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Numerical Study of Taper Type Turbine Blade at a 5° Angle

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Abstract—Renewable energy has emerged as a critical solution to the global challenges of climate change and continued reliance on fossil fuels. Wind turbines play an important role in this context as sources of clean energy that can meet electricity needs with minimal environmental impact. With its vast wind potential, Indonesia has a unique opportunity to drive the transition to renewable energy. As a result, a thorough understanding of wind turbine technology and the factors influencing its efficiency is becoming increasingly important. This article uses Q-Blade software to simulate the effect of blade angle on a taper type wind turbine with a 5° angle. The main findings show that the angle of attack has a significant impact on wind turbine performance. According to the dynamic pressure distribution on the airfoil profile, the optimal angle of attack peaks at half chord, resulting in maximum lift. Despite the fact that the power coefficient (Cp) value is slightly lower than the theoretical limit of the Betz principle This turbine can convert approximately 30.7% of the wind's kinetic energy into mechanical power. The findings of this study provide important information for the development of more efficient and sustainable local wind turbine technology in Indonesia, which is consistent with the vision of energy sustainability and Indonesia's role in global renewable energy. Developers can design more efficient wind turbines, reduce global carbon footprints, and support the transition to environmentally friendly renewable energy with a better understanding of angle of attack. This article is an important step toward a cleaner, more sustainable future in energy provision for Indonesians and the rest of the world.

Keywords—blade angle; taper type; Q-blade; wind turbine

I. INTRODUCTION

Renewable energy has emerged as a critical solution to global challenges such as climate change and reliance on fossil fuels. Wind turbines play an important role in this context as sources of clean energy that can meet electricity needs with minimal environmental impact [1]. Wind turbines generate electricity by harnessing the kinetic energy of the wind, and the sustainability of this natural resource makes it one of the top choices in a renewable energy portfolio [2]. With the world's energy demand increasing, a thorough understanding of wind turbine technology and the factors that influence its efficiency is becoming increasingly important. In this context, research on simulating the influence of a taper type turbine's blade angle of 5° using Q-Blade becomes relevant and strategic in assisting with the development of efficient and environmentally friendly wind turbines.

Addressing climate change, reducing carbon emissions, and achieving energy sustainability is becoming an increasingly urgent global challenge. Continued reliance on fossil fuels has resulted in significant environmental damage and increased the risk of unpredictable climate change [3]. In the midst of these challenges, Indonesia has a unique opportunity to play an important role in driving the transition to renewable energy, thanks to its abundant natural wealth, which includes enormous wind potential. The country can play a strategic role in lowering the world's carbon footprint while meeting rising energy demands [4]. As a result, efforts to introduce efficient and sustainable wind turbine technology in Indonesia are a step toward energy sustainability, which will provide long-term benefits to the country and our planet as a whole.

A number of previous studies have made significant contributions to our understanding of the relationship between turbine blade angle and wind turbine efficiency. As an example, similar simulation techniques were employed to examine the impact of altering blade angles on wind turbine performance. The findings revealed a notable enhancement in efficiency at particular angles; however, achieving optimal design for specific conditions remains a challenge [5]. In the meantime, emphasis is placed on the significance of blade angle characteristics in crafting specialized wind turbines for particular environments, including regions with low wind conditions, as highlighted in [6]. Exploring aerodynamic aspects in connection with blade angles, the research detailed in [7] significantly advances our understanding of the intricate patterns of wind flow surrounding turbine blades. This comprehensive investigation delves into the dynamics of airflow, shedding light on the critical role that blade angles play in influencing the efficiency and performance of wind turbines. Furthermore, a study highlighted in [8] explores the feasibility of employing state-of-the-art automatic monitoring and control technology for the real-time optimization of turbine blade angles. The uniqueness of this research lies in its specific focus on taper type turbines featuring a 5° blade angle. Such an approach offers the potential to gain further insights into the efficiency and design of wind turbines, particularly in the context of renewable energy in Indonesia. Consequently, this study is expected to offer a more precise and pertinent viewpoint in endeavours to enhance the efficiency of indigenous wind turbines.

The background to this research reflects the need to understand in greater depth the influence of taper type turbine blade angles in efforts to increase the efficiency of local wind turbines in the increasingly urgent context of maximizing the potential of wind energy as a renewable energy source in Indonesia. This study investigates the possibility of increasing efficiency by focusing on a turbine blade angle of 5°, which is regarded as one of the most important factors in wind turbine design. Thus, the primary goal of this research is to use Q-Blade simulations to investigate the effect of changing the blade angle of a taper type turbine on wind turbine performance. It is hoped that the findings of this study will provide valuable insights for the development of more efficient and sustainable local wind turbine technology, as well as contribute to the achievement of Indonesian and global energy sustainability targets.

II. RESEARCH METHODS

2.1. Wind Turbine Design

In the initial stage of the experiment, a wind turbine model with a certain configuration was prepared. This wind turbine uses a NACA 4412 airfoil with Taper-shaped blades, consisting of four blades, and has a blade radius of 0.3 meters. This configuration was chosen to achieve the research objectives which include analysis of blade angle variations.

2.2. Variation in Blade Angle

Variation in blade angle is a critical variable in this study. Experiments were conducted to test the effect of blade angle on wind turbine performance by varying the turbine blade angle by 5 degrees. These variations in blade angle will provide detailed insight into how changes in blade angle affect wind turbine performance.

2.3. Wind Speed Options

The speed of the wind is an important factor in this experiment. Throughout the test, the wind speed was kept constant at 12 m/s. Wind speeds must be stable to ensure consistent and comparable results.

2.4. Simulation with Q-blade

The Q-Blade software is used in this experiment to simulate a wind turbine with varying blade angles. This software allows for precise modeling and the calculation of performance parameters such as generated power or power coefficients. The first step is to enter the turbine geometric parameters, which include the airfoil type (NACA 4412), the number of blades (4), the blade radius (0.3 meters), and the blade type (Taper). It also specifies the curvature of the airfoil profile used by the blades to produce accurate aerodynamic properties. The wind speed is then set to 12 m/s based on the experimental parameters that have been determined. Determine the speed and direction of wind flow along the turbine blade for each of the tested blade angles. The next step is to run a numerical simulation of the wind flow around the turbine blades for each blade angle variation, as well as monitor parameters like pressure, speed, and aerodynamic forces on each blade to calculate the power produced.

2.5. Data Collection and Analysis

The data generated by each simulation is meticulously recorded and analyzed. This entails calculating the resulting power or power coefficient for each variation in blade angle. This data will be analyzed to determine how different blade angles affect wind turbine performance.

2.6. Validation and Mearument Error

It is critical to note that all experimental results must be validated and measurement errors identified. Quality control measures are put in place to reduce errors that may occur during experiments. If significant differences are discovered, make changes to the simulation settings to ensure more consistent and precise results.

2.7. Statistics and Processing Data

The collected data will be statistically analyzed to gain a better understanding of blade angle variations. The advantages and disadvantages of each blade angle tested will be determined using statistical analysis. This research will be able to reveal in depth how a 5° taper type turbine blade angle affects wind turbine performance by using this detailed experimental method. This methodology enables systematic and dependable experiments to back up the findings and conclusions in this article.

III. RESULTS AND DISCUSSION

Figure 1 shows that the NACA 4412 blade has a camber of 4%, which means that the profile is 4% higher or lower than the chord line. The upper and lower sides of the airfoil profile are not symmetrical in this case; there is a larger curve above the midline. Meanwhile, the camber value of the spline foil is 0%. This camber is crucial in determining the aerodynamic properties of the airfoil profile and the overall performance of the propeller.

Furthermore, the spline foil is 9.03% thick, while NACA 4412 is 12% thick. This means that NACA 4412 is thicker than spline foil. Greater thickness can affect the aerodynamic performance of the airfoil profile by increasing drag resistance and changing the pressure distribution along the airfoil profile. However, in practical applications, the impact is also affected by other factors such as angle of attack and Reynolds number [9]. This approach will be the focus of this study.

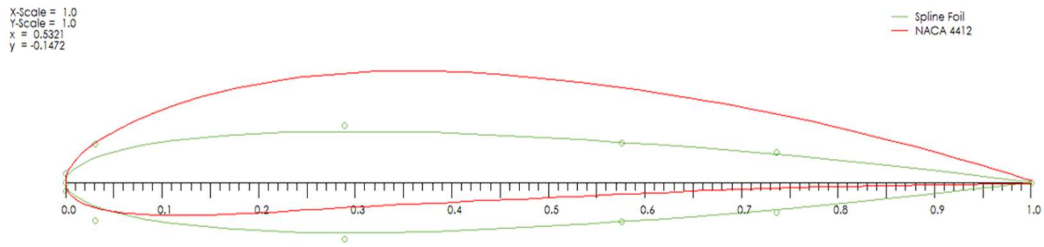

Fig. 1. NACA 4412 blade profile

Figure 2 depicts the pressure distribution around the blade at a 5 degree attack angle. The illustration shows how the x/c axis is used to indicate the relative position on the propeller profile in units normalized to chord length. The x/c value will range between 0 (front end) and 1 (back end). In the meantime, the axis denoting Q/Vinf represents the ratio between dynamic pressure and the speed of the surrounding wind flow. This measurement indicates the level of pressure acting upon the airfoil profile and its impact on aerodynamic efficiency [10].

The Q/Vinf value is shown to be less than zero at the beginning of the airfoil profile, namely from X = 0 to X = 0.44. This demonstrates that the dynamic pressure on the airfoil profile produces a force in the opposite direction of the external wind flow in this section. Aerodynamically, this indicates that this section contributes negatively to lift force and may cause drag. The Q/Vinf value then abruptly peaks at X = 0.5 with a value of 3.1. This demonstrates that the airfoil profile reaches the optimal angle of attack to produce maximum lift at position This is the location where the airfoil profile reaches the optimal angle of attack to produce maximum lift. This optimal angle of attack is commonly referred to as the stall angle of attack, because it occurs before the stall point (sudden loss of lift) [11].

The Q/Vinf value then drops and stabilizes at around 1.4 after reaching a peak at X = 0.5. This demonstrates that the airfoil profile still produces significant lift force in this section, but the value is lower than the peak at X = 0.44. The airfoil profile still generates lift well, but its efficiency is slightly reduced when compared to the optimal position at X = 0.44.

These results represent the typical dynamic pressure distribution on the airfoil profile during wind flow operation. The airfoil profile reaches the optimal angle of attack and produces maximum lift force at a specific point on the chord (in this case, X = 0.44), which is important in wind turbine performance. Understanding this dynamic pressure distribution aids in the design of an efficient airfoil profile for a specific purpose in aerodynamic analysis [12].

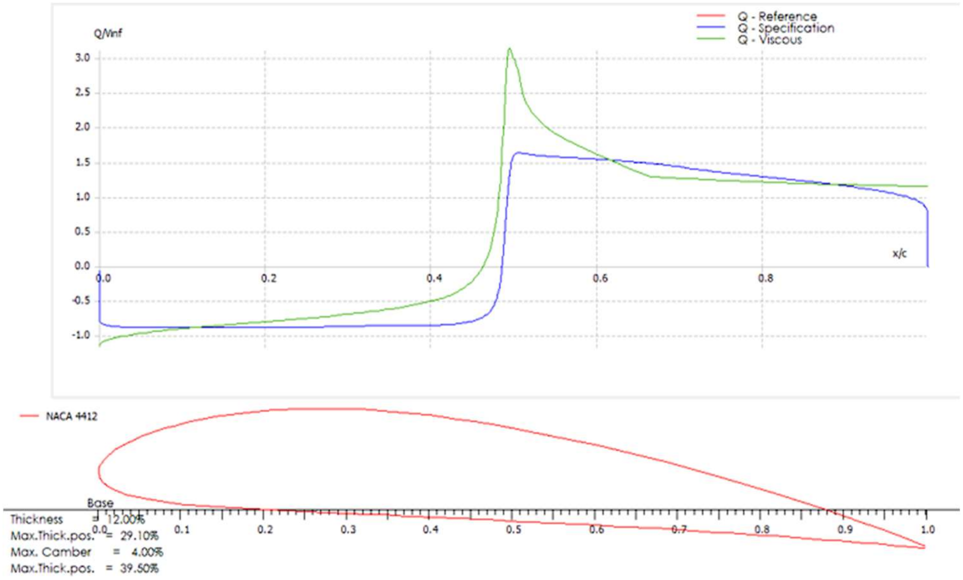

Fig. 2. Pressure distribution on the airfoil or blade profile

Figure 3 depicts the simulated performance of a wind turbine using Q-Blade software. According to the findings, the power produced by the wind turbine was 1.72345 kW. In the meantime, the power pressure coefficient is 0.306698. The efficiency of a wind turbine in converting the kinetic energy of the wind flow into mechanical power is measured by Cp (coefficient of power). A high Cp value indicates that the wind turbine produces power efficiently [13]. The pressure difference between the static pressure at a point in the fluid flow and a defined reference static pressure is measured by Cp. The Cp value can be used to identify areas of higher or lower pressure on an object's surface relative to a reference pressure, which can be useful in aerodynamic analysis [14].

According to the Betz Wind Turbine principle, a wind turbine cannot convert all of the kinetic energy of the wind flow into mechanical power with 100% efficiency. This principle states that the maximum efficiency that can be achieved in converting wind kinetic energy into mechanical power is approximately 59.3%, or approximately 16/27. This means that an ideal wind turbine can capture and convert approximately 59.3% of the kinetic energy contained in the wind flow [15]. According to the findings of this study, 30.7% of wind kinetic energy is converted into mechanical power. This result is half of the Betz principle's maximum value, but it is still considered quite good.

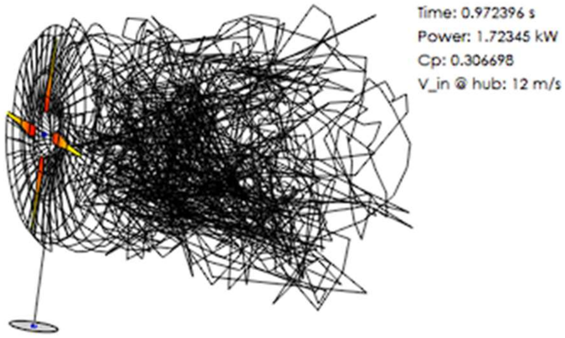

Fig. 3. Blade's movement pattern and pressure coefficient.

IV. CONCLUSION

In the context of the increasing importance of renewable energy, this study examines the effect of blade angle on a taper type wind turbine with a 5° angle using Q-Blade. The study's main finding is that the angle of attack has a significant impact on wind turbine performance. The dynamic pressure distribution on the airfoil profile shows that the optimal angle of attack, which peaks at X = 0.44, produces maximum lift, which is essential for power generation. Although the power coefficient (Cp) value is approximately 0.306698, which is less than the theoretical limit of the Betz principle, this turbine can still convert approximately 30.7% of the wind kinetic energy into mechanical power.

These findings offer important insights into the development of more efficient and sustainable local wind turbines in Indonesia. This research, in conjunction with Indonesia's vision of energy sustainability and the enormous potential in renewable energy, assists in identifying key factors that influence wind turbine performance. Developers can design more efficient wind turbines with a better understanding of angle of attack, helping Indonesia meet its energy sustainability targets and reducing environmental impacts.

As a result, this research contributes significantly to global efforts to reduce reliance on fossil fuels, address climate change, and achieve energy sustainability by utilizing Indonesia's large wind energy potential. With an improved comprehension of the angle of attack, steps can be taken towards a more environmentally friendly and sustainable energy future for both the Indonesian population and the global community

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