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Comparative Modelling and Simulation of Small Wind Turbine System Using MATLAB/Simulink Based on Various Power Coefficient Models in Kupang-Indonesia

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Abstract— With the rapid depletion of fossil fuels that cause environmental impact such as climate change while the need for energy, especially electricity, is increasing in demand, the use of renewable energy must be immediately executed. One of the types available in most parts of the world is wind energy. In Indonesia, this energy can be implemented in Kupang, Nusa Tenggara Timur due to its high potential in which in contrast, has faced electricity crisis and frequent blackouts. Thus, this research aims to models and compares small wind turbines based on existing power coefficient mathematical approaches which are polynomial, sinusoidal, and exponential using MATLAB/Simulink. The result of this study is based on the selected model, which is the Ovando et al. model with a coefficient of 0.4513. This model produced power in the range of 9000–16000 W under the assumption of periodic wind speeds of 50–60 km/h. The calculations were based on pre-determined parameters, including a blade radius of 2 m, a tip speed ratio (λ) of 7, a pitch angle (β) of 0, and an air density of 1.225 kg/m^3 .

Keywords—renewable energy, small wind turbine system, Kupang, MATLAB/Simulink, Power coefficient mathematical model

I. INTRODUCTION

Renewable energy is essential for generating electricity and meeting energy demands, largely due to its environmental benefits and reduced dependence on fossil fuels [1], [2]. Yet, challenges such as weather impacts, low efficiency, high investment costs, and transportation issues are undeniable [2], [3], [4], [5]. These address the implementation of energy modelling through simulation in its early phase before decision making [6], [7]. Simulation software like Matrix Laboratory or generally MATLAB, particularly its Simulink toolbox, allows for effective modeling of energy systems, including solar and wind energy. Wind energy has garnered global attention, with many countries establishing wind farms to produce clean energy in line with the Kyoto Protocol. [8]. In the case of Indonesia, as to meet the requirement of Peraturan Pemerintah No. 79 Tahun 2014 for the national energy regulation, the usage

of wind energy has become significant to meet the target of 23% of renewable energy in the energy mix by 2025, currently 14%, in Rencana Umum Ketenagalistrikan Nasional (RUKN) and Net Zero emissions [9]. The Ministry of Mineral and Energy Resources estimates Indonesia's wind energy potential at 154.88 GW, consisting of 60.65 GW onshore and 94.2 GW offshore [9], with optimal locations primarily in eastern regions like South Sulawesi and Nusa Tenggara Timur (NTT) [10].

Aside from potential and location, one of the important parameters that have been studied and simulated is the power coefficient (C_p) of turbine which shows the relationship between the actual power to the available potential (the ambient wind turning the turbine). C_p mathematical model has been developed throughout the years, giving many approaches, generally expressed in polynomial, sinusoidal, and exponential functions [8], [11], [12]. However, these studies either only review the existing models or invent a new model.

Several other studies determine how to model the wind turbine in Indonesia using MATLAB/Simulink. The study in Manado used data collection, model creation, testing and simulation on one year wind speed data with maximum power 8000 W (in nighttime) and 3322 W in average based on the wind speed [13]. The study in Tegal uses similar methods, however without accounting for certain period of wind speed, which fixes the speed of 3 m/s and determines the blade radius by 6 m, and rotor angular speed by 4 rad/s, resulting in 768.55 W and torque of 192.1 Nm [14]. Then, the study in Cilacap with the same method is done to produce mechanical power output of 221.9 W and a torque of 6.448 Nm [15]. These previous studies implement one power coefficient approach which lacks the comparison for another coefficient. Thus, this research will emphasize the use of various power coefficients to provide broader analysis and results.

Corresponding to the necessity of energy supply, along with the potential presented, a study can be conducted specifically in Kupang, Nusa Tenggara Timur, Indonesia, as electricity crisis

and regular blackout occur often due to natural disaster [16], [17], [18]. Moreover, *Perusahaan Listrik Negara* (PLN) data shows about 94.04% or 1.190.641 family in NTT have access to electricity while the rest, specifically about 215 village are unreachable [18]. Knowing that the highest potential in this area lies on wind energy by 10.188 MW [18], [19], this study is conducted to provide comparative analysis on small wind turbines models based on MATLAB/Simulink simulation, specifically for horizontal axis type with three blades for various selected power coefficients from existing literatures to find the potential power to solve Kupang's electricity issues.

II. POWER COEFFICIENT THEOREM

Power coefficient is one of the parameters used to obtain the power of wind turbines. Tracing back, the wind turbine is based on kinetic energy which depends on mass airflow to express the following equation (1).

$$P_w = \frac{1}{2} \rho A v^3 \quad (1)$$

P_w stands for wind power (W), ρ for density (kg/m^3), A for area (m^2) and v for wind speed (m/s). However, in reality, the kinetic energy cannot be directly converted to mechanical energy. Ideally, the amount that can be converted is 59.25% (Betz's Limit). Thus, the power turbine is now expressed as equation (5):

$$P_m = \frac{1}{2} \rho \pi R^2 v^3 C_p(\lambda, \beta) \quad (2)$$

In which P_m represents mechanical power (W), R as blade radius of the turbine (m), v as wind speed (m/s), C_p as power coefficient, λ as tip speed ratio, and β as pitch angle ($^\circ$). The power coefficient (C_p) is a vital aspect in wind energy conversion system [12]. It can be defined as the ratio of wind energy extracted to real potential when the air kinetic energy reaches the turbine. Power coefficient can be obtained through several methods such as numerical analysis to make mathematical functions, algorithms approaches or wind turbines testing in which data will be collected and processed to make $C_p(\beta, \lambda)$ variation graph. Several of the approaches in polynomials, sinusoidal, and exponential representations for three blade models can be further described as follows [8], [12]:

- Polynomials models is a common model to represent C_p in which the curve can be generated based on the equation (3) which is detailed in Table I.

$$C_p(\lambda) = \sum_{i=0}^n a_i \lambda^i \quad (3)$$

TABLE I. Constants of Power Coefficient in Polynomial Functions Related Studies

Constants	Polynomial Order Functions for Power Coefficient			
	Third [20]	Fourth [21]	Fifth [22]	Seventh [23]
a_0	-0.02086	0.11	0.0344	0
a_1	0.1063	-0.2	-0.0864	0.0051
a_2	-0.004834	0.097	0.1168	-0.0022
a_3	-0.000037	-0.012	-0.0484	0.0052
a_4	0	0.00044	0.00832	-0.00051425
a_5	0	0	-0.00048	-0.00002795
a_6	0	0	0	0.0000046313
a_7	0	0	0	-0.0000001331

- Sinusoidal models in the general equation based on the existing functions are expressed in equation (4) and Table II.

$$C_p(\lambda, \beta) = [b_0 + b_1(\beta + b_2)] \sin\left(\frac{\pi(\lambda + b_3)}{b_4 + b_5(\beta + b_6)}\right) + b_7(\lambda + b_8)(\beta + b_9) \quad (4)$$

TABLE II. Constants of Power Coefficient in Sinusoidal Related Studies

Constants	Sinusoidal Order Functions for Power Coefficient				
	Moussa [20]	Coto [24]	Xin [25]	Merahi [26]	Nouira [27]
b_0	0.5	0.44	0.44	0.5	0.5
b_1	-0.00167	0	-0.0167	-0.0167	0.0167
b_2	-2	0	0	-2	-2
b_3	0.1	-1.6	-3	0.1	0.1
b_4	18.5	15	15	10	18.5
b_5	-0.3	0	-0.3	-0.3	-0.3
b_6	-2	0	0	0	-2
b_7	0.00184	0	0.00184	-0.00184	-0.00184
b_8	-3	0	-3	-3	-3
b_9	-2	0	0	-2	-2

- Exponential models have several studies regarding the function that can be generalized as the following equation (5) in which the constant values are shown in Table III.

$$C_p(\lambda, \beta) = c_0 \left(\frac{c_1}{\lambda_i} - c_2 \beta - c_3 \beta \lambda_1 - c_4 \lambda_1^{c_5} - c_6 \right) e^{-\left(\frac{c_7}{\lambda_i}\right)} + c_8 \quad (5)$$

TABLE III. Constants of Power Coefficient in Exponential Related Studies

Constants	Exponential Order Functions for Power Coefficient							
	Kotti [28]	Khajuria [29]	Ovando [30]	Feng [31]	Llano [32]	Shi [33]	Bustos [34]	Ahmed [35]
c_0	0.5	0.5	0.5176	0.22	0.5	0.73	0.44	1
c_1	116	116	116	116	72.5	151	124.99	110
c_2	0	0.4	0.4	0.4	0.4	0.58	0.4	0.4
c_3	0.4	0	0	0	0	0	0	0
c_4	0	0	0	0	0	0.002	0	0.002
c_5	0	0	0	0	0	2.14	0	2.2
c_6	5	5	5	5	5	13.2	6.94	9.6
c_7	21	21	21	12.5	13.125	18.4	17.05	18.4
c_8	0	0	0.0068	0	0	0	0	0
c_9	0.008	0	0.08	0.08	0.08	0.02	0.08	0.02
c_{10}	0	0.088	0	0	0	0	0	0
c_{11}	0.035	0.035	0.035	0.035	0.035	0.003	0.001	0.03

III. METHOD

The research method starts with problem identification, literature review, data collection, modelling and simulation as well as analysis and conclusion. However, the data collection and modelling-simulation can be discussed in this section extensively below.

1. Data Collection

a. Wind Speed in Kupang

Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) of Indonesia data from 2020 to 2022 shows that Kupang City has an average wind speed of 2.05 m/s in Kupang District and a maximum of 7.5 m/s in Eltari District [36], with the lowest by 1 m/s [37]. While recent reports indicate wind speeds in NTT reaching 50-60 km/h (about 13.89 m/s to 16.67 m/s) [38], [39]. However, the given data is recorded for areas around the city. In consideration of the possibility of making small wind turbines farms, an open area is needed. Thus, using other sources such as Global Wind Atlas, an analysis for location

selection can be made. The data shows that for open areas, in which has been identified with the help of Google Earth as well as geospatial data from Dukcapil and Landsat 8 data, possible areas in the context of relatively high wind speed and power density are within Naioni Village as shown in Fig. 1 a) which is the view and data from the Global Wind Atlas as well as b) as the view from the Google Earth.

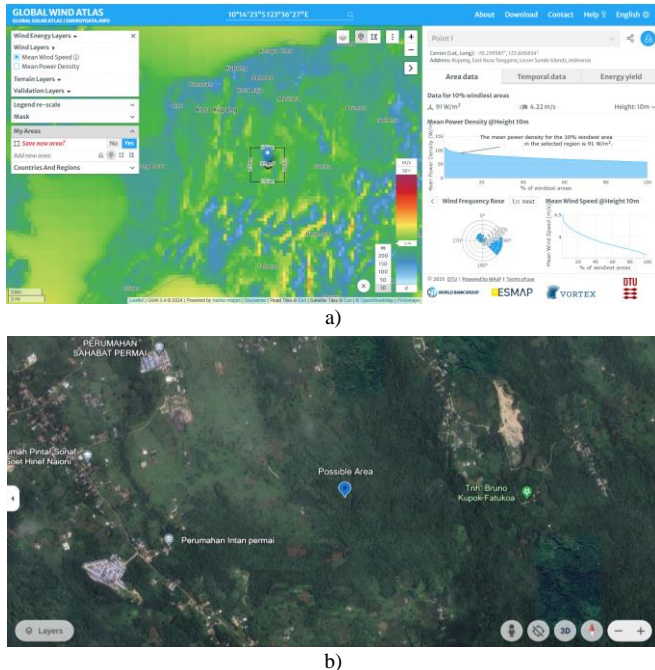


Fig. 1. Naioni Village, Kupang by a) Global Wind Atlas and b) Google Earth

Global wind atlas data shows the mean wind speed of 4.22 m/s in the 10% of the windiest area for 10 m turbine hub height from the ground level, with an increase to 5.9 m/s for 50 m, 6.92 m/s for 100 m, 7.69 m/s for 150 m, and 8.19 m/s for 200 m. In comparison to BMKG data, this is more reliable since it provides better approximation based on the height's variation, showing the fulfillment to the minimum speed for small wind turbines by 4-4.5 m/s [40], [41]. Based on the scope (small wind turbine), it is assumed that the installation height will be at least 10 m from ground level. Thus, the range of wind speed from 1 m/s, 4.22 m/s, 13.89 m/s, and 16.67 m/s will be used as the basis for simulation for comparison purposes.

b. Wind Turbine Model Reference

Based on these criteria that the minimum wind speed in Kupang is 1 m/s, the researcher chose an existing model called AWI-E1000T as reference that backs up the idea of the wind turbine modelling in this research scope. This turbine comes in different variation based on the power specifications [42]. With the survival wind speed of 60 m/s, its blade radius is accounted approximately 2 m with the weight of 18.5 kg overall.

c. Tip Speed Ratio (λ), Pitch Angle (β), and air density.

Several reports and studies have suggested that the optimum tip speed ratio (λ) for three blade wind turbines is 7 which can range from 6-8 (recommended for 6-12 m/s incoming wind

speed) [43], [44], [45]. Whilst the same goes with the pitch angle (β) in which to obtain the maximum power point (correlated to C_p), the angle should be 0 degree [46], [47], [48]. Finally, the air density is also assumed to be 1.225 kg/m³. Therefore, in this research, the λ is predetermined to be 7, β to be 0, and air density of 1.225 kg/m³.

2. Modelling-Simulation

The power equation for wind turbines in (1) is used with additional equations (4) shown below.

$$\omega = \frac{\lambda v}{R} \quad (4)$$

In which tip speed ratio (λ) means the ratio of wind turbine blade tip speed to wind speed, which can determine the angular speed or (ω). The angular speed used in the calculation are 3.5 rad/s, 14.77 rad/s, 48.615 rad/s, and 58.345 rad/s for the selected wind speed.

The power equation is then highly dependent on the power coefficients mathematical model. For the polynomial functions, modeling only focuses on the tip speed ratio as the input based on angular speed equation. Whereas for the sinusoidal and exponential function, the only difference with polynomial modelling lies in the input for tip speed ratio (λ) shown in Fig. 2. Fig. 2 a) and b) are the breakdown of the function and the subsystem adjustment based on the C_p input.

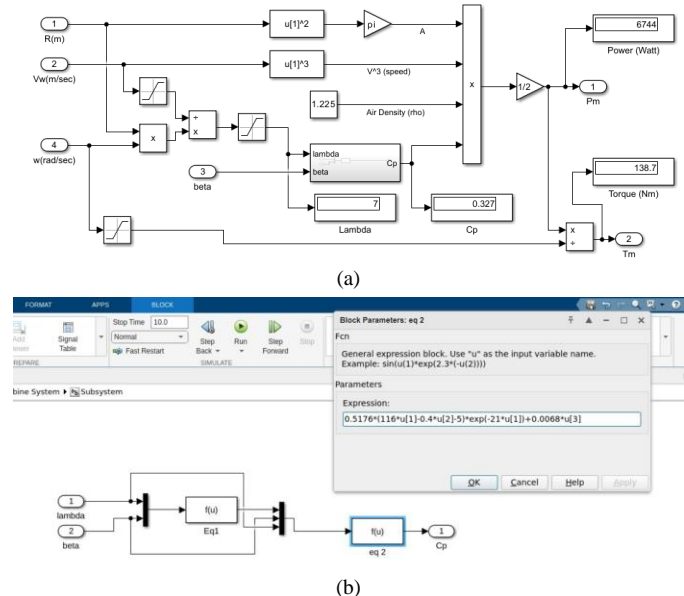


Fig. 2. System for exponential and sinusoidal model a) Breakdown for Exponential and Sinusoidal Model for Small Wind Turbine and b) The Subsystem Adjustment According to the Input for C_p

For additional information, torque or T (Nm) is also calculated alongside in which is obtained by dividing the power as P (W) to the angular speed as ω (rad/s), shown on the equation (12).

$$T = \frac{P}{\omega} \quad (12)$$

Moreover, for validation purposes to the modelled system, comparison between the designed model by researchers with existing literatures are shown in Table IV.

TABLE IV. Validation for Power Coefficients Models Based on Existing Literatures

Power Coefficient Models Input Parameters	Parameters for Validation	Literatures References	Research Models Result
Third Order Polynomial for wind speed of 8.2 m/s, radius of 3.61 m, and rotational speed of 22.7 rad/s [20]	Lambda and Cp	10 and 0.500	9.9 and 0.520
Fourth Order Polynomial for wind speed of 7 m/s, radius of 2 m, and rotational speed of 21 rad/s [21]		6 and 0.400	6 and 0.380
Fifth Order Polynomial for wind speed of 4 m/s, radius of 1.525 m, and rotational speed of 15.7 rad/s [22]		6 and 0.400	5.98 and 0.393
Sixth Order Polynomial for wind speed 8 m/s, radius of 2.5 m, and rotational speed of 12.8 rad/s [23]	Lambda and Ct	4 and 0.040	4 and 0.043
Sinusoidal Model (Moussa) wind for speed of 8.2 m/s, radius of 3.61 m, and rotational speed of 18.17 rad/s [20]	Lambda and Cp	8 and 0.480	7.99 and 0.470
Sinusoidal Model (Coto) for wind speed of 16 m/s, radius of 2 m, and rotational speed of 32 rad/s [24]		4 and 0.250	4 and 0.210
Sinusoidal Model (Xin) for wind speed of 13 m/s, radius of 3 m, and rotational speed of 65 rad/s [25]		15 and 0.270	15 and 0.259
Sinusoidal Model (Merahi) for wind speed of 11 m/s, radius of 2 m, and rotational speed of 33 rad/s [26]		6 and 0.520	6 and 0.529
Sinusoidal Model (Nouira) for wind speed of 10 m/s, radius 2 m, and rotational speed of 20 rad/s [27]		4 and 0.300	4 and 0.295
Exponential Model (Kotti) for wind speed of 13 m/s, radius of 2 m, and rotational speed of 39 rad/s [28]		6 and 0.330	6 and 0.330
Exponential Model (Khajuria) speed of 10 m/s, radius of 2 m, and rotational speed of 30 rad/s [29]		6 and 0.330	6 and 0.320
Exponential Model (Ovando) for wind speed of 10 m/s, radius of 1 m, and rotational speed of 100 rad/s [30]		10 and 0.400	10 and 0.403
Exponential Model (Feng) for wind speed of 4 m/s, radius of 2 m, and rotational speed of 12 rad/s [31]		6 and 0.440	6 and 0.436
Exponential Model (Llano) for wind speed of 3 m/s, radius of 3 m, and rotational speed of 6 rad/s [32]		6 and 0.400	6 and 0.403
Exponential Model (Shi) for wind speed of 11.4 m/s, radius of 63 m, and rotational speed of 0.724 [33]		4 and 0.190	4 and 0.187
Exponential Model (Bustos) for wind speed of 12 m/s, radius of 2 m, and rotational speed of 48 rad/s [34]		8 and 0.450	8 and 0.450
Exponential Model (Ahmed) for wind speed of 12 m/s, radius of 2 m, and rotational speed of 36 rad/s [35]		6 and 0.440	6 and 0.4395

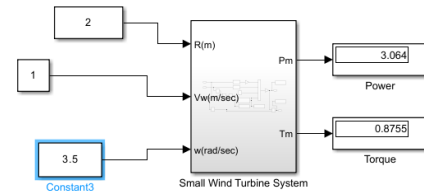


Fig. 3. Small Wind Turbine System Sample Model

IV. RESULTS AND DISCUSSION

The result of the simulation can be shown below with the given parameters in Table V. For the selected wind speed from the lowest, average, and highest by 1 m/s to 16.67 m/s, the power and torque for each power coefficient approaches show various results, ranging from about 3-20000 W and 1-290 N/m. It is considered that for a turbine system, a good coefficient power in relative ranges from 0.4 to 0.5 [49]. Therefore, selecting from the given range, three polynomial models satisfy the criteria (since the 5th order polynomial had exceeded the range). Similarly, sinusoidal functions have 3 satisfied models and exponential functions have 4 satisfied models. The highest power coefficient in terms of the range consideration lies in the third order of 0.4034 followed by [30] at 0.4513 and [26] at 0.474 from smallest to largest. For the maximum power, the [26] model reached 16900.6 W, slightly higher than [30]. The same for the torque producers, which are 289.7 Nm. Several other models do fall vaguely from the criteria such as [24], [28], [29], and others.

Finally, the model can be made simpler to give better visualization that can highlight important data as shown in Fig. 3. as follows:

TABLE V. Power Coefficient Simulation Results

Cp	Speed (m/s)	1		4.22		13.89		16.67	
	Output	Power (W)	Torque (Nm)	Power (W)	Torque (Nm)	Power (W)	Torque (Nm)	Power (W)	Torque (Nm)
Polynomial									
0.4737	3 rd [20]	3.6	1.0	274.0	18.6	9770.0	201.0	16889.3	289.5
0.4034	4 th [21]	3.1	0.9	233.0	15.8	8322.0	171.2	14384.7	246.5
0.5757	5 th [22]	4.4	1.3	333.0	22.5	11874.0	244.3	20526.0	351.8
0.4423	7 th [23]	3.4	1.0	256.0	17.3	9123.0	187.7	15769.7	270.3
Sinusoidal									
0.4483	Moussa [20]	3.5	1.0	259.3	17.6	9247.0	190.2	15984.3	274.0
0.3981	Coto [24]	3.1	0.9	230.3	15.6	8212.0	168.9	14195.2	243.3
0.327	Xin [25]	2.5	0.7	189.1	12.8	6744.0	138.7	11658.7	199.8
0.474	Merahi [26]	3.6	1.0	274.2	18.6	9777.0	201.1	16900.6	289.7
0.4439	Nouira [27]	3.4	1.0	256.8	17.4	9157.0	188.4	15828.9	271.3
Exponential									
0.39	Kotti [28]	3.0	0.9	225.6	15.3	8043.0	165.5	13904.0	238.3
0.39	Khajuria [29]	3.0	0.9	225.6	15.3	8043.0	165.5	13904.0	238.3
0.4513	Ovando [30]	3.5	1.0	261.0	17.7	9308.0	191.5	16090.6	275.8
0.4292	Feng [31]	3.3	0.9	248.2	16.8	8852.0	182.1	15301.9	262.3
0.3423	Llano [32]	2.6	0.8	197.9	13.4	7060.0	145.2	12203.6	209.2
0.4409	Shi [33]	3.4	1.0	255.0	17.3	9095.0	187.1	15721.1	269.5
0.4228	Bustos [34]	3.3	0.9	244.5	16.6	8720.0	179.4	15073.4	258.4
0.3528	Ahmed [35]	2.7	0.8	204.1	13.8	7277.0	149.7	12579.0	215.6

Using the highest output turbine model from [26] and assuming that the seasonal wind speed reaches 50-60 km/h periodically, the power generated reaches nearly 10000-17000 W with a torque of 200-290 N/m. However, since [26] states that the turbine was designed for 1.5 MW, this simulated research result is out of scope. Therefore, the best-selected model stands for [30] which provides power exceeding 9000-16000 W and torque range of 190-270 N/m, slightly lower than the prior. At the lowest speed of 1 m/s, the turbine produces 3 W while on the average speed of 4.22 m/s, it produces 261 W.

The outputs presented in their exact values will be different from the actual conditions, as they will vary with speed changes. The accumulated power will then be converted into electricity through a series of electrical systems transmitted for energy usage. This process could help meet the electricity demands in Kupang while addressing the urgent need to reach 23% of renewable energy by 2025 in RUKN and also from the *Rencana Usaha Penyediaan Tenaga Listrik Tahun 2021-2030 (RUPTL)* for a replacement of 23.231 kW of diesel capacity in this region specifically [50]. Hence, given the region's high wind energy

potential and the research output, it is recommended to consider small wind turbine systems to provide local communities with electricity.

In consideration, further solutions and implementation plans are to be addressed to overcome the practical challenge including seasonal wind variations, maintenance, and integration into external systems (generators and power electronics) as well as local power grids. This includes the use of statistical methods to predict wind behavior over a period [51], implementation of artificial intelligence with fuzzy logics, neural networks, etc. for generators and power electronics systems performance control [52] as well as the use of financial and greenhouse gas reduction analysis to greater enhance the overall estimation results. This will give a strong basis for the next step, which is the social impact towards the local acceptance and support.

V. CONCLUSION

This study demonstrates small wind turbine models from MATLAB/Simulink simulation to show potential power supply to Kupang based on comparative analysis from existing power coefficient models, specifically for the horizontal-axis type with three blades. This project utilizes wind speed data of 1m/s, 4.22 m/s and 13-17 m/s. Featuring a blade radius of 2 m, a tip speed ratio of 7, a pitch angle of 0, and an air density of 1.225 kg/m³, power coefficients were analyzed based on the selected functions which are polynomial (third order, fourth order, fifth order and seventh order), sinusoidal ([20], [24], [25], [26], [27]) as well as exponential ([28], [29], [30], [31], [32], [33], [34], [35]). The best selected implementation model [26] yields a power coefficient of 0.4513, generating above 9000-16000 W per turbine rotation for seasonal wind. This output can meet almost of the 23.231 kW demand for diesel power replacement, provide energy to underdeveloped areas and help in preventing blackouts in NTT. Future research should consider wind prediction analysis, artificial intelligence for managing external systems, and assessments for financial viability and greenhouse gas emissions to ensure social acceptance. In addition, this may collaborate with local institutions to expedite development.

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REFERENCES

- [1] Neha and J. Rambeer, "Renewable Energy Sources: A Review," in *Journal of Physics: Conference Series*, IOP Publishing Ltd, Aug. 2021. doi: 10.1088/1742-6596/1979/1/012023.
- [2] D. Maradin, "Advantages and disadvantages of renewable energy sources utilization," *International Journal of Energy Economics and Policy*, vol. 11, no. 3, pp. 176–183, 2021, doi: 10.32479/ijeeep.11027.
- [3] M. N.S., G. N.A., and A. G.A., "Role of Renewable Energy Sources in the World," *Journal of Renewable Energy, Electrical, and Computer Engineering*, vol. 2, no. 2, p. 63, Nov. 2022, doi: 10.29103/jreece.v2i2.8779.
- [4] W. Wisatesajja, W. Roynarin, and D. Intholo, "Analysis of influence of tilt angle on variable-speed fixedpitch floating offshore wind turbines for optimizing power coefficient using experimental and cfd models," *International Journal of Renewable Energy Development*, vol. 10, no. 2, pp. 201–212, 2020, doi: 10.14710/ijred.2021.33195.
- [5] A. I. Osman *et al.*, "Cost, environmental impact, and resilience of renewable energy under a changing climate: a review," *Environ Chem Lett*, vol. 21, no. 2, pp. 741–764, Apr. 2023, doi: 10.1007/s10311-022-01532-8.
- [6] P. Cabrera, H. Lund, J. Z. Thellufsen, and P. Sorknaes, "The MATLAB Toolbox for EnergyPLAN: A tool to extend energy planning studies," *Sci Comput Program*, vol. 191, p. 102405, Jun. 2020, doi: 10.1016/J.SCICO.2020.102405.
- [7] A. A. Adeleke *et al.*, "Simulation Technology in Renewable Energy Generation: A Review," in *2023 2nd International Conference on Multidisciplinary Engineering and Applied Science, ICMEAS 2023*, Institute of Electrical and Electronics Engineers Inc., 2023. doi: 10.1109/ICMEAS58693.2023.10429880.
- [8] O. C. Castillo, V. R. Andrade, J. J. R. Rivas, and R. O. González, "Comparison of Power Coefficients in Wind Turbines Considering the Tip Speed Ratio and Blade Pitch Angle," *Energies (Basel)*, vol. 16, no. 6, 2023, doi: 10.3390/en16062774.
- [9] Dian Galuh Cendrawati, Nurry Widya Hesty, Bono Pranoto, Aminuddin, Arief Heru Kuncoro, and Ahmad Fudholi, "Short-Term Wind Energy Resource Prediction Using Weather Research Forecasting Model for a Location in Indonesia," *International Journal of Technology*, vol. 14, no. 3, pp. 584–595, May 2023, doi: https://doi.org/10.14716/ijtech.v14i3.5803.
- [10] N. W. Hesty, D. G. Cendrawati, R. Nepal, and M. I. Al Irsyad, "Wind Energy Potential Assessment Based-on WRF Four-Dimensional Data Assimilation System and Cross-Calibrated Multi-Platform Dataset," *IOP Conf Ser Earth Environ Sci*, vol. 897, no. 1, p. 012004, Nov. 2021, doi: 10.1088/1755-1315/897/1/012004.
- [11] M. Carpintero-Renteria, D. Santos-Martin, A. Lent, and C. Ramos, "Wind turbine power coefficient models based on neural networks and polynomial fitting," *IET Renewable Power Generation*, vol. 14, no. 11, pp. 1841–1849, Aug. 2020, doi: 10.1049/iet-rpg.2019.1162.
- [12] J. G. González-Hernández and R. Salas-Cabrera, "Representation and estimation of the power coefficient in wind energy conversion systems," *Revista Facultad de Ingeniería*, vol. 28, no. 50, pp. 77–90, 2019, Accessed: Mar. 29, 2024. [Online]. Available: https://www.redalyc.org/journal/4139/413958523006/html/
- [13] A. Septy Wauran, J. T. Elektro, and P. N. Manado, "Pemodelan Penggunaan Energi Turbin Angin Untuk Daerah Manado," *JURNAL MIPA*, vol. 8, no. 3, pp. 188–191, 2019, [Online]. Available: http://ejournal.unsrat.ac.id/index.php/jmuo
- [14] Fahmy Rinanda Saputri and Sarah Delana Wijaya, "Modeling of Wind Power Generation in Tegal Region using," *Indonesian Journal of Computer Science*, 2024, doi: doi.org/10.33022/ijcs.v13i1.3752.
- [15] F. R. Saputri and N. Pranata, "Modeling and Simulation for Wind Power Plant Based on Wind Potency in Coastal Area Using Matlab Simulink: Case Study in Cilacap, Indonesia," in *Advances in Transdisciplinary Engineering*, IOS Press BV, Jun. 2024, pp. 522–528. doi: 10.3233/ATDE240351.
- [16] Makson Saubaki, "Siap-Siap! PLN Pemadaman Listrik Selama 6,5 Jam, Simak Waktu dan Lokasinya," *Kupang Berita*, 2024. Accessed: Mar. 28, 2024. [Online]. Available: https://kupangberita.com/2024/01/23/siap-siap-pln-pemadaman-listrik-selama-65-jam-simak-waktu-dan-lokasinya/
- [17] Yufengki Bria, "Sinyal-Listrik Mati, Siswa SD di Kupang Ikuti Simulasi Olimpiade di Hutan," *detikbali*, 2024. Accessed: Mar. 28, 2024. [Online]. Available: https://www.detik.com/bali/nusra/d-7243451/sinyal-listrik-mati-siswa-sd-di-kupang-ikuti-simulasi-olimpiade-di-hutan
- [18] Dwi Tamara, "Sejauh Mana Pemanfaatan Energi Terbarukan di Provinsi Nusa Tenggara Timur?," Coaction Indonesia. Accessed: Mar. 28, 2024. [Online]. Available: https://coaction.id/sejauh-mana-pemanfaatan-energi-terbarukan-di-provinsi-nusa-tenggara-timur/
- [19] Pemerintah Provinsi Nusa Tenggara Timur, "Pedoman Rencana Umum Energi Daerah Provinsi Nusa Tenggara Timur Tahun 2019-2050," 2019.
- [20] I. Moussa, A. Bouallegue, and A. Khedher, "Design and implementation of constant wind speed turbine emulator using Matlab/Simulink and FPGA," in *2014 Ninth International Conference*

- on *Ecological Vehicles and Renewable Energies (EVER)*, 2014, pp. 1–8. doi: 10.1109/EVER.2014.6844051.
- [21] Md. Arifujjaman, M. T. Iqbal, and J. E. Quaicoe, “Maximum Power Extraction from a Small Wind Turbine Emulator using a DC - DC Converter Controlled by a Microcontroller,” in *2006 International Conference on Electrical and Computer Engineering*, 2006, pp. 213–216. doi: 10.1109/ICECE.2006.355328.
- [22] L. G. González, E. Figueres, G. Garcerá, and O. Carranza, “Maximum-power-point tracking with reduced mechanical stress applied to wind-energy-conversion-systems,” *Appl Energy*, vol. 87, no. 7, pp. 2304–2312, Jul. 2010, doi: 10.1016/J.APENERGY.2009.11.030.
- [23] W. Li, D. Xu, W. Zhang, and H. Ma, “Research on Wind Turbine Emulation based on DC Motor,” in *2007 2nd IEEE Conference on Industrial Electronics and Applications*, 2007, pp. 2589–2593. doi: 10.1109/ICIEA.2007.4318881.
- [24] J. Coto, G. Díaz, J. Gómez-Aleixandre, J. C. Aladro, I. García Álvarez, and G. Díaz González, “Wind speed model design and dynamic simulation of a wind farm embedded on distribution networks.” [Online]. Available: <https://www.researchgate.net/publication/266889500>
- [25] W. Xin, Z. Wanli, Q. Bin, and L. Pengcheng, “Sliding mode control of pitch angle for direct driven PM Wind turbine,” in *The 26th Chinese Control and Decision Conference (2014 CCDC)*, 2014, pp. 2447–2452. doi: 10.1109/CCDC.2014.6852584.
- [26] F. Merahi, S. Mekhilef, and E. M. Berkouk, “DC-voltage regulation of a five levels neutral point clamped cascaded converter for wind energy conversion system,” in *2014 International Power Electronics Conference (IPEC-Hiroshima 2014 - ECCE ASIA)*, 2014, pp. 560–566. doi: 10.1109/IPEC.2014.6869640.
- [27] I. Nouira, A. Khedher, and A. Bouallegue, “A Contribution to the Design and the Installation of an Universal Platform of a Wind Emulator using a DC Motor,” *International Journal of Renewable Energy Research*, vol. 2, no. 4, 2012.
- [28] R. Kotti, S. Janakiraman, and W. Shireen, “Adaptive sensorless Maximum Power Point Tracking control for PMSG Wind Energy Conversion Systems,” in *2014 IEEE 15th Workshop on Control and Modeling for Power Electronics (COMPEL)*, 2014, pp. 1–8. doi: 10.1109/COMPEL.2014.6877181.
- [29] S. Khajuria and J. Kaur, “Implementation of pitch control of wind turbine using simulink (Matlab),” *International Journal of Advanced Research in Computer Engineering & Technology*, vol. 1, pp. 196–200, Mar. 2012.
- [30] R. I. I. Ovando, J. Aguayo, and M. Cotorogea, “Emulation of a Low Power Wind Turbine with a DC motor in Matlab/Simulink,” in *2007 IEEE Power Electronics Specialists Conference*, 2007, pp. 859–864. doi: 10.1109/PESC.2007.4342101.
- [31] F. Gao, D.-P. Xu, and Y.-G. Lv, “Hybrid automation modeling and global control of wind turbine generator,” in *2008 International Conference on Machine Learning and Cybernetics*, 2008, pp. 1991–1997. doi: 10.1109/ICMLC.2008.4620733.
- [32] D. Llano, M. Tatlow, and R. McMahon, “Control algorithms for permanent magnet generators evaluated on a wind turbine emulator test-rig,” in *7th IET International Conference on Power Electronics*, 2014.
- [33] G. Shi, M. Zhu, X. Cai, Z. Wang, and L. Yao, “Generalized average model of DC wind turbine with consideration of electromechanical transients,” in *IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society*, 2013, pp. 1638–1643. doi: 10.1109/IECON.2013.6699378.
- [34] G. Bustos, L. S. Vargas, F. Milla, D. Sáez, H. Zareipour, and A. Nuñez, “Comparison of fixed speed wind turbines models: A case study,” in *IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society*, 2012, pp. 961–966. doi: 10.1109/IECON.2012.6388937.
- [35] D. Ahmed, F. Karim, and A. Ahmad, “Design and modeling of low-speed axial flux permanent magnet generator for wind based micro-generation systems,” in *2014 International Conference on Robotics and Emerging Allied Technologies in Engineering (iCREATE)*, 2014, pp. 51–57. doi: 10.1109/iCREATE.2014.6828338.
- [36] Badan Pusat Statistik NTT, “Kecepatan Angin Menurut Kabupaten/Kota (m/det), 2020-2022,” 2022.
- [37] Badan Pusat Statistik Kota Kupang, “Kecepatan Angin Menurut Kabupaten/Kota (knots), 2021-2023,” 2023. Accessed: Mar. 29, 2024. [Online]. Available: <https://ntt.bps.go.id/indicator/151/960/1/kecepatan-angin-menurut-kabupaten-kota.html>
- [38] Alberto Linbes Kuluantuan, “Angin Kencang di NTT dengan Kecepatan 50-60 Km Per Jam, Kepala BMKG Ungkapkan Hal Ini,” *BATASTIMOR.com*, 2023. Accessed: Mar. 29, 2024. [Online]. Available: <https://www.batastimor.com/news/8059724685/angin-kencang-di-ntt-dengan-kecepatan-50-60-km-per-jam-kepala-bmkg-ungkap-hal-ini>
- [39] Anna Lopo, “Waspada! Potensi Peningkatan Kecepatan Angin di NTT,” *Radio Republik Indonesia*. Accessed: Apr. 02, 2024. [Online]. Available: <https://rri.co.id/daerah/128311/waspada-potensi-peningkatan-kecepatan-angin-di-ntt>
- [40] S. Clarke, “Electricity Generation Using Small Wind Turbines for Home or Farm Use,” 2018.
- [41] O. Ajayi, O. Ojo, and A. Vasei, “On the need for the development of low wind speed turbine generator system,” *IOP Conf Ser Earth Environ Sci*, vol. 331, p. 012062, Oct. 2019, doi: 10.1088/1755-1315/331/1/012062.
- [42] A-WING International, “A-WING-Japan-Wind-Turbine-1KW-Catalogue,” 2019.
- [43] Thunder Said Energy, “Windy physics: how is power of a wind turbine calculated?,” 2022.
- [44] M. A. Yurdusev, R. Ata, and N. S. Çetin, “Assessment of optimum tip speed ratio in wind turbines using artificial neural networks,” *Energy*, vol. 31, no. 12, pp. 2153–2161, Sep. 2006, doi: 10.1016/J.ENERGY.2005.09.007.
- [45] Ragheb, “OPTIMAL ROTOR TIP SPEED RATIO,” 2014. Accessed: Jun. 16, 2024. [Online]. Available: https://users.wpi.edu/~cfurlong/me3320/DProject/Ragheb_OptTipSpeedRatio2014.pdf
- [46] Yu Zhou, “Induction Generator in Wind Power Systems,” *Induction Motors - Applications, Control and Fault Diagnostics*, 2015.
- [47] B. O. Omijeh, C. S. Nmom, and E. Nlewem, “Modeling of a Vertical Axis Wind Turbine with Permanent Magnet Synchronous Generator for Nigeria,” *International Journal of Engineering and Technology*, vol. 3, pp. 212–220, Feb. 2013, Accessed: Jun. 16, 2024. [Online]. Available: https://www.researchgate.net/publication/264496063_ISSN_2049-3444_C_2013_-_IJET_Publications_UK_All_rights_reserved_212_Modeling_of_a_Vertical_Axis_Wind_Turbine_with_Permanent_Magnet_Synchronous_Generator_for_Nigeria
- [48] S. Hafsi, D. Mehdi, and S. Lassaad, “Advanced Control of a PMSG Wind Turbine,” *International Journal of Modern Nonlinear Theory and Application*, vol. 05, pp. 1–10, Feb. 2016, doi: 10.4236/ijmnta.2016.51001.
- [49] M. Mahmoud, T. Salameh, A. Al Makky, M. A. Abdelkareem, and A. G. Olabi, “Case studies and analysis of wind energy systems,” *Renewable Energy - Volume 1: Solar, Wind, and Hydropower Definitions, Developments, Applications, Case Studies, and Modelling and Simulation*, vol. 1, pp. 363–387, Jan. 2023, doi: 10.1016/B978-0-323-99568-9.00019-4.
- [50] PT PLN and Menteri Energi dan Sumber Daya Mineral Republik Indonesia, “Rencana Usaha Penyediaan Tenaga Listrik Tahun (RUPTL) 2021- 2030,” 2021.
- [51] M. A. Alanazi, M. Aloraini, M. Islam, S. Alyahya, and S. Khan, “Wind Energy Assessment Using Weibull Distribution with Different Numerical Estimation Methods: A Case Study,” *Emerging Science Journal*, vol. 7, no. 6, pp. 2260–2278, Dec. 2023, doi: 10.28991/ESJ-2023-07-06-04.
- [52] A. H. Abdulwahid, “Artificial Intelligence-based Control Techniques for HVDC Systems,” Apr. 01, 2023, *Ital Publication*. doi: 10.28991/ESJ-2023-07-02-024.