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Assessment of Wind Energy Potential in Indonesia Using Weibull Distribution Function

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Abstract: The wind characteristic information will be useful in identifying prospective areas for wind-energy applications. The purposes of this study are to analyze the wind characteristic for selected locations in Indonesia based on available data. The wind characteristic for Bali, Balikpapan, Surabaya and Jayapura were analyzed based on the daily average wind speed which is available in National Oceanic and Atmospheric Administration (NOAA) website. The wind characteristics were analyzed using statistical analysis and the Weibull parameter as the Weibull distribution generally accepted methodology used to estimate the wind speed frequency distribution. Even though, wind characteristic analysis indicates low potential of wind energy in Indonesia, the result of this study can be useful information about wind research in Indonesia. Evaluation of the potential of wind energy resources in Indonesia need to be conducted as there is very limited research on the assessment of wind energy potential in Indonesia.

Key words: Wind energy, Weibull distribution, GIS, speed frequency, wind research, Japan

INTRODUCTION

Rising fuel prices and environmental concern to mitigate the emissions support the growth opportunities for renewable energy such as wind energy utilization around the world. One of the options among renewable energy such as wind energy technology requires the preliminary resources assessment such as wind characteristics and wind profile.

Utilizing renewable energy in Indonesia becomes a challenge because of the country's geography and there is energy problem exist. Indonesia consists of thousand islands, located between Asia and Australia continent which have huge population. The demand of energy in Indonesia is increasing due to the growth of population as well as the growth of quality life necessity. It is facing power reserve shortage in the urban and low ratio electrification in the rural. As the reason stated previous, the renewable energy source need to be developed to overcome energy problem in Indonesia. Moreover, developments of renewable energy in Indonesia become one point of energy policy.

At present, energy policy in Indonesia focus to utilize renewable energy for diversification energy, wind energy is one of the sources to be explored. However, recently there is no report about wind energy assessment over Indonesia. The study about wind characteristic in Indonesia has not been conducted and yet wind resource maps over Indonesia have not been developed. The monthly mean wind speed, wind speed distribution as well as the wind power densities should be analyzed before utilizing wind energy system and determining site selection for wind farm. The effective utilization of wind energy requires detail knowledge of the wind characteristics at the particular location.

The purpose of this study is to analyze wind data characteristic for the selected locations (Bali, Balikpapan, Surabaya and Jayapura) in Indonesia. The daily wind speed data for Bali, Balikpapan, Surabaya and Jayapura are taken from NOAA website.

MATERIALS AND METHODS

Wind speed characteristic: Wind speed distribution mainly provides the information about the performance of wind power system in the site. Once the speed distribution is known, the wind power potential and the feasibility study for utilizing the source of wind energy could be obtained.

In literature, many studies base on their statistical analysis of wind characteristics and wind energy potential on the assumption that the Weibull distribution estimates wind speed profile in many locations by many researchers. In Rwanda, Safari (2011) investigated wind

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speed and wind power distributions based on the Weibull model. Wind energy analysis of Grenada using Weibull density function reported by Weisser (2003). A statistical analysis of wind power density based on the Weibull and Rayleigh Models at the Southern region of Turkey reported by Ali (2003). Wind characteristics and wind energy potential in Kirklareli, Turkey studied by Gokcek *et al.* (2007). Determination of Weibull parameters for wind energy analysis of Izmir, Turkey reported by Ulgen and Hepbasli (2002). The Weibull distribution was identified to be the best distribution representing the wind data characteristic.

Among several distributions, the Weibull distribution function is the most commonly used in applications. To describe wind speed distributions, as the natural distribution often matches the Weibull shape. The variation of wind velocity is often described using the Weibull two parameter density function. This statistical method is widely accepted for evaluating local wind load probabilities and can be considered as a standard approach (Keyhani *et al.*, 2010).

Data: The daily average wind speed data taken from NOAA database for Bali, Balikpapan, Surabaya and Jayapura were chosen to be analyzed. The selected locations of study in Indonesia map are shown in Fig. 1. Geographical of the four selected locations and their latitude and longitude were shown in Table 1. The daily average wind speed data which is available in the NOAA website for the year 2010 is used to analyze the wind speed distribution using statistical analysis and the Weibull distribution.

Methods: Wind speed data available for four locations in Indonesia were analyzed for the year of 2010. Based on these data, calculations were done to obtain the Weibull distribution parameters in term of scale parameter (k) and shape parameter (c), average wind speed ($\bar{v}$), standard deviation (σ), most probable wind speed (v_{mp}), wind speed carrying maximum energy (v_{Emax}) as well as average wind power density at the height of 10 and 80 m above the ground. The mean wind speed ($\bar{v}$) and the standard deviation (σ) of the known wind speed data are determined by using Eq. 1 and 2 as follows:

$$\bar{v} = \frac{1}{n}\left[\sum_{i=1}^{n} v_i\right] \quad (1)$$

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(v_i - \bar{v})^2\right]^{\frac{1}{2}} \quad (2)$$

Estimation of the two Weibull parameters, k and c are obtained using Eq. 3 and 4, respectively:

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (3)$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} v_i^{\,k}\right)^{\frac{1}{k}} \quad (4)$$

The Weibull parameter k and c represent the wind characteristic potential of the study site. The scale parameter c indicates whether high or low wind speed at the site whereas, the shape parameter k indicates the wind stability. The Weibull Distribution Function is a generally

Table 1: Geographical latitude and longitude of the four locations of the study

Location	Latitude	Longitude
Bali	8°39'S	115°13'S
Balikpapan	1°17'S	116°50'E
Surabaya	7°17'S	112°45'E
Jayapura	2°28'S	140°38'E

Fig. 1: The selected locations of study in Indonesia map

accepted methodology used to estimate the wind speed frequency distribution. Probability density function such as Weibull function used to determine the wind speed distribution of a windy site in a period of time such as monthly and yearly (Islam *et al*., 2011). The Weibull function is defined by Eq. 5:

$$f(\nu) = \left(\frac{k}{c}\right)\left(\frac{\nu}{c}\right)^{k-1} \exp\left[-\left(\frac{\nu}{c}\right)^{k}\right] \quad (5)$$

Cumulative Density Function (CDF) is defined by Eq. 6:

$$F(\nu) = 1 - \exp\left[-\left(\frac{\nu}{c}\right)^{k}\right] \quad (6)$$

Where:

f (ν) = The probability of observing wind speed
ν, ν = The wind speed
c = A Weibull scale parameter in m sec^{-1}
k = A dimensionless Weibull shape parameter
F (ν) = The cumulative distribution function of observing wind speed ν

The accuracy of the Weibull statistical distribution result in the estimation of the wind speeds with respect to the actual values was evaluated using Root Means Square Error (RMSE). RMSE indicates accuracy that calculated by using Eq. 7:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_p - y_d)^2} \quad (7)$$

Where:

y_p = The predicted value based on Weibull Model
y_m = The actual value based on data

The wind power density is a function of the distribution of wind speeds and the effect of air density. In the current study, the wind power density was estimated from the Weibull parameters by Eq. 8:

$$P = \frac{1}{2}\rho c^{3}\left(1 + \frac{3}{k}\right) \quad (8)$$

Where air density of the site $\rho = 1.23$ kg m^{-2}, P is the wind power density (W m^{-2}). Note that wind power density, P is proportional to cube of the speed and the speed varies with height according to 1/7 power law. Therefore, if P_1 at a certain height h_1 (such as at 10 m) has been known, the power density at the height h_2 can be calculated by using Eq. 9.

$$P_2 = P_1\left(\frac{h_2}{h_1}\right)^{\frac{3}{7}} \quad (9)$$

The most probable wind speed inform the most frequent wind speed for a given wind probability distribution. From the scale parameter and the shape parameter of Weibull distribution function, the most probable wind speed (ν_{mp}) can be obtained using Eq. 10:

$$\nu_{mp} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad (10)$$

The maximum wind energy carrying by the wind speed (ν_{Emax}) can be calculated from the scale parameter and the shape parameter of Weibull distribution function by using Eq. 11:

$$\nu_{Emax} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad (11)$$

RESULTS AND DISCUSSION

The monthly Weibull parameter k and c were calculated for Bali, Balikpapan, Surabaya and Jayapura were calculated and shown in Table 2-5, respectively. Also, the monthly average wind speed (ν), standard deviation (σ), the most probable wind speed (ν_{mp}), the maximum wind energy carrying by the wind speed (ν_{Emax}), Wind Power Density (WPD) based on the Weibull parameter for height 80 m were calculated and presented. The results show that the parameters are different from month to month over a whole year. For Bali, the value of c is lowest in February and the value is the highest in January. The yearly average wind speeds were found to range between 2 and 4 m sec^{-1}. The values of the Weibull shape parameter (k) were found in the range between 1.96 and 4.70. The scale parameters (c) were found in the range between 2.16 and 4.47 m sec^{-1}. The highest most probable wind speed was estimated 4.03 m sec^{-1} in August. The wind speed carrying maximum energy was estimated 5.33 m sec^{-1} at Bali. The highest mean power density regarding observed data was calculated at 110 W m^{-2} (at 10 m height) in the month of January for the year of 2010.

For Balikpapan, the value of c is lowest in September and the value is the highest in February. The average wind speeds were found to range between 2.06 and 4.02 m sec^{-1}. The values of the Weibull shape parameter (k) were found in the range between 2.91 and 4.80. The scale parameters (c) were found in the range between 2.25 and 4.39 m sec^{-1}. The highest most probable wind speed was estimated 4.08 m sec^{-1} in February. The wind

Table 2: The monthly average wind speed ($\bar{v}$), standard deviation (σ), shape parameter (k), scale parameter (c), the most probable wind speed (v_{mp}). The maximum wind energy carrying by the wind speed (v_{Emax}), Wind Power Density (WPD) at 10 m height and 80 m height for Bali

Months	$\bar{v}$	σ	k	c	WPD at 10 m	v_{mp}	v_{Emax}	WPD at 80 m
Jan	3.97	1.48	2.93	4.47	110.87	3.87	5.33	270.31
Feb	1.98	0.74	2.91	2.16	12.67	1.87	2.59	30.89
Mar	2.05	0.59	3.84	2.26	12.69	2.09	2.52	30.94
Apr	2.04	1.10	1.96	2.24	17.51	1.55	3.21	42.69
May	2.48	1.06	2.52	2.79	29.39	2.28	3.52	71.66
Jun	3.55	1.01	3.92	3.89	63.72	3.6	4.32	155.35
Jul	3.55	1.28	3.03	3.93	74.45	3.45	4.65	181.52
Aug	3.89	0.94	4.70	4.24	76.99	4.03	4.58	187.70
Sep	3.35	1.05	3.51	3.70	57.65	3.36	4.20	140.55
Oct	2.62	1.01	2.83	2.98	33.58	2.55	3.60	81.88
Nov	2.00	0.60	3.70	2.19	11.68	2.01	2.46	28.48
Dec	2.91	1.43	2.17	3.30	52.77	2.48	4.46	128.66

Table 3: The monthly average wind speed ($\bar{v}$), standard deviation (σ), shape parameter (k), scale parameter (c), the most probable wind speed (v_{mp}). The maximum wind energy carrying by the wind speed (v_{Emax}), Wind Power Density (WPD) at 10 m height and 80 m height for Balikpapan

Months	$\bar{v}$	σ	k	c	WPD at 10 m	v_{mp}	v_{Emax}	WPD at 80 m
Jan	2.52	0.65	4.33	2.77	22.09	2.61	3.02	53.86
Feb	4.02	1.13	3.96	4.39	91.51	4.08	4.87	223.09
Mar	3.44	1.29	2.91	3.87	72.20	3.34	4.63	176.03
Apr	2.55	0.73	3.91	2.78	23.38	2.58	3.09	57.00
May	2.44	0.77	3.50	2.71	22.80	2.47	3.09	55.58
Jun	2.10	0.72	3.20	2.38	16.12	2.12	2.77	39.30
Jul	2.25	0.86	2.84	2.51	20.04	2.16	3.03	48.86
Aug	2.47	0.79	3.43	2.70	22.71	2.44	3.09	55.38
Sep	2.06	0.54	4.30	2.25	11.85	2.11	2.46	28.90
Oct	2.63	0.69	4.26	2.93	26.27	2.75	3.20	64.05
Nov	2.21	0.52	4.80	2.39	13.71	2.28	2.57	33.43
Dec	2.68	0.80	3.71	2.93	27.91	2.69	3.29	68.05

Table 4: The monthly average wind speed ($\bar{v}$), standard deviation (σ), shape parameter (k), scale parameter (c), the most probable wind speed (v_{mp}). The maximum wind energy carrying by the wind speed (v_{Emax}), Wind Power Density (WPD) at 10 m height and 80 m height for Surabaya

Months	$\bar{v}$	σ	k	c	WPD at 10 m	v_{mp}	v_{Emax}	WPD at 80 m
Jan	2.58	1.42	1.91	2.90	38.44	1.97	4.21	93.71
Feb	2.27	0.73	3.43	2.51	18.13	2.27	2.86	44.21
Mar	1.97	0.65	3.33	2.19	12.28	1.97	2.52	29.94
Apr	1.87	0.60	3.44	2.09	10.44	1.89	2.38	25.46
May	2.11	0.66	3.55	2.40	15.64	2.18	2.72	38.13
Jun	2.35	0.73	3.54	2.61	20.14	2.37	2.96	49.10
Jul	2.67	0.86	3.44	2.98	30.36	2.69	3.40	74.01
Aug	2.94	0.90	3.61	3.29	40.22	3.01	3.72	98.07
Sep	2.47	0.70	3.91	2.70	21.51	2.51	3.01	52.44
Oct	2.29	0.88	2.81	2.52	20.43	2.16	3.06	49.81
Nov	1.98	0.64	3.40	2.18	12.02	1.97	2.50	29.31
Dec	2.47	0.79	3.43	2.79	25.12	2.53	3.19	61.25

Table 5: The monthly average wind speed ($\bar{v}$), standard deviation (σ), shape parameter (k), scale parameter (c), the most probable wind speed (v_{mp}). The maximum wind energy carrying by the wind speed (v_{Emax}), Wind Power Density (WPD) at 10 m height and 80 m height for Jayapura

Months	$\bar{v}$	σ	k	c	WPD at 10 m	v_{mp}	v_{Emax}	WPD at 80 m
Jan	1.50	0.98	1.58	1.47	5.65	0.78	2.46	13.76
Feb	2.20	1.15	2.02	2.08	13.67	1.48	2.92	33.34
Mar	2.21	1.14	2.06	2.49	23.45	1.80	3.47	57.18
Apr	2.00	0.93	2.31	2.26	16.28	1.76	2.96	39.70
May	2.47	0.93	2.88	2.74	25.92	2.37	3.29	63.20
Jun	2.49	1.07	2.49	2.79	29.50	2.27	3.54	71.91
Jul	3.14	1.06	3.26	3.47	49.27	3.10	4.02	120.12
Aug	3.02	1.12	2.92	3.37	47.67	2.92	4.03	116.21
Sep	2.41	0.86	3.05	2.66	22.84	2.33	3.13	55.68
Oct	2.75	0.89	3.40	3.03	32.27	2.74	3.47	78.67
Nov	2.62	0.70	4.17	2.87	25.10	2.69	3.16	61.20
Dec	2.71	0.92	3.22	3.01	32.42	2.68	3.50	79.03

speed carrying maximum energy was estimated 4.87 m sec^{-1} at Balikpapan. The highest mean power density regarding observed data was calculated at 91.51 W m^{-2} (at 10 m height) in the month of February for the year of 2010. For Surabaya, the value of c is lowest in April and the value is the highest in August. The average wind speeds were found to range between 1.87 and 2.94 m sec^{-1}. The values of the Weibull shape parameter (k) were found in the range between 1.91 and 3.91. The scale parameters (c) were found in the range between 2.09 and 3.29 m sec^{-1}. The highest most probable wind speed was estimated 3.01 m sec^{-1} in August. The wind

Table 6: The yearly average wind speed ($\bar{v}$), standard deviation (σ), scale parameter c and shape parameter k for Bali, Balikpapan, Surabaya and Jayapura

Location	$\bar{v}$	σ	k	c
Bali	2.87	1.28	2.41	3.25
Balikpapan	2.61	0.97	2.93	2.95
Surabaya	2.42	1.12	2.30	2.72
Jayapura	2.33	0.87	2.92	2.63

speed carrying maximum energy was estimated 4.21 m sec^{-1}. The highest mean power density regarding observed data was calculated at 40.22 W m^{-2} (at 10 m height) in the month of August for the year of 2010.

For Jayapura, the value of c is lowest in January and the value is the highest in July. The yearly average wind speeds were found to range between 1.5 and 3.14 m sec^{-1}. The values of the Weibull shape parameter (k) were found in the range between 1.58 and 4.17. The scale parameters (c) were found in the range between 1.47 and 3.47 m sec^{-1}. The highest most probable wind speed was estimated 3.10 m sec^{-1} in July. The wind speed carrying maximum energy was estimated 4.03 m sec^{-1}. The highest mean power density regarding observed data was calculated at 50 W m^{-2} (at 10 m height) in the month of July for the year of 2010. Based on the result obtained, the monthly average wind power density value were found to range between 5-110 W m^{-2} indicates these location of the study area corresponded to the wind power class of 1. The density value is <100 W m^{-2} indicates very low wind power. Therefore, the wind energy potential is low.

The yearly available wind energy is determined by studying wind speed distribution. The Weibull reliability distribution function is used to describe the variations of wind speed for the four locations of the study. The yearly average wind speed ($\bar{v}$), standard deviation (σ), scale parameter c and shape parameter k for Bali, Balikpapan, Surabaya and Jayapura were shown in Table 6. The yearly average of wind speed was found to be highest at Bali while the lowest at Jayapura. The yearly Weibull shape parameter k was found to be highest at Balikpapan while lowest at Surabaya. The yearly Weibull scale parameter c was found to be highest at Bali while lowest at Jayapura. The monthly averages of wind speeds for the four location of the study were plotted in Fig. 2. There are significant differences in the magnitude of the wind speed between the months with the highest and lowest average wind speeds. For example, at Bali the highest monthly average wind speed is 4 m sec^{-1} (January) while the lowest value is 2.0 m sec^{-1} (February). At Balikpapan, the highest value is 4.0 m sec^{-1} (February) and the lowest is 2 m sec^{-1} (June). At Surabaya, the highest value is 3 m sec^{-1} (August) and the lowest is 1.9 m sec^{-1} (April). At Jayapura, the highest value is 3.14 m sec^{-1} (July) and the lowest is 1.5 m sec^{-1} (January). The Weibull distribution for describing the wind speed profile of the selected locations in Bali, Balikpapan, Surabaya and Jayapura were obtained.

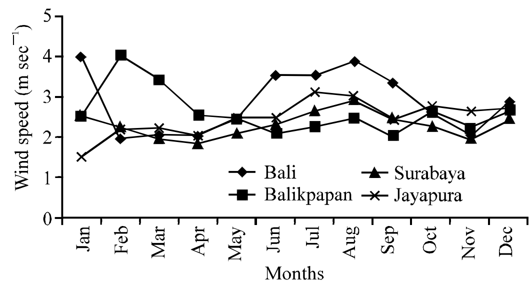

Fig. 2: The monthly average wind speeds for the four locations of the study

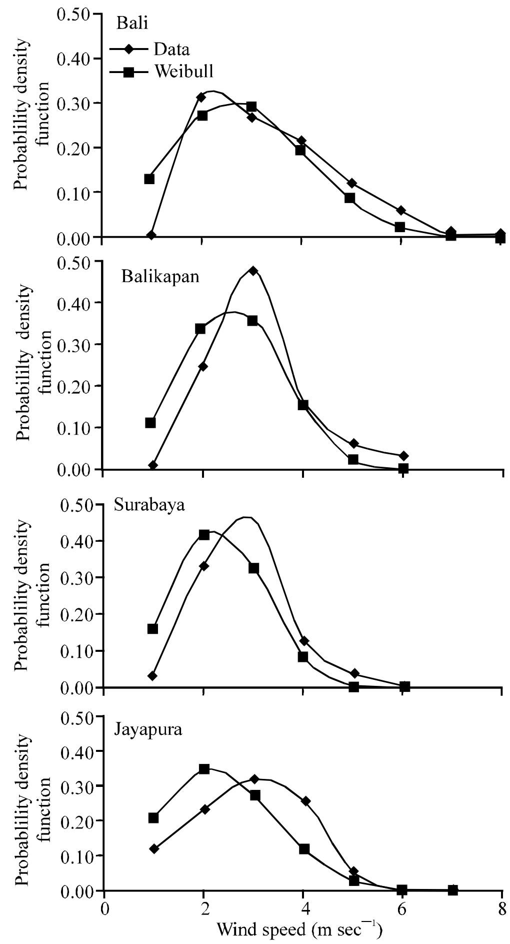

Fig. 3: The comparison between probability distribution Function calculated from the Weibull function and wind speed distribution based on data for the locations studied

The comparison between probability distribution Function calculated from Weibull function and wind speed distribution based on data for the locations studied also were shown in Fig. 3. The accuracy of the Weibull statistical distribution result in the estimation

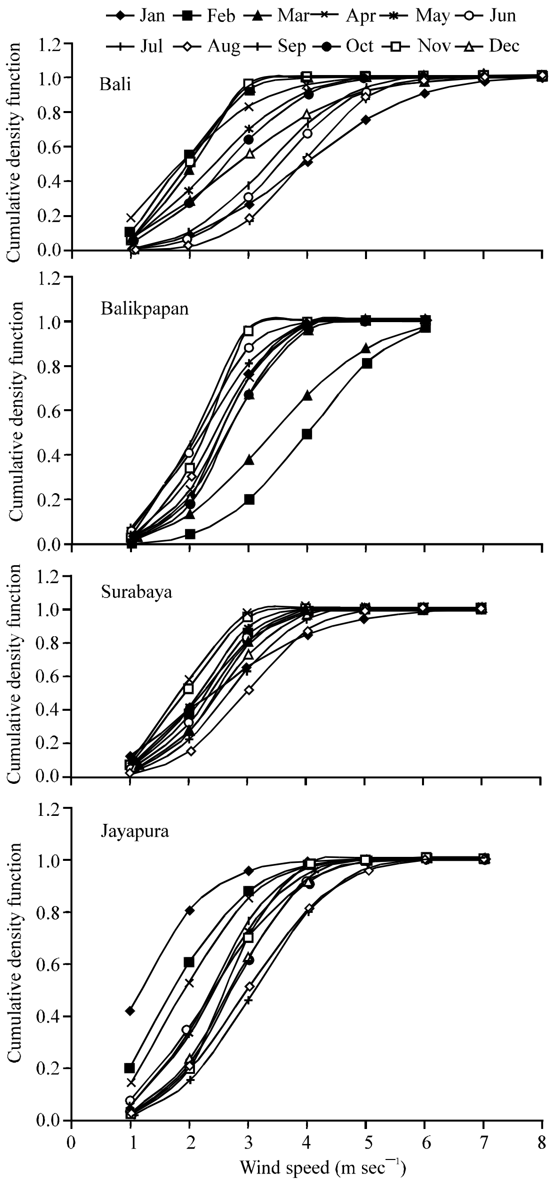

Fig. 4: Monthly cumulative distribution function from the Weibull analysis (for Bali, Balikpapan, Surabaya and Jayapura)

of the wind speeds with respect to actual values was evaluated using Root Mean Square Error (RMSE). The results showed 4.1, 7.8, 8.5 and 7.5% for Bali, Balikpapan, Surabaya and Jayapura, respectively. There are indicates good agreement between data and Weibull Model for these 4 locations selected. The monthly Cumulative Distribution Function (CDF) also were analyzed and presented as wind speed profile characteristic for the four locations of the study. The cumulative distribution functions based on the Weibull parameter for each month in a year were plotted in Fig. 4. Based on the

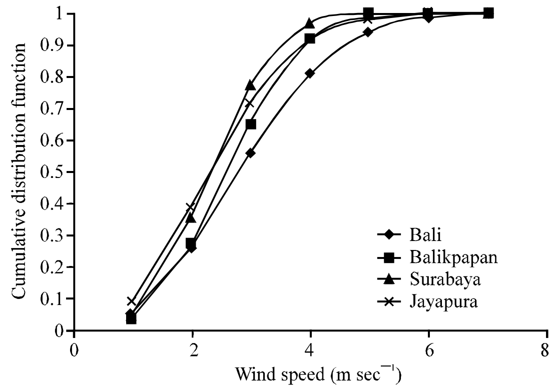

Fig. 5: Yearly Cumulative Distribution Function (CDF) from the Weibull analysis

result, the operating possibility from monthly CDF if 3 m sec^{-1} are used as the cut-in speed for wind turbines, Bali will have the highest operating possibility of 80% in August and the lowest operating possibility of 2% in November. Balikpapan will have the highest operating possibility of 80% in February and the lowest operating possibility of 0% in September. Surabaya will have the highest operating possibility of 50% in August and the lowest operating possibility of 1% in October. Jayapura will have the highest operating possibility of 55% in July and the lowest operating possibility of 5% in January.

The comparisons of yearly cumulative distribution function between four selected locations were shown in Fig. 5. This analysis indicated the spatial variability of wind speed cumulative distribution functions. Based on the analysis from yearly the Weibull CDF, 55% of Bali's yearly wind speed, 65% of Balikpapan's yearly wind speed, 75% of Surabaya's yearly wind speed and 70% of Jayapura's yearly wind speed data lies below 3 m sec^{-1} as cut-in wind speed. The result indicates these locations selected have low wind energy to be tapped. If 3 m sec^{-1} are used as the cut-in speed for wind turbines, Bali will have the highest operating possibility and Surabaya will have lowest operating possibilities.

CONCLUSION

In this study, the assessment of the wind characteristics and wind power potential in the selected locations of Indonesia using Weibull distribution were investigated. It is used to fit the wind speed distributions over a time period, monthly and yearly analysis. The Weibull distribution function has been found to fit the wind speed data in Indonesia. The wind profile characteristic at four different locations in Indonesia, i.e., Bali, Balikpapan, Surabaya and Jayapura has been investigated by statistical analysis and the Weibull distribution. The Weibull distribution presented in the four selected location has been studied and analyzed indicates a good agreement between Weibull Model and data. Also, the Weibull parameter has been obtained as they represent the wind characteristic of Indonesia site. The assessment of the wind characteristics for Bali, Balikpapan, Surabaya and Jayapura shown poor wind power potential indicated by the low monthly and yearly mean wind speed and power density values. The maximum and minimum power densities were found to be 110 and 5 W m^{-2}, respectively. The result indicates these particular site correspondents to the wind power class of 1. The selected location where the data available indicated the site studied is not suitable for electric wind application in a large scale.

Based on this study, it is concluded that these sites are unsuitable for the large scale wind energy generation. The wind speed is not very conducive for developing large on-grid wind power projects. Under the current wind turbine technology this area may not be suitable for year round large-scale electricity generation. However, the wind characteristic of wind speed in selected locations of Indonesia has been analyzed and presented. This study is expected become a reference in the very rare research about wind energy resources in Indonesia. For further study, it is consider to analyze the wind speed characteristic based on ground data from selected location where data available from meteorological station as comparison.

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