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An Experimental Study of Weibull and Rayleigh Distribution Functions of Wind Speeds in Kosovo

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Abstract

This paper compares two commonly used functions, the Weibull and Rayleigh distribution functions, for fitting a measured wind speed probability distribution at a given location over a certain period. The monthly and annual measured wind speed data at 84 m height for the years have been statistically analyzed for the country with a large capacity - Kitka. The analysis is made in the case of the implementation of all the predicted capacity of wind turbines and by virtue of the probability of power distribution. The Weibull and Rayleigh probability distribution functions have been determined and their parameters have been identified. The average wind speed and the wind power density have been estimated using both distribution functions and compared those estimated from the measured probability distribution function. The Weibull distribution function fits the wind speed variation better than Rayleigh distribution function. The average wind speed was found to be 4.5 m/s and the average wind power density was 114.54 W/m According to results, we can conclude that such a distribution of winds in this region yields an appropriate average value of wind power.

***Keywords**: weibull distribution, rayleigh distribution, wind energy, wind data in kosovo*

1. Introduction

Kosovo as a signatory of the Energy Community Treaty plans the construction and use of renewable energy capacities in the value of 20%. One of the ways of using renewable energy in Kosovo is the use of wind power. Investments that are made in the energy sector are very large investments that need to give you a proper analysis of the feasibility of the respective project and of the economic side as well. One of the studies in recent years is energy generation by using wind potential that shows great improvement in the world, especially in Europe.

Kosovo is a rich country in terms of wind potential. Energy, Kosovo's techno-economic wind potential from studies conducted mainly by private companies in the field of energy for investment purposes, highlight high capacity. The capacity currently installed in Kosovo, based on the measurements made by UNDP in 2012 comes to 1.35MW. One of the ways that show the potential of the wind at any place is the distribution of Weibull and Rayleigh. This is what is being done for the place called Kitka in the municipality of Kamenica in Kosovo.

The energy source from wind is still a new field for Kosovo, as the wind was previously used only for mechanical work (e.g. windmills). Nowadays, in particular, wind energy is one of the fastest growing, cost-effective, lightweight, high efficiency and the environmentally accepted mean of electric power generation. The estimate terrain elevation above sea level is 1142 meters. In Kitka is planned to installs 13 wind turbines [1, 2]. In the present study, hourly time-series wind speed data in Kitka (latitude: 42° 39' 56'' (42.6656°) north, Longitude: 21° 39' 36'' (21.66°) east) measured for the year 2015, have been statistically analyzed as shown in Figure 1.

The location of wind turbine positioning in Kitke represents a fairly windy ground, which makes it a very suitable place for both wind power generation and exploitation [3, 4]. A met tower as shown in Figure 2 is used to measure wind speed, wind direction, temperature, barometric pressure, relative humidity, and few other atmospheric conditions [5-7].

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Figure 1. Places in Kosovo (42.6026° N, 20.9030° E) where wind energy can be used [1]

Figure 2. The pillar in which anemometry is set to make measurements at different altitudes ranging from 40m, 60m, 80m, and 84m

2. Rayleigh and Weibull Distribution

Air density, and hence power in the wind, depends on atmospheric pressure as well as temperature. Since air pressure is a function of altitude, it is useful to have a correction factor to help estimate wind power at sites above sea level. There are various methods for getting characteristic of wind speed. Weibull and Rayleigh's distribution are the most preferred methods. Probability density function and cumulative density function are determined with this distribution method [8, 9, 10, 11]. These methods are suitable for wind speed distribution, easy in terms of the determination of parameters and flexible so they are used enormously. Weibull distribution was found by Swedish physicist Waloddi Weibull in the 1930s. In order to realize the optimum design of turbines and to minimize the cost of their production, more accurate information on distribution and wind power needs to be obtained. When wind speeds are measured over a year, it is noted that: in most areas, strong storms are rare, while light and moderate winds are very common. For a given terrain, the variation of wind speeds is decomposed with the so-called "Weibull Distribution" [12, 13,14].

The distribution consists of two parameters. Weibull probability density function that is used in the determination of the most frequent wind speeds is expressed as in equation:

$$f_v\,(w) = \left(\frac{k}{c}\right).\left(\frac{w}{c}\right)^{k-1}\; exp\left[-\left(\frac{w}{c}\right)^{k}\right] \tag{1}$$

Where: w – air velocity, k – is the Weibull shape parameter and the c is Weibull scale parameter. Once the mean speed, and the variance , of data, are known, the following approximation can be used to calculate the Weibull parameter, k is:

$$k = \left(\frac{\sigma}{w_m}\right)^{-1.086} \tag{2}$$

Where, - variance of wind velocity, m/s.

$$c = \frac{2 \cdot w_m}{\pi} \tag{3}$$

The main limitation of the Weibull density function is that it does not accurately represent the probabilities of observing zero or very low wind speeds. Nevertheless, Persaud proposes an alternative hybrid Weibull function as well as referring to the Dirac Delta function allowing for probabilistic assessment of zero and low wind speeds. When Weibull distribution is applied to wind data, shape parameter takes the value of one near the equator, two for temperate latitudes and three for continuous wind zones. One of the main issues contained in this data is the fact that there are data equal to zero. Because the Weibull distribution is only for data that is greater than zero, this caused several problems for our parameter estimation [15, 16].

Rayleigh distribution is a special form of Weibull distribution and shape parameter is always equal to two. Mean wind speed is enough to determine wind characteristic in this distribution. It is known that wind distribution is more applicable to Rayleigh distribution when mean wind speed is greater than 4.5 m/s. Rayleigh distribution function is shown in equation 4. Frequency probabilities of wind and blowing time in one year can be established thanks to this distribution. The distribution is shown graphically, where the area under it is equal to 1.

$$f_R(w) = \frac{\pi \cdot w}{2 \cdot w_m^2} \cdot \cdot \exp\left[- \cdot \left(\frac{\pi}{4}\right)\left(\frac{w}{w_m}\right)^2 \right] \tag{4}$$

The power coefficient is not a static value as defined in the main question; it varies with the tip speed ratio of the turbine [17]. Tip speed ratio is defined as:

$$\lambda = \frac{blade\,tip.speed}{wind.speed} \tag{5}$$

$$blade\,tip.speed = \frac{rotational\,speed(rpm) \cdot \pi \cdot D}{60} \tag{6}$$

2.1. Wind Data

Based on the Electricity Balance in the Kosovo Power System it is estimated that for the production of electricity from the primary power plants by the RES, the factor of the respective capacity for the production of electricity from wind energy is that the capacity factor is CF = 0.2. Wind data for Kitken, shows a high potential for installing wind generators. The overall capacity that is planned to be installed there is in the value of 30MW.

An important parameter when wind turbines are to be implemented is the accuracy of wind speed data. In the case of Kitkes, in order to correctly determine the wind speed, measurements by an anemometer are made in 4 different altitudes, for every minute throughout the year as shown in Figure 3. By analyzing wind speed data, from May to December, we can see that in the summer months there is an almost constant wind speed value, and as a whole an average wind speed value, while in the months in winter, in some cases the wind speeds reach even negative values, even in December, in some cases it reaches the value of -11.09 m/s.

Table 1. Average Wind Data per Year [1]

Data	C1-Thies 4.3351(m/s) in 84m ESE-10 min	C2-Thies 4.3351(m/s) in 80m ESE-10 min	C3-Thies 4.3351(m/s) in 60m ESE-10 min	C4-Thies 4.3351(m/s) in 40m ESE-10 min
Average per year	6.671	6.642	6.44	5.92

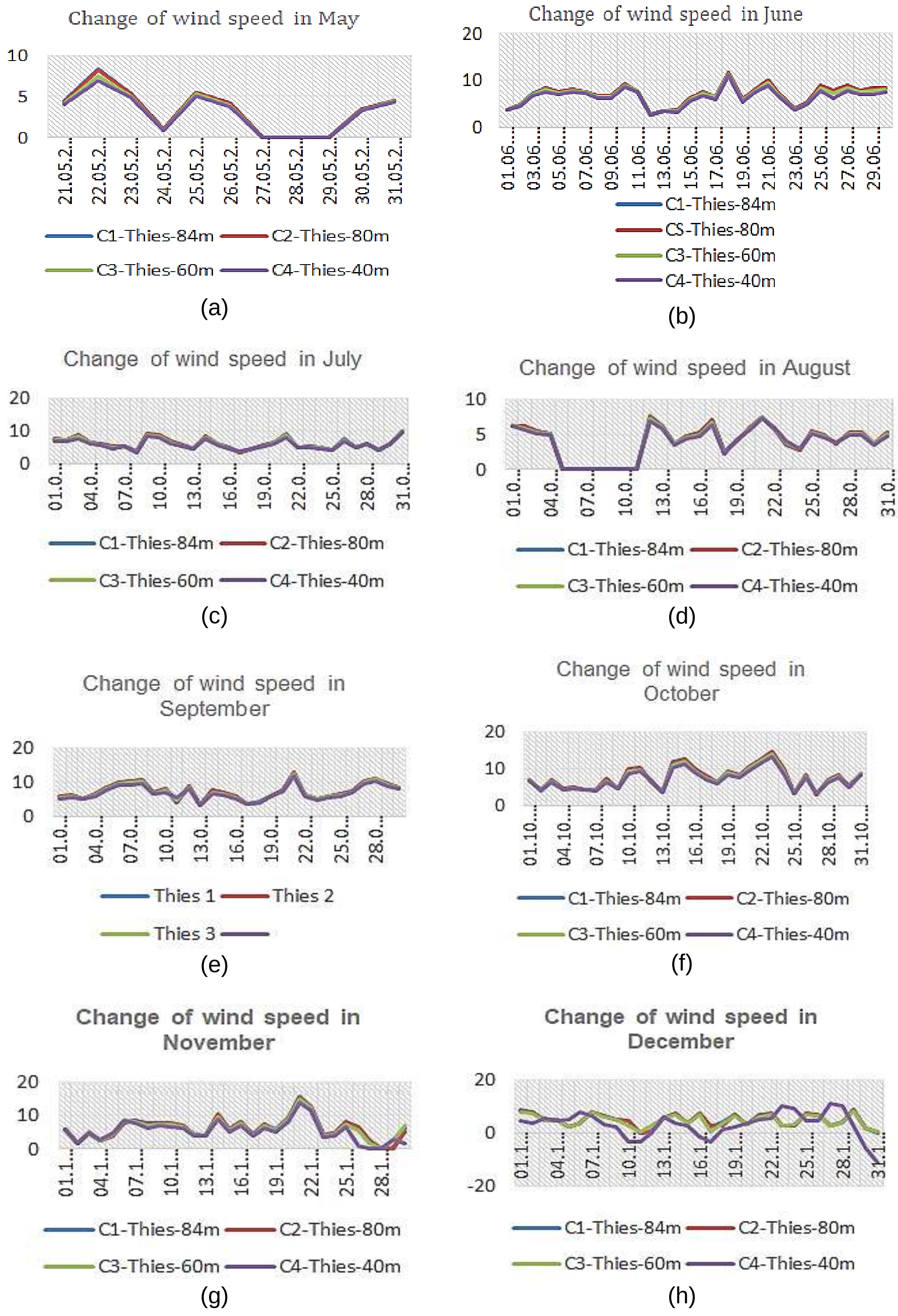
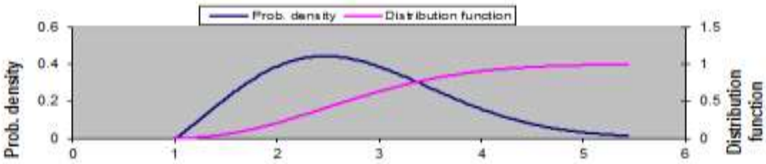


Figure 3. Wind data for Kitka between May to December 2015

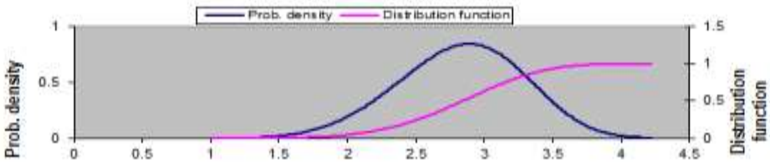
Analyzing the average wind speed values during the year, then we see that the average velocity value in the case of wind turbine installation at the height of 80m and 84m, have very small variations in velocity, and in this case the setting at an altitude of 84m turbines would impact at a very high cost of installation of all turbines.

3. Results and Analysis

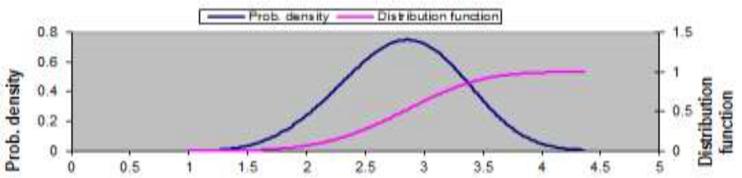
Assuming that one of the potential wind turbine manufacturers used in the Kitka case is Amperax, it follows that the technical data of the turbines used will be as follows: 3 blades, diameter equal to 116m, and tilt angle of 4 degrees. In the absence of wind speed variance data, taking into account the exact location of wind turbine deployment, it has been assumed that the Weibull distribution factor scale is equal to 1 and then calculating the factor c in each month, Weibull's graphic representation of the distribution was extracted. Weibull distributions functions from May-December as shown in Figure 4.



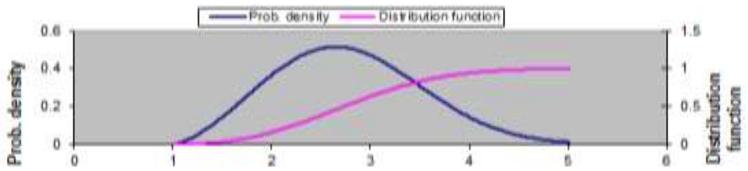
(a) Weibull distributions – May



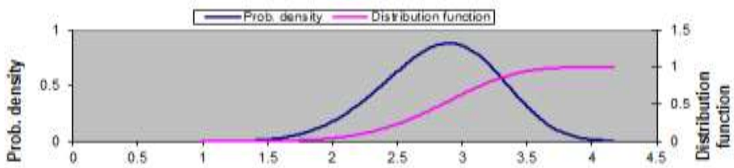
(b) Weibull distributions –June



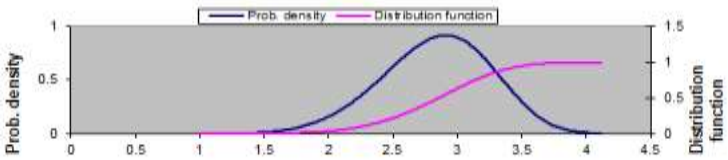
(c) Weibull distributions – July



(d) Weibull distributions – August

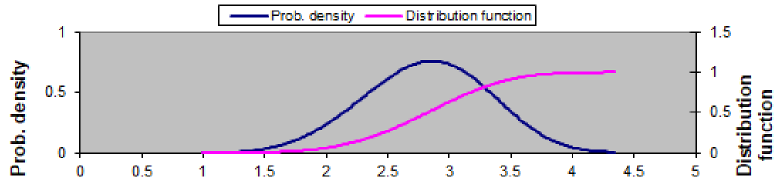


(e) Weibull distributions – September

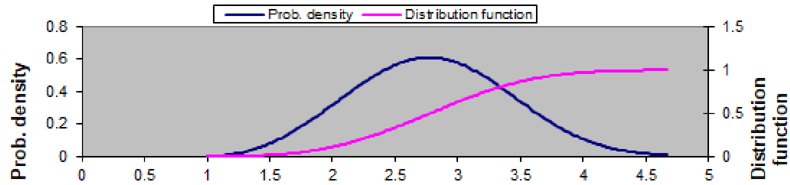


(f) Weibull distributions – October

Figure 4. Weibull distributions functions



(g) Weibull distributions – November



(h) Weibull distributions – December

Figure 4. Weibull distributions functions

3.1. Rayleigh Simulations

In addition to Weibull's distribution analysis, another important parameter in the case of the analysis of the velocity and wind power distribution is the Rayleigh distribution, which is equal to the Weibull distribution when the shape parameter is equal to 2.

The ratio between blade tip speed and wind speed, as an important indicator between the correct solution of the type and size of the wind turbine, in the case of the case analysis Kitka, is that it is exact value. If we take into account the fact that wind turbines for an optimum power range from 15 to 20 revolutions per minute, and if we receive a value of 18 revolutions per minute, as the average value between the two above mentioned values, then the ratio between blade tip speed and wind speed will be 0.273. This measurement is performed when wind speed is measured when wind turbines are located at 84m high. Also, if we analyze the difference between observed and fitted distributions, in the case of Rayleigh distribution, for 18 different values of x, and the Rayleigh function presented as a function of x values. After the distributions are fitted, it is necessary to determine how well the distributions you selected fit to your data.

Also, if we analyze the difference between observed and fitted distributions, in the case of Rayleigh distribution, for 18 different values of x, and the Rayleigh function presented as a function of x values. After the distributions are fitted, it is necessary to determine how well the distributions you selected fit to your data. As a result, you will select the most valid model describing your data.

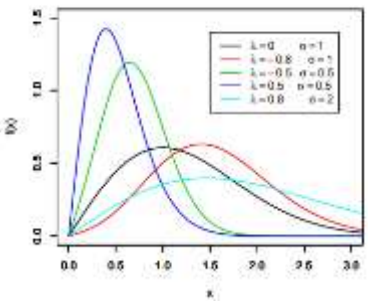


Figure 5: The various transmuted Rayleigh distributions

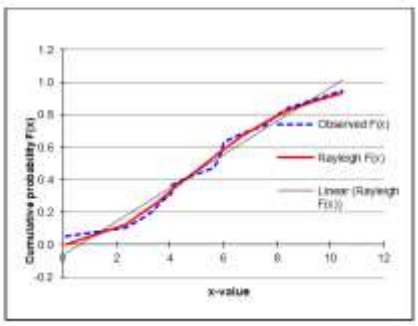


Figure 6. Difference between observed and fitted distributions at rayleigh distribution

4. Conclusion

From the above analysis, we can conclude that the proposed simulation model is applicable for assessing the potential of wind power generation. From our study, it is seen that it is necessary to calculate the monthly wind speed change using the Weibull estimation, as the potential of wind power may change significantly. According to the results of the simulation, it was shown that Weibull parameters directly affect the available wind power as during the duration of the electricity production. Therefore, the accurate wind forecast and correlation with a load of electricity load can allow a high wind power penetration. It is recommended that further steps be taken to develop this renewable energy source in Kitka, although the values shown in the Weibull distribution show a high potential for using such a source for most of the time. Both Weibull and Rayleigh distribution methods, made when the wind turbine is moved to an altitude of 84m, indicates the wind speed production. The Weibull model is better in fitting the measured monthly probability density distributions than the Rayleigh model. This is shown from the monthly correlation coefficient values of the fits Figure 4. The Weibull model provided better power density estimations in all 12 months than the Rayleigh model. As a result, we can conclude that the Weibull distribution estimates wind power density with less error than the Raleigh distribution.

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