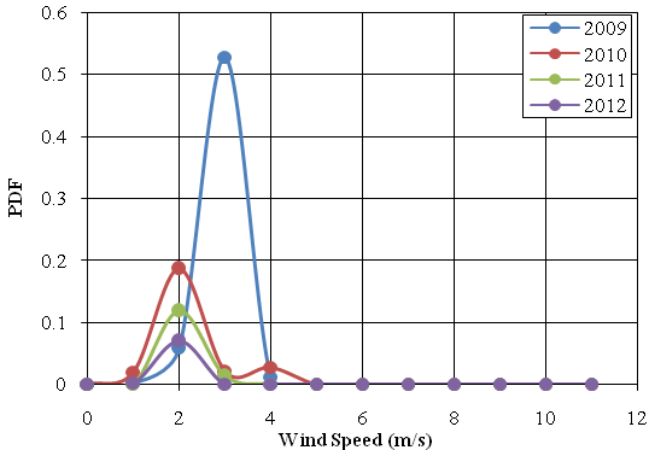

Fig. 1. Probability density functions (PDF) of annual wind speed distribution

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Fig. 1 shows the probability density functions of annual wind distribution over the period of 2009 to 2012. The trend of curves followed for all the years are almost similar. From the figure it is observed that, the most frequent maximum wind speed anticipated almost same for all the years i.e., 10 m/s.

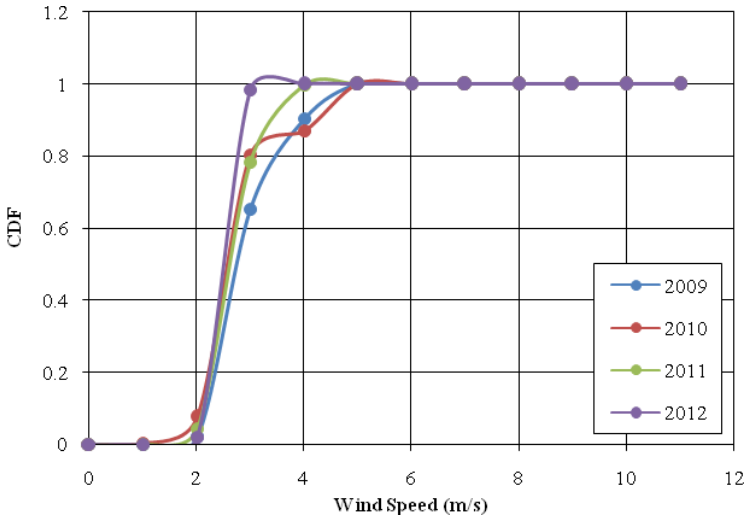

Fig. 2. Cumulative density functions (CDF) of annual wind speed distribution

The CDF function of the wind speed mainly depicts the wind speed at specific time interval. The distribution of the wind speed is shown in Fig. 2. For wind speeds greater than or equal to 2 m/s cut- in wind speed have frequencies of about 67.9%, 63.81%, 65.90% and 55.90% from 2009 to 2012 respectively. According to Adama site a wind turbine system with a design cut-in wind speed of 3.0 m/s is used in these sites for wind energy resource for power generation. As the mean wind speed is less than designed cut-in wind speeds, this wind energy can be utilized for other applications.

The monthly variation of the mean wind speed characteristics, mean power density and mean energy density along with annual values of these parameters at a height of 10 m are presented in Tables 1, 2, 3 and 4. The monthly mean wind speed varies between 1.68 m/s in September to 3.88 m/s in July in the years 2009 to 2012, and the monthly mean power density varies between 3.35 W/m^2 in September to 36.04 W/m^2 in July in the years 2009 to 2012.

Table 1. Characteristic Speeds and Mean Power Density in 2009

Month	WS_m *(m/s)*	*k*	*C (m/s)*	V_F *(m/s)*	V_E *(m/s)*	P_d *(W/m^2)*
Jan	2.827239	2.053235	3.191522	2.305683	4.444781	13.84183
Feb	3.585029	6.491537	3.84079	3.743075	4.003026	28.22177
Mar	3.567406	6.090734	3.838297	3.726923	4.021476	27.80762
Apr	2.739123	5.468327	2.96818	2.860558	3.142284	12.58754
May	2.656043	2.886072	2.981622	2.572994	3.578318	11.47656
Jun	3.182217	7.637878	3.371649	3.310268	3.475898	19.73765
Jul	3.53216	6.325724	3.790749	3.689021	3.959008	26.99151
Aug	2.510024	4.249445	2.763268	2.594192	3.025813	9.685893

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Sep	2.04679	5.356131	2.220946	2.136887	2.356488	5.252014
Oct	2.356452	4.533561	2.584075	2.445867	2.801	8.014598
Nov	2.955635	5.420134	3.204647	3.086302	3.39583	15.81461
Dec	2.955635	5.541619	3.200011	3.087135	3.382993	15.81461
Annual	2.909479	5.1712	3.16298	2.963242	3.465576	16.27052

In year 2009, the monthly mean wind speed varies between 2.04 m/s in September to 3.58 m/s in February with annual mean 2.90 m/s at AMA in Adama as shown in table 1. The most probable wind speed (V_F) is varies between 3.74 m/s in February to 2.13 m/s in September. The wind speed carrying maximum energy (V_E) varies between 4.44 m/s in January to 2.35 m/s in September. The monthly mean power density varies between 28.22 W/m^2 in February to 5.25 W/m^2 in September and annual mean power density is 16.27 W/m^2.

Table 2. Characteristic Speeds and Mean Power Density in 2010

Month	WS_m *(m/s)*	*k*	*C (m/s)*	V_F *(m/s)*	V_E *(m/s)*	P_d *(W/m^2)*
Jan	3.287955	7.096664	3.501274	3.427136	3.625937	21.77127
Feb	2.580516	5.474326	2.796109	2.694956	2.959776	10.52509
Mar	3.124313	4.764478	3.415575	3.2508	3.676313	18.67969
Apr	2.419391	4.153199	2.667098	2.495941	2.931867	8.674099
May	2.797028	2.936808	3.137785	2.7231	3.744823	13.40283
Jun	3.469221	8.004372	3.66388	3.6033	3.767406	25.57419
Jul	3.889656	7.072239	4.142987	4.054636	4.291478	36.04455
Aug	3.182217	6.247939	3.418025	3.323927	3.573378	19.73765
Sep	1.88063	5.698324	2.032396	1.964724	2.142575	4.073953
Oct	2.562893	5.24727	2.784664	2.67469	2.961415	10.31092
Nov	3.788953	10.55982	3.92502	3.888215	3.990022	33.31683
Dec	2.766817	5.737561	2.988745	2.890632	3.148656	12.97321
Annual	2.979132	6.08275	3.20613	3.082671	3.401137	17.92369

In year 2010, the monthly mean wind speed varies between 3.88 m/s in July to 1.88 m/s in September with annual mean 2.97 m/s for AMA at Adama as shown in Table 2. The most probable wind speed (V_F) is varies between 4.05 m/s in July to 1.96 m/s in September. The wind speed carrying maximum energy (V_E) varies between 4.29 m/s in November to 2.14 m/s in September. The monthly mean power density varies between 36.04 W/m^2 in July to 4.07 W/m^2 in September and annual mean power density is 17.92 W/m^2.

Table 3. Characteristic Speeds and Mean Power Density in 2011

Month	WS_m *(m/s)*	*k*	*C (m/s)*	V_F *(m/s)*	V_E *(m/s)*	P_d *(W/m^2)*
Jan	3.204875	6.834866	3.421553	3.343274	3.552485	20.16227
Feb	3.287955	7.216363	3.497274	3.425726	3.617862	21.77127

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Mar	3.335789	5.199396	3.626583	3.480614	3.860843	22.73536
Apr	2.522612	4.91599	2.752352	2.627922	2.950253	9.832351
May	2.454637	4.462595	2.694343	2.545434	2.927454	9.058746
Jun	3.016057	5.933882	3.250726	3.15118	3.413808	16.80446
Jul	3.136901	4.696688	3.432405	3.261818	3.701708	18.90638
Aug	2.736606	4.282962	3.0113	2.830035	3.293141	12.55286
Sep	1.762304	3.636364	1.957285	1.791625	2.207981	3.352342
Oct	2.87759	6.067735	3.096882	3.006317	3.245752	14.59462
Nov	2.729053	7.156874	2.904435	2.843994	3.006184	12.44922
Dec	3.19984	7.634301	3.39043	3.328648	3.495354	20.06739
Annual	2.855352	5.669835	3.086297	2.969716	3.272735	15.19061

In year 2011, the monthly mean wind speed varies between 3.33 m/s in February to 1.76 m/s in September with annual mean 2.85 m/s for AMA at Adama as shown in table 3. The most probable wind speed (V_F) is varies between 3.48 m/s in February to 1.79 m/s in September. The wind speed carrying maximum energy (V_E) varies between 3.86 m/s in March to 2.20 m/s in September. The monthly mean power density varies between 22.73 W/m^2 in February to 3.35 W/m^2 in September and annual mean power density is 15.19 W/m^2.

Table 4. Characteristic Speeds and Mean Power Density in 2012

Month	WS_m *(m/s)*	*k*	*C (m/s)*	V_F *(m/s)*	V_E *(m/s)*	P_d *(W/m^2)*
Jan	3.260262	9.249226	3.408808	3.366898	3.481724	21.22577
Feb	3.396211	6.070048	3.654932	3.548131	3.8305	23.9933
Mar	3.270332	7.083599	3.482946	3.408915	3.607395	21.42307
Apr	2.097141	5.231336	2.279057	2.188483	2.42456	5.649229
May	2.977034	9.184179	3.114209	3.075364	3.181736	16.16061
Jun	3.177182	6.043733	3.420209	3.319366	3.585873	19.64411
Jul	3.182217	7.07333	3.389437	3.317179	3.510884	19.73765
Aug	2.190292	4.549853	2.401336	2.273855	2.601542	6.43594
Sep	1.683	5.989067	1.812832	1.758369	1.902181	2.919836
Oct	2.813392	6.459328	3.015115	2.937615	3.143693	13.63945
Nov	2.727794	7.167206	2.902809	2.842581	3.00422	12.432
Dec	2.895213	6.965195	3.086985	3.019055	3.200912	14.86441
Annual	2.805839	6.755508	2.99739	2.921318	3.122935	14.84378

In year 2012, the monthly mean wind speed varies between 3.39 m/s in February to 1.68 m/s in September with annual mean 2.80 m/s for AMA at Adama as shown in table 4. The most probable wind speed (V_F) is varies between 3.54 m/s in February to 1.75 m/s in September. The wind speed carrying maximum energy (V_E) varies between 3.60 m/s in February to 1.90 m/s in September. The monthly mean power density varies between 23.99 W/m^2 in February to 2.91 W/m^2 in September and annual mean power density is 14.84 W/m^2.

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IV. CONCLUSIONS

In this study, the wind speed and wind energy potential over a period of 2009 to 2012 was analysed discussed in the above sections. According to the analysis of results, the mean wind speed in any given year is maximum in February and March and minimum in the month of September. So, it is concluded that the installation of wind turbine for small scale wind energy production units is recommended in the months of maximum wind speed that is in February and March.

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