A Comparison of the Straight Blade and Swept Back Blade Horizontal Axis Wind Turbines

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Abstract
In this thesis, the idea of designing Horizontal Axis Wind Turbine with different airfoil sections has been introduced in the straight and swept back blades for the better performance of the blades. Another main idea of sweeping the blade is also introduced for the comparison of straight blade over the swept back blade with the help of the design and analysis software QBLADE. As the results obtained in the analysis, In the comparison of the blades the straight blade managed to produce 250 KW at the peak wind speed of 36 m/s seconds and stalls. Whereas the swept back blade managed to produce 310KW at the peak windspeed of 40 m/s. As per the results it is finally selected that the swept back blade possess better performance in comparison of the straight blade has been identified.

Keywords - *HAWT, Swept Blade, Horizontal axis, wind power generator*

I. INTRODUCTION

In today’s world while considering the adverse effect in the environmental safety and the need for the sustainable energy, the energy resources plays an important role in this topic which shows the importance and need of renewable energy resources. In renewable energy resources, the most important one is the wind. Wind turbines, which is the most sustainable form of energy production technique in which the energy can be gained from the wind in small and large scale based on the size and types of the wind turbine. While speaking about the wind turbine types, basically of two types which are Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). As the thesis mainly focusing on the horizontal axis wind turbine, the working principle of the HAWT has been discussed. The important parts in the horizontal axis wind turbine consists of the following parts

- Rotor hub
- Low speed shaft
- Gearbox
- Brake
- High speed shaft

A. Working Principle

In the working principle of the horizontal axis wind turbine the main rotor consists of the rotor blades which is attached to the hub tends to rotate as the air passes on the blades that rotates the rotor hub. These rotations are transferred in to a low speed shaft, as the low speed shaft starts rotating the next part of the HAWT is the gear box which heavily increases the rotation speed in to 100 times than the low speed shaft and transfer the higher rotation to the high-speed shaft and this transferred in to the generator which converts mechanical energy in to electrical energy for the production of electricity thus the basic working principle of the horizontal axis wind turbine.

As the proposed title focusing on the blades of the horizontal axis wind turbine. The blades are the important part of the turbine which is the most responsible for the power production as the rotation of the blades are key point to produce electricity. Since the wind turbine always possess an aerodynamic shape for the smooth flow of air in the blades for the rotation. The most important work focusing on the selected project is to design and simulation the straight blade, also to design and simulation of the swept back blade of horizontal axis wind turbine (HAWT) and analysing of both the blades also compare the results of the swept back blade over the straight blades which leads to find the better performance of the turbine design.

B. Historical Background and Development

When considering the historical developments of wind turbines, the early developments of wind turbine models possess the rotation axis of horizontal or near horizontal axis rotation. On taking the wind turbine, the blades are energy capturing elements which is rotating in a horizontal axis of a vertical plane that is perpendicular to the direction of the wind. In the blade type, two or three straight or twisted blades are used, and the pitch can be fixed or variable.

II. METHODOLGY

In this chapter of methodology, the methods required and selected to implement in the project. Also, the overview of the selected method and how it is performed to be outlined and discussed.

A. Qblade Software Methodology

The QBLADE is the software which is used in both the horizontal axis and vertical axis wind turbine blades design and simulation process to obtain the results. For the software process, there are many important steps involved and to be followed, the most important one in the QBLADE software is the selection of the axis. As the axis in the current topic is horizontal axis wind turbine blades the axis to be selected is HAWT.

B. Aerofoil Design

When comes to the blade designing in the QBLADE software. The software methodology includes the aerofoil design which is the base for the blade shape and in the software the first step is the aerofoil design. In this section, the aerofoil can be generated by NACA aerofoil with the implementation of the aerofoil digits in the NACA foils tab and another method of generating aerofoil is that can able to import the data foil for the selected aerofoils with the required x and y coordinates in the data file of the aerofoil shapes. Another one method available is the custom-made aerofoil shapes with the spline foils as it is customised with the user's requirements as the available option to change the coordinates. Using these aerofoil design concepts, the required aerofoil for the blade design can be achieved in the software.

C. Xfoil Direct Analysis

The X Foil direct analysis is the next step in the software methodology after the aerofoil design. The X Foil is a program which is used to analyse the aerofoils selected for the wind turbine blade designing. The analysis includes the computation of various flows around the subsonic aerofoils. In this validation, the important inputs to be needed are the Reynolds number and the angle of attacks ranges i.e. The upper limit and the Lower limit, at which the aerofoil to be analysed. The above value which are given by forming a new polar in the X Foil module of the software. The X Foil direct analysis converging on the viscous and inviscid of an aerofoil which considering the transition
of the forced or free transition and the stall angle of the aerofoil of lift and drag and the trailing edge separation which is limited to the proposed angle of attack. Which the analysis of the graphs of the coefficient of lift and drag at the which above the stall angle of the aerofoil can be achieved.

D. Polar Extrapolation 360

The polar extrapolation 360 is the next step after the X Foil. As the given aerofoil analysed in the X Foil for the coefficient of lift and drag values at the angle of attack of 180 polar can be achieved and the polar needs to be extrapolated to 360 which is essential for the BEM analysis in the rotor or turbine or the rotation for 360 degrees is essential for the wind turbine simulation. Which the given range of angle of attack the aerofoils achieved coefficient of lift and drag value above the stall angle which is then extrapolated to 360 for the further simulations in the QBLADE software and In the extrapolation another submodule of Montgomery also to be considered, which consists the options for the fine tuning of the polar which the graph achieved in the 360 degree in extrapolation can be highlighted according to the requirements and can able to update the slope and the angle of original polar values as required.

E. Rotor Blade Design

In the QBLADE software the next important part is the rotor blade design. In the rotor blade designs the proposed rotor blade for the selected wind turbine can be constructed or designed with the required parameters which has been enacted as inputs in the software before. In the rotor blade design the parameters required are the

- Chord length.
- Twist angle
- Hub radius. (in metres)
- Foil selection for the sections of the blade
- Number of blades
- Total length of the rotor blade.

F. Blade Element Momentum Method

The blade element momentum method is the combination of the momentum theory or disk actuator theory i.e., analytical expressions of an ideal actuator disc, and blade element theory. The BEM method is basically analysing two kinds of methods in the operation of wind turbines, here the first one is the momentum balance on a rotating or gyrating annular stream which is passing through a turbine. The another one is that Whereas the momentum theory focuses in the relative windspeed that is been calculated for every section of the blade which implies the computation of angle of attack and the calculation of the coefficients of lift and drag of the selected profile. With the attained coefficients and the elements area the thrust and torque can be calculated. Which all then added up for the final thrust and torque value for different wind speed and rotational speed.

G. Turbine BEM Simulation

The final simulation of the process is the turbine BEM simulation. In this module of the QBLADE, the wind turbines final form is created and simulated to achieve the power value for the designed rotor blade. The power graph can be generated for the power vs wind speed at which speed the optimum performance of the turbine power is achieved can be plotted via graph. For the turbine generation, the following parameters are required

- V cut in
- V cut out
- Rotational speed

- Variable losses
- Fixed losses

II. SELECTION OF AEROFOILS

In this section of methodology, the aerofoil selected for the design and simulation of the horizontal axis wind turbine straight blade and swept back blades are the NACA and DU aerofoils.

A. NACA Aerofoils

The NACA aerofoils which is selected for the blade construction is based on the interest of these aerofoils in the higher usage of these types of aerofoils in the wind turbine blade designing. Since for the selection of the aerofoils based on NACA it is studied about the relations in the wind turbine blade design.it is understood that the three families of NACA aerofoils is highly preferred for the turbine blade design which are NACA 63, 64 and 65 families. As these aerofoil families vary with the other families with the chord wise location of least pressure. In these families of NACA aerofoils the last two digit distinguish it by the thickness of the aerofoil and the following two aerofoils are considered for the rotor blade design

- NACA 63415
- NACA 63418

B. DU Aerofoils

The DU aerofoils stands for Delft University aerofoil which is been selected because of these aerofoils are required top section of the blade at which the thickness of the aerofoil need to be higher and also the DU aerofoils thickness is higher which is specifically made for the wind turbine blades for the upper end of the rotor blades and DU aerofoils are used in the major designing and application of the wind turbine blades which is familiar for its thickness. When considering the medium type blade, the aerofoil in the DU family of DU 99 -W350 is been familiar and has the thickness of 35% of the chord length and DU 97 – W300 has the thickness of 30% of the chord length which matches the requirement of the blade proposed to design and therefore from the DU family, the below mentioned aerofoils has been selected.

- DU 99 – W350
- DU 97-W300

III. HAWT DESIGN AND SIMULATION

In this chapter, the designing and simulation of horizontal axis wind turbine straight blade and horizontal axis wind turbine swept back blade has been carried out. Where the blades to be generated using the design and simulation software QBLADE and analysed for the power output of the wind turbine blades.

A. HAWT Straight Blade Design and Simulation X Major Components

In this section, with the help of the QBLADE, the design and simulation of the horizontal axis wind turbine straight blade with the parameters obtained to generate the results. The first step involves in the software is the selection of the HAWT mode from the top toolbar.

B. Aerofoil Design

The Aerofoil design is the important part of the blade since it decides the basic aerodynamics of the blades such as lift and drag. The first part of the design is to generate all the selected aerofoil in to the QBLADE software using the aerofoil design tab. Since the selected aerofoils are from DU and NACA which are listed in the table below. The Aerofoils are generated in the QBLADE by selecting the foil from the top toolbar and generated the NACA Aerofoils with the specific series number in the aerofoils. When comes to the DU aerofoils it cannot be generated directly using the DU series numbers. Therefore, it is generated by importing the data file which consists the x and y coordinates for the generation of the aerofoil. Thus, the aerofoil design has been imported in to the QBLADE by finishing the aerofoil design section as the first part. The figure above shows the generated aerofoil in the QBLADE using the mentioned techniques.

C. Polar Extrapolation 360

After the X foil direct analysis, the next step of the rotor blade design has been carried out by the polar extrapolation 360 of the QBLADE software. In this section, the aerofoils which has been analysed in the previous sections are undergo an extrapolation to 360 as the wind turbine is a 360-polar rotational object and so far, the aerofoil has been analysed only 180 polar, that are not suitable for the blade simulation and design. Therefore, in the extrapolation menu from the upside tab has been selected for the creation 360 polar. The selected tab leads to a selection to tab of Montgomerie and in that select, extrapolate and the finetuning of polar, the slope and the range of original polar can be altered if necessary and the C_D and C_L graphs has been extrapolated to 360 polar form for the rotor blade design and simulation. In this section, it can be able to adjust the graph thickness and highlights of the curves if necessary. The figure below shows the extrapolated aerofoil in the QBLADE software.

D. Straight Rotor Blade Design

In the rotor blade design, the straight blade for the horizontal axis wind turbine is designed with the selected parameters such as chord length, twist and positions of the aerofoil in the blade sections has been listed in the table below. The blade length is being fixed as 4 metres and the number of blades is fixed as the hub radius is selected as 4 metres. Since the overall length of the blade is 4 meters and it has been divided in to 34 sections with the selected aerofoils in the below table as order has been positioned accordingly with the segment from the blades top mid and tail section which the chord length of the aerofoil changes respectively for the shape of the blade and the aerofoils which has been selected for each section are generally been used for the designing of the real-time wind turbines.

E. Rotor BEM Simulation – Swept Back Blade

In the rotor BEM simulation for swept back blade the process is same as the straight blade. As the swept back blade in the part has been analysed for the graphs of power coefficient, thrust coefficient mad the optimum tip speed ratios can be plotted by the BEM algorithm of the QBLADE. The main the parameters required for this section of the simulation is the ranges of the tip speed ratios and same as the straight blade rotor simulation the tip speed ranges used for the swept back blade are from 1 to 10 as the start and end ratios and the delta value has been given as the 0.5 for the graph plotting. The tip speed ratio obtained against the power coefficient shows the rotor blades capacity in achieving the higher power. The graphs below show the swept back blades rotor BEM simulation results.

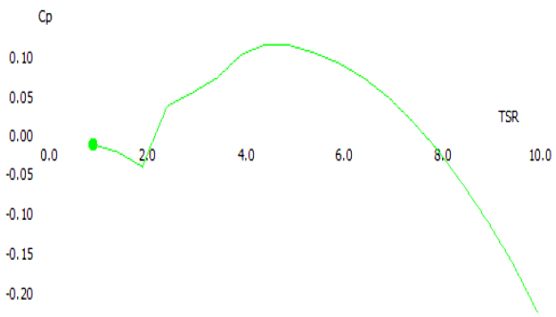

Fig 1: COEFFICIENT OF POWER (CP) VS TIP SPEED RATIO (TSR)

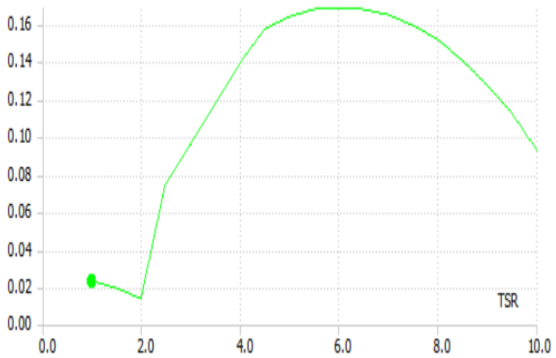

Fig 2: COEFFICIENT OF POWER (CP) VS TIP SPEED RATIO (TSR)

IV. RESULTS AND DISCUSSIONS

In this section of the thesis the results which occurred in the simulation of the straight blade and the swept back blades are considered and compared to find the better blade profile which induces higher power generation and the below sections of results are detailly analysed for the better conclusion of the optimal blade.

A. Rotor BEM Simulation Straight Vs Swept Back Blade

As the simulation starts from the rotor BEM simulations, the results obtained in this section has been taken in comparison of the both the straight and swept back blades. Since the tip speed ratio of the rotor blades generated involved in the part of power generation. The below figures are the obtained results of both the blade profiles where the red curve indicates the straight blade and the green curve indicates the swept back blade

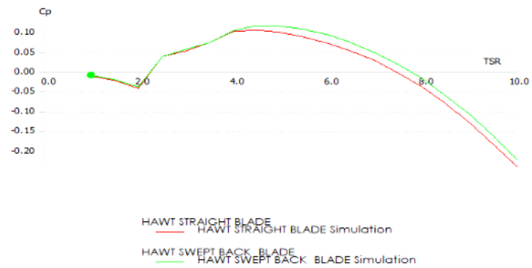

Fig 3: COMPARISON OF COEFFICIENT OF POWER (Cp) vs TIP SPEED RATIO (TSR)

The graph above shows the Cp vs TSR results obtained. Here the red curve represents the straight blade and the green curve represents the swept back blade. From this graph, it is understood that in terms of power coefficient vs tip speed ratio the swept back performs well and achieve higher power coefficient than the straight blade, as the straight blade drops its power coefficient at the tip speed ratio of 5 and begins to stall as seen on the graph above. But the swept back possess to rise in power coefficient at the optimum tip speed ratio 5 However, the straight possesses the power coefficient of 0.10 whereas the swept back blade achieved 0.12.

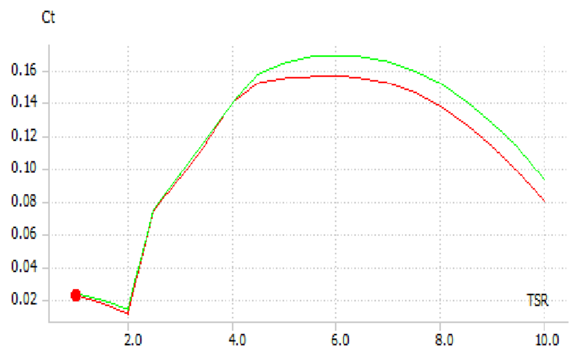

Fig 4: COMPARISON OF COEFFICIENT OF THRUST (Ct) vs TIP SPEED RATIO (TSR)

In this graph, the red curve represents the straight blade and the green represents the swept back blade. As seen in the graph the thrust coefficient obtained in the BEM simulation and the coefficient of thrust is 0.18 for the swept back at optimum tip speed ratio 6 and the coefficient of thrust for the straight has only 0.16 at the tip speed ratio of 6. With the help of the graph it is evident that the swept back possess high coefficient of thrust at the optimum tip speed ratio.

B. Turbine BEM Simulation Straight Vs Swept Back Blade

In this section, the turbine results of the both the swept back blade and the straight blade is compared. As the power generation is the key target the comparison needs to be carried out to prove the better blade geometry in the power generation of the blades. The graphs below consist of both the straight and swept back turbines for the comparison of the results.

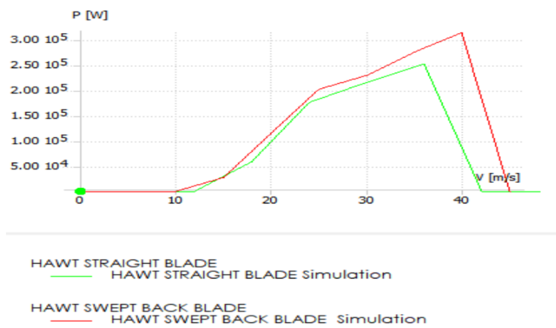

Fig 5: POWER vs WINSPEED COMPARISON OF STRAIGHT AND SWEPT BACK BLADES

In the figure, the graph represents the green curve as straight blade and the red curve as the swept back blade. The results show that the straight blade achieves 250 KW at the wind speed of 36 m/s. whereas the swept back turbine achieves 310KW at the wind speed range of 40 m/s. From the graph, it is evident that the swept back blades performance is much higher than the straight blade in terms achieving higher power and as well the tolerance of the wind speed at higher range.

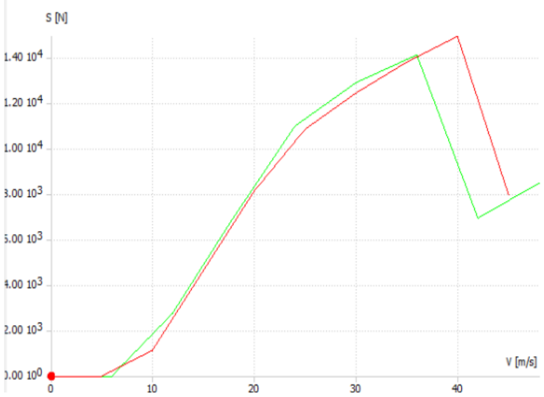

Fig 6: THRUST vs WINDSPEED COMPARISON OF STARIGHT AND SWEPT BACK TURBINE

When comparing the thrust vs windspeed graphs of the sweptback vs straight blade. Here the red curve shows the swept back turbine and the green shows the straight turbine. As discussed in the simulation results earlier. From the graph, it shows clearly that the thrust generated in the swept back is much higher than the straight blade. Whereas from the simulation results it is evident that the thrust generated at the straight blade is 14000 N at the wind speed range of 36 m/s and whereas in the sweptback blades which managed to produce 15000 at the higher wind speed of 40m/s. so it is evident that the swept back possess higher thrust when compared to the straight blade.

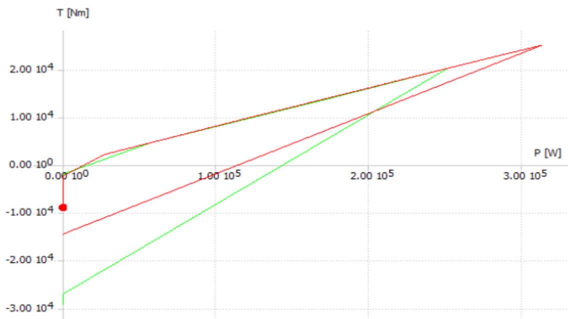

Fig 7: TORQUE VS POWER COMPARISON OF STRAIGHT AND SWEPT BACK TURBINE

In the torque vs power graph as mentioned in the figure above as similar to the thrust and power graph the red curve shows the swept back and the green curve shows the straight turbine. As mentioned earlier the torque connection in the power generation.it is important to compare the torque and power generation of the turbines. From the figure above, it states that the torque and power achieved by the swept back turbine is much higher than the torque and power generation in straight blade turbine. As shown in the simulation results torque generated by the swept back blade turbine are 30000 Nm and the power generation is 310KW whereas the straight blade turbine managed to produce the torque of 20000 Nm and the power generation is low a 250 KW. Therefore, it is evident that the swept back is doing better. As the comparisons of all the simulated results of the swept back vs straight blade turbines. It is evident that the swept back blade is doing better performance and higher power generation.

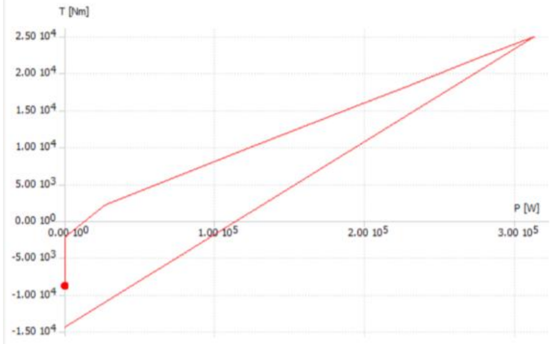

Fig 8: TORQUE vs POWER SWEPT BACK WIND TURBINE

The final graph occurred from the swept back blade of HAWT is the torque vs power graph, which is shown in the figure above. In this graph, it has been understood that the power generated is related to the torque and the maximum torque generated by the swept back blade turbine are 30000 Nm and the power generated which same as the optimum power generated earlier in the power graph which 310KW. Thus, the torque vs power graph also has been achieved.

CONCLUSION

The HAWT straight blade and swept back blade designing has been successfully carried out with the help of wind turbine design and simulation software QBLADE. The HAWT straight blade has been constructed with the selection of aerofoils of DU 99 – W350, DU 97 -W300, NACA 63415 and NACA 63418 are selected based on its thickness and chord wise positions in the blade sections and analyzed the aerofoils with the different range of Reynolds number accordingly for the different flow variations of the aerofoil. The blade is then designed with required and calculated design parameters such as chord length, twist and length of the blade. The blade has been subjected in to series of simulations such as rotor simulations and turbine simulations and the results has been plotted for tip speed ratio results in 5 and power coefficient results in 0.16 in the rotor sections simulations for the power generation has been carried out in the wind speed of 0 to 50 m/s and achieved the power value for the straight blade as 250 KW. In the comparison of the results of the swept back and the straight blade with the simulation results. It is understood that the swept back blade is optimal, and the performance of the swept back blade is comparatively higher than the straight blade by achieving higher power in a higher range of wind speed. Since the swept shape is more aerodynamical shape.in consideration of the straight blade. Therefore, it is concluded that the swept back blade design is better than the straight blade in terms of power generation of wind turbines.

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