Design of Low Wind Speed horizontal axis Wind Power Generator

MAHENDIRAN C R¹, JAVID AHAMED S², AND RAJA PRABU R³

Abstract—In this work was carried out the aerodynamics design of a 500W horizontal axis wind turbine by using blade element momentum theory (BEM). Strip theory was used for the aerodynamic performance evaluation. Correction factors introduced in the ideal flow equation were the tip loss factor and drag coefficient. The best approximation of the power coefficient calculation was for tip speed ratio less than 6. BEM method is a tool for practical calculation and can be used for the design and evaluation of wind turbines when the flow rate is not too turbulent and radial velocity components are negligible. Making horizontal axis of wind power generation for standalone system and their set up. By using z-source inverter topology used for producing ac output voltage

Index Terms—Wind Turbine Design; BEM; BET; Tip Speed Ratio; Tip Lost Factor; HAW; rectifier; inverter; model setup.

I. INTRODUCTION

Small scale turbines for residential use are available; they are generally approximately 1–7.6 m in rotor blade diameter and produce power at a rate of 300 to 10,000 watts at their rated wind speed. The efficiency of the system transformation is related to the blade shape. Therefore it is critical to design the most efficient blade shape possible. Blade element momentum (BEM) theory is widely used when designing a HAWT blade shape. This theory wants to combine the two-dimensional (2D) airfoil data to get the optimum blade shape, including the distributions of chord length and the twist angle along the span wise direction.

Manuscript received April, 2015.

MAHENDIRAN C R¹, Department of Electrical & Electronics in major Power System Engineering at B.S. Abdur Rahman University, chennai, India.

JAVID AHAMED S², Department of Electrical & Electronics in major Power Electronics And Drives at B.S. Abdur Rahman University, chennai, India.

Dr. R. RAJA PRABU³, Department of Electrical & Electronics at B.S. Abdur Rahman University, chennai, India.

It should be noted that the optimization of a HAWT blade is done at the design tip speed ratio (λd) and the design angle of attack (αD). In other words, if the optimal blade is operated at a different tip speed ratio than the one for which it has been designed, it will no longer be optimal. However, for this paper the performances of the blade are tested for the entire range between the tip speed ratios of 0 and 9 by theoretical method. The purpose of this study is to construct a HAWT system with variable-speed operation in which the optimum blade is determined using BEM theory.

Here, the power coefficient (Cp), which is the efficiency transferred from the blade, was successfully calculated using a torque transducer. In addition, it was found that both the generator’s efficiency and the system’s total efficiency can be determined in this wind tunnel experiment. For example, the National Aerospace Laboratory successfully developed a wind turbine with a 500 kW, low-cost, horizontal-axis, downwind staggered and stall regulated two-bladed model using the method to consider the optimum blade design and performance analysis.

Figure 1-Overview of A Wind Turbine System

II. BACKGROUND

The air flow gives rise to lift and drag forces on the airfoils. Lift and drag play an important role on the performance of a wind turbine. A high amount of drag would inhibit a rotor’s motion, ultimately wasting energy that is captured from the wind.

Wind turbines come in various shapes and sizes. The focus of this project is primarily on horizontal axis wind turbines. These are the kind typically thought of and usually consist of propeller-like blades.
Lift devices instead use airfoils. These turbines are lift devices, as opposed to drag devices. Drag devices rely on the wind to push parts. This is relatively inefficient. The rotors of this type of wind turbine are shaped to create lift as wind flows past. A component of the generated lift creates a torque on the blade which causes them to rotate around an axis. With this setup, the rotational speed of the blade can exceed that of the wind (wind energy).

When air flows over an object such as an airfoil, the air stream is forced to move around it as depicted in Figure 1. Typically the object is shaped in such a way that an air stream has to travel further over one side than the other. This difference forces one air stream to travel faster than the other. The Bernoulli Effect tells us that as fluid’s flow velocity increases, the static pressure it exerts decreases. The difference in flow speeds creates a pressure differential. The pressure difference creates a kind of circulation around the airfoil which speeds up the flow above and slows the flow below. This results in the force commonly known as lift. Lift is perpendicular to the wind direction (Figure 1).

Figure 2-lift generation from fluid flow over an airfoil

In practice, an airfoil is not generally aligned with the air flow. The angle at which an airfoil makes with the oncoming wind is known as the angle of attack. Generated lift is heavily dependent on the angle of attack. The lift coefficient is linearly proportional to the angle of attack, and has an approximate slope of 20 radian (Aerodynamics). There is a limit at which the angle of attack will no longer increase lift. At this point, the airfoil stalls. At high angles of attack the drag component caused by pressure, which is normally miniscule, becomes very large. The boundary layer of the air also begins to separate.

The drag force is created by the air as it flows over the airfoil. Because of the no-slip condition, a fluid exerts a tangential shear force on the surface of the airfoil. This force is in the direction of motion of the fluid. Normal pressure forces exerted by the air also have components which contribute to drag. Drag acts to oppose the motion of the airfoil. And in doing so, drag reduces the efficiency of a wind turbine.

Coefficients are used as a way to quantify the lift and drag forces on an object. These coefficients are determined by the frontal area, wind speed, density of the fluid, and the force experienced by the object due to the fluid flow.

The relation that determines the speed of one turbine is the tip speed ratio (TSR). The TSR is the ratio between tangential velocity and free stream velocity, the main parameters which dominate the behavior of torque and efficiency curves for each configuration are the number of rotor blades, radial distribution of the chord, airfoil aerodynamic characteristics and twist angle distribution. From the energy and structural point of view, the flow behavior behind the rotor is important in the operation.

Figure 3-lift and drag generation and AOA

High pressure gradients in the wake produce vibration and efficiency losses. The contribution of power in the blade increases in the radial direction. But in the region near the tip, the power coefficient decreases due to vortex generation. This phenomenon can be significantly reduced by modifying the tip shape.

III. Wind Turbine Design

This paper develops the design of a 500W wind turbine power, using Blade Element Theory (BET) and Momentum (BEM) at each blade element. The procedure develops a preliminary design of the turbine blades by solving Equations (2)-(7) for each differential blade elements in each radial position.
**TABLE 1: General Description Of The Wind Turbine**

<table>
<thead>
<tr>
<th>Item</th>
<th>Selection</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor Axis</td>
<td>Horizontal</td>
<td>Vertical axis turbine are proved less efficient</td>
</tr>
<tr>
<td>Rotor position</td>
<td>Upwind</td>
<td>Avoids tower shadow</td>
</tr>
<tr>
<td>Yaw control</td>
<td>Free</td>
<td>Uses tail</td>
</tr>
<tr>
<td>Rotor speed</td>
<td>Variable</td>
<td>Generator is permanent magnet, so even at low speed the batteries can be charged</td>
</tr>
<tr>
<td>No. of blades</td>
<td>Three</td>
<td>Economic and easy to balance</td>
</tr>
<tr>
<td>Power control</td>
<td>Tail furling</td>
<td>Simple, although some power loss occurs</td>
</tr>
<tr>
<td>Tower</td>
<td>Guyed Tower</td>
<td>Easy To Construct And Transport</td>
</tr>
</tbody>
</table>

**TABLE 2: Possible Design Variables:**

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>Design variables type</th>
<th>Design variables</th>
<th>Dependence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rotor shape</td>
<td>Rotor diameter, chord, Twist Relative Thickness, Shell Thickness</td>
<td>Scalar, Blade Radius</td>
</tr>
<tr>
<td>2</td>
<td>Airfoil characteristics</td>
<td>Lift Characteristics, Drag Characteristics</td>
<td>Angle Of Incidence, Relative Thickness</td>
</tr>
<tr>
<td>3</td>
<td>Regulation</td>
<td>Rotational Speed, Tip Pitch Angle</td>
<td>Scalar/wind speed</td>
</tr>
</tbody>
</table>

This short document describes a calculation method for wind turbine blades, this method can be used for either analysis of existing machines or the design of new ones. More sophisticated treatments are available but this method has the advantage of being simple and easy to understand. This design method uses blade element momentum (or BEM) theory to complete the design and can be carried out using a spreadsheet and lift and drag curves for the chosen airfoil. The latest version of this document should be available from the author’s website. Any comments on the document would be gratefully received. Further details on Wind Turbine Design can be found in Manwell et al. (2002) which provides comprehensive coverage of all aspects of wind energy. Walker and Jenkins (1997) also provide a comprehensive but much briefer overview of Wind Energy.

**1 Blade Element Momentum Theory:**

Blade Element Momentum Theory equates two methods of examining how a wind turbine operates. The first method is to use a momentum balance on a rotating annular stream tube passing through a turbine. The second is to examine the forces generated by the aerofoil lift and drag coefficients at various sections along the blade. These two methods then give a series of equations that can be solved iteratively.

![Figure 1: Axial Stream tube around a Wind Turbine](image-url)
2 Momentum Theory:

2.1 Axial Force:

Consider the stream tube around a wind turbine shown in Figure 1. Four stations blades, 3 just after the blades and 4 some way downstream of the blades. Between 2 and 3 energy is extracted from the wind and there is a change in pressure as a result. Assume \( p_1 = p_4 \) and that \( V_2 = V_3 \). We can also assume that between 1 and 2 and between 3 and 4 the flow is frictionless so we can apply Bernoulli’s equation. After some algebra:

\[
p_2 - p_3 = 1/2 \rho (V_1^2 - V_2^2) \quad (1)
\]

Noting that force is pressure times area we find that:

\[
dFx = (p_2 - p_3) dA \quad (2)
\]

\[
dFx = 1/2 \rho (V_1^2 - V_2^2) dA \quad (3)
\]

Define \( a \) the axial induction factor as:

\[
a = (V_1 - V_2)/(V_1) \quad (4)
\]

It can also be shown that:

\[
V_2 = V_1(1-a) \quad (5)
\]

\[
V_4 = V_1(1-2a) \quad (6)
\]

Substituting yields:

\[
dFx = 1/2 \rho V_1^2 [4a(1-a)] 2\pi r dr \quad (7)
\]

2.2 Rotating Annular Stream tube:

Consider the rotating annular stream tube shown in Figure 4. Four stations are shown in the diagram 1, some way upstream of the turbine, 2 just before the blades, 3 just after the blades and 4 some way downstream of the blades. Between 2 and 3 the rotation of the turbine imparts a rotation onto the blade wake. Consider the conservation of angular momentum in this annular stream tube. An “end-on” view is shown in Figure 3. The blade wake rotates with an angular velocity \( \omega \), and the blades rotate with an angular velocity of \( \Omega \).

Recall from basic physics that:

\[
\text{Moment of Inertia of an annulus, } I = mr^2 \quad (8)
\]

Angular Moment,

\[
L = I \omega \quad (9)
\]

Torque,

\[
T = dL/dt \quad (10)
\]

\[
T = dI \omega /dt = d(mr^2 \omega)/dt = (dm/dt)2\omega \quad (11)
\]

So for a small element the corresponding torque will be:

\[
dT = dm^\prime wr_2 \quad (12)
\]

For the rotating annular element

\[
dm^\prime = \rho AV_2 \quad (13)
\]

Define angular induction factor \( \hat{a} \):

\[
\hat{a} = \omega/2\Omega \quad (16)
\]

Recall that \( V_2 = V(1-a) \) so:

\[
dT = 4 \hat{a} (1-a) \rho V_2^3 \omega r^2 dr \quad (17)
\]

Moment theory has therefore yielded equations for the axial (Equation 7) and tangential force (Equation 17) on an annular element of fluid.

3 Blade Element Theory:

Blade element theory relies on two key assumptions: There are no aerodynamic interactions between different blade elements.

The forces on the blade elements are solely determined by the lift and drag Coefficients.
ten and twenty) of elements and calculating the flow at each one. Overall performance characteristics are determined by numerical integration along the blade span.

3.1 Relative Flow:

Lift and drag coefficient data area available for a variety of aerofoils from wind tunnel data. Since most wind tunnel testing is done with the aerofoil stationary we need to relate the flow over the moving aerofoil to that of the stationary test. To do this we use the relative velocity over the aerofoil. More details on the aerodynamics of wind turbines and aerofoil selection can be found in Hansen and Butterfield (1993).

From Figure 5 these following relation is apparent:
\[
W = V(1 - a)/\cos \beta
\]  

(22)

Figure 7: Flow onto the turbine blade
In practice the flow is turned slightly as it passes over the aerofoil so in order to obtain a more accurate estimate of aerofoil performance an average of inlet and exit flow conditions is used to estimate performance. The flow exit from the blade row the flow rotates at rotational speed \( \omega \). That is over the blade row wake rotation has been introduced around the blades starts at station 2 in Figures 2 and 1 and ends at station 3. At inlet to the blade the flow is not rotating, at . The average rotational flow over the blade due to wake rotation is therefore \( \Omega \). The blade is rotating with speed \( \Omega \). The average tangential velocity that the blade experiences is therefore \( \Omega r + 1/2 \omega r \). This is shown in Figure 5.

Examining Figure 5 we can immediately note that:
\[
\Omega r + \omega r/2 = \Omega r(1 + \delta)
\]  

(18)

Recall that (Equation 5): \( V_2 = V_1(1 - a) \) and so:
\[
\tan \beta = \Omega r(1 + \delta)/V(1 - a)
\]  

(19)

This gives a moderately complex shape and a linear distribution of chord vary from blade element to blade element. The local tip speed ratio \( \lambda_r \) is defined as:
\[
\lambda_r = \Omega r/V
\]  

(20)

So the expression for \( \tan \beta \) can be further simplified:
\[
\tan \beta = \lambda_r(1 + \delta)/(1 - a)
\]  

(21)

The forces on the blade element are shown in Figure 6, note that by definition the lift and drag forces are perpendicular and parallel to the incoming flow. For each blade element one can see:
\[
dF_0 = dL\cos \beta - dD\sin \beta
\]  

(23)

may be considerably easier to make. Where \( V \) is used to represent the incoming flow velocity \( V_1 \). The value of will
\[
dF_x = dL\sin \beta + dD\cos \beta
\]  

(24)

where \( dL \) and \( dD \) are the lift and drag forces on the blade element respectively.\( dL \) and \( dD \) can be found from the definition of the lift and drag coefficients as follows:
\[
dL = CLV^2c dr
\]  

(25)

\[
dD = CDV^2c dr
\]  

(26)

Lift and Drag coefficients for a NACA 0012 airfoil are shown in Figure 7, this graph shows that for low values of incidence the airfoil successfully produces a large amount of lift with little drag. At around \( i = 14^\circ \), a phenomenon known as stall occurs where there is a massive increase in drag and a sharp reduction in lift. If there are \( B \) blades, combining Equation 23 and equation 25 it can be shown that:

\[
dF_0 = B \frac{1}{2} \rho W^2 (CL \sin \beta + CD \cos \beta) c dr
\]  

(27)

\[
dF_0 = B12 \rho W^2 (CL \cos \beta - CD \sin \beta) c dr
\]  

(28)

The Torque on an element, \( dT \) is simply the tangential force multiplied by the
radius.
\[ dT = B(1/2) \rho W^2 (CL \cos \beta - CD \sin \beta) rdr \]  

(29)

The effect of the drag force is clearly seen in the equations, an increase in thrust force on the machine and a decrease in torque (and power output). These equations can be made more useful by noting that \( \beta \) and \( W \) can be expressed in terms of induction factors etc. (Equations 21 and 22). Substituting and carrying out some algebra yields:
\[ dF_x = \sigma \pi \rho (V^2(1 - a)2 \cos 2 \beta) (CL \sin \beta + CD \cos \beta) rdr \]  

(30)
\[ dT = \sigma \pi \rho (V^2(1 - a)2 \cos 2 \beta) (CL \cos \beta - CD \sin \beta) \rho r 2 \text{dr} \]  

(31)

where \( \sigma \) is called the local solidity and is defined as:
\[ \sigma = \frac{Bc}{2 \pi r} \]  

(32)

4 Tip Loss Correction:
At the tip of the turbine blade losses are introduced in a similar manner to those found in wind tip vortices on turbine blades. These can be accounted for in BEM theory by means of a correction factor. This correction factor \( Q \) varies from 0 to 1 and characterises the reduction in forces along the blade.
\[ Q = (2 \pi \cos 1) \exp \{- (B/21 - r/(r/R) \cos \beta)\} \]  

(33)

The results from \( \cos 1 \) must be in radians. The tip loss correction is applied to Equation 7 and Equation 17 which become:
\[ dF_x = Q_0 \rho V^2 [4a(1 - a)] \pi r 2 \text{dr} \]  

(34)
\[ dT = Q_4 a(1 - a) \rho \omega R^3 \pi \text{dr} \]  

(35)

5 Blade Element Momentum Equations:
We now have four equations, two derived from momentum theory which express the axial thrust and the torque in terms of flow parameters (Equations 35 and 34):
\[ dF_x = Q_0 \rho V^2 [4a(1 - a)] \pi r 2 \text{dr} \]  

(36)
\[ dT = Q_4 a(1 - a) \rho \omega R^3 \pi \text{dr} \]  

(37)

We also have two equations derived from a consideration of blade forces which express the axial force and torque in terms of the lift and drag coefficients of the airfoil (Equations 30 and 31):
\[ dF_x = \sigma \pi \rho (V^2(1 - a)2 \cos 2 \beta) (CL \sin \beta + CD \cos \beta) rdr \]  

(38)
\[ dT = \sigma \pi \rho (V^2(1 - a)2 \cos 2 \beta) (CL \cos \beta - CD \sin \beta) \rho r 2 \text{dr} \]  

(39)

To calculate rotor performance (Equations 35 and 34) from a momentum balance are equated with Equations 30 and 31. Once this is done the following useful relationships arise:
\[ a(1 - a) = \sigma [CL \sin \beta + CD \cos \beta]/[4Q \cos 2 \beta] \]  

(40)

\[ \frac{d(1 - a)}{\cos \beta} = CL \cos \beta - CD \sin \beta/[4Q \cos 2 \beta] \]  

(41)

Equation 40 and 41 are used in the blade design procedure.

6 Power Output:
The contribution to the total power from each annulus is:
\[ dP = \Omega dT \]  

(42)

The total power from the rotor is:
\[ P = \int_{r_h}^{R} \omega dP r \int_{r_h}^{R} \Omega dT dr \]  

(43)

Where \( rh \) is the hub radius. The power coefficient \( CP \) is given by:
\[ C_p = \frac{P}{\rho \omega U^2 \int_{r_h}^{R} \Omega dT [\frac{1}{(\frac{3}{2}) \rho \omega R^3 \pi}] \]  

(44)

7 Blade Design Procedure:
1. Determine the rotor diameter required from site conditions and \( P = CP \eta 0.5 \rho \omega R^2 V^3 \)
where:
   - \( P \) is the power output
   - \( CP \) is the expect coefficient of performance (0.4 for a modern three bladed wind turbine)
   - \( \eta \) is the expected electrical and mechanical efficiencies (0.9 would be a suitable value)
   - \( R \) is the tip radius
   - \( V \) is the expected wind velocity.
2. Choose a tip speed ratio for the machine. For water pumping pick \( 1 < \lambda < 3 \) (which gives a high torque) and for electrical power generation pick \( 4 < \lambda < 10 \). Choose a number of blades B, using Table 1, which is based on practical experience. Select an airfoil. For low curved plates can be used rather than an air foil shape. Obtain and examine lift and drag coefficient curves for the airfoil in question. Note that different air foils may be used at different spans of the blade, a thick air foil may be selected for the hub to give greater strength. Choose the design aerodynamic conditions for each airfoil. Typically select 80% of the maximum lift value, this choice effectively fixes the blade twist. On long blades a very large degree of twist is required to obtain 80% of the maximum lift near the hub. This is not necessarily desirable as the hub produces only a small amount of the power output, a compromise is to accept that the airfoils will have very large angles of attack at the hub. Choose a chord distribution of the airfoil. There is no easily physically accessible way of doing this but a simplification of an ideal blade is given by:
\[ \frac{8 \pi \rho \cos \beta}{\lambda} \]

3 Blanmura \( \lambda \)
Divide the blade into N elements. Typically 10 to 20 elements would be used. As a first guess for the flow solution use the following equations. These are based on an ideal blade shape derived with wake rotation, zero
drag and zero tip losses. Note that these equations provide an initial guess only. Calculate rotor performance and then modify the design as necessary. This is an iterative process.

The essential outputs of a wind turbine design are the number of blades, the airfoil shape, the chord distribution and the twist distribution. Although the design procedure above provides some simple recommendations it is quite likely the designer will have to spend a considerable amount of time refining the twist and chord distribution to reach an acceptable solution.

Generator efficiency \( \eta_{gen} \) is 0.8. With data from the output of the generator and the wind speed of the fan is calculated the performance given by Equation (44).

Table 3. Tip Speed Ratio versus power coefficient

<table>
<thead>
<tr>
<th>Tsr (tip speed ratio)</th>
<th>Power coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.000</td>
</tr>
<tr>
<td>0.5</td>
<td>0.238</td>
</tr>
<tr>
<td>2.0</td>
<td>0.515</td>
</tr>
<tr>
<td>3.0</td>
<td>0.537</td>
</tr>
<tr>
<td>4.0</td>
<td>0.541</td>
</tr>
<tr>
<td>5.0</td>
<td>0.547</td>
</tr>
<tr>
<td>8.0</td>
<td>0.565</td>
</tr>
<tr>
<td>9.0</td>
<td>0.570</td>
</tr>
</tbody>
</table>

Table 4. Rotor Parameters.

<table>
<thead>
<tr>
<th>DESIGN PARAMETER</th>
<th>REAL SIZE</th>
<th>PROTOTYPE MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>1MW</td>
<td>500W</td>
</tr>
<tr>
<td>DIAMETER</td>
<td>56m</td>
<td>2m</td>
</tr>
<tr>
<td>Blade number</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Wind velocity</td>
<td>8m/s</td>
<td>8m/s</td>
</tr>
<tr>
<td>Average density</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>Tsr (tip speed ratio)</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

where \( P_e \) is electric power, \( \eta_{gen} \) is electric generator yield, \( E \) is voltage and \( I \) is electric current.

Figure 10. Prototype model blade design structure

Figure 11 Prototype model swept area structure.

BEM considers no velocity components in the radial direction and the effect of a blade element is not taken into account in the calculation of the other elements. Loss phenomena at the root and tip are approximate only through adjustment factors. Rotation wake and pressure gradients that are carried on this are not considered also. All these phenomena cause significant errors in the performance calculation mainly for large tip speed ratios.

Figure 12 (a) Prototype Model:

Table 4. Rotor Parameters.

<table>
<thead>
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<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Wind velocity</td>
<td>8m/s</td>
<td>8m/s</td>
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<tr>
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<td>0.94</td>
</tr>
<tr>
<td>Tsr (tip speed ratio)</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

where \( P_e \) is electric power, \( \eta_{gen} \) is electric generator yield, \( E \) is voltage and \( I \) is electric current.

Figure 12(b) Prototype Model:

Figure 13 shows a comparison of aerodynamic performance achieved by the wind rotor designed in this work when different models are used to predict the power coefficient. The comparison is based on a numerical analysis by using an idealized model which considers no aerodynamic losses, another that considers only the tip loss factor and one more that considers the tip loss factor and aerodynamic drag.

Figure 13 shows an increase in the aerodynamic performance when it is not considered in equations tip

Figure 13 shows a comparison of aerodynamic performance achieved by the wind rotor designed in this work when different models are used to predict the power coefficient. The comparison is based on a numerical analysis by using an idealized model which considers no aerodynamic losses, another that considers only the tip loss factor and one more that considers the tip loss factor and aerodynamic drag.

Figure 13 shows an increase in the aerodynamic performance when it is not considered in equations tip
loss factor and drag, ideal condition, dotted line, and shows the best performance because it is not considered any loss factor. For this condition the performance of the turbine is 0.4739. The dashed line shows the calculation considering only the tip loss factor without considering drag, for this condition yield was 0.4613. The solid line shows the calculation using the tip loss factor and drag, for this condition yield had the lower value of yield and is expected to be closest to the experimental data.

Experiment results developed in the axial fan are shown in Figure 10 along with the results obtained with BEM, Equations (8)-(12). The discrepancy of results is most striking for tip speed ratio greater than 6. This means when there are turbulent flow effects calculations become less predictable to find the aerodynamic performance.

The relative error calculated with respect to the experimental and BET is greater than 10% for tip speeds ratios greater than 6.

![Figure 13. Yield comparisons using different correction factors.](image1)

**Figure 13. Yield comparisons using different correction factors.**

**Figure 14. BEM and experimental results.**

**Conclusion**

BEM theory is a useful tool for quick calculation of turbine performance. For practical purposes, this method gives approximate results in small tip speeds where turbulent and three-dimensional effects are not as marked. The experimental data can improve BEM theory to achieve better results by adjusting factors. Experimentation allows the delimitation of the area where it is possible to obtain reliable results with BEM. For design purposes of large scale wind turbines, combined theory for the design of the blades is not sufficient to ensure optimum performance for the power generation. To achieve an efficient design, other design techniques applying the BEM simple qualities should be used. Combining BEM and any optimization algorithm is more advisable to develop a more sophisticated design.

**IV Permanent magnet synchronous generators:**

Small scale wind power requires a cost effective and mechanically simple generator in order to be reliable energy source. The use of direct driven generators instead of geared machines reduces the number of drive components, which offers the opportunity to reduce the number of drive components. Also it offers the opportunity to reduce the costs and increase system reliability and efficiency. For such applications, characterized by low speed is particularly situated, since it can be design with a large pole number and high torque density, most efficient type of generators matching the above criteria is the permanent magnet generators. So the group have decided to consider permanent magnet generators for the design. The permanent magnet synchronous generators are constructed in different ways. Two design characteristics of a construction type are:

- The orientation of the magnetic flux within the machine.
- The type of rotor construction with permanent magnets.

![Figure 15. PMSG](image2)

Theoretical result and parameter used in prototype model generator type: synchronous permanent magnet 3 phase AC magnetic steel material:38SH NdFeB, class of insulation:B housing material:cast iron, shaft material:45# steel rated rotate speed:80 RPM, rated voltage: 12VAC/24VAC grade of protection: IP54 weight: 45kg start up torque:0.9Nm, rated torque at rated speed:66.6Nm.

**Table 5: prototype model**

<table>
<thead>
<tr>
<th>RPM</th>
<th>14</th>
<th>30</th>
<th>47</th>
<th>63</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-load voltage (V)</td>
<td>9.1</td>
<td>19.6</td>
<td>30.2</td>
<td>40.7</td>
<td>51.26</td>
</tr>
<tr>
<td>Load voltage(V)</td>
<td>5.5</td>
<td>11.4</td>
<td>16.6</td>
<td>21</td>
<td>25</td>
</tr>
</tbody>
</table>
Z-source inverter

ZSI (Z-source inverter) has been proposed to overcome the disadvantage of the conventional scheme with a unique impedance network. ZSI can buck or boost the input voltage using the shoot-through state and the modulation index in a single stage. Besides, no dead time is needed, thus the output voltage is free from voltage distortion. Due to these good features, the ZSI has been applied to the single stage conversion, such as the PV system, the fuel cell system, and the ac motor drive system.

Similarly, the average dc-link voltage across the inverter bridge can be found as follows:

\[ V_{\text{dc}} = \frac{1}{2} V_{\text{in}} \]

It is well defined that the input voltage of QZSI can be boosted by using the shoot-through ratio. If this shoot-through ratio is not controlled well, the system can be affected by this. During the shoot-through state, in case of ZSI, the input current is zero due to the blocking diode. The output voltage of ZSI and QZSI is zero during the shoot through time interval. If the shoot-through time interval is in the switching state, the output voltage is affected. Thus the shoot-through time interval should be located within the zero state in order not to affect the output voltage. Figure 3 shows the grid connected PV system using the QZSI. In contrast with the traditional PV system, only one PWM is used for all control and the number of power switches can be reduced.

**Wind turbine with PMSG matlab circuit diagram:**
CONCLUSION
Based on the analysis as above, it was concluded that:
1. The results of the design of wind turbines with simulation for wind speed 7.5 m / s, and a pitch angle position 0 produced the maximum Cp=0.59 and of the wind turbine prototype generated f 4.5%. When the blade pitch angle position is 15°, the wind turbine simulation results have a value of Cp=0.47 and the wind turbine prototype maximum Cp=0.545. Difference of the two Cp values 0 has Cp=0.42, so that differences in Cp values of simulation results and wind turbine prototype has value = 5%.
2. At wind speeds 7.5 m / s., the wind turbines simulation is capable of generating power production at = 479 Watt, and the wind turbine prototype turbine generates power = 426 Watt. For wind speed blows 4 m / s. the wind turbines simulation power produce for = 373 Watt and wind turbine prototype = 345 Watt. Thus, if the difference in power production are expressed in percent, then for wind speed 7.5 m / s. = 11.06% and for wind speeds of 4 m / s = 6.97%

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MAHENDIRAN C R1 received B.E degree in Electrical & Electronics in Sri Sai ram Engineering College Chennai. He is pursuing Master of Engineering in Power system engineering at B.S. Abdur Rahman University Vandalur Chennai.

JAVID AHAMED S2 received B.E degree in Electrical & Electronics in PSNA college of Engineering and technology dindigal. He is pursuing Master of Engineering in Power electronics and drives at B.S. Abdur Rahman University Vandalur Chennai.

Dr. R. RAJA PRABU is working as Professor with 24½ years of Teaching Experience in the Department of Electrical & Electronics at B.S. Abdur Rahman University. He is interested in bio-electrics, outdoor insulators, power quality, digital protection, Nano dielectrics and renewable energy area and has presented and published papers in Journal, National and International Conferences. He is lifetime member.