TECHNIUM
Romanian Journal of Applied Sciences and Technology
ISSN: 2668-778X

IJCST

vol. 17 / 2023

The 7th International Conference on Science Technology

organized by
Faculty of Social Science and
Law Universitas Negeri Manado and
Consortium of International Conference
on Science and Technology

The Innovation Breakthrough in Digital and Disruptive Era

PLUS COMMUNICATION

International
Communication & PR

Technium: Romanian Journal of
Applied Sciences and Technology
Vol. 17, 367-372, November, 2023
ISSN: 2668-778X
www.techniumscience.com

Analysis of Blade Quantity Variations on Horizontal Axis Wind Turbine Type Taperless Airfoil SG6043 Using Blade Element Momentum (BEM)

Pratama Ricky Novianto[1,*] Fahrudin Fahrudin[2*] , Damora Rhakasywi[3] Tatik Juwairiyah[4]

[1,2,3] *Mechanical engineering program study, UPN Veteran Jakarta*
[4] *Naval architecture program study, UPN Veteran Jakarta*
[*] *Corresponding author. Email: Pratamaricky2311@gmail.com, fahrudin@upnvj.ac.id*

ABSTRACT

The design of taperless blades using the SG6043 Airfoil with different blade quantities through BEM simulation method is expected to serve as a reference for determining the design that yields the best operational efficiency. Simulation results show that the highest Cp value for the Taperless blade design is achieved with a variation of 3 wind turbine blades, resulting in a Cp value of 0.45 in the BEM simulation. The highest Cp value for the Taperless blade design with 4 wind turbine blades is 0.48 in the BEM simulation. Meanwhile, the highest Cp value for the Taperless blade design with 5 wind turbine blades is 0.47 in the BEM simulation. For low TSR values within the range of 1-4, turbines with 5 blades perform the best among various blade quantity variations, resulting in the highest Cp value. On the other hand, for high TSR values within the range of 5-10, turbines with the fewest blades, specifically 3 blades, achieve the highest Cp value.

Keywords: *Airfoil SG6043, BEM, Coefficient Power, HAWT, Taperless.*

1. INTRODUCION

Energy is something that is highly needed for the advancement of human civilization. Due to remarkable progress in various fields such as industry, transportation, and economy, the demand for energy has increased [1]. As a result of market demand, the world tends to utilize renewable energy as a clean and environmentally friendly alternative, such as solar, tidal, wave, and wind energy [2]. The utilization process of wind energy in the form of a Wind Energy Conversion System (WECS) requires adjustments both in terms of technology and the design of wind turbine blades to match the characteristics of the surrounding wind speed where the wind turbine will be used. This is because different types of wind turbines and their constructions will undoubtedly have varying influences and characteristics in terms of their application or implementation [3].

The Indonesian region has abundant wind potential, and the average detected wind speeds in Indonesia generally range from 3.5 m/s to 7 m/s [4]. Based on the characteristic data of wind flow speeds falling into the category of moderate wind speeds, the Indonesian region is well-suited for improvising or developing small-scale (10 kW) to medium-scale (10–100 kW) wind power generators [5].

In the process of creating a Horizontal Axis Wind Turbine, blades play a vital role in converting wind energy into mechanical energy. Taperless blade types have more stable torque values and rotate more easily than taper blade types. Additionally, the structural composition of these taperless blades is stronger when compared to inverse taper blades. Designing taperless blade types with the same chord length simplifies the manufacturing process compared to the other two blade types. Therefore, the author employs taperless blade types for this research. The design of taperless blades, using the SG6043 Airfoil with different blade number variations through the Blade Element Momentum simulation method, is expected to serve as a reference for determining the most efficient design suitable for application in Indonesia's region. This design should operate or perform with optimal values in generating electrical energy at the wind speeds present in that area.

2. MATERIALS AND METHODS

2.1. HAWT Taperless Airfoil SG6043 Geometry

The design of horizontal axis wind turbines in the Q-Blade software can be seen in Figures 1. Meanwhile, the geometry data of the horizontal axis wind turbine blades, referring to this research, can be seen in Table 1.

Figure 1. Modeling Blade with Airfoil SG6043 Geometry Taperless HAWT in Q-Blade Software

Tabel 1. Simulation Parameters in BEM Software

Name	**Information or Value**
Reynolds number	1000000
Blade Type	Taperless
Blade Length used	1 Meter
Number of Blade	3, 4, and 5
Hub Radius	0.17 m
Wind speed	12 m/s

2.2. Performance Parameters HAWT Taperless Airfoil SG6043

To assess the turbine blade's performance, this research solely employs the analytical approach facilitated by Q-Blade software. Q-Blade utilizes the Euler-Bernoulli Beam Module. The blade's airfoil profile is scrutinized within a range of -5° to 50° angle of attack using Q-Blade, while maintaining a Reynolds number of 100,000. Following this, the Q-Blade software furnishes the lift coefficient (Cl) outcomes corresponding to the angle of attack (AoA). The Q-Blade application constructs the turbine blade's geometry by inputting values for position, chord, and twist. This configuration is subsequently evaluated across tip speed ratios (TSR) ranging from 1 to 10, with wind density at 1.225 kg/m³ and viscosity at 0.0000178 kg/ms. The Q-Blade yields power coefficient (Cp) outputs based on the TSR assessments. To derive position, chord, and twist values, the subsequent parameter equation is employed [6]. The initial parameter required for this calculation involves determining the blade element's position (r), as indicated by the following equation [7].

$$\boldsymbol{r = 0,17 + \left[\frac{R-0,17}{\pi} . (elemen)\right]}$$
(1)

Where R represents the blade's length in meters(m), and n corresponds to the quantity of blade elements. The subsequent essential parameter involves the computation of the fractional Tip Speed Ratio (λr) for every blade component through the employment of equation [7],

$$\lambda_r = \frac{r}{R}\lambda \qquad (2)$$

with λ being the pre-established TSR for calculation purposes, assumed to be 7. The subsequent parameter needed pertains to the determination of chord width (Cr) for each blade element using equation [7],

$$C_l = \frac{16\, x\, \pi\, x\, R\, x \frac{R}{r}}{9\, x\, \lambda^2\, x\, B\, x\, Cr} \qquad (3)$$

where C/ signifies the lift coefficient acquired from the design outcomes, while B represents the quantity of blades. The fourth parameter necessitates calculating the flow angle (θ) for each blade element, as guided by the equation [7].

$$\emptyset = \frac{2}{3} arctan \frac{1}{\lambda_r} \qquad (4)$$

The fifth parameter involves determining the twist angle (β) for each blade element, calculated using the equation [7],

$$\boldsymbol{\beta = \phi - \alpha} \qquad (5)$$

where the angle of attack (α) is predetermined to be 6° based on design results. These five parameters collectively play a role in shaping both taper and taperless blade configurations. The parameters necessary for evaluating blade performance begin with the calculation of wind kinetic power P_{Kin} using the formula [7],

$$\boldsymbol{P_a = \frac{1}{2}\rho A v^3} \qquad (6)$$

where p denotes wind density (1.225 kg/m³), A signifies the swept area of the turbine (m²), and V represents the ocean wind speed (m/s). Additionally, the assessment of turbine mechanical power (Pt) is computed through the equation [7],

$$P_t = C_p \, x \, P_a \quad (7)$$

with Cp denoting the power coefficient obtained from design findings. Finally, the last performance factor involves determining the quantity of generated electrical power (Pi) through the application of equation [7],

$$P_l = \eta_{sys} \, x \, P_t \quad (8)$$

where Sys represents system efficiency achieved through the multiplication of blade efficiency (Cp), generator efficiency (90%), controller efficiency (90%), and transmission efficiency (100%).

3. RESULT AND DISCUSSION

3.1. Comparative Assessment

To obtain valid or accurate simulation results, a validation process is necessary. Research validation can be carried out by comparing the simulation methods used with previous studies or simulations. If the obtained results are in accordance or have a small error percentage, the research can be deemed valid and can proceed to the process of variation or innovation from the previous study.

The validation process in this research utilizes a study by Emre Koç and Onur Günel, 2016, titled 'MINI-SCALED HORIZONTAL AXIS WIND TURBINE ANALYSIS BY QBLADE AND CFD' [8]. The study analyzes the performance of a Taper-type Horizontal Axis Wind Turbine (HAWT) with SG6043 Airfoil using CFD and BEM methods. In this validation phase, Q-Blade software is employed to compare power coefficient and torque values that occur in the case of a 3-blade turbine at a speed of 12 m/s within the TSR range of 2.5 to 6.5. The following graph represents the validation results of this research compared to the previous study conducted by Emre Koç and Onur Günel, 2016 [8].

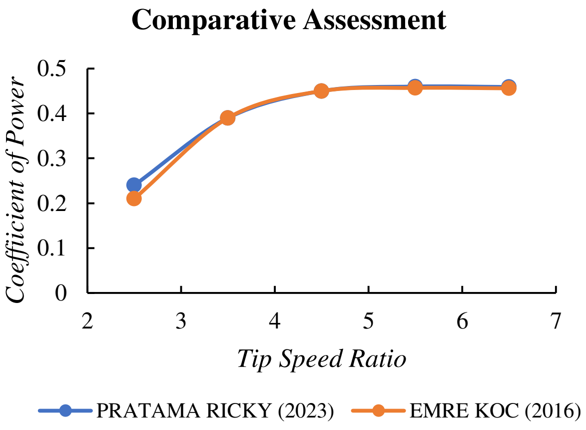

Figure 2. Comparative Assessment with Previous Research

In Figure 4, there are graphs depicting the results of the previous study and the validation results from the author's research. In the previous study, the maximum Cp value obtained was 0.457 in QBlade at a tip speed ratio of 5.5. Meanwhile, in this study, the maximum Cp value obtained was 0.47 in QBlade at a tip speed ratio of 5.5. The difference between the BEM modeling in the research by (Emre Koç, Onur Günel, 2016) [8] and the simulation results in this study shows a slight disparity of less than 5%, which renders this validation acceptable.

3.2. The calculation of blade geometry

The geometric calculation of wind turbine blades aims to determine values for the length of wind turbine blade radius to be used, the selected airfoil type, blade width (chord), and the twist angle to be applied in the wind turbine blade design. In this study, the blade type employed is taperless, which will then be varied in terms of blade count.

Based on Eq. 1, the partial radius values for the taperless blades are obtained. The partial radius on each element of the taper and taperless blades are the same. It is caused by the same hub position of both types (r = 0.17 m) and the same blade length, which is 1 m. So, the calculation of the same partial radius is obtained for each element. The partial radius or position of the taper and taperless blade positions on elements 1 to 10 are 0.17 m, 0.25 m, 0.34 m, 0.42 m, 0.50 m, 0.59 m, 0.67 m, 0.75 m, 0.83 m, 0.92 m, and 1 m.

The value of the twist angle obtained is then linearized at the position of the blade element by 75% of the length of the blade or the 7th and 8th points, and obtained the result of linearization of the twist angle at 75% with a linear equation of $y = -4.8219x + 14.001$ for taperless blades. In this stage the value of y is the equation of the linear twist angle and x is the value of the partial radius of each element of the wind turbine blade that has been obtained previously. This twist angle linearization is needed to facilitate the manual manufacturing process of wind turbine blades, but still take into account and consider the efficiency of wind turbine blade performance.

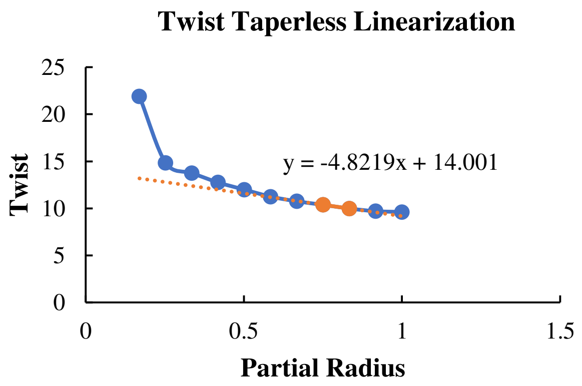

Figure 3. Twist Taperless Linearization

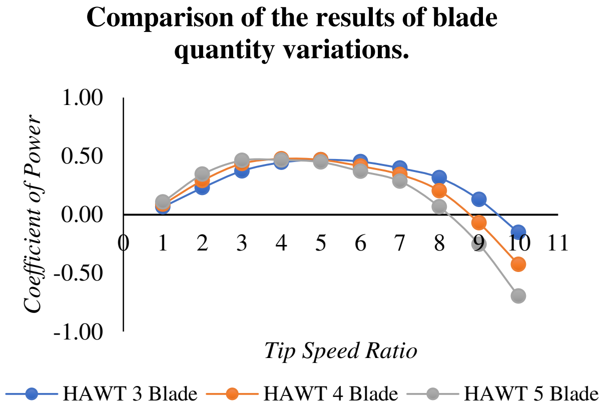

Figure 4. Comparison of the result of blade quantity variation

The decrease in wind speed after passing through the turbine has a major impact on the energy delivered. The smaller the value of the wind speed, the greater the energy utilized. In this case, blades with a greater number of blades produce the lowest wind speed among the three turbine blade types, and this results in a better coefficient of power value at low TSR. Variations in the configuration of taperless type wind turbine blades also affect the torque value so that the more blades, the higher the torque value due to the density between one blade and another blade will also affect the size of the turbine rotation. The closer the distance to other blades will affect the number of wind capture blades, the turbine rotation increases. With a small number of wind turbine blades, the area of the wind turbine blades will also be small and the rotation speed is lower too, on the contrary, the more the number of blades also the higher the wind speed, of course, the more area of the wind turbine blade to capture the wind and also the rotation of the wind turbine rotor shaft will be higher, the higher the rotation. A small number of blades will certainly cause wind to easily pass through the gaps between the turbine blades so that the force that rotates the turbine blade will also be small so that the rotational speed of the turbine blade will also be small or low.

One reason why there is such a difference is that the Xfoil software has over-predictions in obtaining lift and thrust coefficients. Although the BEM method applies a type of three-dimensional correction model, the CFD results provide a more detailed visualization of the wind turbine's response to the aerodynamic characteristics that occur. The BEM method has computational limitations in modeling rotational motion compared to CFDs. In CFDs, predetermined aerodynamic data is not used to predict performance. In the CFD solver, fluid equations are calculated for all directions around the blade by an iterative process. This approach allows the blades to analyze wind speeds along the blades as well as the effects of three-dimensional fluid interactions, including frictional losses that cannot be analyzed by the BEM method. In conclusion, it can be mentioned that the BEM method can be used to estimate the initial performance of wind turbines, and then the design of wind turbines can be optimized by detailed observations using the CFD method.

The simulation results obtained the largest Cp value in the Taperless blade design is a blade design with variations in the number of 3 wind turbine blades that have a Cp value = 0.45 in the BEM simulation. The largest Cp value in the Taperless blade design is the blade design with variations in the number of 4 wind turbine blades which have a value of Cp = 0.48 in the BEM simulation. While the largest Cp value in the Taperless blade design is the blade design with variations in the number of 5 wind turbine blades which have a value of Cp = 0.47 in the BEM simulation.

In this BEM method, the largest Cp value in the Taperless blade design is a blade design with a variation in the number of 4 wind turbine blades that have a value of Cp = 0.48. Of course, this result is caused by several factors that have been explained in the previous paragraph. To be a reference or more valid results, of course, further research can be done with the CFD method. This is because the BEM method can only be used to estimate the initial performance of wind turbines and then the design of wind turbines can be optimized with detailed observations using the CFD method. Based on the calculation data above using the BEM method, it can be seen that the addition of the number of blades or blades can increase the power coefficient at a low TSR value and achieve maximum performance at TSR = 4.0 on taperless type horizontal axis wind turbines. While at a higher TSR value, the least number of blades, namely 3 blades, will produce the best performance

4. CONCLUTION

In this study regarding the analysis of taperless wind turbine blades with various blade quantity variations on the performance of horizontal-axis wind turbines using the BEM and CFD methods, the following conclusions can be drawn:

1. The specifications of the designed taperless wind turbine blade include a length of 1 meter with 10 elements, a maximum twist of 13.18 degrees, a minimum twist of 9.18 degrees, and a constant chord length of 0.12 meters. Linearization was applied to elements 7 and 8 to minimize the twist difference.
2. Simulation results show that the highest Cp value for the Taperless blade design is achieved with a variation of 3 wind turbine blades, yielding a Cp value of 0.45 in the simulation. The highest Cp value for the Taperless blade design with 4 wind turbine blades is 0.48 in the BEM simulation. Meanwhile, the highest Cp value for the Taperless blade design with 5 wind turbine blades is 0.47 in the BEM simulation.
3. Based on the calculated data using the BEM method, it is evident that increasing the number of blades can enhance the power coefficient and achieve maximum performance at TSR = 4.0 for horizontal-axis taperless wind turbines. For low TSR values within the range of 1-4, turbines with 5 blades perform the best among the various blade quantity variations, resulting in the highest Cp value. On the other hand, for high TSR values within the range of 5-10, turbines with the fewest blades, specifically 3 blades, achieve the highest Cp value.
4. For more valid reference or results, the CFD method should be used. This is because the BEM method is only suitable for initial estimation of wind turbine performance, and turbine design can be further optimized through detailed observations using the CFD method.

AUTHORS' CONTRIBUTIONS

"Authors' Contributions: [PRATAMA RICKY NOVIANTO] designed and supervised this study, conducted data analysis, and [FAHRUDIN FAHRUDIN] wrote and edited the manuscript. All authors contributed significantly to the planning, implementation, and completion of this work."

ACKNOWLEDGMENTS

THANK YOU TO THE UPN VETERAN JAKARTA FACULTY OF ENGINEERING FOR THE SUPPORT

REFERENCES

[1] A. Mansi and D. Aydin, "The impact of trailing edge flap on the aerodynamic performance of small-scale horizontal axis wind turbine," *Energy Convers. Manag.*, vol. 256, no. December 2021, p. 115396, 2022, doi: 10.1016/j.enconman.2022.115396.

[2] N. L. Panwar, S. C. Kaushik, and S. Kothari, "Role of renewable energy sources in environmental protection: A review," *Renew. Sustain. Energy Rev.*, vol. 15, no. 3, pp. 1513–1524, 2011, doi: 10.1016/j.rser.2010.11.037.

[3] N. H. Sari and W. G. Laksamana, "Perancangan bilah tipe taperless pada kincir angin: Studi kasus di PT. Lentera Bumi Nusantara Tasikmalaya," *Din. Tek. Mesin*, vol. 9, no. 2, p. 104, 2019, doi: 10.29303/dtm.v9i2.286.

[4] V. A. Permana and I. Haryanto, "Perancangan Awal Sudu Turbin Angin Dengan Kapasitas 3200 Watt," *J. Tek. Mesin*, vol. 3, no. 1, pp. 51–58, 2015.

[5] A. Rachman, "Analisis Dan Pemetaan Potensi Energi Angin Di Indonesia," *Skripsi tidak diterbitkan*, p. 64, 2012.

[6] M. Madi, T. Tuswan, I. D. Arirohman, and A. Ismail, "Comparative Analysis of Taper and Taperless Blade Design for Ocean Wind Turbines in Ciheras Coastline, West Java," *Kapal J. Ilmu Pengetah. dan Teknol. Kelaut.*, vol. 18, no. 1, pp. 8–17, 2021, doi: 10.14710/kapal.v18i1.32486.

[7] INAYAH N. ZAHRA, "'Dasar-dasar perancangan bilah' Bahan Materi Pembelajaran Lentera Bumi Nusantara, Indonesia," 2020.

[8] T. Y. Emre Koç, Onur Günel, "Mini-Scaled Horizontal Axis Wind Turbine Analysis By Qblade and Cfd," *Int. J. Energy Appl. Technol.*, vol. 3, no. 2, pp. 87–92, 2016.