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An Efficient Modeling of Wind Turbine Using QBlade Software

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Abstract - Due to the energy sector's rapid growth, there is an increasing demand to boost wind turbine energy efficiency and longevity. The most essential and expensive component of the wind system is thought to be the wind blades. So it's critical to fully comprehend how turbine blades behave. In this study work, comprehensive information was provided to examine and improve the working conditions & functionality of the wind turbine blade of the Small Horizontal Axis Wind Turbine (SHAWT) less than 1 KW. To simulate Wind Turbine (WT) blades throughout the operational settings efficient QBlade Software was implemented and the Blade Element Momentum (BEM) approach served as the foundation for the mathematical formulae employed in this. The impact of design parameters Chord length & Twist angle on the operation and effectiveness of the WT was thoroughly investigated. A SG6043 airfoil with a 1.17 m blade length was employed in 10 distinct sections. The results were highly accurate, and it was demonstrated that the proposed technology is trustworthy for analyzing wind turbine blades. The document outlines the procedures that must be followed in order to construct and optimize a WT blade, and also benefits & and features of the software.

Keywords – Wind Turbine Energy (WTE), QBlade Software (QBS), Blade Element Momentum (BEM), Twist angle (TA), Chord length (CL), Airfoil.

INTRODUCTION

One of the most crucial topics of our day is finding solutions to the world's energy problems [1]. Wind power generation has lately shown to be a viable choice owing to a rising demand for more environmentally friendly energy sources [2]. Improving the wind turbines efficiency by maximizing the blade design is necessary to get the most energy possible from it [3]. Researchers have created a variety of approaches and strategies over the past several years to improve performance (efficiency), based on a precise study & modernization of constructional features of WT blades [4]. One of the key techniques for simulating and optimizing the performance of WT blades is BEM [5]. A compact WTB was formed and developed with the goal of maximizing the no. of blades and choosing the tip speed ratio that best matched the solidity [6].

An SHAWT with two airfoils is intended to have a rated output of one kilowatt & specified speed of 08.40 m/s [7]. Employing 2 computational approaches such as QBlade Software, and XFOIL and one experimental method, the performance of the newly developed airfoils and blades was examined (wind tunnel testing) [8]. At various Reynolds values, the airfoil experiments were conducted in the wind tunnel [9]. A variety of angles of attack were used to calculate the drag & lift coefficients [10]. Two computational techniques—QBlade and ANSYS CFX—were used in order to evaluate the performance of the blade [11]. Lift coefficient and drag coefficient were used to compare the performance of the built-in miniature turbine blades at a wind speed of 08.40 m/s [12].

LITERATURE SURVEY

By utilizing several kinds of airfoils, Dhurpate et al examined how well the tiny WT rotor blade (horizontal axis) performed. It was expected that the wind turbine operates at low wind speeds and low Reynolds numbers (5105). It was regarded as a separate airfoil throughout the whole blade span. The rotor has three blades and a 2 m diameter. The model of the blade was constructed using four different airfoil types (DU86-084, E387, & SD2030), with a tip speed ratio of 7.

By using several techniques, Dimitriadis et al investigated the working of HAWT. Two methods were used in the theoretical research: computational fluid dynamics (CFD) and blade element momentum (BEMT). Comparisons were made between the results of the various tactics. Studies in two and three dimensions were carried out to examine the flow field around the wind turbine blades. The obtained results for the drag and lift coefficients at different angles of attack were evaluated in light of the provided experimental results. Comparisons between CFD modeling and BEMT demonstrate its superior performance and benefits. The findings shown that the flow around an airfoil may be precisely computed using CFD calculations.

The performance of the blades on the rotor of WT (07.00 MW, HAWT) with a 165 m diameter was examined and assessed by Soland and Thuné. To complete the computations, XFLR5 (XFoil) and QBlade were employed. By using BEM theory, the blade was evaluated using the chosen airfoils. The performance of the wind turbine rotor utilizing various airfoils under various operational loads was thoroughly studied [13].

The above stated survey reveals that the analysis of various wind turbines with some small draw backs, to overcome that a multiple variables construction & modeling of micro (< 1 KW) WT blades were carried out using BEM simulation in QBlade, with graphs of C_P and power being plotted versus tip speed ratio at the specified wind speed of 08.40 m/s. The SG6043 airfoil was chosen because it has the highest lift coefficient of 01.63. Additionally, using the QBlade software, 01.20m of blade length was simulated. Due to their capacity to catch wind blowing from any direction, vertical axis wind turbines (VAWTs) are more effective than horizontal axis wind turbines (HAWTs) for low wind speed applications [15]. High drag and turbulent force created by the blade are the main VAWT limitations that have been noticed. In order to get around the constraints, the VAWT rotor blade design was proposed. Within the necessary range of Reynolds numbers and wind speeds, the NACA 0018 airfoil is chosen and examined in the QBlade software.

METHODOLOGY

The blade element momentum method (BEM) is considered as the key to investigating the aerodynamic characteristics of wind turbine blades. The theoretical study of the WTB in this research report was accomplished using the QBlade software.

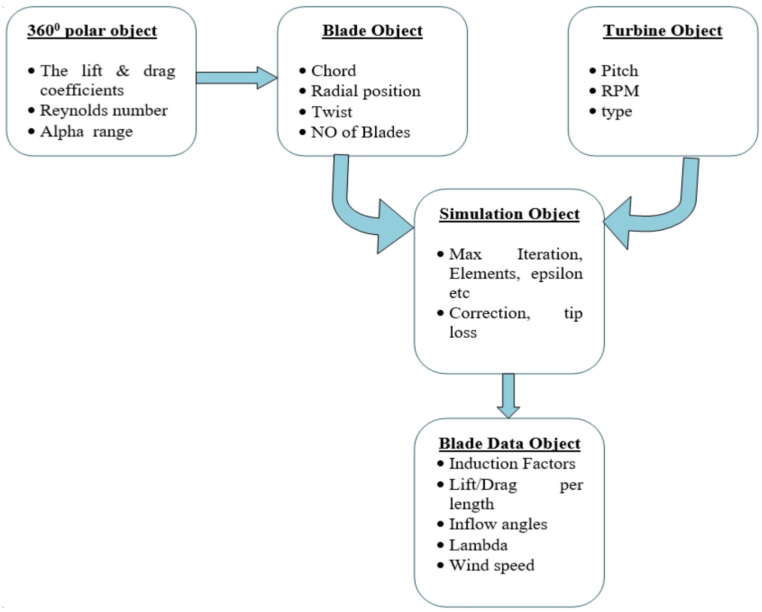

Figure 1. The study of WT through QBS.

Focus will be placed on the HAWT in the case study. A division of the examination of the HAWT into three categories using the programme QBlade is clearly shown in figure 1 as:

1. The WT blade's design and optimization.
2. The WT rotor's design and simulation.
3. The whole WT simulation.

THEORETICAL FORMULATION

The introduction of all design parameters will occur in this section. The lift and drag coefficients must be determined in order to compute the drag force (D) and lift force (L). The following is a possible way to write the drag coefficient (CD) and lift coefficient (CL) in written form:

$$C_D = \frac{D}{0.5\rho A v^2} \qquad (1)$$

$$C_L = \frac{L}{0.5\rho A v^2} \qquad (2)$$

Where the air density, the effective object area, and the wind speed are represented, respectively, by ρ, A, and v. The Power Coefficient (Cp), which is the ratio of the actual generated power (PT) to the total power of wind flowing through the turbine blades at a specific wind speed, can be regarded as the most crucial factor in choosing a wind turbine (P0). The efficiency of the mechanical parts (shaft bearings and gears), generator, and power electronics were only a few of the many variables that went into calculating The Power Coefficient (Cp). Operating factors like blade angle, wind speed, rotational speed, etc., have an impact on (Cp value.)'s The Power Coefficient's form can be written (Cp)

$$C_P = \frac{P_T}{P_0} = \frac{\frac{1}{4}\rho A(V_1^2 - V_2^2)(V_1 + V_2)}{\frac{1}{2}\rho A V_1^3} \qquad (3)$$

Where v1 and v2 are the upstream and downstream wind speeds of the wind turbine blades, respectively. As a result, the power coefficient may be expressed as follows as a function of the axial induction factor (a):

$$C_P = 4a(1-a)^2 \qquad (4)$$

Where the wind speed at the rotor and upstream are both fractionally reduced by the axial induction factor (a). As a function of the axial induction factor (a), the thrust coefficient (CT) can also be represented as follows:

$$C_T = 4a(1-a) \qquad (5)$$

The size and shape of the rotor that is chosen, as well as other variables like wind speed, pitch angle, etc., determine how much torque the wind turbine will produce. The highest possible output torque may be attained at,

$$T_{max} = F_{max} R \qquad (6)$$

Where Fmax is the maximum thrust and R is the radius of rotor

RESULTS AND DISCUSSIONS

In order to get the most output power from the wind turbine, the chord and twist angle for the airfoil (SG6043) are optimized in this research. Table 1 lists ten alternative sections for the wind turbine blade (L=1.17 m). The creation of the airfoil might be regarded as the initial stage.

Table 1. Modernized Chord & Twist angle for SG6043

Pos (m)	Chord (m)	Twist	Foil
00.00	00.076	00.00	Circular foil
00.09	00.126	00.00	Circular foil
00.21	00.118556	18.3186	SG6043
00.33	00.0755927	12.1912	SG6043
00.45	00.0625495	08.65956	SG6043
00.57	00.054959	06.3787	SG6043
00.69	00.0495343	04.78876	SG6043
00.81	00.0452978	03.61874	SG6043
00.93	00.0417521	02.72238	SG6043
01.05	00.0388034	02.01403	SG6043
01.17	00.0634851	01.44033	SG6043

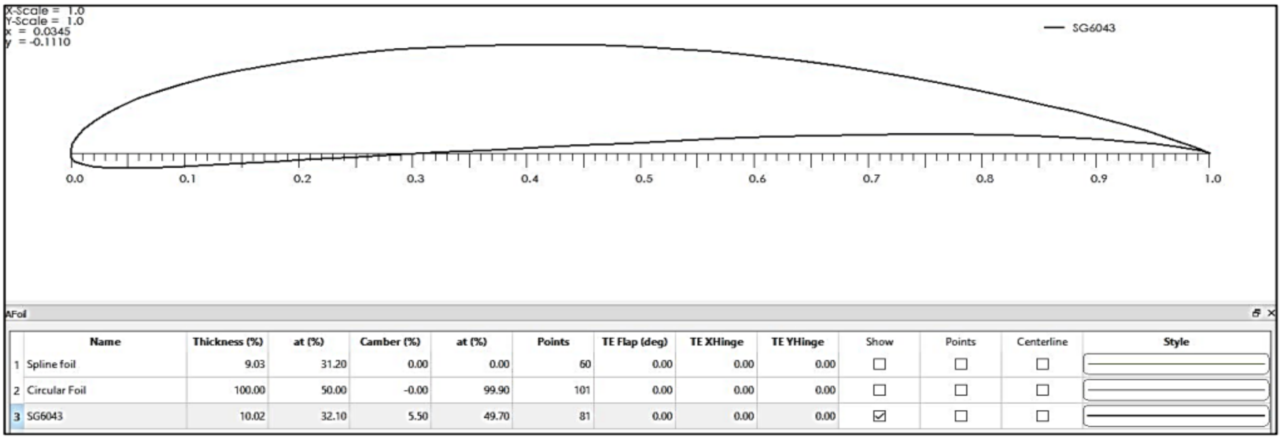

Figure 2. QBlade software's airfoil design.

The airfoil (SG6043) creation process is depicted in Figure 2, and it was carried out using the import of a DAT file. The simulation may begin after choosing the appropriate airfoil for the blade.

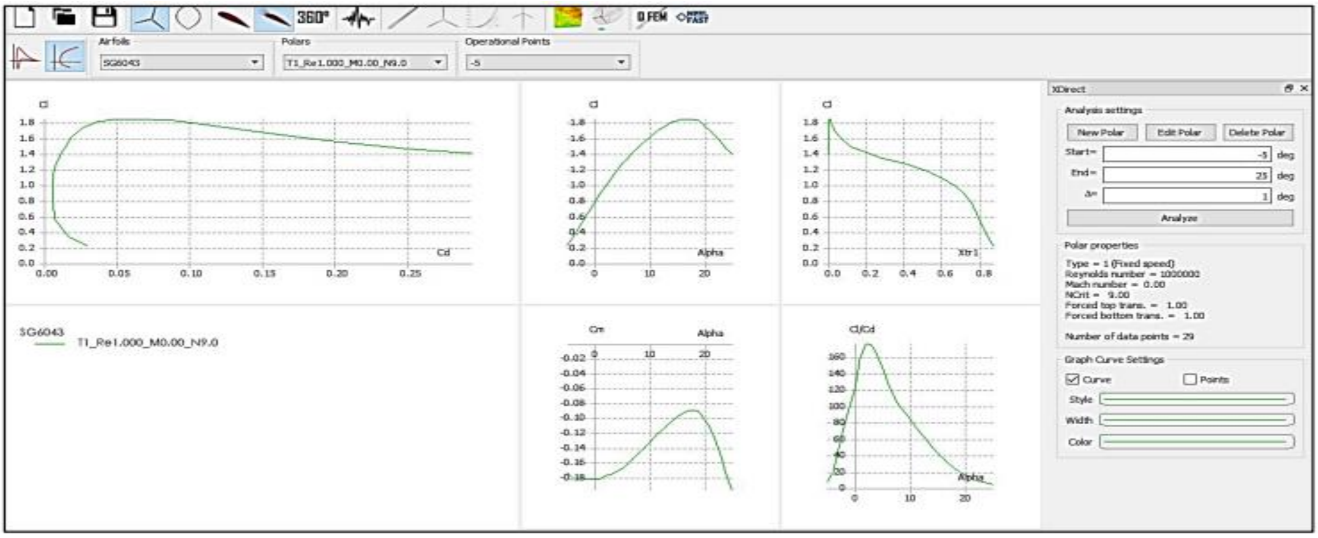

Figure 3. CL/CD Vs. α.

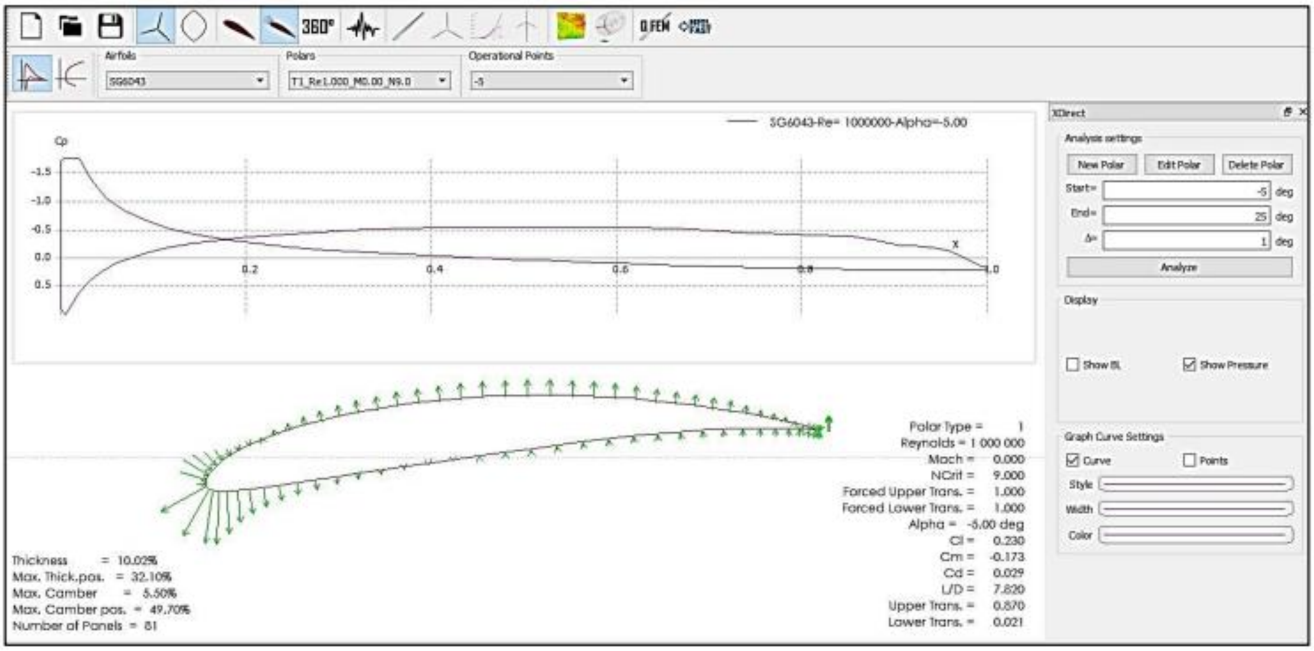

Figure 4. The pressure & boundary layer formed.

A novel analysis is defined using XFOIL direct analysis and a polar perspective. At low Reynolds numbers, laminar flow is anticipated for aerofoils; 105 Reynolds numbers are utilized in this work. The variation CL, CD, and CL/CD with angle of attack are shown in Figure 3. Operating point view depicts the pressure and boundary layer created, as seen in Figure 4.

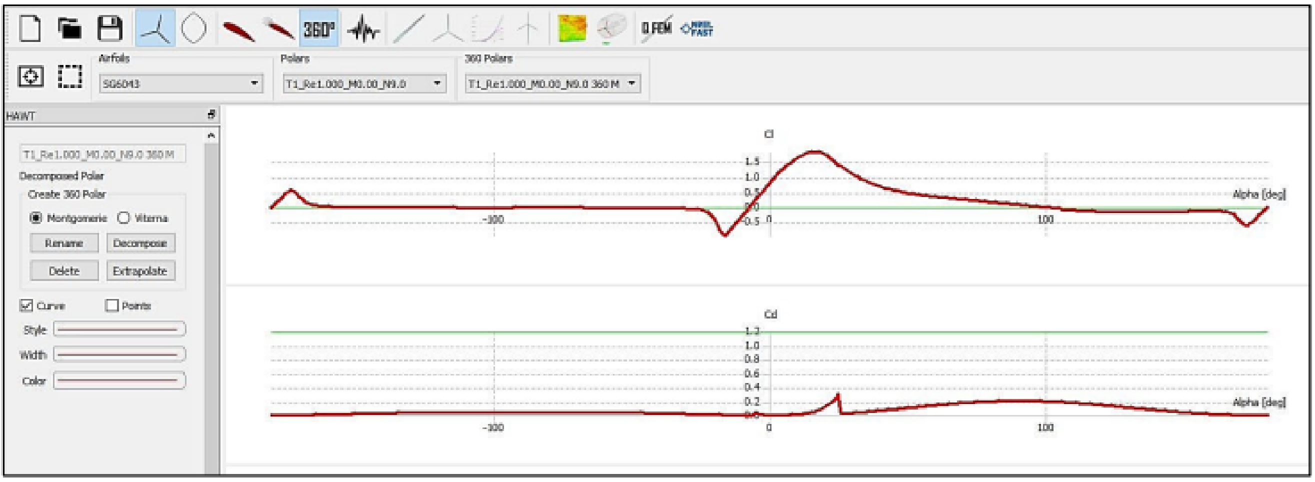

Figure 5. Polar extrapolation to 360^0.

As shown in figure 5, a circle with a diameter equal to the chord of the airfoil is extrapolated using 360-degree polar extrapolation. In this investigation, ten segments of HAWT were produced. The chord was identified based on the taper ratio.

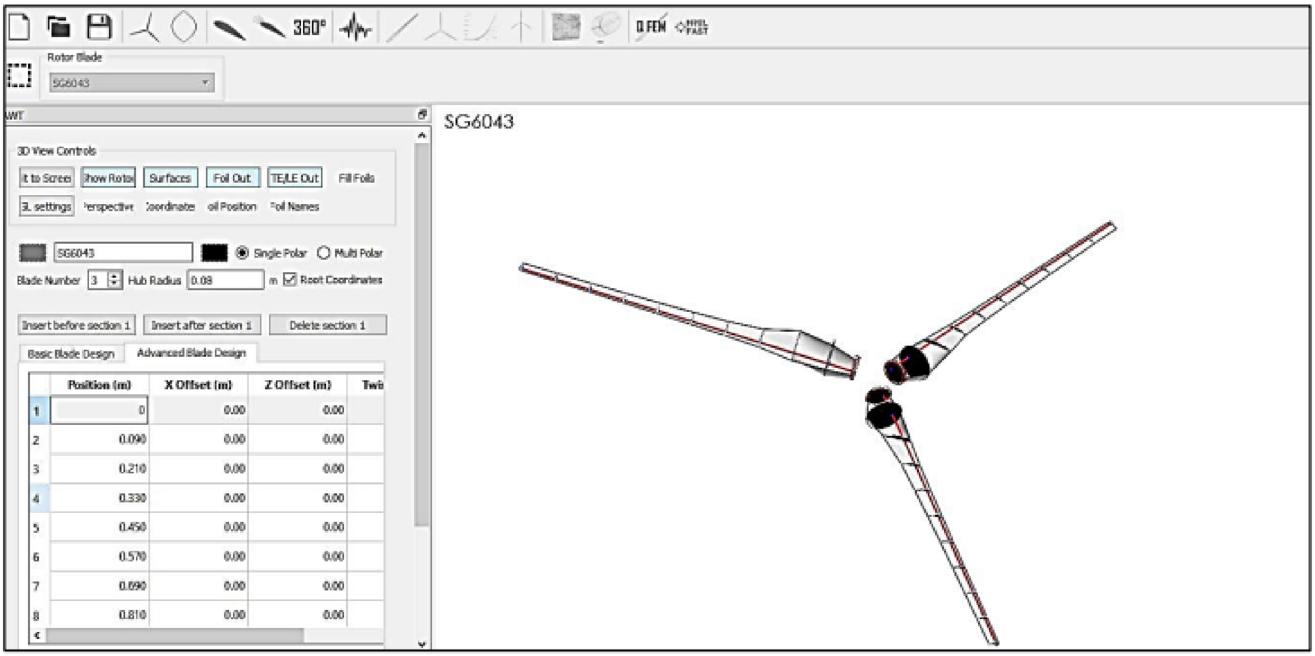

Figure 6. modern blade construction with a centering thread.

The maximum thread thickness at the centerline was achieved utilizing cutting-edge blade design, as shown in Figure 6. The twist value for the planned blades was obtained by optimization, as indicated in table 1. First, the optimization method requires the maximum value (CL/CD). Figure 3 shows the greatest value of (CL/CD), which in the current investigation equals 2. The angle of attack () is the name given to this variable.

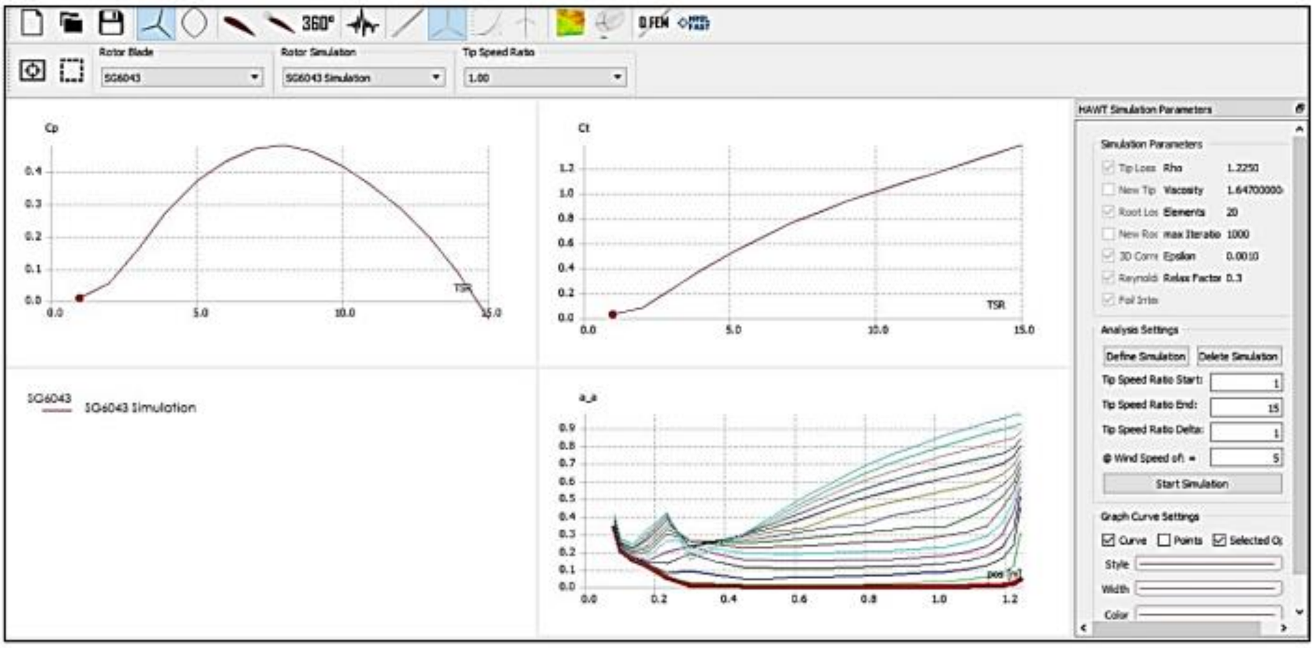

Figure 7. Tip speed ratio, axial induction factor, and CP, CT vs. radial location.

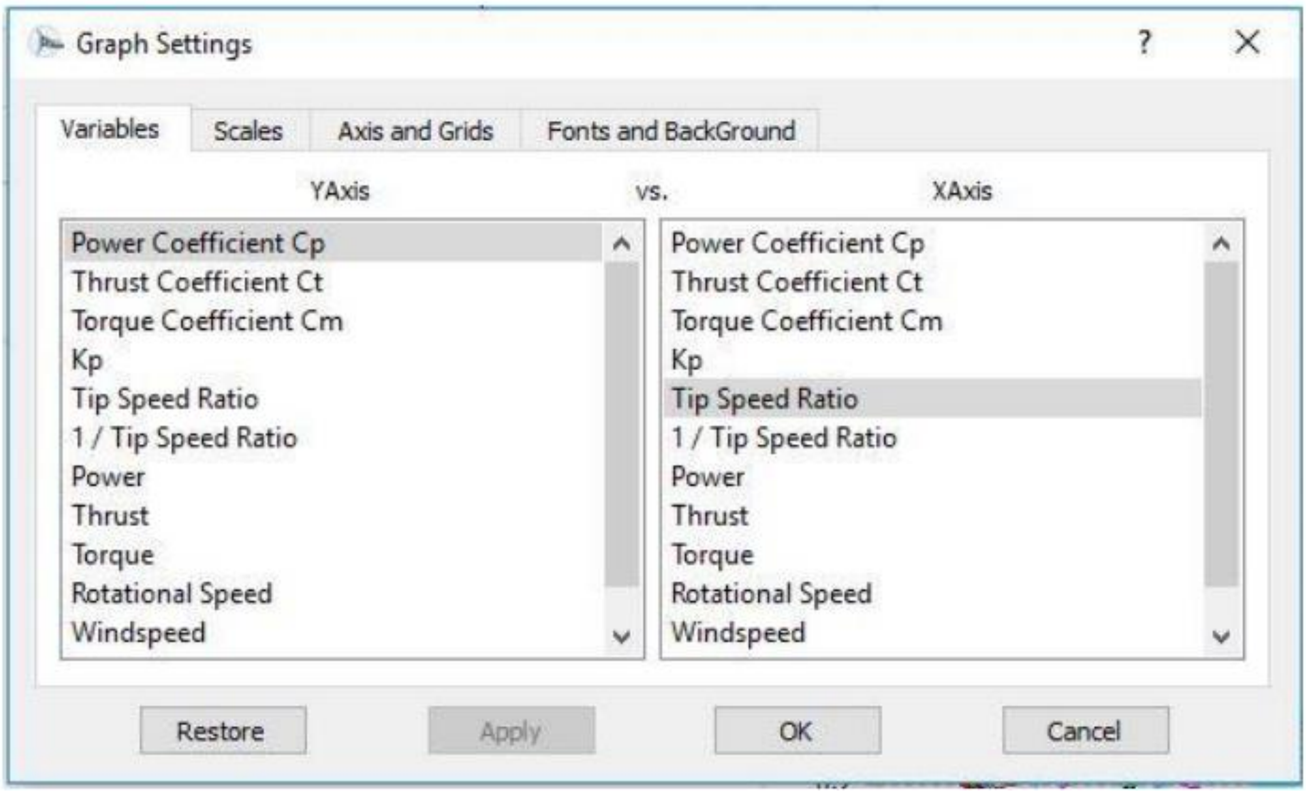

Figure 8. X and Y axis selection choices for variables.

Rotor (BEM) simulation tab is chosen to do the Blade Element Momentum Analysis (BEM). Figure 7 illustrates the simulation's output for the power coefficient (CP), thrust coefficient (CT), and axial induction factor (a). In figure 8, by double clicking on the results graph, the X and Y axis settings may be changed.

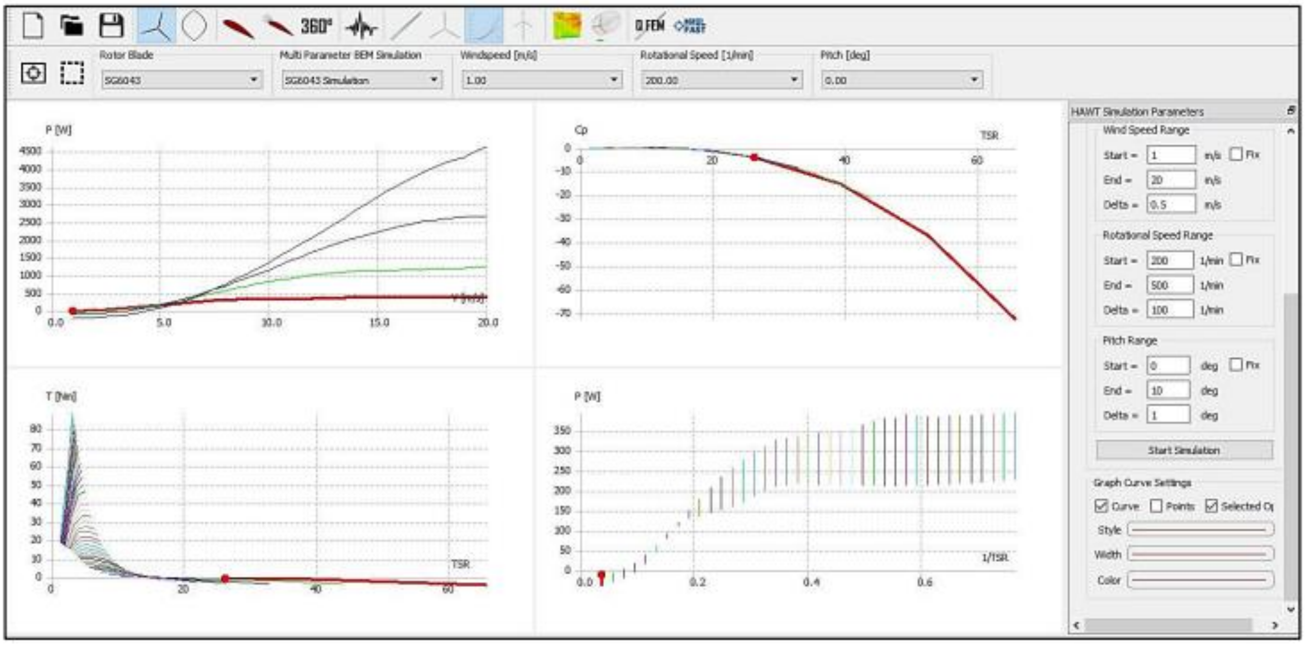

Figure 9. Results of the multi-parameter BEM simulation.

By moving to multiparameter BEM simulation, the other significant output values, such as the Power and torque, are recorded. Figure 9 displays the outcomes for various pitch angle, wind speed, and rotational speed parameters.

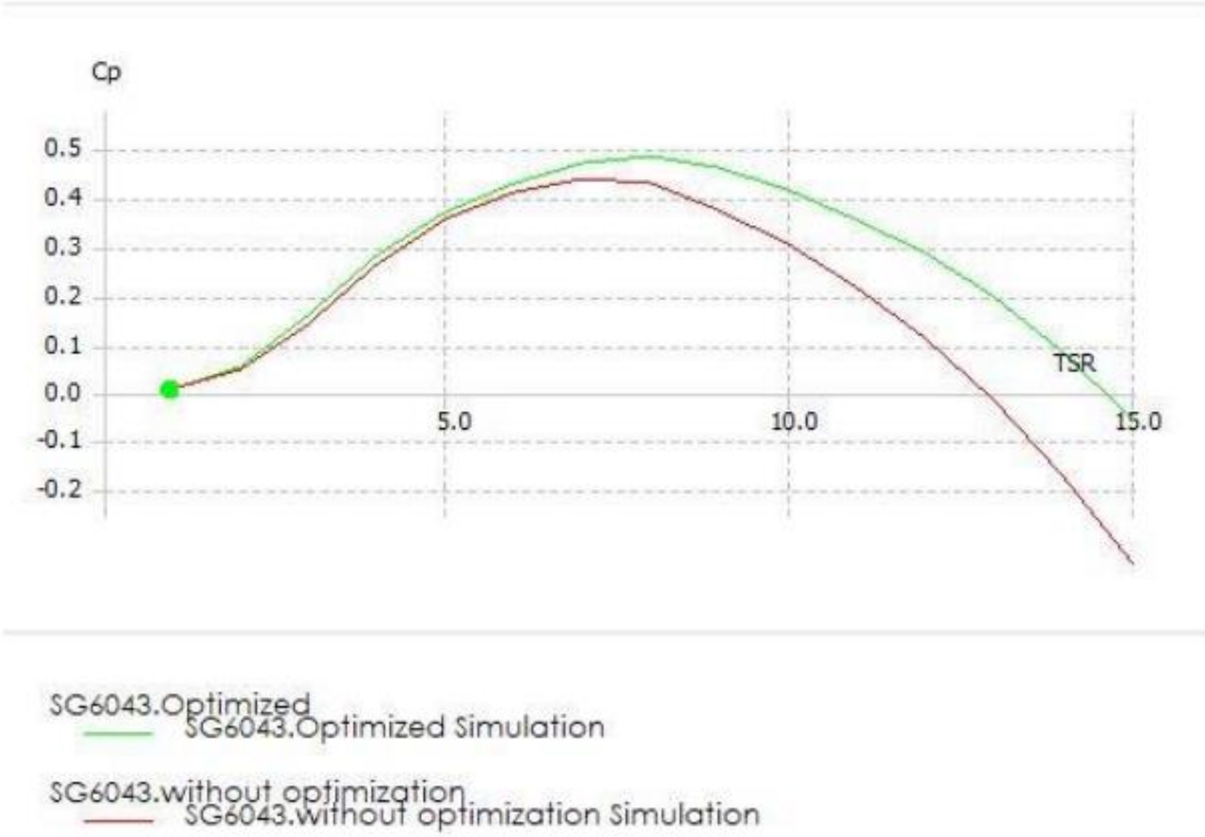

Figure 10. A comparison of the C_p before & after optimization.

A comparison of the power coefficient before and after the optimization process is shown in Figure 10, and it is obvious that the post-optimization values are greater than the pre-optimization values. As a result, the new chord and twist angle blade geometry is selected.

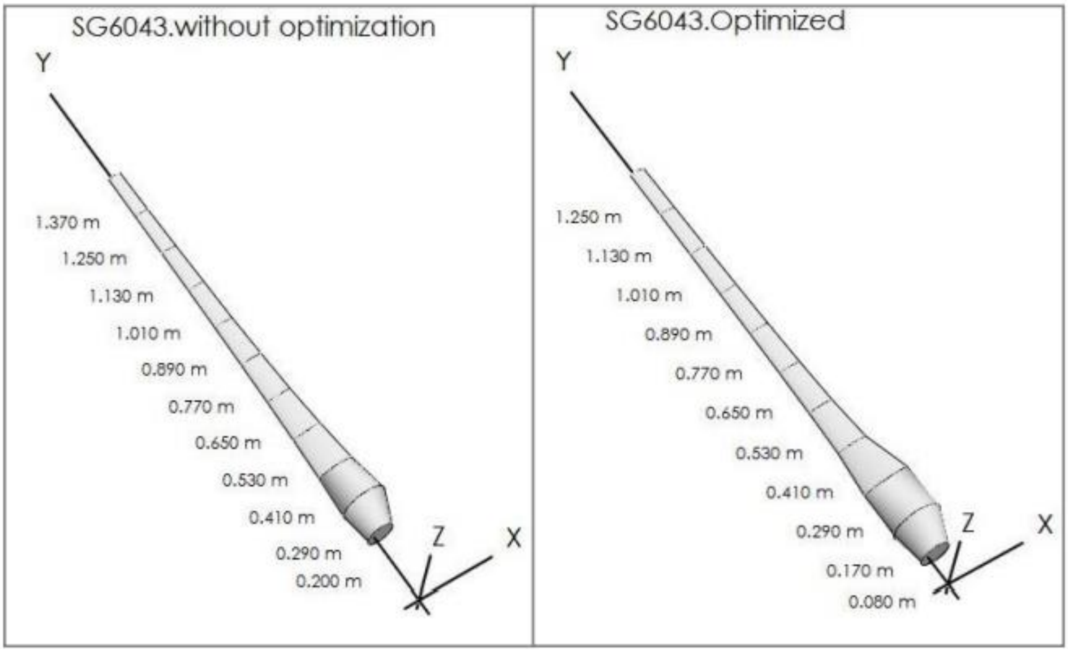

Figure 11. Older design and improved wind turbine blades.

As demonstrated in Figure 11, which uses the airfoil type SG6043 to represent both the original and optimized wind turbine blade models, improvements were made to the chord and twist angle to provide the best possible model of the wind turbine blade.

CONCLUSION

In this work, the rotor of a horizontal axis wind turbine (HAWT) blade is designed and optimised using the QBlade programme at lower operational wind speeds. The blade element momentum hypothesis served as the design's foundation (BEM). Ten different parts of the 1.17 m blade length were selected based on the results of the optimization of the twist angle and chord length of the blade. The computational procedures and results are illustrated using the geometry of the SG6043 airfoil. It was shown that the maximum value of (CL/CD) may be attained when the angle of attack () is equal to 2°. Furthermore, it was shown that the rotor functions optimally at a tip speed ratio of 8. In general, it was discovered that employing QBlade produced high-resolution outputs; also, the programs user-friendly interfaces. The results were highly accurate, and it was demonstrated that the proposed technology is trustworthy for analyzing wind turbine blades. The document outlines the procedures that must be followed in order to construct and optimize a wind turbine blade, as well as the benefits and features of the software.

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