日本船舶海洋工学会講演会論文集（Volume No. and paper No. will be put by the society）

Ocean Wind Energy Potential and Analysis at Eastern Indonesia

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Key Words: *Wind Energy, Weibull Distribution, density function, Energy Density, East Indonesia*

1. INTRODUCTION

It is commonly known that renewable energy have become important than ever to be explored and utilized due to the reduction of energy sources from fossils as well as environmental concerns arisen as a result of these conventional energy usage. Therefore, it could be predicted that research and investment to support renewable energy development and application will increase significantly in the future.

It is certain that this is also the case with Indonesia. Indonesia actually has abundant renewable energy sources such as biomass, geothermal, solar, wind, wave, etc. which have a large potential to be explored. However, data from Indonesian Ministry of Energy and Mineral Resources show that it is still less than 2% of total wind energy of Indonesia which have been implemented and utilized by 2012[1].

Especially for wind energy, its application could be considered to be more suitable in offshore than onshore considering that Indonesia is as an archipelago country where approximately 2/3 of its total areas are ocean. Moreover, placing wind energy generation system in offshore will cause fewer concerns to population due to noise and other environmental problems compared to the ones in onshore.

In order to optimally explore and utilize this ocean wind energy, information about distribution, speed and direction of the wind in these sea areas need to be collected and analyzed. As a result, it is important to conduct a study to analyze ocean wind energy potential in Indonesia. For that purpose, the present study will focus on the ocean wind energy potential analysis at eastern part of Indonesia especially around Sulawesi and Maluku islands.

In the present study, wind data are collected from two weather and meteorological stations that perform wind data measurements and collections in the sea areas around Sulawesi and Maluku islands. These stations are located at Makassar and Kendari cities. Using the data, energy density in the area can be obtained.

In order to represent the characteristics and distribution of the wind model, Weibull distribution with two parameters is used. The distribution parameters which are shape and scale factors can be determined using several methods. In the present study, 3 (three) methods will be implemented which are linear regression method (LRM), maximum likelihood method (MLM) and moment method (MM). The computation results from these methods are compared to investigate the accuracy of the methods.

Moreover, the distribution parameters obtained using these methods are also used to compute the probability density function (PDF) and the cumulative distribution function (CDF). After that, the energy density of each area can be determined straightforwardly using these parameters as well. However, because of limited spaces, only data from one sea area which will be demonstrated in computation to show the applicability of the methods. Computation results from other sea areas will be directly shown. The methods are also implemented in self-coded software called wind energy conversion system analysis (WECSA)[2),3)].

2. WIND ENERGY ANALYSIS

The main objective of the wind energy analysis in the present study is to obtain distribution functions to represent the wind model as well as to determine the wind energy density in particular areas. For that purposes, Weibull distribution with 2 (two) parameters is used in the present study. The Weibull parameters which are shape (k) and scale (c) factors are estimated using 3 methods which are linear regression method (LRM), maximum likelihood method (MLM), and moment method (MM). The explanation about the methods can also be found in Mathew[4)], Al-Fawzan[5)], and Bhattacharya and Bhattacharjee[6)].

2.1 Weibull Distribution

Wind distribution is commonly represented by Weibull distribution. The Weibull distribution is characterized by two functions which are probability density function (PDF) and cumulative distribution function (CDF). The probability density function can be determined by the following equation

$$f(v)=\frac{k}{c}\left(\frac{v}{c}\right)^{k-1}e^{-\left(v/c\right)^{k}} \tag{1}$$

where k is the Weibull shape factor, c is scale factor and v is wind speed. The cumulative density function is obtained by integrating (1) as follows

$$F(v)=\int_{0}^{\infty}f(v)dv=1-e^{-\left(v/c\right)^{k}} \tag{2}$$

There are several methods which can be used to determine k and c. In the present study, 3 methods will be used which are

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linear regression method (LRM), maximum likelihood method (MLM) and moment method (MM). After k and c can be determined, it is straightforward to compute the energy density (E_D) using the following equation.

$$E_D = \frac{\rho_a c^3}{2} \frac{3}{k} \Gamma\left(\frac{3}{k}\right) \tag{3}$$

where ρ_a is the air density and symbol Γ denotes gamma function.

3. PARAMETERS ESTIMATION METHOD

3. 1 Linear Regression Method (LRM)

In linear regression method (LRM), CDF is transformed into a linear form, adopting logarithmic scales. The expression of CDF can be rewritten as follows

$$1 - F(v) = e^{-\left(\frac{v}{c}\right)^k} \tag{4}$$

Taking the logarithmic twice on both sides, we obtain the following equation

$$\ln\left\{\ln\left[\frac{1}{1-F(v)}\right]\right\} = k\ln(v_i) - k\ln c \tag{5}$$

By plotting ln v_i as x-axis and right side of (5) as y-axis, a straight line equation $y = ax + b$ can be obtained. The slope of the straight line equation (b) is the shape factor (k) and its intercept (a) represents the value of $-k\ln c$. Therefore, the scale factor (c) can be determined using the following formula

$$c = e^{-\left(\frac{b}{a}\right)} \tag{6}$$

3. 2 Maximum Likelihood Method (MLM)

The maximum likelihood method is one of popular methods for computing shape and scale factors because its ability to deal with large number of data. In the maximum likelihood method, the likelihood function is given as

$$L = \prod_{i=1}^{n} f_{v_i}(v_i, k, c) \tag{7}$$

where n is the number of data. By substituting PDF shown in (1) into (7), we get the following equation

$$L(v_1, v_2, \ldots v_n, k, c) = \prod_{i=1}^{n} \left(\frac{k}{c}\right)\left(\frac{v_i}{c}\right)^{k-1} e^{-\left(\frac{v_i}{c}\right)^k} \tag{8}$$

In order to obtain the shape (k) and scale (c) factors which maximize the function $L(v,k,c)$, then logarithmic of (8) is taken; derived with respect to k and c; and equalized with zero. By performing these procedures, the following equations are obtained.

$$\frac{\partial \ln L}{\partial k} = \frac{n}{k} + \sum_{i=1}^{n} \ln v_i - \frac{1}{c}\sum_{i=1}^{n} v_i^k \ln v_i = 0 \tag{9}$$

$$\frac{\partial \ln L}{\partial c} = -\frac{n}{c} + \frac{1}{c^2}\sum_{i=1}^{n} v_i^k = 0 \tag{10}$$

By eliminating c from (9) and (10) and simplify it, we have

$$\frac{\sum_{i=1}^{n} v_i^k \ln v_i}{\sum_{i=1}^{n} v_i^k} - \frac{1}{k} - \frac{1}{n}\sum_{i=1}^{n} \ln v_i = 0 \tag{11}$$

(11) can be solved by a standard iterative procedure. In the present study, the following Newton-Raphson method will be used

$$k_{n+1} = k_n - \frac{f(k)}{f^{'}(k)} \tag{12}$$

where $f(k)$ and $f'(k)$ can be obtained from (11) as follows

$$f(k) = \frac{\sum_{i=1}^{n} v_i^k \ln v_i}{\sum_{i=1}^{n} v_i^k} - \frac{1}{k} - \frac{1}{n}\sum_{i=1}^{n} \ln v_i \tag{13}$$

$$f^{'}(k) = \sum_{i=1}^{n} v_i^k (\ln v_i)^2 - \frac{1}{k^2}\sum_{i=1}^{n} v_i^k (k \ln\ln v_i - 1) - \left(\frac{1}{n}\sum_{i=1}^{n} \ln v_i\right)\left(\sum_{i=1}^{n} v_i^k \ln v_i\right) \tag{14}$$

After k is obtained, c can be computed conveniently using (10) as follows

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} x_i^k\right)^{1/k} \tag{15}$$

3. 3 Moment Method (MM)

The moment method (MM) is another technique commonly used in estimating parameters. The n^{th} moment M_n of the Weibull distribution is given by

$$M_n = c^n \Gamma\left(1 + \frac{n}{k}\right) \tag{16}$$

If M_1 and M_2 are the first and second moments, respectively, c can be obtained as

$$c = \frac{M_2}{M_1} \frac{\Gamma\left(1 + \frac{1}{k}\right)}{\Gamma\left(1 + \frac{2}{k}\right)} \tag{17}$$

Similarly,

$$\frac{M_2}{M_1^2} = \frac{\Gamma\left(1 + \frac{2}{k}\right)}{\Gamma^2\left(1 + \frac{1}{k}\right)} \tag{18}$$

In this method, M_1 and M_2 are calculated from wind data. Therefore, (18) can be rewritten as follows

$$\frac{\sum_{i=1}^{n} v_i^2}{\left(\sum_{i=1}^{n} v_i\right)^2} = \frac{\Gamma\left(1+\frac{2}{k}\right)}{\Gamma^2\left(1+\frac{1}{k}\right)} \quad (19)$$

By solving (19) with a standard iterative procedure, k can be obtained. The obtained k is then inserted into (17) to obtain c. In order to solve (19), the Newton-Raphson method shown in (12) is also used. For this case, $f(k)$ and $f'(k)$ are shown as follows

$$f(k) = \frac{M_2}{M_1^2}\frac{\Gamma^2\left(1+\frac{1}{k}\right)}{\Gamma\left(1+\frac{2}{k}\right)} - 1 \quad (20)$$

$$f'(k) = \frac{-2M_2\Gamma^2\left(1+\frac{1}{k}\right)\psi\left(1+\frac{1}{k}\right)}{k^2} + \frac{2M_1^2\Gamma\left(1+\frac{2}{k}\right)\psi\left(1+\frac{2}{k}\right)}{k^2} \quad (21)$$

Where ψ denotes digamma function.

4. RESULTS AND ANALYSIS

4. 1 Location

In the present study, the area on eastern part of Indonesia especially around Sulawesi and Maluku islands will be the focus of investigation. The exact location of the research can be seen in the following figures.

Fig.1 Location of the research

Fig. 1 shows the map of Indonesia and its sea areas. The sea areas are divided into several sea areas which are covered by several observation stations around Indonesia. Because of limited data, the sea areas investigated in the present study are the ones marked by L1-L11 and P1-P5. The name of the sea areas and their observation station location are shown in the following table

Table 1. Sea areas name and its observation station

Code	Sea Names	Stations
L1	Balikpapan Sea	Makassar
L2	Kota Baru Sea	Makassar
L3	Northern Makassar Strait	Makassar
L4	Middle Makassar Strait	Makassar
L5	Southern Makassar Strait	Makassar
L6	Western Sulawesi Sea	Makassar
L7	Sabalana Sea	Makassar
L8	Selayar Sea	Makassar
L9	Northern Bone Bay	Makassar
L10	Southern Bone Bay	Makassar
L11	Flores Sea	Makassar
P1	Bau-bau Sea	Kendari
P2	Manui Sea	Kendari
P3	Eastern Banda Sea	Kendari
P4	Western Seram Sea	Kendari
P5	Kai Sea	Kendari

As shown in Table 1, Makassar station covers sea areas of L1~L11 while Kendari station covers sea areas of P1~P5. Wind speed in these sea areas taken in 2012 are shown in the following table.

Table 2. Wind data from Makassar station

Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Des
L.1	3.09	2.57	2.57	2.57	3.09	4.12	4.12	5.14	5.14	2.57	2.57	2.57
L.2	3.09	2.57	2.57	2.57	3.09	4.12	5.14	5.66	5.14	3.6	2.57	2.57
L.3	3.09	2.57	2.57	2.57	3.6	4.12	3.6	4.63	4.63	2.57	2.57	3.09
L.4	3.09	2.57	2.57	2.57	3.6	4.12	4.63	5.14	5.66	3.6	2.57	2.57
L.5	5.14	2.57	3.6	3.09	4.12	5.66	6.17	6.17	5.66	5.14	3.6	2.57
L.6	3.6	2.57	3.09	3.09	2.57	3.6	4.12	5.14	4.12	3.09	2.57	2.57
L.7	7.72	2.57	4.12	4.12	4.12	6.17	6.17	6.17	5.66	5.66	3.6	2.57
L.8	6.17	2.57	3.6	3.6	3.09	5.66	5.66	6.17	5.66	5.66	3.09	2.57
L.9	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57	2.57
L.10	2.57	2.57	2.57	3.09	2.57	4.12	4.12	4.63	4.12	3.09	2.57	2.57
L.11	5.66	2.57	3.6	4.12	4.63	6.17	4.63	5.14	4.63	3.6	3.09	2.57

Similarly, wind data from Kendari station in 2012 are shown in the following table.

Table 2. Wind data from Kendari station

Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Des
P1	4.64	4.13	5.67	5.56	6.53	8.41	8.46	8.35	6.36	6.87	4.86	4.50
P2	3.46	2.99	4.16	3.64	5.15	6.46	7.54	6.99	5.68	4.59	3.80	3.17
P3	12.28	4.17	2.74	9.62	9.26	12.20	16.34	13.80	11.29	8.47	6.96	no data
P4	4.85	3.42	3.38	3.01	4.36	15.00	6.99	10.51	6.48	4.43	3.23	3.23
P5	8.43	7.19	8.57	8.70	9.07	15.88	17.70	17.42	13.03	11.81	7.43	3.44

4. 2 Weibull Parameters Estimation

In order to demonstrate the computation procedures of the 3 methods used in the present study, wind data from one sea area will be taken as a computation example. For this purpose, data from Flores Sea (L11) is chosen. The results of the computation are shown in the following table.

Table 3. Computation results for Flores sea

Method	Shape	Scale	Energy Density (*watt/m*^{2})
LRM	3.8336	4.6489	57.0389
MLM	4.2621	4.6254	55.1174
MM	4.2622	4.6151	54.7498

From Table 3, it can be seen that the computation results of MLM and MM are almost similar while slight difference can be noticed for the ones from LRM. By considering results shown in Table 3, it would be reasonable to choose the computation results from either MLM or MM to determine the highest energy potential available in the sea areas investigated in the present study.

Using the shape and scale parameters shown in Table 3, the probability density function (PDF) of the Weibull distribution for Flores Sea can be obtained using (1). The computation results are shown in the following figure.

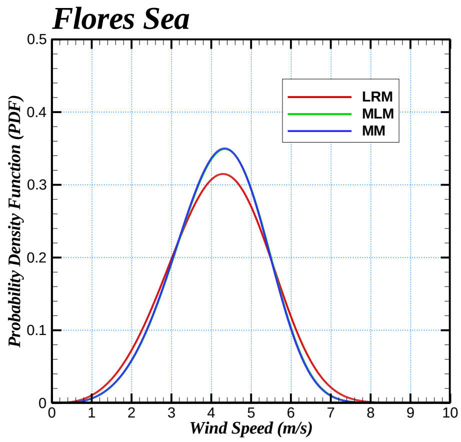

Fig. 2 PDF of Flores Sea

It could be expected that because there is only a slight difference of computation results of shape and scale factors obtained using MLM and MM, the difference of the PDF computed with MLM and MM as shown in Fig. 2 cannot be noticed. Moreover, it can also be observed from Fig. 2 that the forms of obtained PDFs are almost symmetric where the highest wind speed probabilities are in the range 3-5 m/s for all methods.

The cumulative distribution function (CDF) for wind data of Flores Sea can be computed using (2). The computation results are shown in the following figure.

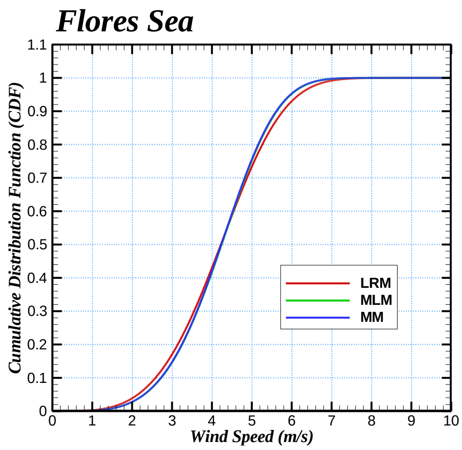

Fig. 3 CDF of Flores Sea

Similar to the previous figure, the computation results of MLM and MM shown in Fig. 3 are similar as well. However, slight difference can be found for the ones using LRM which is due to less accuracy of the results. Moreover, it can also be noticed from Fig. 3 that most wind speed are below 7 m/s.

With similar procedures, other sea areas also can be computed. The computation results of the energy density of all sea areas are shown in the following table

Table 4. Energy density of all sea areas

Code	Energy Density (*watt/m²*)	Code	Energy Density (*watt/m²*)
L1	28.5981	L9	10.3969
L2	35.7227	L10	24.0075
L3	25.8392	L11	54.7498
L4	34.8242	P1	173.0769
L5	68.1299	P2	87.2112
L6	26.7675	P3	877.9616
L7	92.8205	P4	270.5727
L8	70.8732	P5	1297.96

It can be seen from computation results in Table 4 that wind energy densities of the sea areas measured at Kendari station are all higher than the ones measured by Makassar station. It can also be pointed out that the highest energy densities can be found in Kai Sea area (P5) which is approximately 1,297 kwatt/m^2.

5. CONCLUSION

In the present study, ocean wind energy potential of several sea areas in eastern Indonesia are investigated. The wind characteristics are represented by Weibull distribution with 2 parameters. The parameters are computed using 3 methods which are linear regression method (LRM), maximum likelihood method (MLM) and moment method (MM). It can be concluded from this study that the computation results using MLM and MM are closed to each other while slight difference is obtained for the ones from LRM. It is also found from this study that the highest energy density can be found in Kai Sea area (P5).

ACKNOWLEDGMENT

This work was supported by Unggulan Perguruan Tinggi (UPT) research grant from Indonesian Directorate General of Higher Education and Hasanuddin University, Makassar for fiscal year 2014.

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