

RESEARCH ARTICLE

EFFECT OF VERTICAL MOVEMENT IN HAWT

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Manuscript Info

Abstract

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..... It is known that to work properly, the horizontal-axis turbine needs the wind to flow at a right angle to the blades. If it blows from a different direction than the blades are facing, the turbine gets much less energy from the wind. To accommodate changes in wind direction, the turbine has a yaw drive that rotates the unit's direction. By contrast, a vertical turbine runs well regardless of wind direction, making it better-suited to urban areas with tall buildings where wind turbulence is a given. The vertical-axis design allows it to operate on lower wind speeds than is possible with the horizontal turbine. So, this paper focusses on the pitch movement as well as the nacelle and tower movement of the turbine in three dimensions with respect to the ground as the wind should be at right angle to the blade of the turbine or the attack of angle to the blades should be 0°. This paper analyses if the increase in efficiency of the HAWT turbine due to the pitch movement is significant as well as the cost set up for the vertical movement is reasonable with the increase in efficiency (i.e., power increment ultimately leads to the profit increment). For this NACA0012 aerofoil was chosen as the wind turbine blade in this blade. Since, it is well known as DU, FX and NACA-63 and NACA-64 series aerofoils are commonly used for the blades of HAWT turbine. The aerofoil was simulated using ANSYS 15 software at assumed 10 m/s wind velocity for the attack angles 0^0 , 15^0 and 30° and analysis of power difference is to be analysed.

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Introduction:-

As the world continues to use up non-renewable energy resources, wind energy will continue to gain popularity. A new market in wind energy technology has emerged that has the means of efficiently transforming the energy available in the wind to a usable form of energy, such as electricity.

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The cornerstone of this new technology is the wind turbine. A wind turbine is a type of turbo machine that transfers fluid energy to mechanical energy using blades and a shaft and converts that form of energy to electricity using a generator.

Wind turbines have two main design categories: HAWT and VAWT. The horizontal-axis turbine typically has a three-blade vertical propeller that catches the wind face-on. The vertical turbine has a set of blades that spins around a vertical axis. Each has its own merits and demerits.

Corresponding Author:- Dipankar Chatterjee Address:- B. Tech 3rd Year, Mechanical Specialization in Energy Engineering, VIT University, Vellore. Horizontal-axis turbines convert more of the wind's energy into useful mechanical motion if the blades are perpendicular to wind direction, and then the blades would pick up the maximum energy throughout their range of movement. By comparison, the blades on a vertical-axis turbine suffer an efficiency disadvantage, capturing energy from the wind only on the front side; at the rear part of their rotation, they drag on the system.

Same goes for VAWT. If the VAWT is at an angle to the wind direction the power output will get affected (output power is reduced).

Since, HAWT requires a yaw mechanism to adjust to changing wind direction, the horizontal-axis turbine is mechanically more complex than the vertical design.

The HAWT is optimum at the tall towers as long blades work well only in wide-open spaces. VAWT are generally much more compact and can be placed on building rooftops and other urban locations with fewer restrictions. The vertical unit's low height also makes it suitable for areas where wind picks up speed between buildings or over hilltops.

Methodologies:-

Used for Aerofoil Analysis:

General Idea for Power Calculation of Turbine

The efficiency of the wind turbine depends on the area swept by the blades as well as the wind velocity perpendicular to the area swept by the blades. If the nacelle is **not parallel** to the ground. The area will not be perpendicular to the wind and will be at an angle (say x). The area will become (A cosx) therefore, the power will reduce.

Governing Equations:

The continuity equation for the two dimensional, steady and incompressible flow is:

$$\nabla_{\cdot}(\rho V) = \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0$$

 $P = (0.5) \times \rho \times A \times V^3$ (Theoretical Maximum Power)

In equation:

$$\begin{split} \rho &= Density \ of \ fluid \\ V &= Velocity \ vector \\ \rho V &= Mass \ flux \\ \nabla &= Vector \ operator \\ \nabla.(\ \rho V) &= Divergence \ of \ \rho V \\ \rho u, \ \rho v &= Rate \ of \ mass \ entering \ in \ x, \ y \ direction \ respectively. \\ u &= Velocity \ vector \ in \ x \ direction. \end{split}$$

Theoretical Analysis of Wind Turbine:

- 1. If the angle of attack changes, the velocity which is useful to the turbine will also change. The velocity perpendicular to the cross section will now become $V \cos(x)$.
- 2. Since, the velocity is cubed for power calculations for wind turbine then this will reduce the power output significantly.
- 3. Let for x= 30° , cos(x)=0.8660. Therefore new V³=(0.6495) V³ (old velocity) as well as new area A=(0.8660)A (old area).
- 4. Then the new power obtained will

 $P_{new} = (1 - (\cos(30))^4)P_{old}$

 $P_{new} = 0.5625 P_{old}$

Then, reduction or loss in power generation is:

 $\Delta P = (1-0.5625) P_{old}$

 $\Delta P = 0.4375 P_{old}$

Then, there is 43.75% in power reduction which cannot be neglected.

 $\Delta P = P_{old} - P_{new}$

Geometry and Simulation:

NACA0012 was taken into consideration for 1 m length was solved in ANSYS 15 fluent. The governing equation for the aerofoil or the formula for the shape of a NACA 00xx foil, with "x" being replaced by the percentage of thickness to chord, is:

where:

 $y_t = 5t [0.2969x^{0.5} - 0.1260x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4]$

- 1. x is the position along the chord from 0 to 1.00, (0 to 100%)
- 2. y_t is the half thickness at a given value of x (centerline to surface), and
- 3. t is the maximum thickness as a fraction of the chord (so t gives the last two digits in the NACA 4-digit denomination divided by 100).

Note that in this equation, at (x/c) = 1 (the trailing edge of the airfoil), the thickness is not quite zero. If a zero-thickness trailing edge is required, for example for computational work, one of the coefficients should be modified such that they sum to zero. Modifying the last coefficient (i.e. to -0.1036) will result in the smallest change to the overall shape of the airfoil. The leading edge approximates a cylinder with a radius of:

$$r = 1.1019 (t^2/c)$$

The geometry was created by importing the coordinates file into the ANSYS software and meshing was using the edge sizing and inflation method in which number of layers were given the value of 15 and Growth rate as 0.05. For this case, left, top and bottom surface of the bigger geometry were considered as inlet, right boundary was considered as outlet and the region excluding the aerofoil body was considered as wall.

Geometry and Meshing:

2-D analysis was done on the NACA 0012 aerofoil.





Figure 1:-





Figure 3:-

Set-Up Meshing:





Contours:

Pressure Contours:

These pressure contours depicts the pressure exerted by the wind velocity of assumed value of 10 m/s for the different attack angles namely 0° , 15° , 30° .



Figure 5:- (a)



Figure 7:- (a)

Velocity Magnitude Contours:

The respective figures depicts the velocity magnitude observed for the different attack angles specified below. Based on that the average value of wind velocity for each attack angle is used.

1 18+01 1 12+01 1 12+01 1 10+01 9 47+00 8 88+00 8 29+00 7 70+00 7 70+00 7 10+00 6 51+00 5 92+00 5 32+00 4 74+00 4 14+00 3 55+00 2 36+00 2 36+00 1 365+00 1 365+00 1 365+00 1 18+00 5 50+01 0 00++00		ANSYS RES.O Academic
Contours of Velocity Magnitude (n/s) O°	Figure 5:- (b)	Oct 30, 2019
15(e-0)		







Figure 7:- (b)

Velocity (Tangential and Radial) Contours:

Like the aforesaid velocity magnitude contours, these figure depicts the tangential and radial velocity magnitude for each of the attack angles specified below. It is found to assume the wind velocity as for the above one and also to observe the uniformity of velocity distribution through the blades when passed through it as uneven velocity magnitude may create uneven dynamic pressure which may damage the blades.



Contours of Tangential Velocity (m/s)









Figure 6:- (c). (i).



Figure 6:- (c). (ii).



Figure 7:- (c). (ii).

Cost Calculations:

Cost required for motor installation:

Since, it is given that for 1.5 MW turbine that mass of the nacelle is around 56000 kg if mass of the blade assembly is 36000 kg. Then the total mass of the assembly system will be 92000 kg. It is also known that length of the blades is about 36 m having mass of about 11000 kg if the blade assembly is 36000 kg.

Then, for our case mass of each blade will be (11000/36) kg. = 305 kg. (approx.). Then the mass of the total blade will be (3×305) kg. = 915 kg.

Then the mass % of the other parts of blade and blades will be: % $M_{others} = (3000/36000) \times 100 = 8.33.$

% $M_{\text{blade}} = (33000/36000) \times 100 = 91.67.$

Then, for our case let us assume the blade assembly be:

 $M_{bl.ass.} = [\{(3000/33000) \times 915\} + 915] \text{ kg.} = 998.2 \text{ kg.}$

Then the weight of the nacelle will be:

 $M_{nacelle} = (56000/36000) \times (998.2) \text{ kg.} = 1552.75 \text{ kg} (approx.)$ Then total weight of the turbine system be $M_{Total} = (1552.75 + 998.2) \text{ kg.} = 2551 \text{ kg.}$ (approx.)

Let us consider the body of the system as a point mass so power required to rotate a body to the required angle for which angle of attack to the blades becomes 0 degrees.

Then, power required to rotate 15°:-

 $P_{15 \text{ deg.}} = M_{\text{Total}} \times g \times d\theta \times (\pi/180) \times 1 \text{ W}$ (Since, length of blade is 1 m.) $P_{15 \text{ deg.}} = \{2551 \times 9.81 \times 15 \times (\pi/180)\}$ W $P_{15 \text{ deg.}} = 6551.61 \text{ W} = 6552 \text{ W}$ (approx.) $P_{15 \text{ deg.}} = 6.6 \text{ kW} \text{ (approx.)}$ Similarly for 30°:- $P_{30 \text{ deg}} = \{2551 \times 9.81 \times 30 \times (\pi/180)\} \text{ W} = 2 \times P_{15 \text{ deg}}$ $P_{30 \text{ deg.}} = (2 \times 6552) \text{ W} = 13104 \text{ W}$ $P_{30 \text{ deg.}} = 13.2 \text{ kW.}$ (approx.) Let the weight of the motor be power having power of 15 kW be 100 kg. Then, $M_{Total} = (2551+100) \text{ kg.} = 2651 \text{ kg.}$ $P_{15 \text{ deg.}} = \{2651 \times 9.81 \times 15 \times (\pi/180)\} \text{ W} = 6808.43 \text{ W} = 6.809 \text{ kW}$ $P_{30 \text{ deg.}} = \{2651 \times 9.81 \times 30 \times (\pi/180)\} \text{ W} = 13616.9 \text{ W} = 13.617 \text{ kW}$

Then,

Then, motor of having 15 kW power is appropriate for the choice. The cost of the motor of the required power was found to be around Rs. 32,000 - 65,000. Let the cost of the motor for this case be around Rs. 55,000 keeping in view of the quality factor.

Cost difference in power generation due to the attack angles:

Let the C_p(Coefficient of Performance) of the wind be around 0.4 and density of air be taken as 1.225 kg/m³ for all cases as for India C_p is around 0.35 - 0.45.

For 0°:

In this case, for pressure contour inferring that the maximum pressure of about 60.7 bar is applied at the tip of the blade which is negligible. On a range of (0.2-4) bar was seen around the blade.

From the velocity magnitude contour, we infer that the whole region is around the speed range of (10.01 - 11.8) m/s. Tangential and radial contours confirms the assumption as for the tangential contour maximum region indicating a velocity of 10.2 m/s was seen at the perpendicular to the tip of the blade whereas for radial contour, regions of 9.22 to 11.4 m/s was seen along the geometry of the blade. These above conclusions indicate that the velocity of 10 m/s should be reasonable to use for our calculations i.e. V = 10 m/s.

Then power generated per kWh for 0°:-

 $P_0 = [\{(0.5) \times C_p \times \rho \times A \times V^3 \times 3600\}/1000] \text{ kWh}$ $P_0 = [\{(0.5) \times 0.4 \times 1.225 \times (\pi/4) \times 1^2 \times (10)^3 \times 3600\}/1000] \text{ kWh}$ $P_0 = 692.71 \text{ kWh}$

For 15°:

In this case, for pressure contour inferring maximum pressure of 62.8 bar is acting over a reasonable area of blade tip and an unbalanced region of pressure ranging from (0.7 - 62.8 bar) around the blade geometry.

From the velocity magnitude contour we can observe that around the three regions were seen i.e., (9.79 - 10), (5.25 - 9.79), (0.7 - 3.77) m/s. A small region of (11.28 - 11.51) m/s was around the blade. Tangential and radial contours indicates the distortion of the region over the blade geometry. So for this case velocity of 9.2 m/s would be reasonable to choose as it is not according to the theoretical assumption since the region is divided into too many velocity regions. Therefore, V= 9.2 m/s.

Then power generated per kWh for 15°:-

$$\begin{split} P_{15} = & [\{(0.5) \times \hat{C}_p \times \rho \times A \times V^3 \times 3600\}/1000] \text{ kWh} \\ P_{15} = & [\{(0.5) \times 0.4 \times 1.225 \times (\pi/4) \times 1^2 \times (9.2)^3 \times 3600\}/1000] \text{ kWh} \\ P_{15} = & 539.41 \text{ kWh} \end{split}$$

For 30°:

In this case, for pressure contour inferring maximum pressure of 61.5 bar is acting over a more area of blade tip than the previous case and an unbalanced region increased of pressure ranging from (0.84 - 61.5 bar) around the blade geometry. The regions are completely randomized and distorted indicating the blades are exposed to unbalanced pressure.

From the velocity magnitude contour we can observe that velocity regions of lower magnitude are observed around the blade mainly (5.77 - 9.9), (0.825 - 4.12) and a small region of (11.77 - 16.5) m/s was observed that the blade is exposed to uneven velocity magnitude which may cause turbulence around the blade the region. Tangential and radial indicates the same thing as the regions are more distorted from the previous one which doesn't seem to supportive for the blade movement. So for this case keeping in accordance with the theoretical value velocity of 8.1 m/s would be reasonable to choose i.e., V = 8.3 m/s.

Then power generated per kWh for 30°:-

 $\begin{array}{l} P_{30} = [\{(0.5) \times C_p \times \rho \times A \times V^3 \times 3600\}/1000] \text{ kWh} \\ P_{30} = [\{(0.5) \times 0.4 \times 1.225 \times (\pi/4) \times 1^2 \times (8.3)^3 \times 3600\}/1000] \text{ kWh} \\ P_{30} = 396.09 \text{ kWh} \end{array}$

It should be noted that the contours for 30° is not reliable as the solution didn't converged after 2500 iterations as well as 30° of attack angle difference is unrealistic in physical applications as it is assumed that wind turbine blades are not exposed to 30° of attack angle.

Then the power difference due to change in attack angles i.e., (P₀ and P₁₅) is given as:

 $\Delta P = P_0 - P_{15}$ $\Delta P = (692.71 - 539.41) \text{ kWh}$ $\Delta P = 153.3 \text{ kWh}$

Since, rate of wind power generation (R) as of December 2017 is Rs. 2.43/kWh, we assume for our case to be Rs. 2.3 /kWh. Cost saved per hour due to difference of power due to attack angles is:

$$\begin{split} C_{hr.} &= R \times \Delta P \\ C_{hr.} &= (Rs. \ 2.3 \ / kWh) \times 153.3 \ kWh. \\ C_{hr.} &= Rs. \ 352.59. \end{split}$$

If the turbine is exposed to this attack angle difference for at least on an average say 2 hours then cost saved in a day:

 C_{day} = Rs. (2 × 352.59) C_{day} = Rs. 705.2 (approx.)

Therefore, simple payback time $(T_{payback})$ is given as:

 $T_{payback} = (55000/705.2)$ days. $T_{payback} = 77.99$ days = **78 days**. $T_{payback} = 80$ days.

Now, for the case of 30°, power difference: $\Delta P = (692.71 - 396.09) \text{ kWh} = 269.62 \text{ kWh}$

Cost saved per day:

 $C_{day} = 2 \times R \times \Delta P = Rs. (2 \times 2.3 \times 269.62) = Rs. 1240.252$

Therefore, simple payback time:

$$\begin{split} T_{payback} &= (55000/1240.252) \text{ days.} \\ T_{payback} &= 44.34 \text{ days} = \textbf{45 days.} \end{split}$$

For payback time calculations, operational cost, maintenance cost of motor and installation cost was not included.

Result and Conclusion:-

- 1. At the leading edge, the aerofoil surface and near the trailing edge, the velocity is lower while static pressure is higher for the three cases. But as the attack of angle increased, the pressure contours started to distort as the geometry of the blade started to experience uneven pressure regions which may cause wear and tear to the blades. As we know, the difference in pressure across the aerofoil from top to bottom is what generates lift.
- 2. The flow (velocity magnitude) as for 0° it was almost uniform but for the other casesvelocity flow through the top surface of the wing is observed to faster as compared to the bottom surface, this characteristics can be attributed regarding to the wing shape. But as same as the pressure contours, the distortion and unevenness came as the attack angle increased. For 15° and 30°, on the top surface different velocity magnitudes present over small area region, this unevenness may cause turbulence which may inhibit the blade movement as the case of 30° was than the previous which leads to reduced power generation as it was observed in the calculations.
- 3. For tangential and radial contours, same case is applied as the previous ones as when the attack angle increased the contour regions became uneven and hazy as the distinct lines began disappearing and regions started to mix with each other. That may indicate the point as for decrease in power with the increase of attack angle.
- 4. The payback time to compensate the power loss due to 15° was found to be 78 days (~ 80 days) as considering the annual mean wind speed of India (which is about 4-6 m/s) payback time may be 150 160 days at the most.
- 5. For 30°, payback time was found to be 45 days but since it has less physical acceptance as no wind turbine was acknowledged to be set up where blades were experiencing an attack angle of 30°.
- 1. The paper focused on the prototype of the wind turbine as the wind turbine blades are about 40 100 m long. So, the greater power difference is likely to observe for more power capacity wind turbines.
- 2. In the near future, motors are likely to be light-weighted and more efficient having a long life so payback time may decrease.
- 3. NACA0012 aerofoil which is taken as the turbine blades are not suitable asDU, FX and NACA-63 and NACA-64 series aerofoils are common for the blades of HAWT turbine. NACA0012 used for as wingtip of aircrafts as for many it is used for both root and tip.
- 4. The purpose was to show that the power loss was significant when angle of attack changed as for high capacity turbines, this kind of power loss is unavoidable.

So for our case the payback time was found to be acceptable therefore high efficient motors of optimum costs is advised to install in the nacelle for pitch (vertical) movement of the system in order to retrieve the lost power created due to the attack angle difference.

References:-

- 1. P.K. Nigam, Nitin Tenguria, M.K. Pradhan, Analysis of horizontal axis wind turbine blade using CFD, International Journal of Engineering, Science and Technology, Vol. 9, No. 2, 2017, http://dx.doi.org/10.4314/ijest.v9i2.5,2017.
- N. Manikandan, B. Stalin, Design of Naca63215 Airfoil for a Wind Turbine, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 10, Issue 2 (Nov.- Dec. 2013), PP 18-26.2278-1684,www.iosrjournals.org, 2013.

- Ying Guo, Liqin Liu, Xifeng Gao, Wanhai Xu, Aerodynamics and Motion Performance of the H-Type Floating Vertical Axis Wind Turbine, MDPI, Applied Sciences, 9 February 2018.,DOI:http://dx.doi.org/10.3390/app8020262, 2018
- 4. Mr.Laxmikant N.Dhoble1, Dr.A.K.Mahalle2 ,CFD ANALYSIS OF SAVONIUS VERTICAL AXIS WIND TURBINE: A REVIEW, Jan-2016, 2395 -0056.
- 5. Peter J. Schubel, Richard J. Crossley, Wind Turbine Blade Design, MDPI, energies, Energies 2012, 5, 3425-3449, 6 September 2012, 1996-1073,http://dx.doi.org/10.3390/en5093425, 2012.
- 6. Bibek Samantaray, Kaushik Patnaik, A Study of Wind Energy Potential In India, Department of Electrical Engineering, National Institute of Technology, Rourkela, https://pdfs.semanticscholar.org/8f63/5fcfa0f82b7413b6244e3c613909b95d2886.pdf,2010. [Thesis]

Ansys fluent 12.0 user's guide – 31.4.

https://www.wind-watch.org/faq-

size.php#targetText=In%20the%20GE%201.5%2Dmegawatt,total%20weight%20of%20164%20tons.

https://inverterdrive.com/group/Motors-AC/TECA2-160M2-2-Pole-B14-15kW-High-Efficiency-

Motor/#targetText=Face%20mount%20on%20M12%20tapped,Weight%20is%2096.6kg.

https://en.wikipedia.org/wiki/Wind_power_in_India.