UTILIZATION OF WIND ENERGY

The Case Study on Analyzing Hourly Wind Data at
the City of Makassar and its Surroundings

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Abstract

The one-year of mean hourly wind speed recorded in the year of 1997, at the city of Makassar and its surroundings, have been analyzed by using Weibull distribution. The analysis shows that the wind is generally light and irregular and the distribution is relatively high dispersion, since the values of Weibull parameters i.e.: shape factor k and scale factor c are 1.52 and 4.91 respectively. The average winds speed 4.42 knot (2.27 m/s). The necessary calculations of the annual output of windmill for water pumping are explained. From the cost consideration, the price of water supply by windmill is higher than that by the electric pump set. It is clear that in this case, the use of windmill for water pumping is not attractive as alternative energy utilization.

Keywords: Wind energy, Weibull distribution, shape and scale factors.

Introduction

The winds are caused primarily by unequal heating of the earth's surface. The seasonal variations in the heat received from the sun, the diurnal differential heating of land and water, and geographical variation of land will result the variation in velocity and direction of the wind. Because the wind is unsteady and fluctuated from time to time during a year then the accurate result to asses the availability of wind energy is by analyzing the annual winds speed data. In this study we use the one-year hourly wind data (during the year 1997) recorded by meteorological station at the city of Makassar to determine the wind energy available in Makassar and its surrounding.

Available Wind Power

The power due to kinetic energy of a wind streams with speed V (m/s) passing through an area A (m^2) is $\frac{1}{2}\rho A V^3$. The power extracted from the wind by a windmill is $P = C_p \, . \, \eta . \, \frac{1}{2}\rho A V^3$. If air density ρ = 1.204 kg/m^3 , power coefficient of the rotor Cp = 0.35 and the efficiency of the transmission η = 0.5, then power/swept area of rotor is:

$P/A = 0.1\, V^3$ (W/m^2)…………………………………………………..(1)

Statistical Representation of the Wind

Hourly wind data over a period of one year 1997 are provided by meteorological station, Division of Meteorology and Geophysics, Makassar. The data are processed to be the velocity frequency that is shown in Table 1. The anemometer is exposed at WMO (*World Meteorological Organization*) standard height 10.0 m above the ground level over open terrain. The type of anemometer is wind cup anemometer with wind vane. From the table we could determine the following important results.

Table 1. Observed Velocity Frequencies-Based on hourly wind data recorded at Maritime Meteorological Station, Makassar, year 1997

Month Velocity	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	f(*V*) hours
0	13	9	36	42	33	56	71	36	37	48	30	33	444
1	48	48	43	66	62	64	78	61	69	56	53	60	708
2	113	116	132	163	160	156	151	147	154	156	135	130	1713
3	134	105	106	129	134	125	116	123	126	132	110	120	1460
4	103	76	88	99	111	86	87	88	75	91	88	87	1079
5	87	85	71	57	81	60	51	67	37	50	58	93	797
6	73	59	51	58	61	53	53	61	52	41	58	46	666
7	36	33	39	30	40	42	54	41	39	48	58	56	516
8	34	30	34	24	24	31	40	44	39	32	33	39	404
9	27	22	24	23	12	28	15	30	22	21	23	18	265
10	21	25	28	10	11	14	15	20	24	28	36	18	250
11	13	8	15	5	7	2	10	12	18	16	13	16	135
12	15	10	23	10	3	3	1	5	11	11	12	10	114
13	5	6	15	0	2		2	5	7	4	6	8	60
14	5	5	13	4	1			1	5	5	4	3	46
15	4	9	6		1			3	2	2	2	2	31
16	1	3	8		0				1	1	1	2	17
17	2	5	6		1				0	2		2	18
18	3	3	0						0			1	7
19	1	2	0						0				3
20	1	4	0						0				5
21	0	1	1						1				3
22	2	1	1						1				5
23	2	1	1										4
24	0	0	0										0
25	0	0	0										0
26	0	1	0										1
27	0	1	0										1
28	0	1	0										1
29	0	1	3										1
30	0	1											4
31	0	0											0
32	0	0											0
33	1	0											1
34	0	0											0
35	0	1											1
Total (hrs)	774	672	744	720	744	720	744	744	720	744	720	744	8760

Velocity in knot; 1 knot = 0.154 m/s
1 year = 8760 hours

Observed Wind Speed Parameters

i. Average wind speed

The average observed wind speed is calculated by using the formula:

$$\bar{V}_{obs} = \sum_i^n \frac{t_i V_i}{t_i} \qquad (2a)\backslash$$

Standard deviation:

$$\sigma_{obs} = \sqrt{\frac{\sum (V_i)^2 - \frac{(\sum V_i)^2}{n}}{n-1}} \qquad (2b)$$

n = number of observations

ii. Calm period

The calm period is the condition where the wind speed $0 \le V < 1$ knot.

The occurrence of the calm could give good information for the calculation of the size of storage tank. Using the raw data in Table 1 and equation (2) we can calculate the average wind speeds and standard deviations for one year, dry season (April-September) and rainy season (October-March) are shown on Table 2.

Table 2 Observed wind speed parameters

Observed wind speed	$\bar{V}_{obs}$ knots (m/s)	σ_{obs}	Calm hrs (%)
One year	4.42 (2.27)	3.06	444 (5.07)
Dry season	3.97(2.04)	2.82	275 (6.26)
Rainy season	4.86(2.50)	3.71	169 (3.87)

iii. Diurnal variations of the wind

The diurnal variation of wind is as shown in Fig. 1.a, while diurnal variations for dry and rainy seasons are as shown in Fig. 1.b. As expected, the wind speeds are greater the day (11.00 – 18.00) than during the night (18.00 - 10.00).

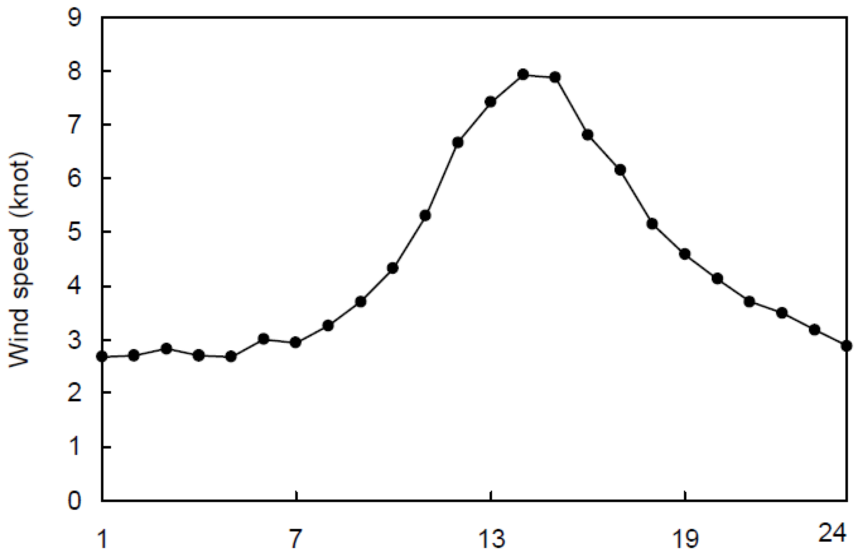

Figure 1a. Diurnal variation of mean wind speed during The year 1997

Considering Table 1, the maximum wind speed is 35 knot (18 m/s), and occurs on February 24, 1997. This greatest speed is used to calculate the strength of the windmill structure and to design the safety mechanism such as brake.

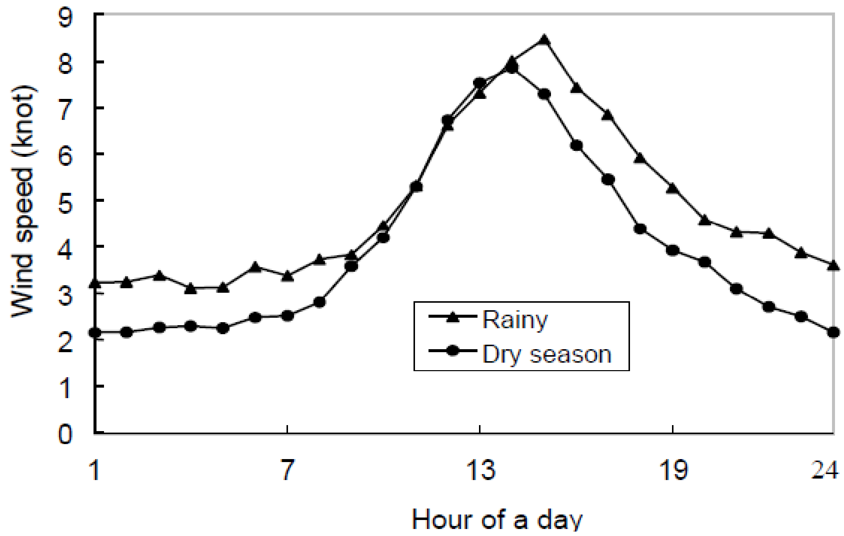

Figure 1b. Diurnal variation of mean wind speed during rainy season (October - March) and dry season (April - September)

Weibull Distribution Parameters

The most frequently used theoretical distribution that describes the wind resources is the Weibull distribution. Experience shows that the Weibull gives a good match with the observation data of the wind. The distribution is characterized by two parameters *c* and *k*. The parameter *c* (velocity dimension) is a scale factor for the wind speed that is large for the strong winds and small for light winds. The parameter *k* (dimensionless) is a shape factor of wind distribution. At a site where winds are stronger and low dispersion, k has the value from 2.0 to 4.0; while the winds are light and high dispersion, *k* has the value between 1.0 and 2.0. Once we know the value of *c* and *k*, the wind distribution at the area is specified.
The cumulative Weibull distribution is:

$$F(V) = 1 - exp\left(-(V/c)^k\right) \qquad (3a)$$

Frequency distribution:

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

V is the wind speed. It is clear that the values of the calm are not included in Weibull distribution. In some cases we want to know where the windmill will operate to produce power. The fraction of time corresponding to the velocities is indicated by velocity duration curve as expressed below:

$$t = exp\left[-\left(\frac{V}{c}\right)^k\right] \qquad (4)$$

For the purpose to determine the Weibull parameters c and k we use Mean Wind Speed-Standard Deviation- method [6,7], the mean wind speed:

$\bar{V} = \pi r^2 = exp \int_0^{\infty} V \frac{dF(V)}{dV} dV = c\Gamma\left(1 + \frac{1}{k}\right)$...(5)

Γ= Gamma function

The standard deviation:

$\sigma = \left(\Gamma(1 + 2/k) - \Gamma^2(1 + 1/k)\right)^{1/2}$ ....(6)

Then: $\frac{\sigma}{\bar{V}} = \frac{\left(\Gamma(1+2/k) - \Gamma^2(1+1/k)\right)^{1/2}}{c\Gamma\left(1+\frac{1}{k}\right)}$...(7)

By numerical iteration we obtain, $k = 1.124\ (\sigma/\bar{V})^{-0.8115}$. Based on Table 2, the value of $\frac{\sigma}{\bar{V}} = 0.69$, then $k = 1.52$ and $c = \frac{4.42}{\Gamma(1+1/1.52)} = \frac{4.42}{0.9} = 4.91$ knot, see equation (5). If we substitute the values of k and c into equation (3.b) we obtain the Weibull velocity frequency. The observed (histogram) and Weibull frequencies (curve) are as shown in Fig. 2.

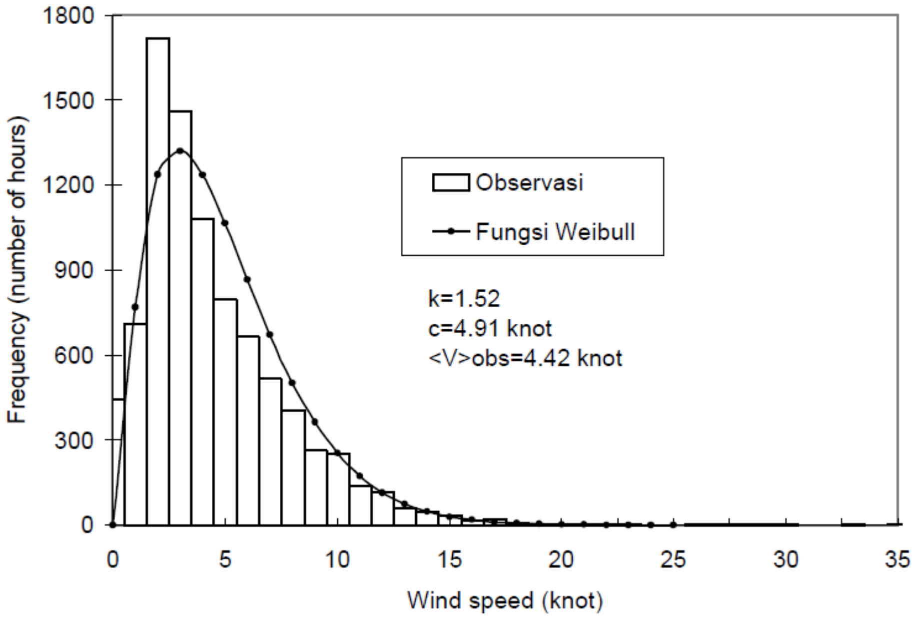

Figure 2.a. Velocity frequency at Makassar during year 1997.
Histogram shows observed frequency, and curve shows Weibull function

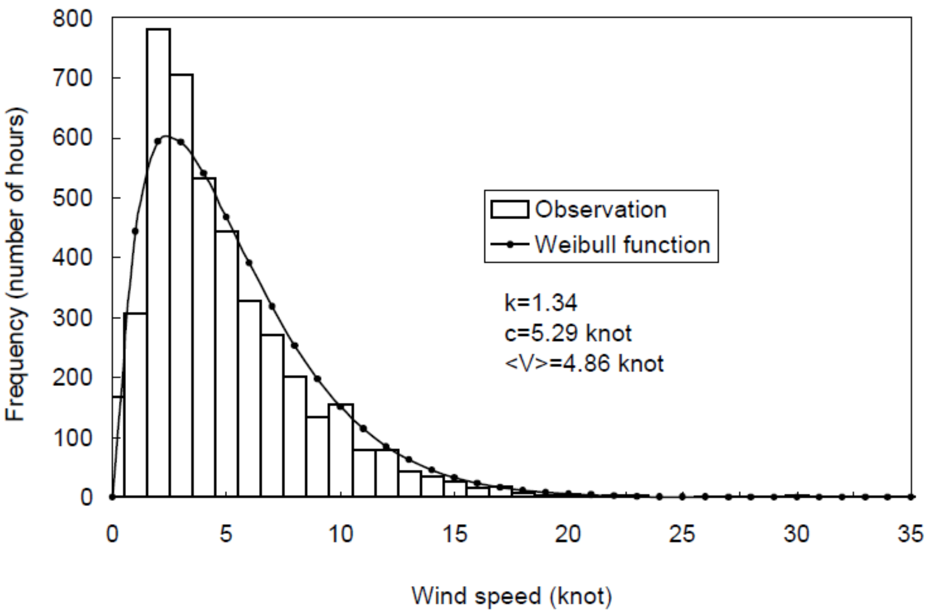

Figure 2.b. Observed and Weibull frequency in rainy season
(October - March

Using equation (2.a) the average wind speed calculated from Weibull velocity frequency $\bar{V}_{Wei}$= 4.93 knot. Since the values of calm are not included, the average wind speed is: $\bar{V}_{cal}$ = (1-*f*) $\bar{V}_{Wei}$, where *f* is the fraction of time that calm reported. The calculated average wind speed becomes $\bar{V}_{cal} = \left(1 - \frac{444}{8760}\right) 4.93 = 4.68$ knot. By the same way we can determine those parameters in the dry and rainy seasons. The values are tabulated as shown on Table 3

Table 3 Parameters of Weibull Distributions

Wind speed	*c* knot	*k*	Average wind speed (knot) Observed	Calculated	Error %
One year	4.91	1.52	4.42	4,68	5.8
Dry season	4.38	1.42	3.97	4.49	5.8
Rainy season	5.29	1.34	4.86	5.36	5.8

The discrepancies between observed and calculated wind velocities are 5.8 %, which are within the acceptable tolerance; so that the Weibull function gives a very good match with the observed data.

Energy Output of Windmill

For the purpose to obtain the energy out put of a windmill, it is necessary to know the velocity and power duration curves. Knowing the values *c* and *k* the velocity duration curve can be shown graphically by using equation (4). The vertical axis represents the velocity *V* and the horizontal axis is the fraction of time *t*. The power/swept area duration curve is obtained by cubing the velocity ordinate, multiply by 0.1, equation (1) and abscissa is kept unaltered. The total energy out put of windmill during period is the area under the power duration curve that is defined by three design speeds i.e.: cut-in speed (V_{ci}), rated speed (V_r) and cut-out speed (V_{co}). Those velocities are indicated in the velocity duration curve.

V_{ci} = wind speed at which the windmill machine starts to produce power
V_r = wind speed at which the windmill machine reaches its maximum out put
V_{co} = wind speed above which the windmill to be stopped to prevent damage

In this study the windmill is used to couple the piston pump for water pumping purposes. According to [2,6], for multiblade rotor the design speeds can be chosen : V_{ci} = 2 m/s (3.9 knot), V_r = 6 m/s (11.7 knot), V_{co} = 8 m/s (15.6 knot). The total energy output of the machine is the area ABCDEA as shown in Fig. 3. Using equation (4) the fraction of time at each design speed: t_{ci} = 0.495, t_r = 0.024 and t_{co} = 0.0031. Thus the available energy for wind pumpset during one year is 0.495 – 0.0031 = 0.4919 or 0.4919 × 8760 = 4309 hours. By using the numerical integration method the energy output (area ABCDEA) is E = 20.46 kWh/m^2 . Let the pump is used to lift water q m^3 /s water over a head 10.0 m. Density of water 1000 kg/m^3 and g = 9.81 m/s 2 . The diameter of windmill rotor is 3.0 m. The water pumped in a year is:

$$Q = \frac{E.A\times 3600}{9810\,H} = \frac{20.46\times 1000\times \frac{\pi}{4}\times 3.0^2\times 3600}{9810\times 10} = 5303\ \text{m}^3$$

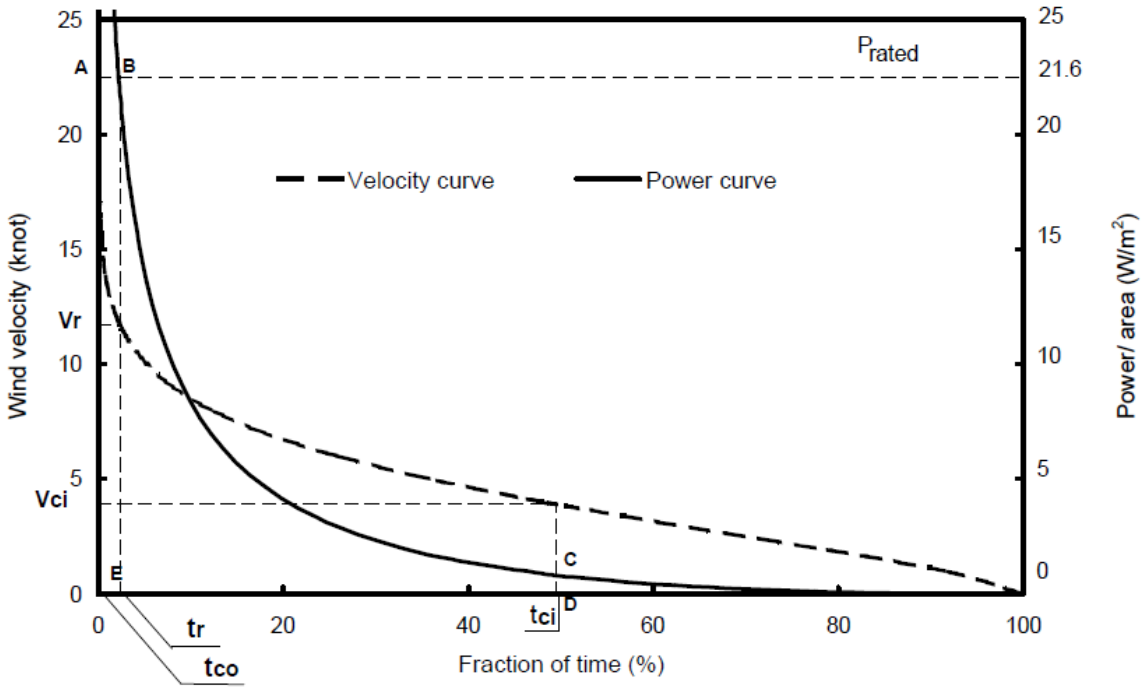

Fig. 3. Velocity and power duration curves

Cost Analysis

In order to determine the possibility of using windmill for pumping water, it is compared to the electric pump set by means of cost analysis at the output of 5303 m^3 water pumped/year. Some estimation with regard to cost analysis are: investment (I), lifetime (*N*), interest rate (*i*) and operation/maintenance (O/M). The investment of wind mill pump set is based on SWD studies, Vel, J.A.C, and Veldhuizen, L., R., v., 1982, and of electric pump set is based on local dealer price.

Wind mill specifications:

- Steel construction
- Rotor diameter: 3.0 m, six blades, horizontal axis
- Piston pump

Electric pump set specifications:

- Trademark: Nasional
- Capacities: 125 W (0.125 kW), 30 l/min (1.8 m^3/h)

  Annual repayment is: annuity factor x

and *i* = 20 %/year. The calculations are tabulated as follows:

Table 4. Cost Analysis of Windmill pump set and Electric pump set

Item	Windmill pumpset	Electric pumpset
1. Construction cost	Rp. 6,750,000.00	Rp. 250,000.00
2. Installation cost	Rp. 1,631,250.00	Rp. 60,500.00
3. Storage tank: brick cons.	Rp. 1,406,250.00	Rp. 1,250,000.00
Investment (1+2+3)	Rp. 9,787,500.00	Rp. 1,560,500.00
a. Annual repayment: 0.24 I	Rp. 2,349,000.00	Rp. 374,520,00
b. O/M cost/year: 0.10 I	Rp. 978,750.00	Rp. 156,050.00
Total (a+b)	Rp 3,327,750.00	Rp. 530,570.00

1 US $ = Rp. 9000.00

To utilize electric pump set, we have to consider the State Electric Enterprises tariffs i.e.: electric energy cost (Rp.111.30/kWh), base load cost (Rp. 4170.00/month) and electric tax (Rp. 6010.00/month). If the pump operates 10 hours/day then the pumping electric cost = 4173.75 (= 30 x 10 x 0.125 x 111.30) + 4170.00 + 6010.00 = Rp. 14,353,75/month. In order to attain 5303 m 3 of water pumped, the pump will be operated during 5303/1.8 = 2946.11 hours or 2946.11/(30 x 10) = 9.8 months (~10 months) in a year. The total expenditure of electric pumpset is 530,570.00 + 10 (14,353.75) = Rp. 674,107.50/year. Thus the cost of water that is supplied by each installation is:

by windmill pump set: 3,327,750.00/5303 = Rp. 627.52/m^3

by electric pump set: 674,107.50/5303 = Rp. 127.12/m^3

It is clear that electric pump set gives cheaper price than windmill pumpset. So the utilization of windmill for water pumping is not attractive compared to electric pump set.

Conclusions

From the analysis we can conclude are as follows

1. the Weibull function gives a good match with the observation data of the wind where the discrepancies between observed and calculated wind speed within 5.8 %.
2. average wind speed is 4.42 knot (2.27 m/s). Weibull parameters i.e.: shape factor k =1.52 and scale factor c = 4.91 knot that mean the winds are light and high dispersion. Average wind velocity in rainy season is higher than in dry season. The maximum wind speed is 35 knot (18 m/s), and occurs on February 24,1997.
3. from cost analysis, the price of m 3 water is higher by windmill pumpset compared to electric pumpset. Thus the utilization of wind energy by windmill in Makassar and its surrounding is not attractive as alternative energy utilization.

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