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Simulation and analysis of wind energy potential for turbine systems in Pekanbaru-Indonesia based on MATLAB Simulink

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ABSTRACT

The widespread use of electricity today, which is primarily generated from fossil fuels, results in significant environmental consequences due to excessive consumption. Renewable energy has been proposed as a solution to mitigate this issue. In Indonesia, particularly in Pekanbaru City, the demand for electricity currently exceeds the supply. However, this region has substantial potential for renewable energy sources. This study presents the modeling and analysis of wind energy, specifically wind turbine systems, using MATLAB Simulink. The methodology involves identifying existing problems, collecting technical data relevant to Pekanbaru and turbine components, and designing the turbine system within MATLAB Simulink. The results of this system indicate a mechanical power output of 1,191 watts, along with a calculated torque of 48.63 Nm. These findings suggest that the system is suitable for small-scale electricity needs. Further research and considerations are necessary to optimize the design and application of turbine systems for sustainable energy production. By improving the efficiency and scalability of wind energy systems, Indonesia can better address its energy deficit while reducing the environmental impacts associated with fossil fuel consumption.

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1. INTRODUCTION

Human life requires energy, whether in the form of food [1], electricity, or other sources of energy. This is essential to sustain life and contribute to human well-being. Today's most widely used type of energy is electricity to power various activities. Energy consumption has been continuously increasing since the rapid development of technology, evident across various sectors such as industrial, commercial, household, and transportation. According to the Indonesian Central Statistics Agency report, there has been an increase in energy consumption [2]. This is also applicable to electricity, as reported by the International Energy Agency (IEA) [3]. The dominant sources of this energy are fossil fuels such as gas, oil, and coal, primarily due to their lower cost compared to other sources.

Nevertheless, the environmental impact of using these fuels has become a global issue, contributing to problems like global warming, climate change, and pollution [4], [5]. This is exacerbated by the fact that the availability of these fuels is significantly diminishing [6]. According to the Ministry of Energy and Mineral Resources (ESDM), especially in Indonesia, the availability of crude oil is projected to last for 9 years, gas for 22 years, and coal for 65 years [7]. Hence, continued reliance on these fossil fuels is unsustainable for future generations, necessitating alternative solutions such as the use of renewable energy [8]. Renewable energy includes solar, wind, hydro, and biomass [9], [10]. These sources are cleaner and can mitigate the impact of global issues resulting from fossil fuel use [11]-[13]. Aside from supplying electricity, renewable energy also helps in job deployment, technology development, as well as minimizing environmental problems [11], [14], [15]. However, several setbacks include unpredictability of the sources, mainly for solar and wind energy, low efficiency, and high initial costs [11], [15]-[17]. Thus, planning for renewable energy must be done to counter this limitation in which may utilize simulation in the early phase. Simulation is a method to replicate physical performance based on systems, processes, and laws using parameters [18]. This method will help in supporting renewable energy development by avoiding unnecessary cost, time, and quality loss using the results analysis. Several software have been used in the case of this source, such as PVSyst, RETScreen, HOMER, and PSCAD.

One of the popular software that is used is called MATLAB or Matrix Laboratory, which facilitates a tool called Simulink to help in creating energy models that will be used as a simulation basis for analysis purposes. Previously, there have been numerous applications based on Simulink in various renewable energy systems. According to a study, a solar tracking system was developed, operating automatically to locate the most optimal light position [19]. To control this system, PID control is employed, consisting of a motor and a solar panel [19]. In another study with geothermal power plants, Simulink was also utilized for simulation by involving two subsystems, P1 and another subsystem for components (VSD and Pump). The results showed that the system's performance was satisfactory, with normal simulation times and responses that did not exhibit significant overshoot [20].

Location selection is also necessary in the early phase of development. In Indonesia, the potential for renewable energy is substantial [21], [22]. Particularly in the Riau province, renewable energy potential is reported as 5950 MW [23]. Table 1 shows the renewable energy potential in Riau, Indonesia.

Therefore, opportunities still exist to create renewable energy-based power generation systems in this area. In contrast with the potential of renewable energy, this region still faces electricity-related problems. Pekanbaru City, serving as the capital of this province, is one of the areas frequently experiencing electricity deficits, making the installation of power generation systems crucial for supplementing the supply [8]. Also, recently, there was a total blackout in the whole city that lasted for hours due to a transmission problem from the State Electricity Company (PLN) in another part of Sumatra Island. This shows how vulnerable the electricity system is if only dependent on this source. For this reason, renewable energy must be implemented as a solution to these issues. Wind energy, along with solar energy, is one of the sources that is mostly available in all parts of the world [24]. Knowing that the potential of this energy has not been implemented, an initial assessment of the wind speed in this area can be made. Using the data from BPS, the wind speed data can be shown in Table 2 [25].

Table 1. The renewable energy potential in Riau [23]

Energy type	Potency	Installed capacity (MW)	Utilization
Geothermal	20 MW	0 MW	0.00%
Water	961,84 MW	114,27 MW	12.00%
Bioenergy-biofuels	7.797.981 TON	3,336,302 MW	42.78%
Bioenergy-biomass	3844 MW	700 TON	18.21%
Bioenergy-biogas	325 MW	33,45 MW	10.29%
Sun	753-1700 MW (4.80 kWh/m^2/day)	1,28 MW	0.02%
Wind	5 MW (3-6 m/s)	0 MW	0.00%
Sea	241 MW	0 MW	0.00%
Total	5.950 MW	848,90 MW	14.27%

Table 2. Pekanbaru wind speed from 2020-2022 [25]

Monthly	Wind speed (m/s)								
	Minimum			Average			Maximum		
	2020	2021	2022	2020	2021	2022	2020	2021	2022
January	0.00	0.00	0.00	1.52	6.00	7.00	9.77	15.00	20.00
February	0.00	0.00	0.00	1.50	6.00	6.00	10.29	25.00	26.00
March	0.00	0.00	0.00	1.40	6.00	6.00	12.86	27.00	28.00
April	0.00	0.00	0.00	1.06	7.00	6.00	9.26	30.00	20.00
May	0.00	0.00	0.00	1.47	6.00	6.00	10.29	21.00	30.00
June	0.00	0.00	0.00	1.60	6.00	6.00	10.29	22.00	20.00
July	0.00	0.00	0.00	1.79	7.00	6.00	10.29	24.00	22.00
August	0.00	0.00	0.00	1.87	7.00	6.00	10.80	27.00	17.00
September	0.00	0.00	0.00	1.80	7.00	6.00	12.86	26.00	24.00
October	0.00	0.00	0.00	1.15	6.00	6.00	8.75	20.00	35.00
November	0.00	0.00	0.00	1.26	6.00	6.00	9.26	27.00	24.00
December	0.00	0.00	0.00	1.47	6.00	6.00	7.72	27.00	26.00

Based on Table 2, the wind speed shows the value of 6-7 m/s average in 2022, which the threshold for small wind turbine implementation lies between 4-4.5 m/s [26], [27]. In correlation with Simulink implementation, several studies regarding wind energy have been reviewed. Two studies show similar context for different regions, namely Cilacap and Tegal [28], [29]. Both discuss the data collection, creation of the turbine model, as well as simulation using parameters such as wind speed, blade radius, air density, tilt angle, and rotor angular speed, which results in 0.2 kW and 0.7 kW, respectively. Even further, another study integrated a generator in the models based on Finite Element Method Magnetics simulation data [30]. Hence, this shows that Simulink serves well features that can facilitate the modeling of wind energy models for research purposes.

In accordance, this research aims to conduct a simulation for the design of a wind turbine system using Simulink-based simulation, specifically in Pekanbaru, Riau, Indonesia. The objective is to provide insights into the potential of wind power generation within the turbine system, focusing on the predetermined location of Pekanbaru. What sets it apart from previous related studies is the choice of a renewable energy source, specifically wind energy, using MATLAB Simulink in this region, which has never been studied. The system's development will then concentrate on designing a turbine system. This study is anticipated to offer a clear understanding of the wind power generation potential in the turbine system, particularly in the specified location. Secondly, the report aims to serve as a reference for further research in comprehending and advancing the integration of artificial intelligence in the context of wind power generation.

2. METHOD

The method applied in this project involves a series of steps to address contemporary issues related to sustainability, particularly in the context of energy. First, the identification of the current issues associated with energy sustainability is done. The next step involves collecting information and data through a literature review, encompassing journals, reports, and other relevant sources.

Subsequently, the selection of the research location becomes a crucial stage, and Pekanbaru is chosen as a suitable research location, given its electricity deficit issues. Information is gathered regarding the technical data on the wind energy potential in Pekanbaru to support the system design. The information is as follows:

- Wind turbine reference model = AWI-E1000T with a radius of 2 meters.
- Wind speed = 7 m/s (maximum) based on Table 2. In 2021 and 2022, the data trend in the average section has a maximum wind speed of 7 m/s.
- Cp = 0.39 (maybe obtained theoretically and through simulations).
- λ = 7 (maybe obtained theoretically and through simulations, based on report reference).
- ω = 24.5 rad/s (obtained through $\lambda = \frac{\omega R}{v}$).
- β = 0 degrees wind turbine (based on the consideration of maximum Cp).

The next step is to design a wind power generation system for the turbine system. After creating the initial design, artificial intelligence is used, specifically Simulink, to execute and analyze the design. In this step, model validations are made by inputting parameters from previous studies to results with similar output. The process and analysis of the results obtained are crucial steps in evaluating the system's performance. In conclusion, the analysis offers a thorough evaluation of the potential and performance of the proposed wind power generation system. This approach presents a structured method for exploring and solving energy challenges in Pekanbaru, with an emphasis on sustainable solutions.

3. RESULTS AND DISCUSSION

3.1. Wind turbine design

The design of the wind turbine will require the help of other website-based data for the value of the velocity of the wind as well as the turbine specification. The equation used for designing the wind turbine is as (1) [31].

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

In (1), P_m is the mechanical power output (W), R is the blade radius (m), and v is the wind speed (m/s). Then, C_p is the power coefficient indicating conversion efficiency, λ is the tip speed ratio between blade tip speed and wind speed. The variable of β is the pitch angle, which controls the blade's orientation to regulate power output. In this case, the component of Simulink is integrated based on the above equation. Subsystems are required to satisfy the equation of several variables such as λ and Cp as (2).

$$\lambda = \frac{\omega R}{v} \tag{2}$$

In (2) satisfies the ratio of wind turbine blade tip velocity to the wind velocity. Whilst λ is also affected by the variable β which will eventually form the Cp equation, given as (3) [24], [31].

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08.\beta} - \frac{0.035}{1+\beta^3} \quad (3)$$

With (3), a subsystem is made. Based on Figure 1, several blocks in Simulink are used as a means of representing the variable. In this case, 1/(u[1] + 0.08*u[2]) – 0.035/(1+u[2]^3) is the equation used in which u[1] as λ (lambda) and u[2] as β (beta). Finally, the Cp equation is formulated (according to the approximation method by [32]-[35]) as shown in (4) [24].

$$C_p = 0.5176\left(\frac{116}{\lambda_i} - 0.4.\beta - 5\right)e^{-\left(\frac{21}{\lambda_i}\right)} + 0.0068\lambda \quad (4)$$

This will require the use of a similar procedure with the prior using blocks that represent the above equation, turning into 0.5176*(116u[1] – 0.4*u[2]-5)*exp(-21*u[1])+0.0068*u[3] in which u[1] acts as $1/\lambda_i$ (the result of the previous block), u[2] as β, and u[3] as λ.

The remaining variables in (1), represented as u^2 and u^3, will be implemented as blocks in Simulink. Specifically, u^2 will compute the square of the radius, while u^3 will calculate the cube of the wind velocity. These outputs will then be multiplied using a gain block set to the value of pi. The complete system layout is illustrated in Figure 2. Finally, these systems can be converted into subsystems, resulting in a simpler visualization of the wind turbine. These can be shown in Figure 3.

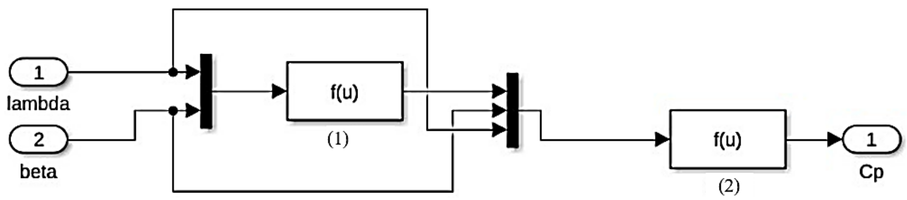

Figure 1. Subsystem for Cp equation

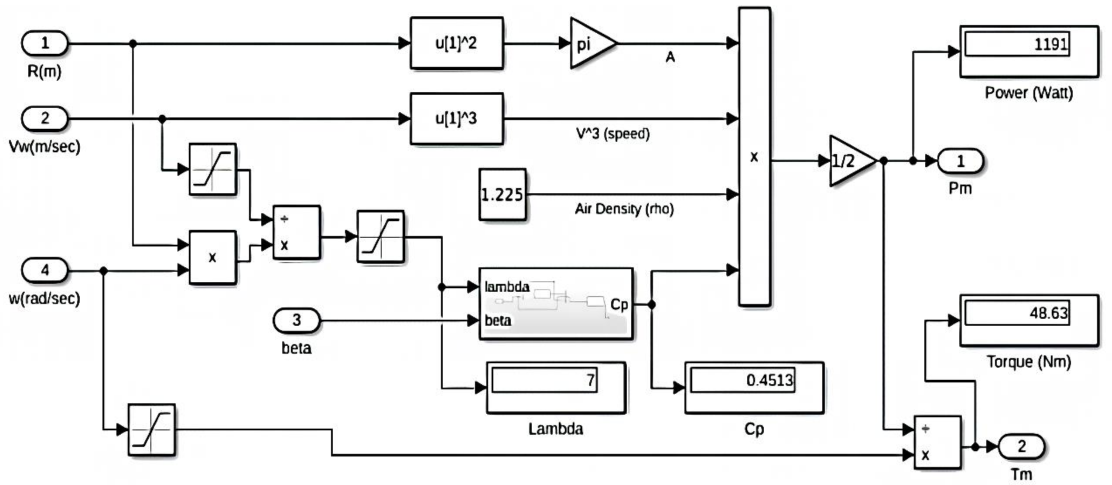

Figure 2. Detailed breakdown of the wind turbine system

3.2. Research analysis

Based on the wind turbine design results generated using MATLAB Simulink, as illustrated in Figure 4, an analysis can be conducted. Using the technical data and (1), the system calculates the mechanical power output of the wind turbine to be 1,191 watts. Additionally, the torque can be determined using (5) [24].

$$P = T\omega \quad (5)$$

Here, P denotes power in watts (W), T represents torque in newton-meters (Nm), and ω stands for angular velocity in radians per second (rad/s). In this case, the calculated torque is 48.63 Nm. These results show that for blades with a radius of 2m, wind speed of 7 m/s, Cp of 0.4513, λ of 7 (recommended for 6-12 m/s incoming wind) [36] and 0 degrees on the βAWI-E1000T wind turbine (with 1,000 W power specification) assumption, the turbine produces power close to 1,000 watts. The selection of 0 degrees for Beta is based on previous similar research that shows that for maximum Cp, Beta should be in 0 degrees [31], [37], [38]. In addition, the Cp obtained through this simulation shows the correlation to the Beta graph, in which for the value 0 degrees and lambda 7, the Cp should be around 0.45, as shown in Figure 4 [39].

Overall, the simulation result is categorized as a small output based on the recommendation in [29], voltage can be generated by wind power generation systems with wind speeds of 2.5 m/s while in this case, the maximum is 7 m/s from the data of Pekanbaru wind velocity) in which this result can be recommended for small-scale electricity needs [29]. This is also supported by the finding that the power coefficient is small (efficiency), and the wind direction in this land area is not too high. Finally, it is also necessary to consider other factors such as geography, proximity to residents, environmental, and noise impacts.

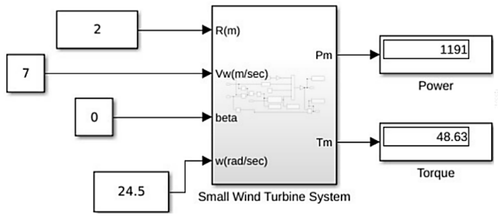

Figure 3. Simplified wind turbine system

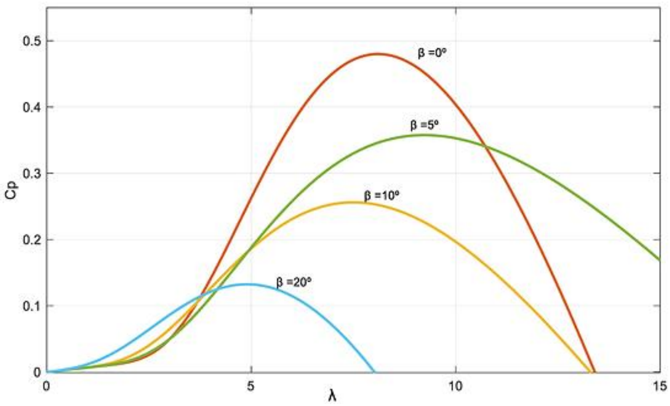

Figure 4. Typical Cp (β, λ) variation graph [39]

4. CONCLUSION

This research presents the simulation results of a specific wind power generation system, particularly focusing on the turbine system, using the equation $P_m = \frac{1}{2}\rho\pi R^2 v^3 C_p(\lambda, \beta)$. Considering technical data, the outcome indicates a mechanical power of 1,191 watts and a torque of 48.63 Nm. This suggests suitability for small-scale electricity needs. For future research, it is recommended to consider factors such as updated wind speed data in Pekanbaru and enhancing the Simulink system by incorporating additional components like generators and batteries, along with their efficiency, including transmission. Furthermore, conducting a comprehensive economic analysis by evaluating different turbine types, product ranges, investment costs, and the resulting benefits could provide deeper insights into the feasibility and optimization of wind power systems. Additionally, integrating environmental impact assessments and exploring hybrid systems combining wind with other renewable energy sources could further enhance the sustainability and effectiveness of renewable energy solutions.

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Fahmy Rinanda Saputri	✓									✓		✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support this study's findings are openly provided by the Indonesian Government Bureau called Badan Pusat Statistik, accessed from its website at https://riau.bps.go.id/id/statistics-table/2/MTQxIzI=/kecepatan-angin.html.

REFERENCES

[1] J. G. Lambert, C. A. S. Hall, S. Balogh, A. Gupta, and M. Arnold, "Energy, EROI and quality of life," *Energy Policy*, vol. 64, pp. 153–167, 2014, doi: 10.1016/j.enpol.2013.07.001.

[2] Secretariat General of the National Energy Council, "Indonesia Energy Outlook (in Bahasa: *Outlook Energi Indonesia*)," 2023. [Online]. Available: https://suaraenergi.com/wp-content/uploads/2024/01/Buku-Outlook-Energi-Indonesia-2023-2033-suaraenergi.com_.pdf

[3] IEA Publication, "Assessing the effects of economic recoveries on global energy demand and CO2 emissions in 2021," 2021. [Online]. Available: https://iea.blob.core.windows.net/assets/d0031107-401d-4a2f-a48b-9eed19457335/GlobalEnergyReview2021.pdf

[4] T. Wambui, M. Hawi, F. Njoka, and J. Kamau, "Performance enhancement and emissions reduction in a diesel engine using oleander and croton biodiesel doped with graphene nanoparticles," *International Journal of Renewable Energy Development*, vol. 12, no. 3, pp. 635–647, May 2023, doi: 10.14710/ijred.2023.51785.

[5] S. A. Moosavi, M. Aghaalikhani, B. Ghobadian, and E. Fayyazi, "Okra: A potential future bioenergy crop in Iran," *Renewable and Sustainable Energy Reviews*, vol. 93, pp. 517–524, Oct. 2018, doi: 10.1016/j.rser.2018.04.057.

[6] ClientEarth, "Fossil fuels and climate change: the facts," ClientEarth. Accessed: Jan. 12, 2024. [Online]. Available: https://www.clientearth.org/latest/latest-updates/stories/fossil-fuels-and-climate-change-the-facts/

[7] Ministry of Energy and Mineral Resources of The Republic of Indonesia, "Minister Arifin: energy transition absolutely necessary (in Bahasa: *Menteri Arifin: transisi energi mutlak diperlukan*)," Kementerian Energi dan Sumber Daya Mineral. Accessed: Mar. 30, 2025. [Online]. Available: https://www.esdm.go.id/id/media-center/arsip-berita/menteri-arifin-transisi-energi-mutlak-diperlukan#:~:text=%22EBT akan mendorong terciptanya pembangunan,lokal khusus di wilayah 3T.&text=Bagikan Ini!

[8] F. R. Saputri, N. Pranata, and F. Dwiputra, "Analysis of solar power plant design using RETScreen and PVSyst in Pekanbaru-Indonesia," in *2023 13th International Conference on Power, Energy and Electrical Engineering (CPEEE)*, IEEE, Feb. 2023, pp. 496–500. doi: 10.1109/CPEEE56777.2023.10217460.

[9] Office of Energy Efficiency & Renewable Energy, "Renewable energy pillar," U.S. Department of Energy. Accessed: Jan. 12, 2024. [Online]. Available: https://www.energy.gov/eere/renewable-energy

[10] L. S. Paraschiv and S. Paraschiv, "Contribution of renewable energy (hydro, wind, solar and biomass) to decarbonization and transformation of the electricity generation sector for sustainable development," *Energy Reports*, vol. 9, pp. 535–544, Sep. 2023, doi: 10.1016/j.egyr.2023.07.024.

[11] D. Maradin, "Advantages and disadvantages of renewable energy sources utilization," *International Journal of Energy Economics and Policy*, vol. 11, no. 3, pp. 176–183, Apr. 2021, doi: 10.32479/ijeep.11027.

[12] C. Chen, M. Pinar, and T. Stengos, "Renewable energy and CO2 emissions: New evidence with the panel threshold model," *Renewable Energy*, vol. 194, pp. 117–128, Jul. 2022, doi: 10.1016/j.renene.2022.05.095.

[13] F. R. Saputri, A. R. Stanlee, I. H. Prasetya, and S. D. Wijaya, "Analysis of solar power plant utilization for public street lighting in Probolinggo, Jawa Timur, Indonesia," *International Journal of Science, Technology & Management*, vol. 4, no. 4, pp. 785–791, 2023, doi: 10.46729/ijstm.v4i4.862.

[14] Neha and R. Joon, "Renewable energy sources: a review," *Journal of Physics: Conference Series*, vol. 1979, no. 1, p. 012023, Aug. 2021, doi: 10.1088/1742-6596/1979/1/012023.

[15] 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, pp. 63–67, Nov. 2022, doi: 10.29103/jreece.v2i2.8779.

[16] W. Wisatesajja, W. Roynarin, and D. Intholo, "Analysis of influence of tilt angle on variable-speed fixed-pitch 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, May 2021, doi: 10.14710/ijred.2021.33195.

[17] A. I. Osman *et al.*, "Cost, environmental impact, and resilience of renewable energy under a changing climate: a review," *Environmental Chemistry Letters*, vol. 21, no. 2, pp. 741–764, Apr. 2023, doi: 10.1007/s10311-022-01532-8.

[18] 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)*, IEEE, Nov. 2023, pp. 1–5. doi: 10.1109/ICMEAS58693.2023.10429880.

[19] M. F. Sigit, R. Ridwan, and S. P. Sari, "PID controller simulation on single axis solar tracking system," *ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika*, vol. 11, no. 1, p. 58, Jan. 2023, doi: 10.26760/elkomika.v11i1.58.

[20] C. R. Costea, S. Dale, D. Zmaranda, and H. Silaghi, "MATLAB-Simulink modeling for the well station of a geothermal power plant," in *2017 14th International Conference on Engineering of Modern Electric Systems (EMES)*, IEEE, Jun. 2017, pp. 172–175. doi: 10.1109/EMES.2017.7980407.

[21] Institut for Essential Services Reform (IESR), "Indonesia energy transition outlook 2025: Navigating Indonesia's energy transition at the crossroads: A pivotal moment for redefining the future," IESR. [Online]. Available: https://iesr.or.id/wp-content/uploads/2024/12/Indonesia-Energy-Transition-Outlook-2025-Digital-Version.pdf

[22] J. Langer, J. Quist, and K. Blok, "Review of Renewable Energy Potentials in Indonesia and Their Contribution to a 100% Renewable Electricity System," *Energies*, vol. 14, no. 21, p. 7033, Oct. 2021, doi: 10.3390/en14217033.

[23] Gubernur Riau, "Points of view on the draft of the new renewable energy bill (RUU EBT) (In Bahasa: *Pokok-pokok pikiran terhadap draft rancangan undang-undang energi baru terbarukan* (RUU EBT))," Riau, 2021. [Online]. Available: https://berkas.dpr.go.id/akd/dokumen/K7-RJ-20210414-011218-6832.pdf

[24] 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*, vol. 16, no. 6, p. 2774, Mar. 2023, doi: 10.3390/en16062774.

[25] Badan Pusat Statistik (BPS), "Wind speed (m/s) 2021-2022 (In Bahasa: *Kecepatan angin* (m/det) 2021-2022)," Statistics of Riau Province.

[26] O. O. Ajayi, O. Ojo, and A. Vasel, "On the need for the development of low wind speed turbine generator system," *IOP Conference Series: Earth and Environmental Science*, vol. 331, no. 1, p. 012062, Sep. 2019, doi: 10.1088/1755-1315/331/1/012062.

[27] S. Clarke, "Electricity generation using small wind turbines for home or farm use," Ontario Ministry of Agriculture, Food and Rural Affairs. Accessed: May 14, 2025. [Online]. Available: https://files.ontario.ca/omafra-electricity-generation-small-wind-turbines-home-farm-use-18-005-en-24-03-2021.pdf

[28] F. Saputri and S. D. Wijaya, "Modeling of wind power generation in Tegal Region using MATLAB Simulink," *Indonesian Journal of Computer Science*, vol. 13, no. 1, Feb. 2024, doi: 10.33022/ijcs.v13i1.3752.

[29] 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 *Power, Energy and Electrical Engineering*, IOS Press, 2024, pp. 522–528. doi: 10.3233/ATDE240351.

[30] T. Benamimour, A. Bentounsi, and H. Djeghloud, "Study of wind turbine based variable reluctance generator using hybrid FEMM-MATLAB modeling," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 1, pp. 1–11, Feb. 2017, doi: 10.11591/ijece.v7i1.pp1-11.

[31] H. Slah, D. Mehdi, and S. Lassaad, "Advanced control of a PMSG wind turbine," *International Journal of Modern Nonlinear Theory and Application*, vol. 05, no. 01, pp. 1–10, 2016, doi: 10.4236/ijmnta.2016.51001.

[32] Y. Guo, S. H. Hosseini, C. Y. Tang, and J. N. Jiang, "An approximate model of wind turbine control systems for wind farm power control," in *2011 IEEE Power and Energy Society General Meeting*, IEEE, Jul. 2011, pp. 1–7. doi: 10.1109/PES.2011.6038985.

[33] Y. Guo, S. H. Hosseini, J. N. Jiang, and C. Y. Tang, "Voltage/pitch control for maximization and regulation of active/reactive powers in wind turbines with uncertainties," in *49th IEEE Conference on Decision and Control (CDC)*, 2010, doi: 10.1109/CDC.2010.5716987.

[34] B. Hamane, M. L. Doumbia, M. Bouhamida, and M. Benghanem, "Control of wind turbine based on DFIG using Fuzzy-PI and Sliding Mode controllers," in *2014 Ninth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, IEEE, Mar. 2014, pp. 1–8. doi: 10.1109/EVER.2014.6844060.

[35] R. 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*, IEEE, 2007, pp. 859–864. doi: 10.1109/PESC.2007.4342101.

[36] Thunder Said Energy, "Windy physics: how is power of a wind turbine calculated?," Thunder Said Energy. Accessed: May 14, 2025. [Online]. Available: https://thundersaidenergy.com/downloads/wind-power-impacts-of-larger-turbines/

[37] Y. Zou, "Induction generator in wind power systems," in *Induction Motors - Applications, Control and Fault Diagnostics*, InTech, 2015. doi: 10.5772/60958.

[38] 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 & Technology (IJET)*, vol. 3, no. 2, pp. 212–220, 2013.

[39] C. I. Martínez-Márquez, J. D. Twizere-Bakunda, D. Lundback-Mompó, S. Orts-Grau, F. J. Gimeno-Sales, and S. Seguí-Chilet, "Small wind turbine emulator based on Lambda-Cp curves obtained under real operating conditions," *Energies*, vol. 12, no. 13, p. 2456, Jun. 2019, doi: 10.3390/en12132456.

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