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Utilization of Weibull Distribution Function to Wind Energy Assessment in Puerto Princesa City

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Abstract:- A small variation in wind speed produces a significant deviation in the output capacity of the wind turbine due to the cubic bonding of these two parameters. The correct estimation of the wind resource at any location is therefore deemed to be of utmost importance. Investigations relating to the evaluation of wind resources have demonstrated considerable enthusiasm for the installation of various wind energy technology such as nano, micro, mini, medium and large-scale wind energy generation. This paper aims to assess wind energy potential using the Weibull distribution function by analyzing the wind structure in the area and determining the wind power density. The data, such as wind speed and direction, were obtained from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), the meteorological station located in Puerto Princesa City. The data analysis involved determining the average wind speed, probability of wind speed, and wind direction. The most probable wind speed was 2.85 m/s, and the daily average wind speed ranges from 2 to 3 m/s. The most dominant wind direction is from the west. At 10 m height, the calculated wind power density is 51.86 W/m^2. The power density of wind is estimated to be 139.4 W/m^2 at 30 m height by extrapolation, which is classified as Class 1. Using this classification, the wind energy resource potential in Puerto Princesa City is marginal and moderate as applied to utility-scale rural power applications, respectively.

Keywords:- *Wind Distribution, Wind Energy Assessment, Wind Power Density, Wind Structure, Weibull Distribution Function.*

I. INTRODUCTION

As the year goes by, the technology and population growth, which corresponds to greater electricity demands. In the Philippines, as a developing country, electrification is a must. However, some of the provinces in the country have no access to power grids. This problem causes delays in the development of the country and its regions.

In Palawan, as of 2020, the power supply is enough to meet the demand. However, the demand will increase each year due to increased customer count, which increases by 7.5% annually for ten years, from 2017 to 2027 [1]. Moreover, the supply will reduce the deficit by 4.04 MW in 2024 and increase to 21.44 MW by 2027. A rise in supply should accompany this increase in demand. In some commercial buildings, solar panels are installed to cut a portion of their power demand, but it is not enough to meet future energy needs. The most popular alternative energy source that could solve the power shortage in Palawan is wind energy. However, selecting the most suitable location to harness wind energy demands precise assessment. Assessment of wind energy is performed using different methods, and the most popular is the Weibull method, and this paper will focus on that method. The Weibull method determines the probability of wind speed in a particular location. This study aims to determine the wind characteristic in Puerto Princesa City using the data obtained from the meteorological station of the PAGASA. The proponents chose the site to investigate since it has the highest electricity demand in the province of Palawan.

The main objective of the study is to determine the wind distribution in Puerto Princesa City. Specifically, the study aims to assess and analyze the wind structure in the area, present models, and wind power density.

The researchers believe that studying the city's wind structure will help renewable energy developers provide a useful assessment to estimate the vicinity's energy.

II. METHODOLOGY

This part of the paper discusses the procedure in conducting this study. Fig. 1 shows the conceptual framework of the study.

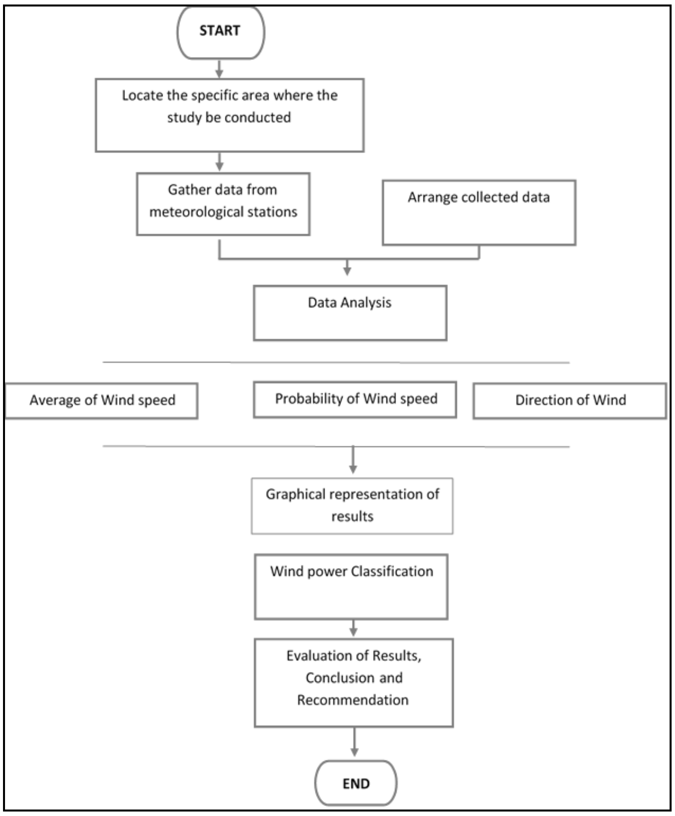

Fig. 1. Conceptual framework

A. Locate the specific area where the study be conducted

The researcher will assess the wind characteristics in Puerto Princesa City—the westernmost city in the Philippines.

B. Gather data from the meteorological station

The data from 2017 to 2019 is obtained from PAGASA meteorological station located in Puerto Princesa City. The station's geographic location is 09°45' N latitude, 118°44' E longitude, and an elevation of 14.9 meters. The station extracts hourly wind data from 0000 to 1200 hours and tri-hourly wind data from 1200 to 0000 hours of the day. The data collected involves wind speed and direction. In this paper, the hourly data will be utilized for the analysis for uniformity of data.

C. Data analysis

The data analysis involves calculating average wind speed in the area, the probability of wind speed, power density, and the probability of wind speed as a function of direction. The average wind speed can be calculated using the equation from [2], which is defined as

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n} v_i \tag{1}$$

C.1 Probability of wind speed

The probability of wind speed can be acquired using the Weibull probability distribution function (Eq. 1). The usefulness of wind speed can be attained using this function [3]. The Weibull distribution was widely adopted to model wind frequency due to its flexibility and simplicity [4]. The most probable wind speed was acquired through the use of Weibull distribution parameters, which is defined as

$$V_{mp} = c\left(1-\frac{1}{k}\right)^{\frac{1}{k}} \tag{2}$$

C.1.1. The parameters

The shape parameter k and scale parameter $c$vof the Weibull distribution will be estimated using the empirical method of Justus [2], [5]-[6]. This method was also recommended for the estimation of Weibull parameters [7]-[11].

C.2. Power density function

Power density is the time rate of energy per unit volume. Based on the Weibull distribution function result, the power density can be calculated using Eq. 3 [12]. The ideal value of air density will be utilized in the analysis, which is equal to 1.225 kg/m^3 [5], [13].

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

C.3. Wind direction

The wind direction can be presented using the wind rose. The data gathered from the meteorological station will be plotted in the wind rose. The wind rose will exhibit the most frequent direction of the wind.

D. Wind power classification

The classes of wind power density that will be utilized for this study will be adapted from the Philippine Wind Atlas [14]. This classification was based on a 30-meter height, as shown in Table 1.

TABLE 1. WIND POWER CLASSIFICATION

Class	Resource Potential		Wind Power Density (W/m^2) at 30 m	Wind Speed (m/s) at 30 m
	Utility	Rural		
1	Marginal	Moderate	100 – 200	4.4 – 5.6
2	Moderate	Good	200 – 300	5.6 – 6.4
3	Good	Excellent	300 – 400	6.4 – 7.0
4	Excellent	Excellent	400 – 600	7.0 – 8.0
5	Excellent	Excellent	600 – 800	8.0 – 8.8
6	Excellent	Excellent	800 – 1200	8.8 – 10.1

Therefore, performing an extrapolation is essential and is done using power law, which is defined as

$$u(z) = u(z_0)\left[\frac{z}{z_0}\right]^{\alpha} \tag{4}$$

where the z is the height above the earth's surface, z_0 is the reference height for wind speed, $u(z_0)$, and α the wind shear coefficient. The power density at a particular height can also be computed as

$$P = P_0 \left(\frac{z}{z_0} \right)^{3\alpha} \quad (5)$$

where P is the unknown wind power at height z, and P_0 is the known power density at the height, z_0. Table 2 gives the value of the coefficient [15].

TABLE 2. SURFACE ROUGHNESS COEFFICIENT

Landscape Type	Friction Coefficient (α)
Lakes, ocean and smooth hard ground	0.10
Grasslands (ground level)	0.15
Tall crops, hedges and shrubs	0.20
Heavily forested land	0.25
Small town with some trees and shrubs	0.30
City areas with high rise buildings	0.40

III. RESULTS AND DISCUSSION

The frequency distribution of wind speed at 10 meters height in the selected location was calculated using Weibull Distribution (Eq. 1). The results of the calculation were plotted in Fig. 1. A one-year wind data set was used in the analysis and taken from PAGASA meteorological station, located at 09°45' N, 118°44' E, and 14.9 meters above sea level. The wind data set was recorded every 3 hours, from January 1 to December 31, 2019. The two parameters of Weibull distribution, the shape, and scale parameter, was estimated using the empirical method and has a value of 2.64 and 3.41, respectively. From the parameters, the most probable wind speed was calculated using Eq. 2 and obtained the result of 2.85 m/s. The result obtained using Eq. 2 matches in the distribution in Fig. 2. The result can also be compared in the graphical representation of daily average wind speed shown in Fig. 2. It can be observed in Fig. 3 that the daily average wind speed mostly varies between 2 to 3 m/s.

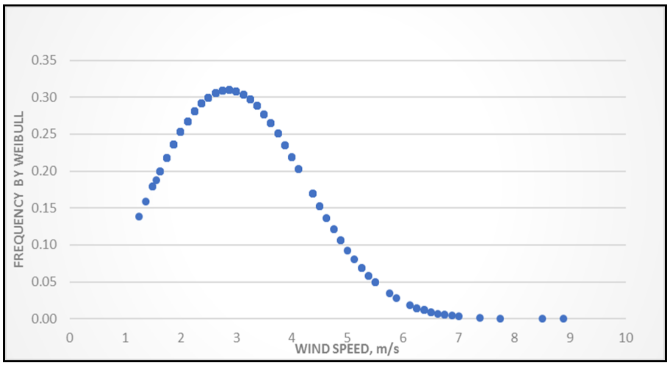

Fig. 2. The wind speed probability distribution of the year 2019

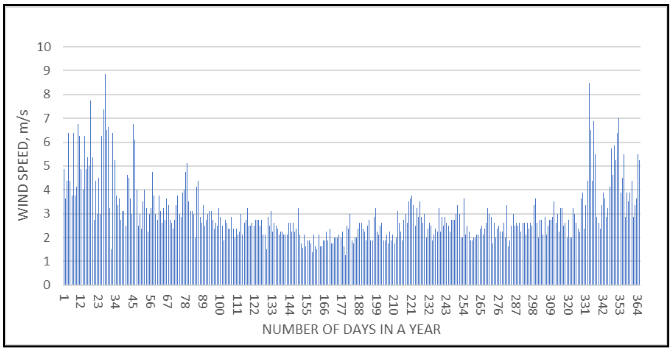

Fig. 3. Variation of daily average wind speed of the year 2019

Eq. 3 was used to achieved the power density of wind. Then, two-parameter of Weibull was used to obtain the result. At the 10-meter height, the result obtained was 51.86 W/m^2. However, the result obtained was not comparable to the Philippine Wind Atlas' wind power classification. In Table 1, the basis of the classification is at 30 meters in height. Thus, extrapolation was necessary to obtain a comparable result, and Eq. 5 was useful in this part. The meteorological station is located in the city; with this, the value of the surface roughness coefficient used is 0.4, as suggested in Table 2. The result obtained from this calculation was 139.4 W/m^2, and wind power can be classified as Class 1.

The wind rose in Fig. 4 shows the most dominant direction of wind speed. The figure shows that the most dominant wind came from the west and was followed by the east.

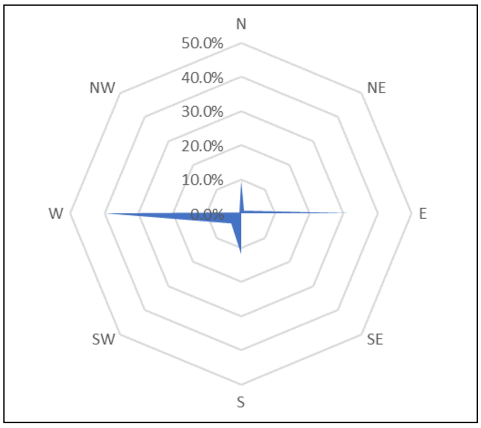

Fig. 4. Variation of daily average wind speed of the year 2019

IV. CONCLUSION

The Weibull distribution function was used in this study in assessing the potential of wind energy in Puerto Princesa City. The one-year data on wind speed and direction from January 1 to December 31, 2019, was obtained from PAGASA meteorological station located in Puerto Princesa City and was used in wind energy assessment.

The wind power density obtained at 10 meters is 51.86 W/m^2. An extrapolation was used to compare this result with the classifications in the Philippine Wind Atlas, which is at 30 meters. The extrapolation yields 139.4 W/m^2, and the wind power is classified as Class 1. Therefore, the wind energy resource potential in Puerto Princesa City is found to be marginal and moderate for utility-scale and rural power applications, respectively.

The researchers recommend future studies to explore other sites in Puerto Princesa and Palawan to find good and excellent wind power sources for utility-scale applications. This can generate additional energy for Puerto Princesa City and Palawan since the energy demand increases alongside economic development.

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