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Analysis of Wind Turbine Using QBlade Software

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Abstract. Owing to the fast development in the energy field, the demands are increasing to improve energy efficiency and lifetime of wind turbine. The wind blades are considered as the most important and expensive part in the wind system. Therefore, it's important to understand deeply the behaviour of turbine blades. In this research paper, full details were presented to analyze and optimize the behaviour and performance of the blade of the small horizontal axis wind turbine (less than 1 KW). QBlade software was used to simulate the wind turbine blade during the working conditions. The mathematical formulations which used in QBlade software were based on the Blade Element Momentum method (BEM). It was studied deeply the effect of design parameters (Twist Angle and Chord length) on the behaviour and performance of the wind turbine. It was used SG6043 airfoil for 10 different sections of 1.17 m blade length. The obtained results were of high accuracy, and it was proved that the QBlade software is reliable to analyze the blades of wind turbine. The paper exhibits the necessary steps to build and optimize the blade of wind turbine, in addition to the features and advantages of the software.

1. Introduction

One of the great topics of our time is solving the world's energy problems. Recently, power generation using wind turbines is becoming viable solution as there is demand for cleaner energy sources. In order to obtain the maximum energy from wind turbine, it should be to improve the efficiency of the wind turbine by optimize the design of the blades. During the last years, there are many methods and techniques were developed by researchers to enhance the efficiency (performance), based on the accurate analysis and optimization of the design parameters of the wind turbine blades. Element Momentum theory (BEM) is one of the important methods which used to simulate and the wind turbine blade and improve its performance [1]. In order to optimized blade number and selection of tip speed ratio corresponding to the solidity, a small wind turbine blade was designed and optimized [2].

Multiple parameters BEM simulation was done in QBlade and graphs of C_P and power is plotted against tip speed ratio for the Design and optimization of micro (less than 1 KW) wind turbine blades at rated wind speed 8.4 m/s. SG6043 airfoil was selected as it gives maximum lift coefficient of 1.63. Simulation of blade length of 1.2m was also done by using QBlade software [3].

Vertical axis wind turbines (VAWTs) are more efficient than the horizontal axis wind turbines (HAWTs) for low wind speed applications because of their ability to capture wind flowing from any direction. Major limitation observed in VAWT is high drag and turbulent force produced by the blade. The VAWT rotor blade design was presented to overcome the limitations. NACA 0018 airfoil is selected and analyzed within the required range of Reynolds numbers and wind speeds in QBlade software [4].

Dhurpate et al. [5] investigated the performance of the small wind turbine rotor blade (horizontal axis) by using different types of airfoils. It was assumed the wind turbine works under low speed of wind and low value of Reynolds number (5×10^5). It was considered the individual airfoil for complete blade span. The rotor diameter was 2m and consists of 3 blades. Four types of airfoils (DU86-084, E387 and SD2030) were selected to build the model of blade and the tip speed ratio was 7. Among all simulated airfoils, it is concluded that the performance of airfoil E387 is the best.

Dimitriadis et al. [6] studied the performance of Horizontal Axial Wind Turbine (HAWT) by using different methods. Two methods were applied to achieve the theoretical analysis; which are Computational Fluid Dynamics (CFD) and Blade Element Momentum (BEMT). The comparisons were made between results which obtain from applied methods. Two and three-dimensional analyses were achieved to study the flow field of the wind turbine blade. The obtained results for the drag and lift coefficients for several angles of attack were evaluated according to the available experimental data. Superior performance and advantages of CFD modeling is shown comparing to BEMT. The conclusions revealed that CFD computations can compute the flow around an airfoil accurately.

Soland and Thuné [7] investigated and analyzed Blade performance of the rotor of wind turbine (7.0 MW, HAWT) with 165 m diameter. It was used XFLR5 (XFoil) and QBlade to achieve the computations. It was tested the blade after using the selected airfoils by using the blade element momentum theory. It was obtained the full details about the performance of the rotor of wind turbine when using different airfoils under different operational loads. It was found that the best airfoils were (NACA 63-6XX and NACA 64-6XX). It was noticed that the performance of the wind turbine improved when using the airfoils (NACA 63-6XX and NACA 64-6XX) instead of the other types of airfoils which used in the analysis.

Two airfoils are designed for a small horizontal axis wind turbine of rated power one kilowatt at rated speed 8.4 m/s. The new designed airfoils and blade were analyzed for performance, using two computational methods (QBlade and XFOIL) and one experimental method (wind tunnel testing). The experimentation on the airfoils was carried out in the wind tunnel at different Reynolds numbers. The lift and drag coefficients were determined at different angles of attack. Two computational techniques (QBlade and ANSYS CFX) were used for performance analysis of the blade. The developed small turbine blade performance was compared based on lift coefficient and drag coefficient at a wind speed of 8.4 m/s [8]. An investigation about the aerodynamic loads effect on wind blade under high wind speed as critical point was presented. The wind turbine has fixed speed and 7.5 m of blade length. The blade airfoil is DU93W210. The wind speed was taken 16m/s as peak point. The result showed that the blade sections operates under pseudo-constant normal loads and low tangential loads effect have considered value in root sections and the stress concentrated on middle sections under variation of defluxion of neighbor sections [9]. New airfoil was developed with the aim of performance improvement of wind turbine. Two different airfoils were designed for root sections and tip sections. Blade Element Momentum theory was used in designing of the small wind turbine blade. The numerical analysis of blade airfoil was carried out by QBlade software. The results obtained were compared with (NACA 2412) and (SG 6042) airfoils. In addition, performances of blades made with individual airfoil are compared by using QBlade software [10].Other research papers were studied the behavior of the rotating blades from other point of view, where these research papers [11,12,13,14,15] focused on the stress and vibration analyses of the rotating blades under different working conditions.

2. Theoretical Formulation

In this section, all design parameters will be introduced. In order to calculate the drag force (D) and lift force (L), it should determine the lift and drag coefficients. The forms of the drag coefficient (C_D) and lift coefficient (C_L) can be written as following [16],

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

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

where ρ, A and v are the density of air, the effective object area and the wind speed, respectively. It can be considered that the most important coefficient to select the wind turbine is the Power Coefficient (C_p), which can be defined as the ratio of the actual produced power (P_T) to the total power of wind which flowing through the blades of wind turbine at particular wind speed (P_0). Many factors were included in The Power Coefficient (C_p) such as the efficiencies of the mechanical components (shaft bearings and gears), generator and power electronics. The value of (C_p) is affected by the operating conditions such as blade angle, wind speed, speed of rotation, etc.). It can writing the form of the Power Coefficient (C_p) as follows [16],

$$C_p = \frac{P_T}{P_0} = \frac{\frac{1}{4}\rho A({V_1}^2 - {V_2}^2)(V_1 + V_2)}{\frac{1}{2}\rho {V_1}^3 A} \quad \text{..................} \quad (3)$$

Where, v_1 and v_2 are the wind speed at upstream and at downstream of the wind turbine blades. So the form of power coefficient as a function of the axial induction factor (a) can be rewritten as follows:

$$C_p = 4a(1 - a)^2 \quad \text{...........................} \quad (4)$$

where the axial induction factor (a) represents the fractional decrease in the wind speed at the upstream and wind speed at the rotor. Also, it can represent the thrust coefficient (C_T) as a function of the axial induction factor (a) as follows,

$$C_T = 4a(1 - a) \quad \text{............................} \quad (5)$$

the magnitude of the output torque from the wind turbine is a function of the selected rotor (size and design of the rotor) and other factors such as wind speed, pitch angle, etc. The maximum output torque which can be obtained is,

$$T_{max} = F_{max} R \quad \text{..............................} \quad (6)$$

where F_{max} is the maximum thrust and R is the radius of rotor.

In this research paper QBlade software was used to achieve the theoretical analysis of the blade of wind turbine. The case study will be focused on the horizontal axis wind turbine (HAWT). A classification of analysis of the horizontal axis wind turbine (HAWT) by using QBlade software into three categories (Figure 1) is:

- The design and optimization of the wind turbine blade.
- The design and simulation of the rotor of wind turbine.
- The simulation of the complete wind turbine.

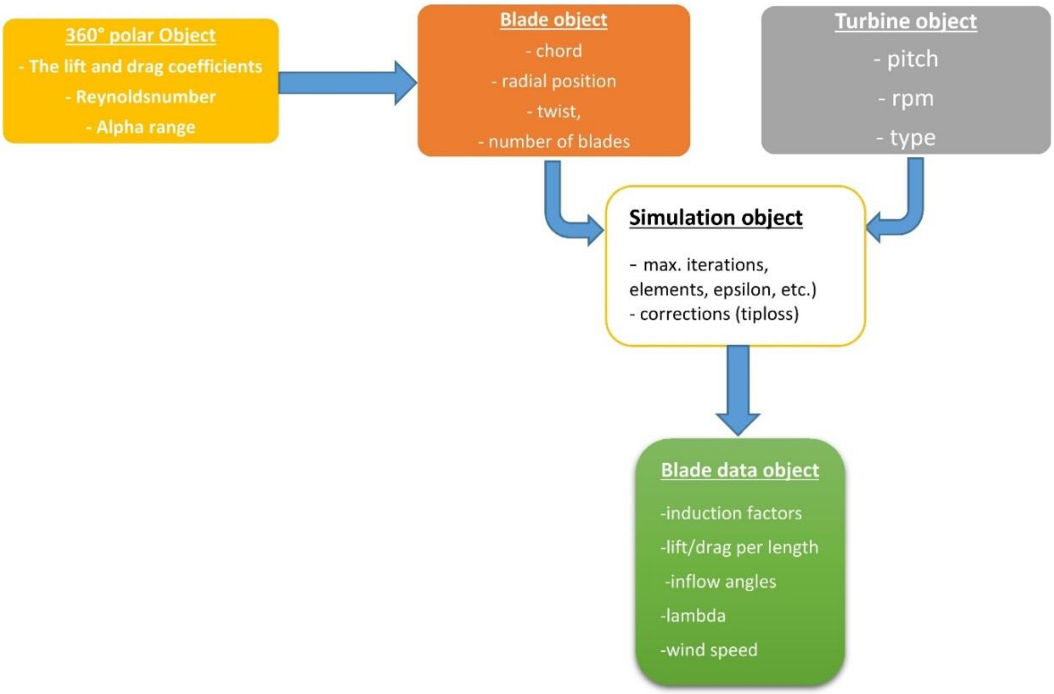

Figure 1. The analysis of the wind turbine by using QBlade software.

3. Results and Discussions

In this paper, the optimization process of chord and twist angle for the airfoil (SG6043) is accomplished in order to obtain maximum output power from the wind turbine. Ten different sections for the wind turbine blade (L=1.17 m) are list in table 1. It can be considered that the design of airfoil is the first step. Figure 2 shows how to create the airfoil (SG6043), this step was done based on the importing of a DAT file. After selecting the proper airfoil for the blade, the simulation can start. XFOIL direct analysis with a polar view is used to define a new analysis. Laminar flow is expected for Airfoils at low Reynolds number, 10^5 Reynold number is used for this analysis. Figure 3 illustrates the variation C_L, C_D, C_L/C_D with angle of attack. Operating point view visualizes the boundary layer and pressure produced as shown in Figure 4. 360-degree polar extrapolation is used to extrapolate a circle with a diameter same as the chord of the airfoil as illustrated in figure 5. Ten segments of HAWT were created in this study. According to taper ratio, chord was defined. By using advanced blade design, thread at centerline maximum thickness could be shown in Figure 6. Optimization process was used to get the twist value for the designed blades as shown in table 1. Firstly, maximum value (C_L/C_D) is needed to complete the optimization process. It can be found the maximum value of (C_L/C_D) from figure 3, which is equal to 2 in the present analysis. This value is called the angle of attack (α).

In order to achieve the Blade Element Momentum Analysis (BEM), rotor (BEM) simulation tab is selected. The resulting simulation is for the power coefficient $\mathbf{C_P}$, thrust coefficient $\mathbf{C_T}$ and axial induction factor **a** as shown in figure 7. In figure 8, it can be adjusting X and Y axes parameters by double click on the graph of results.

The other important outputs results such as the Power and torque are recorded by switching to multi-parameter BEM simulation. Figure 9 shows the results for different values of pitch angle, wind speed and rotational speed.

Figure 10 shows the power coefficient before and after optimization process; it is obviously that the values of power coefficient after optimization are greater than those before optimization. Hence, the new chord and twist angle blade geometry is selected.
It can be seen the

Figure 11 presents the old model and the optimized wind turbine blades using the airfoil type (SG6043), where it can be seen the changes that made in the chord and twist angle to obtain the optimal model opf the wind turbine blade.

Table 1. Optimized Chord and Twist Angle for SG6043.

	Pos (m)	Chord (m)	Twist	Foil
1	0	0.076	0	Circular Foil
2	0.09	0.126	0	Circular Foil
3	0.21	0.118551	18.3186	SG6043
4	0.33	0.0755927	12.1912	SG6043
5	0.45	0.0625468	8.65956	SG6043
6	0.57	0.054959	6.3787	SG6043
7	0.69	0.0495343	4.78876	SG6043
8	0.81	0.0452978	3.61874	SG6043
9	0.93	0.0417521	2.72238	SG6043
10	1.05	0.0388054	2.01403	SG6043
11	1.17	0.0362923	1.44033	SG6043

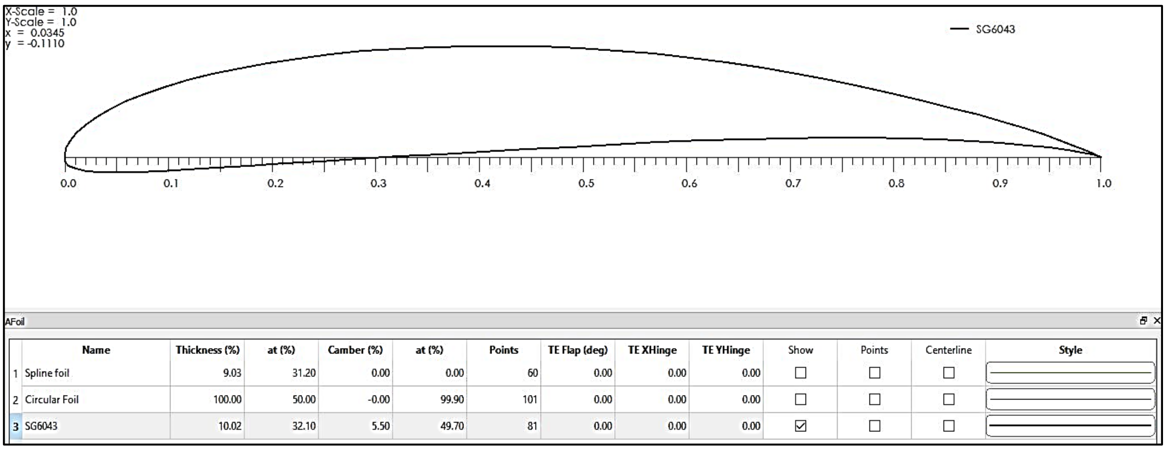

Figure 2. Airfoil Generation in QBlade software.

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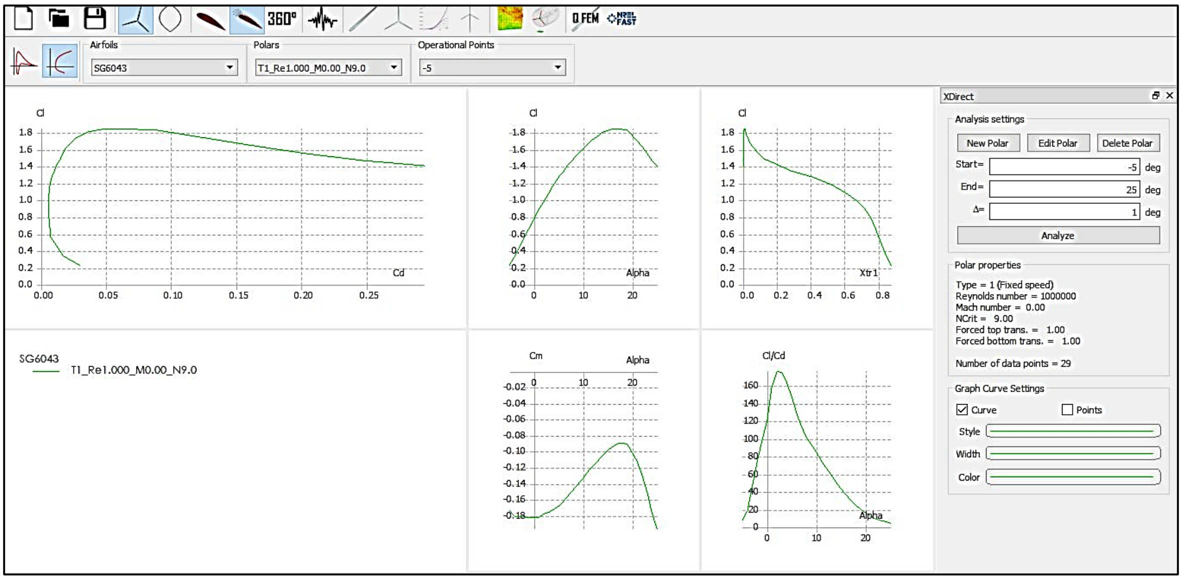

Figure 3. C_L/C_D Vs. angle of attack (α).

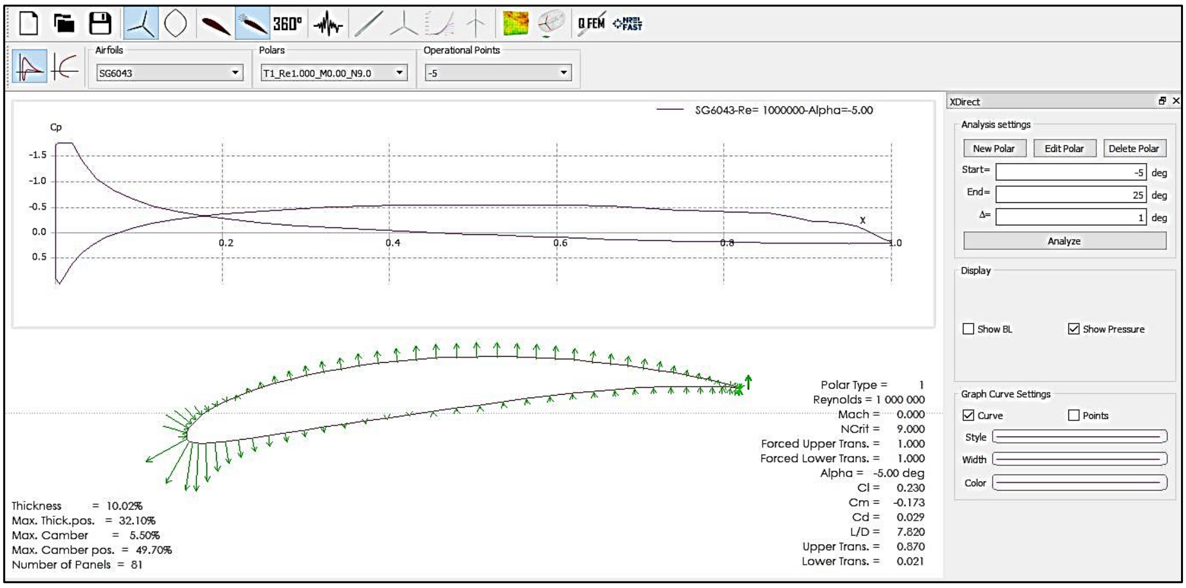

Figure 4. The boundary layer and pressure produced.

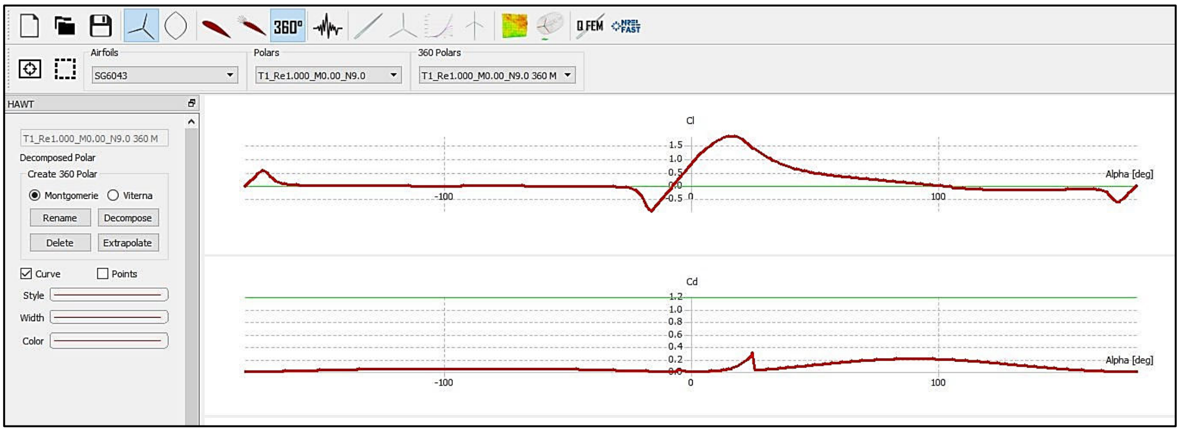

Figure 5. Polar extrapolation to 360-degree.

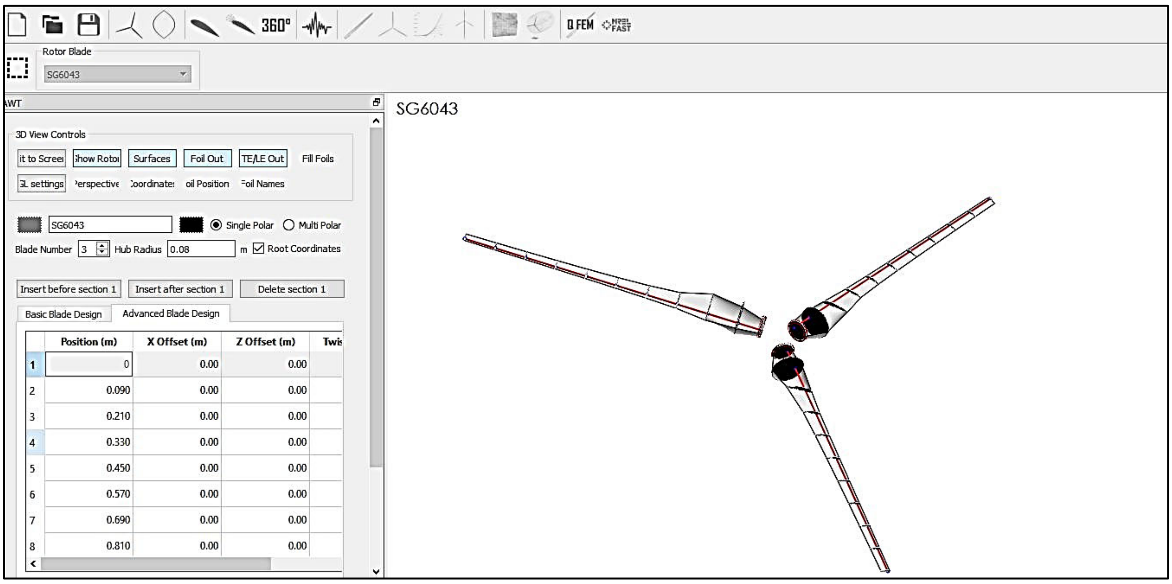

Figure 6. Thread at centerline using advanced blade design.

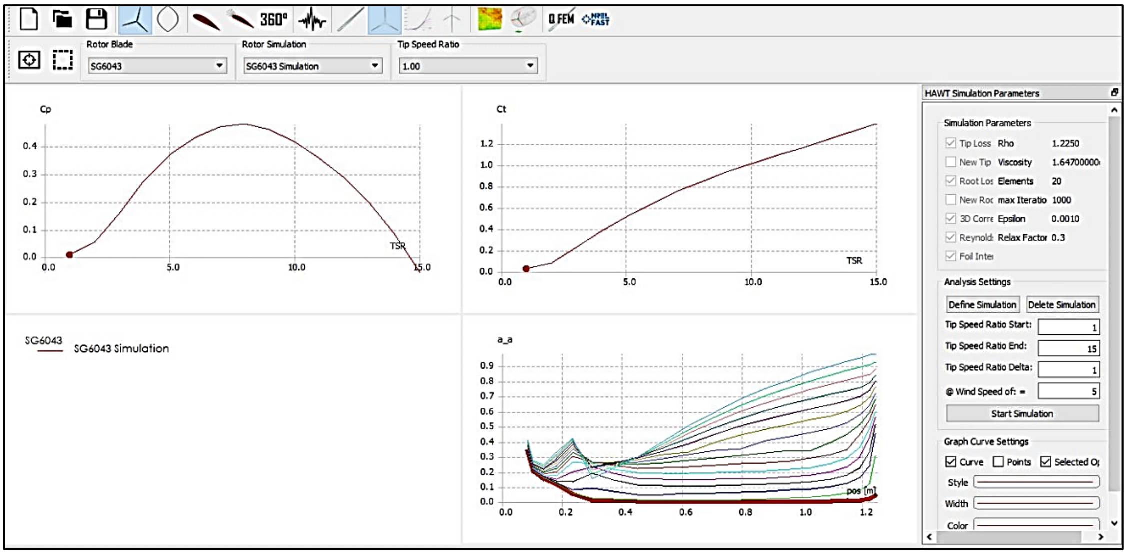

Figure 7. C_P, C_T Vs. Tip speed ratio and axial induction factor Vs. Radial position.

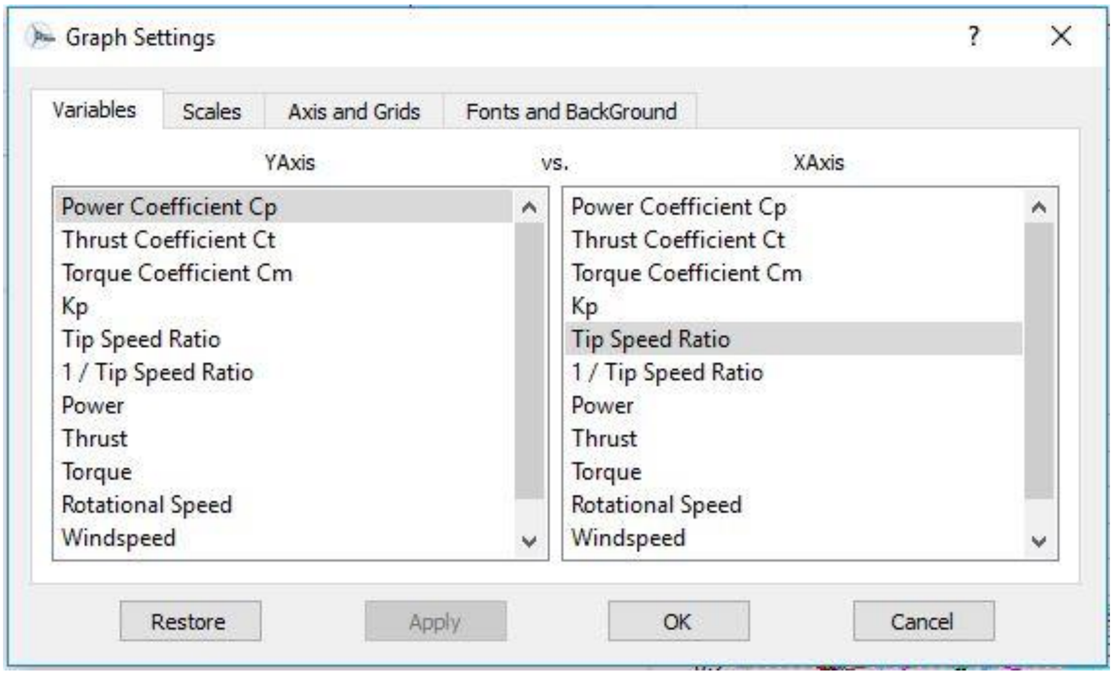

Figure 8. Variables selection options on X and Y axis.

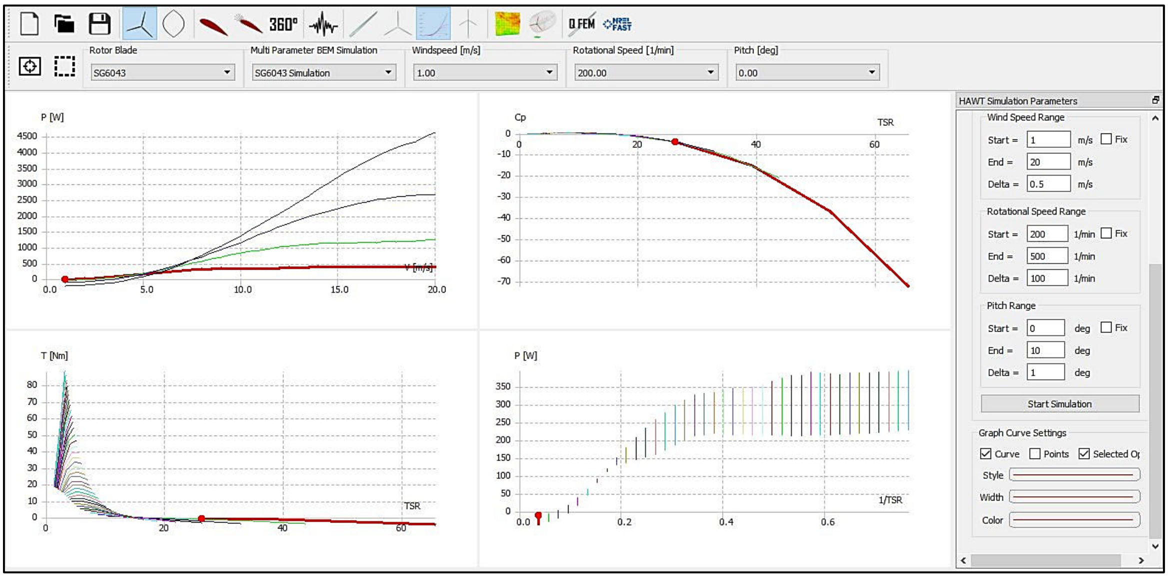

Figure 9. Multi-parameter BEM simulation results.

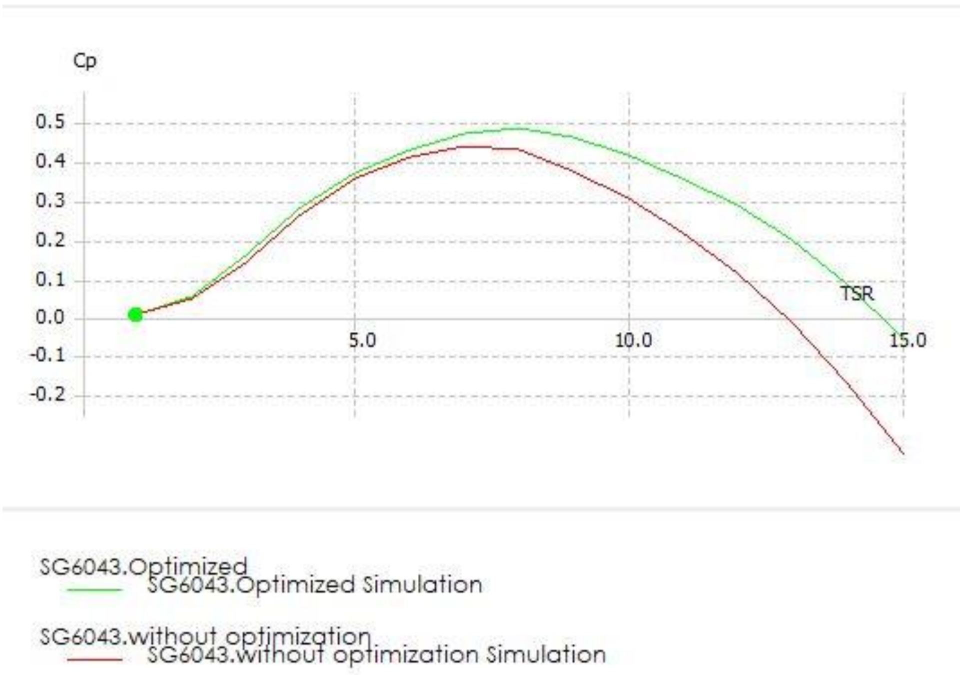

Figure 10. The power coefficient before and after optimization process.

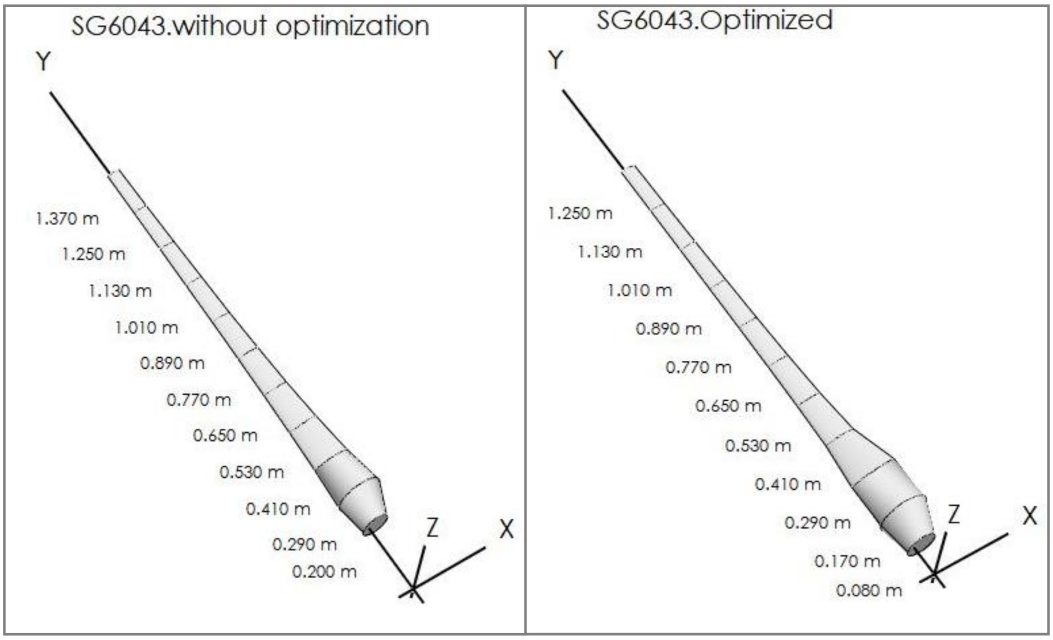

Figure 11. The old model and optimized wind turbine blades.

4. Conclusions and Remarks

This paper presents the design and optimization of the rotor of the horizontal axis wind turbine blade at the lower values of operating wind speed based on blade element momentum theory (BEM) using QBlade software. A 10 different sections of 1.17 m blade length were used based on the results of the optimization of the twist angle and chord length of the blade. In order to demonstrate the computation procedures and results, SG6043 airfoil shape was chosen. It was found that the maximum value of (C_L/C_D) can be obtained when the angle of attack (α) is equal to 2°. Also, it was found that the optimum performance of the rotor occurred when the tip speed ratio is equal to 8.

Generally, it was found that the results obtained by using QBlade were of high resolution; in addition to that the interfaces of the program are friendly to users. Therefore, it can be considered that the QBlade software is one of the most important softwares to design and optimize the blades and rotors for a wide range of the wind turbines.

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