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An Analysis of Wind Speed Distribution and comparison of five numerical methods for Estimating Weibull Parameters at Ormara, Pakistan

JUNAID K. KHAN
N. E. D. University of Engineering & Technology
ZAHEER UDDIN
Department of Physics, University of Karachi, Pakistan
S. TANWEER IQBAL
D. J. Govt. Science College, Karachi
FEROZ AHMED
ASIM AIJAZ[1]
SAIF UDDIN JILANI
Department of Physics, University of Karachi, Pakistan

Abstract

Daily Wind speed data at 12:00 hour from 1998 to 2007 for Ormara, Pakistan has been analyzed and Weibull distribution parameters are estimated by five numerical methods, namely Method of moments (MoM), Empirical Method (EMP), Energy Pattern Factor Method (EPM), Maximum Likelihood Method (MLM) and Modified Maximum Likelihood Method (MMLM). A comparison of these methods has also been shown. The mean wind speed for each month is predicted by values of shape and scale parameters and compared with the corresponding measured mean wind speed.

Keywords: Wind energy, Weibull distribution, Weibull Parameters, Scale and Shape Parameters.

Introduction

Continuous, inexpensive and efficient supply of energy is required to provide high standard and quality life style to human being, to coup accelerated demand and for economic development as well. The utilization of energy by the country is a measure of prosperity level that it could obtain for economic and social comfort. TheUnited Nation development program (UNDP) defined Human Development Index (HDI) which is a tool to compare the economic and social growth of countries. The HDI values and per capita energy

[1] Corresponding author: *Corresponding author: aajaz@uok.edu.pk

consumption are higher for developed countries and values are less for developing countries[1].
It is found that population is growing more rapidly in third world countries than in industrialized countries; due to this fact the energy demand is increasing at the rate of 3.2 percent per annum in developing countries where as only 1.5% per annum in industrialized countries. This trend reflects extensive increase in global energy consumption in the upcoming years [2].

In global energy supply Coal, petroleum, oil and natural gas collectively known as fossil fuels, contribute the major share of around 78.4 percent of the needs, nuclear power is approximately 2.6 percent and all renewable sources supply 19 percent out of which 4.2 percent by Biomass/ geothermal/solar,3.8 percent by hydropower and only 2 percent by Wind/solar/ biomass/ geothermal power [3].

Conventional sources (coal and fossil fuels) of electrical energy have been depleting rapidly. Wind is a free, limitless power source and a good alternative of conventional form of energy. Wind speed is the fuel of electrical energy. Wind energy depends on wind speed, which is not same all the time. It is pollution free, environmental friendly, and economical. The Wind Power is more beneficial for remote places where electrical grid is difficult to provide with. As wind turbines are having verity of range with respect to sizes and power production.and wind potential, this is an attractive option for such areas for electricity production and other mechanical work.

The worldwide wind capacity reached more than 300GW; a large part of our world has been utilizing wind power for generation of electrical energy. China, United States, Germany, Spain, India are the five leading nations using wind energy.

Weibull Distribution

The Weibull distribution is widely used for prediction and analysis of wind speed / energy data. [4]. The Weibull distribution has many other applications.Weibull distribution is flexible and easy to implement. There are different types of Weibull distribution [5], the simplest form has two parameters: the two parameters are known as scale parameter (denoted by 'c') and shape parameter (denoted by 'k'). The parameter 'k' is dimensionless whereas the dimension of the scale parameter 'c' is of velocity [6]. The large value of 'k' indicates high value of kurtosis, i.e. more stability in wind speed pattern, whereas the higher value of 'c' exhibits more spread of wind speed distribution.

Wind speed distribution usually follows Weibull distribution, hence Weibull distribution is a probability density function with wind speed as a random variable [7-13]. The mathematical form of Weibull distribution function is given below:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}}, \qquad (1)$$

and its cumulative distribution function is given by:

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \quad (2)$$

Numerical methods for determination of Weibull parameters

In the following section a brief introduction of five numerical methods for the determination of Weibull distribution's parameters is given.

(i) Method of Moments (MoM)

The method of moments is an efficient method for finding Weibull parameters. The first moments about origin and second moment about mean are used to calculate the parameters 'k' and 'c'; the moments are given in equations (3) and (4) The calculation involve standard deviation and mean wind speed which are obtained from measured wind speed [14].

$$\bar{v} = c\Gamma(1 + 1/k) \quad (3)$$

$$\sigma = c[\Gamma(1 + 1/k) - \Gamma^2(1 + 1/k)]^{1/2} \quad (4)$$

(ii) Empirical Method (EMP)

Empirical method also uses standard deviation and mean wind speed for determining Weibull parameters. It is also called Standard deviation method [15].

The shape parameter **k** is evaluated by eq. (5).

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

And the scale parameter is evaluated by eq. (6).

$$\bar{v} = c\Gamma(1 + 1/k) \quad (6)$$

(iii) Energy Pattern Factor Method (EPM)

EPM also known as power density method, it is simple and easy to implement. It uses average of wind speed cubes (v^3) and cube of average wind speed$(\bar{v})^3$. $\frac{\overline{v^3}}{(\bar{v})^3}$is known as energy pattern factor (E_{pf}). The scale factor is determined directly from energy pattern factor. The equations for finding scale parameters are the same as those used for method of moments and empirical method [16]. These equations are given below:

$$E_{pf} = \frac{\overline{v^3}}{(\bar{v})^3} \quad (7)$$

$$k = 1 + \frac{3.69}{(E_{pf})^2} \quad (8)$$

$$\bar{v} = c\Gamma(1 + 1/k) \quad (9)$$

(iv) Maximum Likelihood Method (MLM)

MLM was suggested by Steven et al. [7]. It adopts an iterative procedure for determination of parameters, k and c. These parameters are found by the eqs. (10) and (11).

$$k = \left[\frac{\sum_i^n v_i^k ln(v_i)}{\sum_i^n v_i^k} - \frac{\sum_i^n ln(v_i)}{n}\right]^{-1} \quad (10)$$

$$c = \frac{\sum_i^n v_i^k}{n} \quad (11)$$

The zero wind speed would make calculation impossible because of Logarithm of zero is indeterminate. An initial and suitable value of k for iteration processis2.

Modified Maximum Likelihood Method (MMLM)

The modified maximum likelihood method employs frequency distribution, i.e. the data should be in Weibull distribution format [17]. like maximum likelihood method,it is also an iterative method. Following equations are used to calculate Weibull parameters 'k' and 'c'.

$$k = \left[\frac{\sum_i^n v_i^k ln(v_i) f(v_i)}{\sum_i^n v_i^k f(v_i)} - \frac{\sum_i^n ln(v_i) f(v_i)}{f(v \geq o)}\right]^{-1} \quad (12)$$

$$c = \frac{\sum_i^n v_i^k f(v_i)}{f(v \geq o)} \quad (13)$$

Result and Discussion

The energy crisis has been a constant issue for Pakistan and developing countries. Government as well as Scientists has been putting a lot of effort to find alternate methods for generation of electrical energy. Wind is one of the best options for clean and uninterrupted energy source at many part of the world. Pakistan's coastal areas have an appreciable potential of wind to generated electrical energy. Ormara, Pakistan is one of the coastal areathat has remarkable wind potential. Ormara town having population of 17000 and area about 1.5km^2 is subdivision ofPasni situated in Gwadar district which is a part of Balochistan province of Pakistan. It is actually located in Makran coast between Gwadar and Karachi (360 km west of Karachi and 230km east of Gwadar). Ormara is one of the important place in Pakistan for extraction of renewable energy having high wind speed potential for efficient utilization which may play vital rule to overcome the current energy crises in Pakistan.

Fig. 1. Map of Ormara, Pakistan

The Weibull distribution parameters have been calculated for 12:00 hour wind speed data from 1998-2007 for Ormara. The shape and scale parameters (k and c) are estimated by five methods, MoM, EMP, EPM, MLM, and MMLM. A comparison of shape parameter (k) and scale parameter (c) by MoM, EMP, EPM,MLM and MMLM, is given in table I. The theoretical probability distribution (PDF) and the cumulative distribution functions (CDF) were generated with the help of shape and scale parameters. Both PDF and CDF are plotted for each month from January to December; measured wind speeds for (1998-2007) are used to generate histogram(see Figure. 2). Table II gives the comparison of measured and predicted mean wind speeds. The last of table II shows the coefficient of correlation between measured and predicted mean wind speeds.

Conclusion:

Ten years (1998-2007) 12:00 hour wind speed data of Ormara have been analyzed and used to compare the performance of five numerical methods (MoM, EMP, EPM, MLM, and MMLM) for determining Weibull distribution parameters. The values of Scale and Shape parameters are estimated by these numerical methods. Theestimated values of ‘k’ and ‘c’ are used to generate PDF and CDF of Weibull distribution. The PDF are compared with the histogram generated from measured wind speed. From the analysis, the following conclusions are drawn:

(i) The values of scale parameters for the months from Jan. to Dec. found by MoM, EMP, EPM,MLM and MMLM are in good agreement ca. 0.01. MMLM finds slightly different values of scale parameter.

(ii) The estimated value of shape parameter found by MoM and EMP are almost identical.

(iii) The EPM estimated value of shape parameter is less than measured value of MoM, EMP, and MLM, except for December where EPM estimated value is highest. The difference is in the range of 0.01.

(iv) Thedifference in estimated value of shape parameter found by MMLM and other four methods is within a margin of 0.3.
(v) The plot of PDF generated by estimated parameters and histogram generated by measured wind speed are in good agreement.
(vi) Correlation between estimated and measured mean values of wind speed indicates all five methods are suitable for determining Weibull parameters and the MoM, EMP and MLM are better than MMLM and EMP.

Table I: The estimated values of Weibull parameters by five numerical methods.

Method	MoM		EMP		EPM		MLM		MMLM	
Months	k	c	k	c	k	c	k	c	k	c
Jan	1.8313	5.2548	1.8563	5.2577	1.7167	5.2366	1.8676	5.2659	1.6802	5.0046
Feb	1.9198	6.5095	1.9443	6.5118	1.8979	6.5072	1.9315	6.5238	1.9218	6.5722
Mar	2.4181	6.9237	2.4352	6.9227	2.2789	6.9297	2.3478	6.9215	2.1471	6.5936
Apr	2.6812	8.5763	2.6925	8.5750	2.6078	8.5838	2.6810	8.5982	2.5934	8.4416
May	2.9267	7.9028	2.9321	7.9022	2.7437	7.9227	2.8266	7.9137	2.7156	7.7937
Jun	2.8334	6.5021	2.8411	6.5014	2.6573	6.5170	2.7065	6.5001	2.5603	6.3296
Jul	2.8546	6.8120	2.8617	6.8113	2.6585	6.8295	2.7198	6.8148	2.6526	6.8890
Aug	3.3057	7.1998	3.3016	7.2003	2.9924	7.2337	3.1294	7.2086	3.0286	7.1340
Sep	2.7035	7.1673	2.7143	7.1663	2.5753	7.1782	2.6567	7.1877	2.6771	7.1785
Oct	2.6128	5.7395	2.6257	5.7386	2.5974	5.7405	2.6162	5.7379	2.4213	5.8017
Nov	2.4260	4.9819	2.4430	4.9812	2.4251	4.9820	2.4347	4.9864	2.7452	5.4576
Dec	2.1010	4.6194	2.1236	4.6196	2.1375	4.6198	2.1161	4.6274	1.7868	4.2521

Table II. The mean wind speed (Measured and Predicted)

Months	Mean Wind Speed					
	Measured	MoM	EMP	EPM	MLM	MMLM
Jan	4.6701	4.6700	4.6267	4.5884	4.6347	4.4028
Feb	5.7645	5.7748	5.7092	5.6949	5.7158	5.7512
Mar	6.1395	6.1386	6.1256	6.1100	6.1134	5.8106
Apr	7.6260	7.6249	7.6226	7.6208	7.6418	7.4941
May	7.0505	7.0495	7.0488	7.0465	7.0476	6.9297
Jun	5.7932	5.7925	5.7923	5.7915	5.7803	5.6185
Jul	6.1115	6.0703	6.0697	6.0675	6.0601	6.1192
Aug	6.4597	6.4589	6.4589	6.4588	6.4495	6.3732
Sep	6.3749	6.3741	6.3737	6.3730	6.3879	6.3814
Oct	5.0993	5.0986	5.0971	5.0968	5.0958	5.1370
Nov	4.4180	4.4173	4.4108	4.4100	4.4146	4.8560
Dec	4.0920	4.0915	4.0783	4.0793	4.0844	3.7499
Correlation between measured and estimated values of mean wind speed		0.999933	0.999841	0.999674	0.999805	0.980642

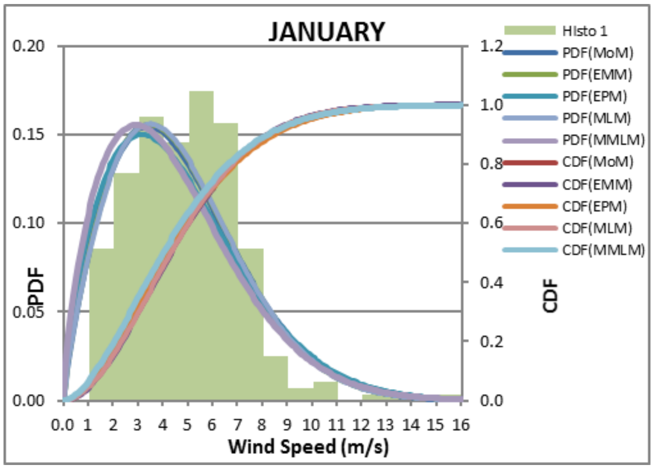


Fig. 2 (a)

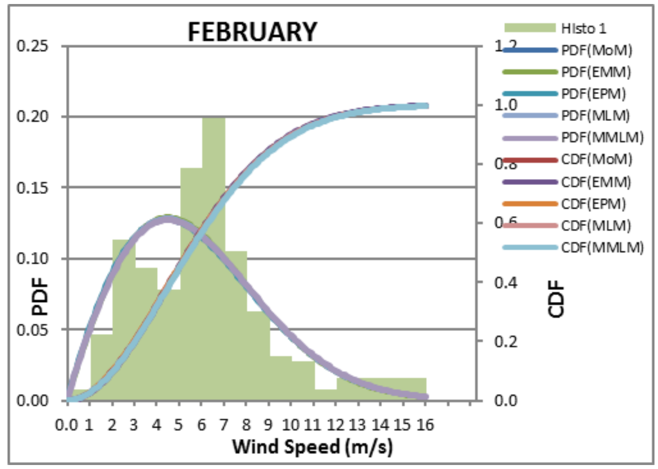
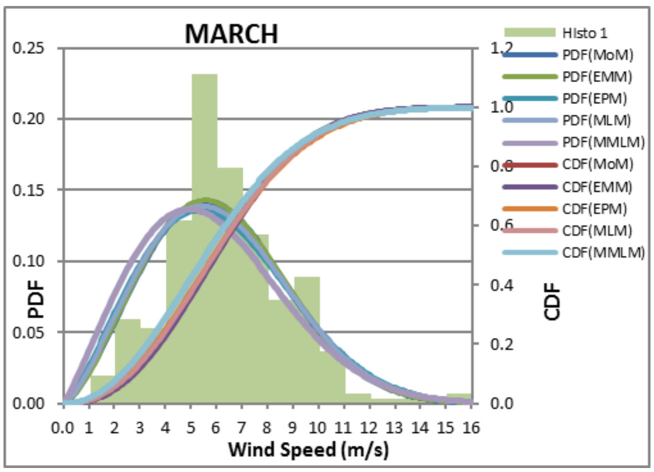


Fig. 2 (b)



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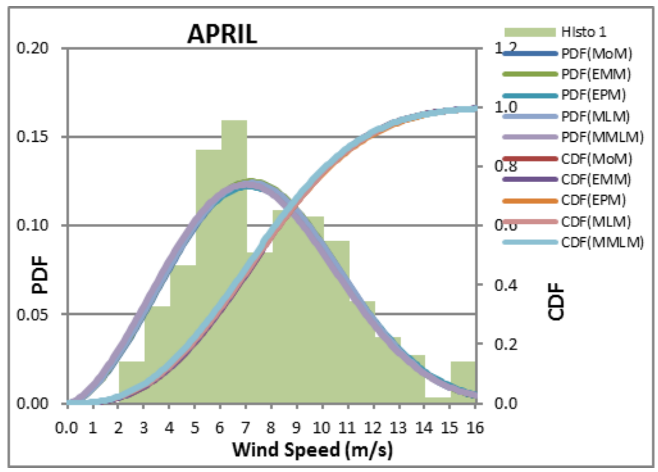

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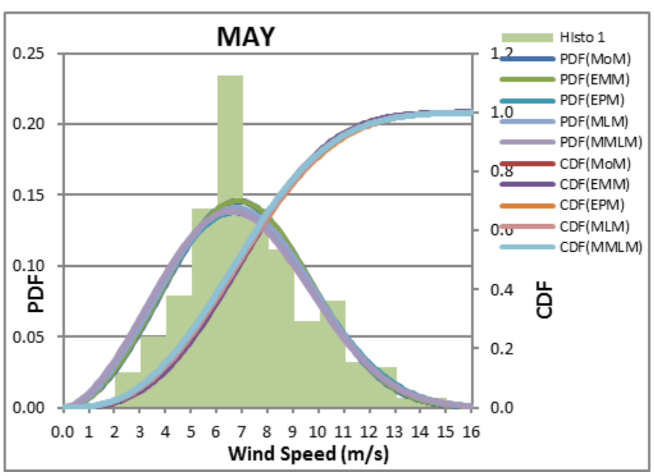

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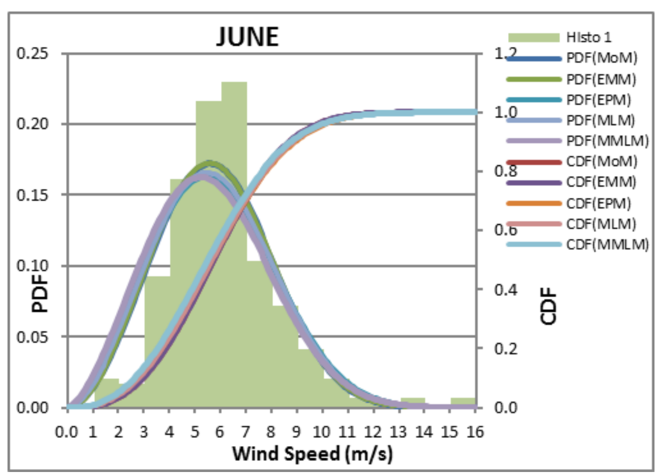

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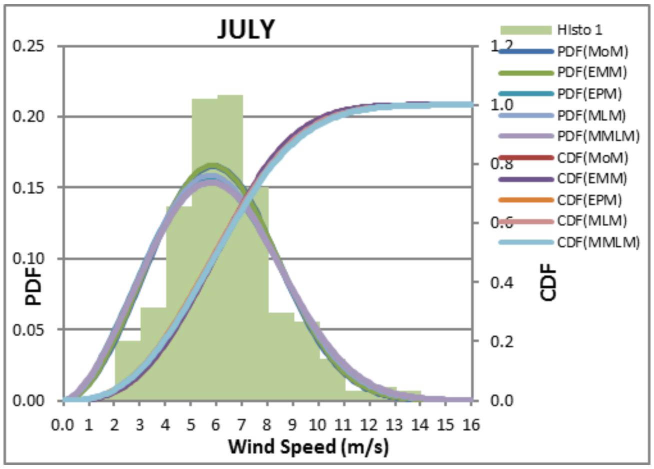

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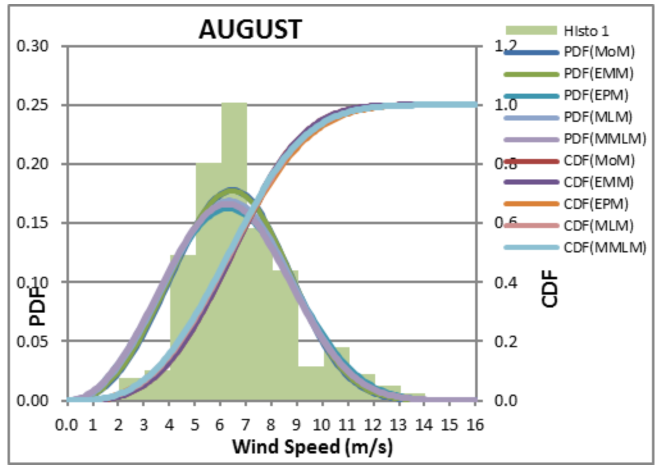

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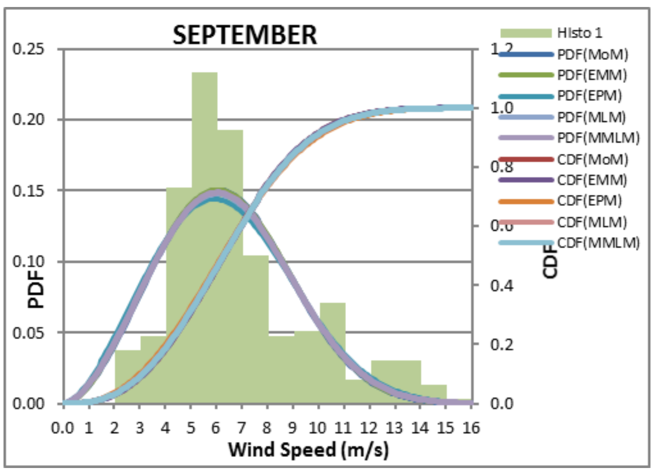

Fig. 2 (i)

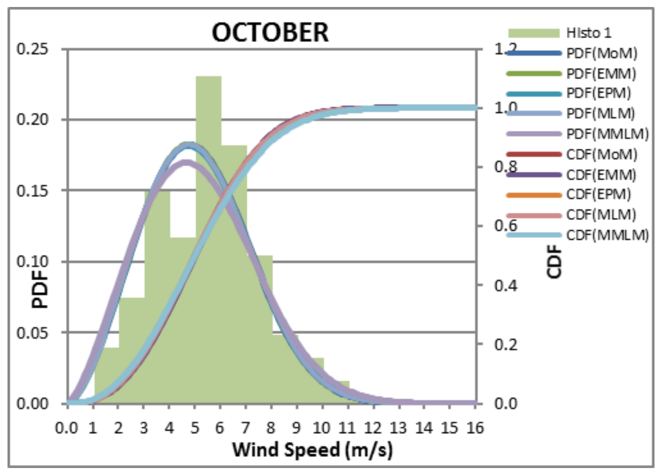

Fig. 2 (j)

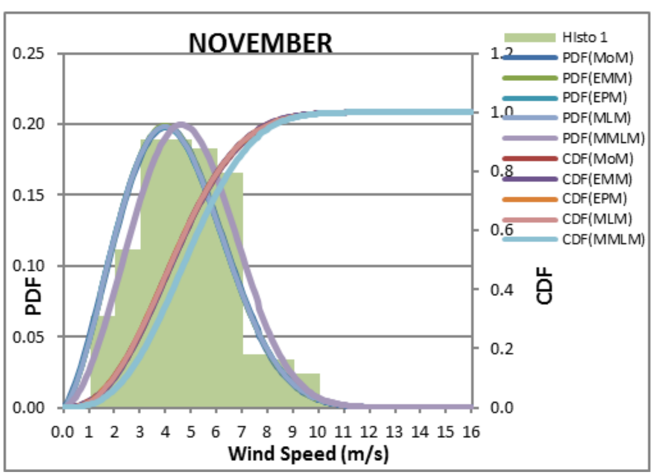

Fig. 2 (k)

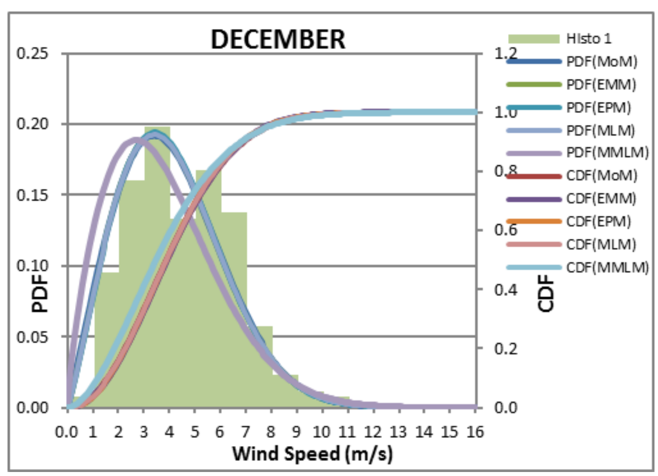

Fig. 2 (l)

Fig. 2. Plot of PDF,and CDF obtained from five methods MoM, EMP, EPM, MLM and MMLM. The histogram is generated by measured wind speed.

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