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DESIGN OF TAPERED WIND TURBINE USING VARIOUS NACA 24112 AIRFOILS IN SEMAYAN VILLAGE CENTRAL LOMBOK REGENCY

Hendry Sakke Tira [1], Muhammad Ponco Zulfikar [2]

[1,2] Department of Mechanical Engineering, Faculty of Engineering, University of Mataram

Jl Majapahit No 62, Mataram 83115 Nusa Tenggara Barat Indonesia

hendrytira@unram.ac.id[1]

Abstract

This research focuses on designing and optimizing a tapered wind turbine employing NACA 24112 airfoils, specifically tailored for Semayan Village in Central Lombok West Nusa Tenggara province. Given the escalating global energy demand and the depletion of fossil fuels, the study aims to explore alternative energy solutions. The chosen horizontal axis turbine, equipped with an increased number of blades, seeks to maximize the power coefficient and overall efficiency. The NACA airfoil model, coupled with Q-Blade v0.963 software, was employed for simulations after conducting wind speed measurements in Semayan Village. The collected data indicated moderate wind speeds, aligning with the selection of the Taper blade design. The blade design process involved comprehensive system efficiency calculations and twist angle optimizations to enhance overall turbine performance and extend its lifespan. Rotor simulations revealed a noteworthy peak in the power coefficient (Cp), reaching 45% at Tip Speed Ratio (TSR) 7, indicating an optimal point for power generation. However, the study emphasizes the importance of selecting an appropriate TSR, as efficiency diminishes at higher TSR values. This research highlights the potential of wind energy as a viable and sustainable solution, particularly for regions with limited access to electricity. It advocates for the broader adoption of renewable energy sources to address the evolving energy landscape.

Key words : *NACA 24112, semayan village, Q-blade, taper blade.*

INTRODUCTION

Access to electricity remains a challenge in many rural and remote areas across the world, where conventional energy infrastructure is often lacking. This issue is particularly prevalent in the island of Lombok, Indonesia, where some regions, especially those in remote and rural locations, still lack access to reliable electricity [1]. Without connection to the national grid managed by the National Electricity Company (PLN), communities in these areas face limitations in economic activities, education, healthcare, and overall quality of life.

One solution to address this challenge is the development of renewable energy sources, particularly wind energy, which can be harnessed in areas with favorable wind resources [2]. Given Lombok's proximity to the ocean, the island experiences consistent winds that provide a viable resource for energy generation. Utilizing wind turbines in these areas can offer a sustainable solution to address the local electricity needs. This approach not only enables off-grid electrification for remote communities but also aligns with global efforts toward sustainable development by reducing dependency on conventional, centralized energy sources [3].

In the context of rural electrification on Lombok, horizontal axis wind turbines (HAWT) have been identified as a suitable technology due to their ability to generate electricity efficiently under local wind conditions [4]. Numerous studies have been conducted to optimize HAWT efficiency, including adjusting blade numbers and refining blade shapes, both of which can significantly influence the power coefficient and, consequently, the total energy output [5]. By optimizing these factors, it is possible to achieve higher energy generation per turbine, reducing the number of turbines needed to meet local demands [6].

The design of wind turbine blades is a crucial aspect in maximizing performance. One commonly used blade design method involves the use of NACA airfoils, which are known for their effective aerodynamic properties and ability to generate the necessary lift force [7]. The aerodynamic characteristics of an airfoil, particularly the lift coefficient (CL), play a significant role in determining the overall efficiency of the turbine [8].

In this study, the focus will be on a village, namely Semayan village, Central Lombok district, West Nusa Tenggara province. In Semayan Village, the wind conditions are generally influenced by seasonal wind patterns, especially during certain months. In Lombok, the wind typically comes from the southeast during the dry season, from May to October, with wind speeds ranging between 10 to 20 km/h. These conditions are favorable for wind energy generation, as the wind speed tends to be consistent and persistent during this period [9].

During the rainy season, from November to April, the winds become more variable, with lower intensities. However, there are still certain periods when the wind can be quite strong, particularly when westward winds occur. This results in shifting wind patterns, which can affect the efficiency of wind energy systems in the region [10]. Overall, the wind conditions in Semayan Village can be optimized with technology capable of harnessing seasonal wind variations for stable renewable energy generation.

Therefore, to identify the optimal blade design for the specific wind conditions in Semayan Village, this study employs specialized software, Q-Blade, which allows for accurate numerical simulations and optimization of blade geometry. Q-Blade facilitates the modeling of blade parameters such as thickness, curvature, and angles of attack, enabling precise adjustments to achieve maximum performance [11].

This study aims to design an efficient wind turbine blade configuration using NACA 24112 airfoils tailored to the wind conditions of Semayan Village in Central Lombok district. The anticipated outcome is to provide a practical solution that can be implemented to improve electricity access for remote and off-grid communities in Lombok. By addressing the unique energy needs of these areas, this research aims to contribute towards a more sustainable and inclusive energy landscape on the island, fostering local development and quality of life improvements.

EXPERIMENTAL METHOD

Wind speed measurement

Before designing a wind turbine, it is essential to determine the wind speed to identify the type of turbine blade to be used. In order to ascertain the wind speed, we utilize the Anemometer Mobile application, which has the capability to predict wind speed in specific areas at different times. In this report, we collected wind speed data in Semayan Village, Praya Subdistrict, Central Lombok district, West Nusa Tenggara.

The average wind speed obtained in the village is 9.7 km/h. Based on table 1, wind speeds ranging from 1-17.9 km/h are still classified as moderate. Therefore, the type of blade we will design and that is suitable for moderate wind speeds is the Taper blade, which has a smaller size at the tip than at the base.

Parameters determination

Blade Blade design is carried out by determining the initial parameters of the blade, namely the overall system efficiency. The overall system efficiency has four important aspects: blade efficiency, transmission efficiency, generator efficiency, and controller efficiency. A previous study indicated that approximately 59% of wind energy can be extracted by the blades, a value recognized as the Betz coefficient (Cp) [12]. In this design, two values of blade efficiency are considered: low efficiency (30%) and high efficiency (40%). For this design, the values of generator, transmission, and controller efficiency are set at 90%. The overall system efficiency is obtained by multiplying these four efficiencies, as indicated in equation 1, resulting in a system efficiency of 22% when the blade efficiency is 30% and 29% when the blade efficiency is 40%. After obtaining the system efficiency, we then use the desired electrical power capacity (We), which is 300 W, with an average wind speed of 9.7 km/s.

$$K = \eta_b . \eta_g . \eta_t . \eta_k \quad \text{..} (1)$$

Where:
K = system efficiency
η_b = blade efficiency
η_g = generator efficiency
η_t = transmission efficiency

In the design of this wind turbine, in addition to the data presented in Table 1, we also used data obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) in the form of wind roses from 1998 to 2020. This annual data is considered to provide comprehensive information as a basis for this wind turbine design. The windrose chart for Central Lombok (1998-2020) shows wind direction frequency and speed distribution (figure 1). Calm conditions (below 4%) are minimal, while the most frequent winds, ranging from 6-15 knots, primarily come from the south and southeast. Higher wind speeds (16-20 knots) occur less frequently, with rare gusts above 20 knots in specific directions. This data is essential for aligning wind turbine design with predominant wind patterns, enhancing energy efficiency and performance by adapting blade orientation to common wind speeds and directions.

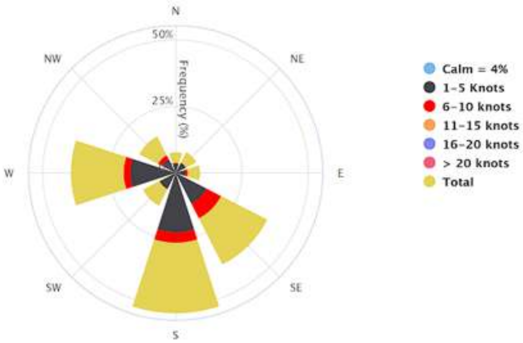

Figure 1 Windrose period at Central Lombok district 1998-2020 [13]

Table 1. Wind speed data

Friday, 17 June 2022		
No	Time (WITA)	Wind speed (km/h)
1	08	1.7
2	09	5.0
3	10	9.1
4	11	13.3
5	12	15.8
6	13	16.9
7	14	17.6
8	15	17.9
9	16	17.6
10	17	14.9
11	18	10.3
12	19	5.0
13	20	2.7
14	21	2.9
15	22	2.5
16	23	2.1
Average		9.7

Determining blade geometry

In In determining the blade geometry, it is essential to establish the angle of attack (α) and Lift Coefficient (Cl). The angle of attack is the angle at which the wind strikes the airfoil, while the lift coefficient (Cl) is the coefficient of lift, where the lift force must be greater than the drag force coefficient to enable the blade to rotate. The values of the angle of attack and lift coefficient are obtained from simulations using the Q-Blade v0.963 software. The simulation results for the NACA 24412 airfoil are presented in figure 2 as follows.

The figure demonstrates the contour and thickness distribution of the airfoil shape, which are crucial for understanding the aerodynamic performance. The red line represents the NACA 24112 airfoil profile, which is defined by the NACA four-digit series for this airfoil type: "2" indicating the maximum camber of 2% of the chord length, "4" denoting the location of maximum camber at 40% along the chord, and "12" indicating a maximum thickness of 12% of the chord length. These characteristics are essential for ensuring efficient airflow and stable lift generation on wind turbine blades [14].

This visual representation helps in verifying the accuracy of the airfoil shape created using Q-Blade software, as it closely matches the original NACA 24112 specifications. Accurate airfoil geometry is crucial for the design process because slight deviations in shape can significantly affect the lift-to-drag ratio and, consequently, the overall efficiency of the turbine. The close alignment between the spline foil and the NACA 24112 profile confirms the reliability of the software in generating precise airfoil geometries suitable for experimental analysis [15].

Figure 2 Airfoil design of NACA 4412

RESULTS AND DISCUSSION

Figure 3 shows the Cl/Cd ratio. The Cl/Cd ratio is a critical indicator of the aerodynamic efficiency of an airfoil, as it represents the trade-off between lift (Cl) and drag (Cd) forces. A higher Cl/Cd ratio signifies a more efficient airfoil, as it can generate greater lift relative to the drag experienced. In the graph, the angle of attack (alpha) is plotted on the x-axis, ranging from -5 to +15 degrees, while the Cl/Cd ratio is shown on the y-axis. The graph helps identify the optimal angle of attack that maximizes the Cl/Cd ratio, which is crucial for selecting the most effective operational angle for the wind turbine blades in this design. The lift coefficient increases as the alpha rises, then decreases after reaching a certain point. This phenomenon is due to stall, where Cl reaches its optimum and does not increase further, while Cd continues to increase. The tip speed ratio (TSR) will be estimated at this stage, although it may change in the final simulation. The TSR estimation is done by referring to the range of 6 to 8 for a 3-blade wind turbine [16]. In this design, a TSR value of 7 is used. Subsequently, the partial radius and twist at each element are obtained. The obtained twist does not form a linear line, making the blade manufacturing process challenging. Therefore, an optimization of the twist angle with linearization of the curve is necessary.

The optimized twist is illustrated in figure 4. In figure 4, it can be observed that there is a systematic decrease in the twist value starting when the optimization value reaches 0.2. This decrease is associated with efforts to optimize the overall performance of the wind turbine. It is intended to enhance the efficiency and power generated by the wind turbine across various wind speeds. Another aspect is to reduce aerodynamic loads. The reduction in twist at a specific point can be employed to alleviate aerodynamic loads on the blade, particularly under certain operational conditions. This can aid in diminishing drag forces or optimizing the pressure distribution on the aerodynamic profile of the blade. Furthermore, the decrease in twist is a response to specific wind conditions [17]. Designs engineered to adapt their twist angles to particular wind speeds or directions can help maximize power generation in various wind conditions. Additionally, the reduction in twist plays a role in improving the stability of the wind turbine, especially when facing fluctuating wind speeds. Adjusting the twist angle can assist in minimizing pressure or stress that might occur on the blade [18]. With the decreasing twist values, it is anticipated that the blade's lifespan can be extended due to its aerodynamic shape that effectively accommodates wind speeds. Similarly, the load experienced by the blade is reduced as it aligns with the wind direction, resulting in a longer blade lifespan [19].

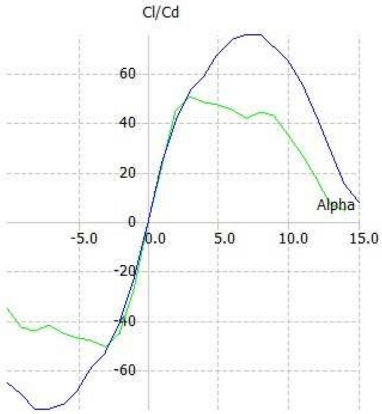

Figure 3 Cl/Cd vc Alpha

The The sharp peak at the start of the twist distribution, followed by a systematic decrease, signifies an intentional design aimed at balancing lift and drag ratios along the blade span. This initial peak allows for an enhanced lift-to-drag ratio near the root of the blade, where wind speeds are generally lower due to the shorter radius from the center of rotation [20]. By concentrating twist in this region, the design ensures that even lower wind speeds contribute effectively to power generation.

As the optimization progresses and twist reduces, this trend aligns with efforts to minimize induced drag and vortex shedding towards the blade tip, where rotational speeds are higher. Lower twist at the blade's outer sections helps to reduce aerodynamic losses and prevents excessive pressure build-up that could cause structural stress or vibration under fluctuating wind conditions.

Additionally, this gradual twist reduction improves structural stability by limiting the torsional load variations that can arise from turbulent wind flows. This characteristic makes the blade more resilient to gusts and sudden shifts in wind direction, ensuring that it maintains optimal aerodynamic efficiency over a broader range of operational conditions [21]. Furthermore, with the decrease in twist towards the tip, the blade's mass and center of gravity are managed to enhance rotational stability, which can contribute to smoother and more efficient turbine performance

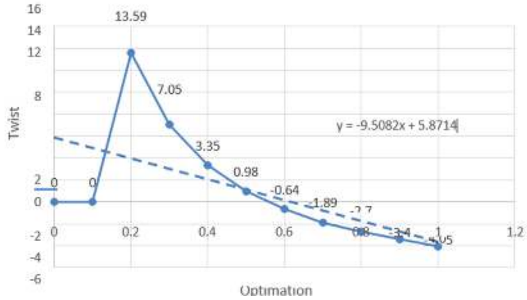

Figure 4 Optimation vs twist

Obtaining the geometric parameters of the blade, the rotor simulation is then conducted using the blade element momentum (BEM) method with Q-Blade v0.963 software. The parameters entered during the simulation include 100 iterations, air density of 1.225 kg/m³, and dynamic viscosity of approximately 1.64 x 10^{-5} Ns/m². The simulation results of the coefficient of power against tip speed ratio (Cp-TSR) are presented in figure 5. According to the simulation, the blade achieves a Cp of 45% at TSR 7.

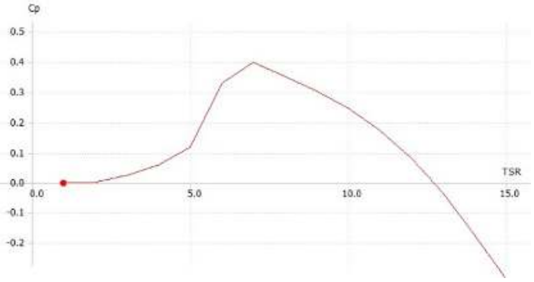

Figure 5 Tip speed ratio vs coefficient of power

From figure 5, it is evident that at TSR = 1, the Cp value is at a minimum. This indicates that no power is generated by the wind turbine under these conditions. This is because the wind turbine cannot efficiently capture wind energy at this TSR. However, there is then an increase in the Cp value until TSR = 7. As TSR increases from 1 to 7, Cp rises and reaches its peak at TSR 7 with a Cp value of 0.4. This increase signifies that the wind turbine is starting to capture and convert more wind energy into power at TSR 7. Subsequently, there is a decline in the Cp value with an increase in TSR. After reaching its peak at TSR 7, Cp starts decreasing steadily with an increase in TSR. This indicates that when TSR is too high, the wind turbine experiences a reduction in efficiency and cannot effectively capture wind energy [22]. Cp even becomes negative at TSR greater than 13. This suggests that the wind turbine on the NACA 24412 blade in this scenario is experiencing overspeeding, where the rotation speed is excessively high. At this point, the wind turbine cannot efficiently convert wind energy into power, and the negative Cp indicates a power loss. This negative Cp indicates an adverse phenomenon of overspeeding, where the rotation speed becomes excessively high, leading to an inefficient conversion of wind energy. Therefore, selecting an optimal TSR is crucial for maximizing efficiency and power generation while avoiding the pitfalls of overspeeding.

CONCLUSION

In summary, the study focused on designing and optimizing a tapered wind turbine using NACA 24112 airfoils for Semayan Village, addressing the rising energy demand, finite fossil fuels, and environmental concerns. The horizontal axis turbine with increased blades aimed at maximizing power coefficient. Key considerations included the NACA airfoil model, Q-Blade v0.963 software for simulations, and wind speed measurements in Semayan Village. The Taper blade was chosen for moderate wind speeds. Blade design involved determining initial parameters, calculating system efficiency, and optimizing the twist angle for enhanced performance and durability. Rotor simulations highlighted a Cp of 45% at TSR 7, indicating optimal power generation, but diminishing efficiency at higher TSR values. This study underscores the potential of wind energy solutions for regions like Semayan Village, emphasizing the need for a renewable energy shift in areas with limited electricity access.

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