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Preliminary study of wind speed characterization to install a 400 W wind turbine

Estudio preliminar de caracterización de la velocidad del viento para instalar un aerogenerador de 400 W

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Abstract

The characterization of wind speed in Cancun, Q. Roo Mexico, had as objectives: 1. To estimate the efficiency and energy produced by a 400W wind turbine at a height of 10 m; 2. To carry out the wind speed characterization. The methodology used was the Weibull distribution. In order to calculate the distribution of the wind speed, with the Wind Rose software we analyzed the energy in different directions and the calculation of potential wind energy based on Rayleigh's analysis. The results showed: that the power generated from the wind speed calculated in (PV) 2.8 m/s was 1.48 W, its capacity factor at 0.004 which does not reach the permissible range of 0.25 to 0.40; the energy produced annually was 14.02 kW/year, it is required to raise the wind turbine to 13.4 m, to reach 12 m/s speed and to be efficient to install a 400 W wind turbine. The paper identifies the preliminary activities and illustrates the method of calculation of wind characterization and energy produced to define the installation conditions of the wind turbine. It also contributes to the scientific advance by estimating the characterization of the wind in Cancun Quintana Roo, Mexico, for future wind turbine installations.

Efficiency, Generated power, Wind speed

Resumen

La caracterización de velocidad del viento en Cancún, Q. Roo México, tuvo como objetivos; 1. Estimar la eficiencia y energía producida por un aerogenerador de 400W a una altura de 10m, 2. Hacer la caracterización de velocidad del viento. La metodología utilizada, fue la distribución de Weibull, para conocer la distribución de velocidad del viento, con el software Rosa de viento se conoce la energía en diferentes direcciones y el cálculo de energía potencial del viento basada en el análisis de Rayleigh. Los resultados arrojaron: que la potencia generada a partir de la velocidad del viento calculada en (PV) 2.8 m/s, fue 1.48 W, su factor de capacidad en 0.004 que no alcanza el rango permisible de 0.25 a 0.40, la energía producida anualmente fue de 14.02 kW/año, se requiere elevar el aerogenerador a 13.4m, para alcanzar 12 m/s de velocidad y sea eficiente instalar un aerogenerador de 400 W. Se contribuye identificando las actividades preliminares e ilustrando el método de cálculo de caracterización del viento y energía producida, para definir las condiciones de instalación del aerogenerador. La aportación al avanece científico es estimando la caracterización del viento en Cancún Quintana Roo México, en futuras instalaciones de aerogeneradores.

Eficiencia, Potencia generada, Velocidad del viento

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Introduction

One source of renewable energy generation is through wind turbines, which, driven by wind energy, spin their blades and produce via induction and magnetic field, an electromotive force or potential difference (V). In order to install a wind turbine, we must analyze certain environmental characteristics, such as: wind speed and direction, humidity, among others. However, it is important to estimate the wind characterization, i.e., identify its speed, constant speed intervals, direction and energy that it can produce for a particular wind turbine; therefore the questions we must answer are: What is the wind speed and direction? What is the potential energy of the wind speed? How many hours a day a wind turbine produces electricity? Is it efficient to install a 400W wind turbine in the city of Cancun?

However, with the wind speed characterization, the aforementioned questions can be estimated and answered.

To establish the wind profile in the city of Cancun, Q. Roo Mexico, we obtained the wind speed data of the Capitanía de Puerto, Cancun, Q. Roo Mexico, in 2018, at a height of 10 m. These data were obtained with the Wind Rose and the techniques of Weibull and Rayleigh, to know the direction, distribution and potential energy of the wind speed respectively.

We present how the wind speed characterization was measured, the relationships to calculate the average wind speed, its distribution through Weibull, the wind energy density E_D in kW/m^2, the intensity of annual energy E_I in kWh/m^2, the wind speed frequency V_E in m/s, the maximum energy speed for the wind V_{Fmax} in m/s and the energy in KW that a 400 W wind turbine will produce, installed at a height of 10 m.

Wind power

To carry out wind power generation projects, wind characterization must be done. It is necessary to know its speed and the direction that prevails at different times. Ecological aspects are also considered for implementation (Mathew, 2006).

(Fatma Gül Akgül, 2016) also mentions two important factors to obtain wind energy efficiently and economically, the first factor is to select the location where the wind system will be installed and the second is to identify the characteristics of the wind speed using the Weibull statistical distribution to model the data, together with the mean square root error and the correlation coefficient R^2 to identify the distribution that best fits the wind speed data and conclude that the inverse Weibull distribution is an alternative for better knowledge and extensive use of the Weibull distribution.

In reference to the calculation of wind energy, wind energy density (E_D) is the energy available by the rotor unit’s regime and time. This energy density is a function of wind speed and distribution. We can obtain the total energy available in the spectrum (E_S) by multiplying the wind energy density by the time factor.

Wind direction is an important variable in an energy conversion system. If the greatest amount of wind energy is received from one direction, it is important to know if there is any obstruction on that side for the wind flow. In this sense, most anemometers have a vane (propeller that is used to identify the wind direction).

On the other hand, the wind speed information and its direction can be presented in the Wind Rose application which indicates the distribution of the wind in different direction. The page is divided into 8, 12 or 16 equal sectors that represent different directions.

The information presented by the Wind Rose software is:

1. The average time of the direction in which the wind is received.

2. The product of this percentage and the average wind speed in this direction.

3. The product of the percentage of time and the wind speed cube.

With this information, the energy that exists in different directions can be identified.

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For the estimation of wind energy potential, it is recommended to analyze and interpret data from a weather station near the site where a wind generator is intended to be installed.

The Wind Rose software shows the distribution of frequencies, speed and energy in different directions. In this way, a preliminary estimate can be made and a profile of the site's potential to generate electricity can be presented.

The average wind speed is given by:

$$V_m = \left(\frac{1}{n}\sum_{i=1}^{n} V_i\right)^{1/3} \quad (1)$$

Where, V is the wind speed and n is the number of data measurements.

The standard deviation indicates the variability and individual deviation of the speeds.

$$\sigma_V = \sqrt{\frac{\sum_{i=1}^{n}(V_i - V_m)^2}{n}} \quad (2)$$

Thus, the lower values of the standard deviation indicate a uniformity of the data set.

If the wind speed values are presented as a frequency distribution, the average and standard deviation are given by:

$$V_m = \left(\frac{\sum_{i=1}^{n} f_i V_{i\ m}^3}{\sum_i^n f_i}\right)^{1/3} \quad (3)$$

$$\sigma_V = \sqrt{\frac{\sum_{i=1}^{n} f_i (V_i - V_m)^2}{\sum_{i=1}^{n} f_i}} \quad (4)$$

Using the accumulated frequencies and histograms, a pattern of wind speed curves can be defined, so that the Weibull and Rayleigh distributions are used to describe the wind variation more accurately.

The distribution function can be used to calculate the time at which the wind speed interval is.

$$P(V_1 < V < V_2) = e^{-\left(V_1/c\right)^k} - e^{-\left(V_2/c\right)^k} \quad (5)$$

$$\text{The turbine generates energy per h number of hours} = \left(e^{-\left(V_1/c\right)^k} - e^{-\left(V_2/c\right)^k}\right) \times 24hrs \quad (6)$$

For the wind regime analysis of the Weibull distribution, the parameter of factor k must be estimated as a parameter to determine wind uniformity, and c as the scale factor.

By the standard deviation method, the factor k is expressed as:

$$k = \left(\frac{\sigma_V}{V_m}\right)^{-1.090} \quad (7)$$

$$c = \frac{V_m k^{2.6674}}{0.184 + 0.816 k^{2.73855}} \quad (8)$$

(R. Ian Harris, 2014) demonstrates that the Weibull distribution is effective for the marginal distribution of the CDF P (V) wind speed and shows the Wind Rose waveforms. On the other hand, (J.V. Seguro, 2000) asserts that when wind speed data is available in a frequency distribution, the medium maximum likelihood method is the one recommended due to its accuracy and superiority in relation to the graphic method.

It is also important to calculate the wind energy density E_D in kW/m^2, the annual energy intensity E_I in kWh/m^2, the wind speed frequency V_E in m/s and the maximum energy speed for the wind V_{Fmax} regime in m/s.

On the other hand, the dependence of wind regimes implies that energy production is variable, so more energy is not always produced in the consumption peaks. That is why the use of wind energy should be considered as a complementary energy, and cannot be regarded as the energy base of a community, region or country. The prediction of the production of a wind turbine installation is very difficult, which creates problems and uncertainties in energy planning.

A wind turbine obtains its input power by converting the wind force into a torque (turning force), acting on the rotor blades; the amount of energy transferred to the rotor by the wind depends on the density of the air, the sweeping area of the rotor and the wind speed. Turbulence decreases the possibility of using wind energy effectively in a turbine, also causing greater breakage and deterioration in the wind turbine; wind turbine towers are usually built high enough to avoid wind turbulence near ground level (Danish wind industry Association, 2003).

With equation 9, it is observed that the speed required for a wind system to be efficient is a function of the ratio of the initial height and the required height.

$$V_2 = V_1 (\frac{h_2}{h_1})^{\alpha} \quad (9)$$

The value of α is set in a range of 0.20 to 0.40.

The effect of a building on wind flow affects wind speed and direction, according to figure 1, (Hemani, 2012).

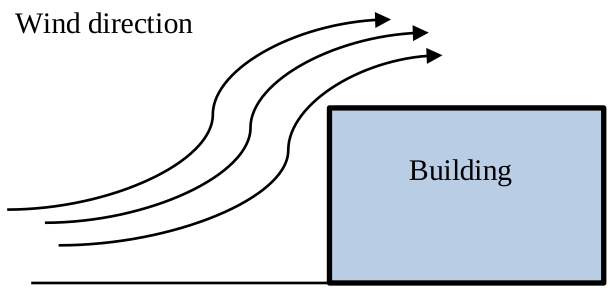


Figure 1 Turbulence generated by obstruction
Source: Ahmad Hemani

Power extracted from wind

According to Betz's law, a wind turbine slows down the wind up to 2/3 of its initial speed by passing through the rotor; this means that it is not possible to take advantage of all the kinetic energy of the wind. For a given value of wind speed, an aerodynamic rotor can only extract 59% of the available wind power (López, 2013).

The power of this air flow through the rotor is the flow of kinetic energy per unit of time, which is partially extracted by the blades varying linearly with the density of the air and by the wind speed cube (López, 2013).

Methodology

The analysis of wind distribution and speed in the city of Cancun; Latitude: 21.0833, Longitude: -86.85 can be done through a Weibull statistical distribution which models the wind speed distribution and therefore determines the average wind time and speed to estimate the electrical power and efficiency of a wind turbine.

With the wind speed data, the wind speed distribution, standard deviation, monthly frequency distribution, the Weibull distribution and the density probability are obtained, which indicates the fraction of time or the speed probability of wind and cumulative distribution function. The number of hours that the turbine generates energy is estimated through the minimum and maximum cutting speed, with a scale factor of c=3.5 and a form factor of k=2.88.

The potential energy estimate based on the Rayleigh analysis allows us to know the monthly wind energy and speed.

Results

Wind data analysis

The wind speed data which were used as first approach were obtained from the weather station of the Capitanía de puerto, in Puerto Juarez, Cancun Quintana Roo, Mexico, of the year 2018, categorized by day.

The data was analyzed and interpreted with the WRPLOT software for the wind rose, the WERA for the monthly analysis of the wind data and the Easy Fit software for statistical analysis.

The statistical data of the wind speed sample is shown in table 1, with an average wind speed of 2.799 m/s and a standard deviation of 1.0674.

Statistics	Value	Percentile	Value
Sample Number	365	Min	0.17
Range	5.66	5%	0.916
Mean	2.79	10%	1.356
Variance	1.13	25% (Q1)	2.105
Standard deviation	1.06	50% (Median)	2.81
Coefficient of variation	0.38	75% (Q3)	3.555
Standard error	0.05	90%	4.158
Asymmetry	-0.04	95%	4.519
Kurtosis	-0.24	Max	5.83

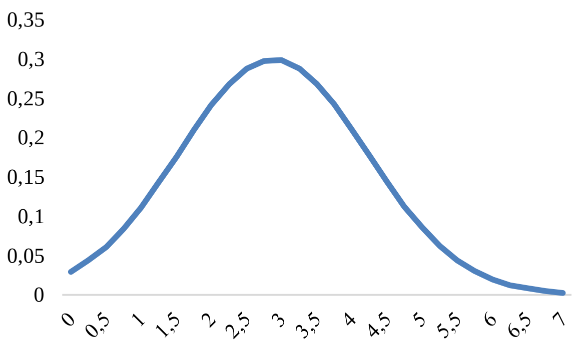
Table 1 Statistics of wind speed data
Source: Prepared by the authors

As shown in Table 2, with the Wera software and Rayleigh analysis we calculated the wind energy density E_D in kW/m^2, the annual energy intensity E_I in kWh/m^2, the wind speed frequency V_E in m/s and the maximum energy speed for the V_{Fmax} wind regime in m/s.

Month	E_D (Kw/m^2)	E_I (Kw/m^2/mes)	$VF_{máx}$ (m/s)	$VE_{máx}$ (m/s)
January	0.02	168.53	2.03	4.05
February	0.07	577.81	3.06	6.11
March	0.05	460.12	2.83	5.66
April	0.04	318.4	2.5	5.01
May	0.02	200.19	2.15	4.29
June	0.04	383.2	2.66	5.33
July	0.01	128.43	1.85	3.7
August	0.02	216.23	2.2	4.4
September	0.02	138.65	1.9	3.8
October	0.03	248.24	2.31	4.61
November	0.01	99.39	1.7	3.4
December	0.03	228.19	2.24	4.48

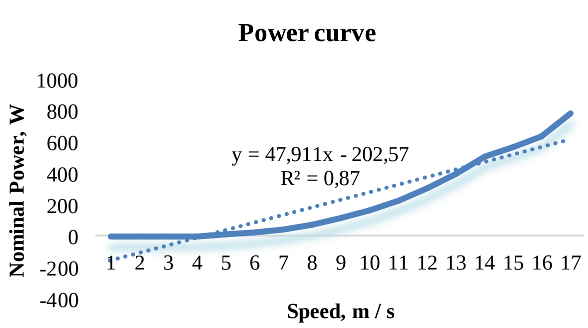
Table 2 Potential wind energy based on Rayleigh's analysis
Source: Prepared by the authors

The probability density and the cumulative distribution function of the Weibull wind regime is shown in Graph 1, the peak of the curve shows that the most frequent wind speed is 2.8 m/s.



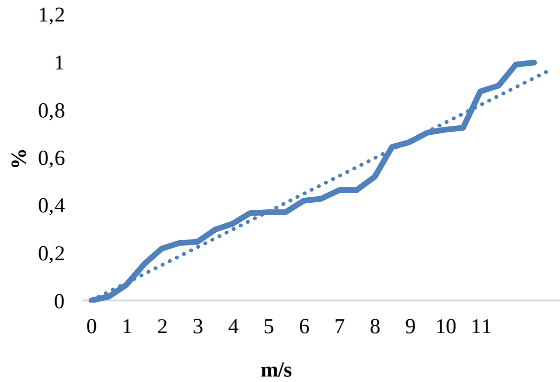
Graph 1 Weibull density probability function
Source: Prepared by the authors

In Figure 2, with an average wind speed of 2.79 m/s during the day and the wind distribution, the turbine will start generating electricity at 2.5 m/s and the generation is interrupted at 15 m/s, the maximum power reached is 1.48 kW which will be produced at 2.79 m/s.



Graph 2 Nominal power curve
Source: Prepared by the authors

Graph 3 shows the Weibull wind speed probability, which indicates the probability percentages, in the Y axis, and their correlation with the wind speed.



Graph 3 Weibull density probability function
Source: Prepared by the authors

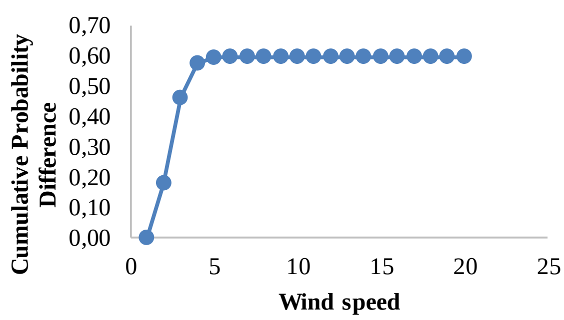
A wind turbine with a cutting speed of 3 m/s to 15 m/s can be installed with a scale factor of c=3.5 and a form factor of k=2.88; we calculated that the number of hours that the turbine generates energy is 14.4 hours.

The turbine generates energy per h Number of hours

$$= \left(e^{-\left(V_1/c\right)^k} - e^{-\left(V_2/c\right)^k}\right) \times 24hrs$$

$$\left(e^{-\left(2.5/3.15\right)^{2.88}} - e^{-\left(15/3.15\right)^{2.88}}\right) \times 24hrs = 0.60 * 24 = 14.4\ hrs.$$

Graph 4 shows the probability of wind speed in a range of 2.5 to 15 m/s, which is calculated by the difference in cumulative probabilities (Eq. 5), and it can be seen that from 5 m/s it stabilizes at a probability value of 0.6.



Graph 4 Probability that the wind does not exceed the cutting speed 15 m/s
Source: Own elaboration of data simulation

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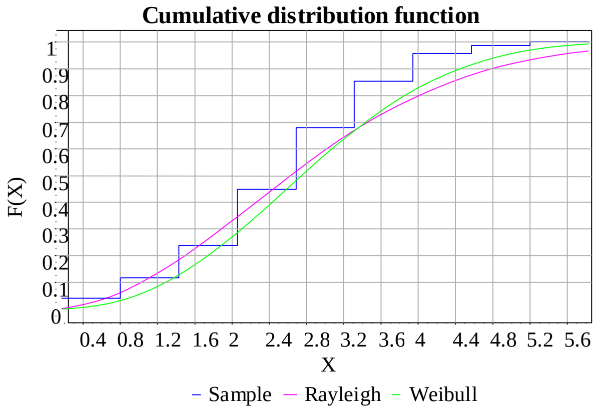
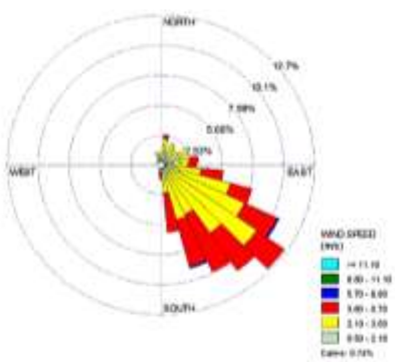


Graph 5 Comparison of the cumulative distribution by the Weibull and Rayleigh method
Source: Own elaboration of data simulation

The results of the Weibull and Rayleigh distributions can be seen in graph 5, which are very similar; in the end, the Weibul cumulative distribution is closer to the speed data.

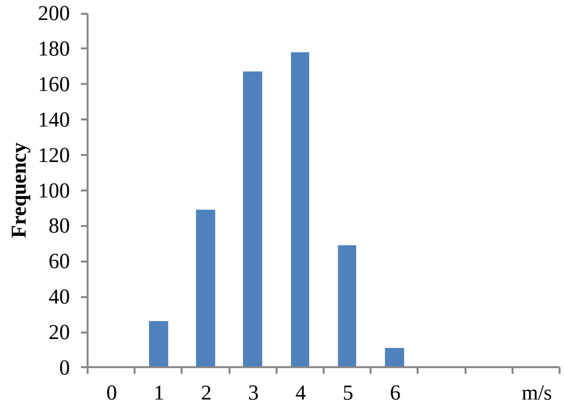
Wind distribution and speed with the wind rose

Figure 6 shows the wind rose, where we can observe that the wind tendency is to the southeast direction and the percentage indicates the probability of occurrence at different wind speeds.



Graph 6 Cancun wind rose
Source: Own elaboration of data simulation

The wind speed density distribution in graph 7 show that the wind speed frequency intervals, the maximum frequency (36), is in the range of 2.8 m/s.



Graph 7 Cancun wind frequency distribution
Source: Own elaboration of data simulation

The wind speed distribution establishes direction intervals and wind speed ranges, as shown in table 3.

Wind speed Distribution

Wind Direction	0.50 - 2.10	2.10 - 3.60	3.60 - 5.70	5.70 - 8.80	8.80 - 11.10	>= 11.10	Total
355.00 - 5.00	0	5	0	0	0	0	5
5.00 - 15.00	4	3	2	0	0	0	9
15.00 - 25.00	4	1	0	0	0	0	5
25.00 - 35.00	2	6	0	0	0	0	8
35.00 - 45.00	4	1	0	0	0	0	5
45.00 - 55.00	4	2	0	0	0	0	6
55.00 - 65.00	4	2	0	0	0	0	6
65.00 - 75.00	5	4	0	0	0	0	9
75.00 - 85.00	4	6	3	0	0	0	13
85.00 - 95.00	4	6	4	0	0	0	14
95.00 - 105.00	4	13	7	0	0	0	24
105.00 - 115.00	7	21	7	0	0	0	35
115.00 - 125.00	5	29	11	1	0	0	46
125.00 - 135.00	1	32	13	0	0	0	46
135.00 - 145.00	3	19	15	0	0	0	37
145.00 - 155.00	4	13	11	0	0	0	28
155.00 - 165.00	5	11	6	0	0	0	22
165.00 - 175.00	3	5	7	0	0	0	15
175.00 - 185.00	3	0	3	0	0	0	6
185.00 - 195.00	4	0	1	0	0	0	5
195.00 - 205.00	2	0	0	0	0	0	2
205.00 - 215.00	0	0	0	0	0	0	0
215.00 - 225.00	0	0	0	0	0	0	0
225.00 - 235.00	0	0	0	0	0	0	0
235.00 - 245.00	0	1	0	0	0	0	1
245.00 - 255.00	0	0	0	0	0	0	0
255.00 - 265.00	1	1	0	0	0	0	2
265.00 - 275.00	0	0	0	0	0	0	0
275.00 - 285.00	0	0	0	0	0	0	0
285.00 - 295.00	0	0	0	0	0	0	0
295.00 - 305.00	0	0	0	0	0	0	0
305.00 - 315.00	0	0	0	0	0	0	0
315.00 - 325.00	1	1	0	0	0	0	2
325.00 - 335.00	0	0	0	0	0	0	0
335.00 - 345.00	2	3	0	0	0	0	5
345.00 - 355.00	2	2	0	0	0	0	4
Sub-Total:	82	187	90	1	0	0	360
		Total:	365	Wind	Speed	2.80	m/s

Table 3 Wind speed distribution
Source: Prepared by the authors

Average Wind Speed: 2.80 m/s, Table 3 shows the frequency distribution of the wind speed and its direction, for a one year period.

Energy produced annually

To evaluate the field performance of a wind turbine, the capacity factor (RC_F) in wind energy conversion systems is used, that the ratio of the power produced at the average speed of the place (P_{Vm}) and the nominal power of the wind turbine.

$$RC_F = \frac{P_{Vm}}{p_R} = \frac{1.48W}{400W} = 0.004 \quad (10)$$

The capacity factor range for a turbine to be efficient is set from 0.25 to 0.4.

The energy produced annually is calculated approximately by multiplying the capacity factor by the nominal power and the period of time.

$$400 \times 0.004 \times 8760\ hours = 14.02\ kW/year$$

Calculation of power as a function of wind speed

By setting the generator capacity of 400W, identifying a starting cut-in speed of 2.5 m/s and cut-out wind speed of 12 m/s, we calculate the wind speed power P_V (W). In table 4 it can be observed that to obtain 400W, an average wind of 12 m/s is required.

n	3	
Rated Power: p	400 W	
Cut - in wind speed: V_I	2.5 m/s	
rated wind speed: V_R	12	
	V	**P_V (W)**
Cut - in wind speed	**2.5** **2.8**	**0.00** **1.48**
	3	**2.66**
	4	**11.30**
	5	**25.55**
	6	**46.81**
	7	**76.47**
	8	**115.95**
	9	**166.64**
	10	**229.94**
	11	**307.26**
Rated wind speed	**12**	**400.00**
	13	**509.56**
	13.5	**571.08**
	14	**637.33**
Cut-out-wind speed	**15**	**784.73**

Table 4 Calculation of power as a function of wind speed
Source: Own elaboration of data simulation

We can see that to have a capacity factor (RC_F) of 0.4, an average wind speed between 8 and 12 m/s must be obtained.

Acknowledgments

Wind speed data was provided by Capitanía de Puerto, Puerto Juárez, Cancun, Q. Roo, Mexico

Conclusions

With the wind speed data captured at a height of 10m by the port captaincy, the average speed calculated by the wind rose method and descriptive statistics, we obtained the value of 2.8 m/s. By applying the wind rose methodology, it is obtained that the wind tendency is to the southeast direction and the percentage indicates the probability of occurrence at different speeds.

With equations 7 and 8, the scale factor and form factor are calculated, at c=3.5, k=2.88 respectively. The estimation of potential energy based on Rayleigh's analysis allowed us to know the wind energy density E_D in kW/m^2, the annual energy intensity E_I in kWh/m^2, the wind speed frequency V_E in m/s and the maximum energy speed for the V_{Fmax} wind regime in m/s. See table 2.

In table 4, we calculated that the power generated from the wind speed (P_V) at 2.8 m/s, yielded a value of 1.48W and its capacity factor at 0.004, which does not reach the permissible range of 0.25 to 0.40. The calculation of its annual produced energy was 14.02 kW/year; therefore, a speed of 12 m/s is required to reach 400W of nominal power according to the manufacturer.

Findings

Because an average speed of 2.8 m/s is obtained at a height of 10m, it is necessary to raise the wind turbine to a height of: 13.4m with an α factor of 0.20, to reach an average speed of 12 m/s and to install an efficient 400W wind turbine.

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