MATHEMATICAL MODEL OF H-TYPE DARRIEUS VERTICAL AXIS WIND TURBINE

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ABSTRACT:This paper presents a simplified mathematical modelling analysis using various parameters in MATLAB2014a to obtain the power output of H-type darrieus Vertical Axis Wind Turbine. A graphical user interface is created to determine the parameters of VAWT. The modelled VAWT is capable of producing the mechanical power output for the low wind speeds ranging from 4 to 6m/s. VAWT are attractive due to their ability to capture wind from all directions. The simulation model designed could provide an easier method of analysis of turbines without having to fabricate prototype models for physical testing which leads expensive especially considering wind turbines.

Key words: VAWT, Vertical axis wind turbine, darrieus rotor, Mathematical Model.

1. INTRODUCTION

VAWT's represent a unique form of power generating technology. Historically, they have been relegated to fulfilling a small niche market in commercially available wind turbines due to their "yaw-less" design. Current VAWT designs lag behind Horizontal Axis Wind Turbine(HAWT) counterparts in terms of efficiency but they have the ability to generate electricity in low wind speed environments.
VAWT's are typically small wind turbines that are characterized by an axis of rotation that is perpendicular to the ground. As a result VAWT's can operate independently of wind direction, which is a major advantage for urban applications where wind direction can change rapidly. The two primary VAWT designs are derived from either the Darrieus(lift-driven)or the Savonius(drag-driven) rotors.
The lift based darrieus design looks like an eggbeater and uses long airfoil shaped blades to extract energy as the wind strikes the blades perpendicularly.The model-based method of design and development emphasises on collective design and development. Meaning, the approach focuses on continuous collaboration and alterations. A domestic VAWT will be designed and analysed virtually before it is compared to actual experimental results. The wind turbine will be initially developed on Matlab to provide the ability to seamlessly adjust the design to develop a better understanding of the wind turbine.

2. METHODOLOGY

The methodology consists of several approaches and steps. The procedures that had been taken are referred from literature survey through many journals, technicalreports and articles. A suitable wind energy system has been selected. A simplified wind energy system circuit model has been developed. As discussed in the literature survey, there are some projects that have been done before for higher wind speeds. This project will extend the previous work by modelling for lower wind speeds and computes output energy is to be produced. A small wind turbine can charge a 12V battery and run various appliances where it is installed. However, to simulate the circuit, four blades wind turbine which has cut in speed of 4m/s to 6m/s have been used.After getting the circuit next procedure is modelling and simulation. At the beginning the softwares tried to simulate the circuit are P-spice and matlabsimulink. P-spice is not suitable to model the wind turbine as it does not have some of the main components. So the good decision is by using matlab simulink since it has components, user friendly and easy to get the data by using some specific toolbox from the internet.After understanding some of theexamples given, and then developed our own model of wind energy system.

2.1 SIMULATION BLOCKS

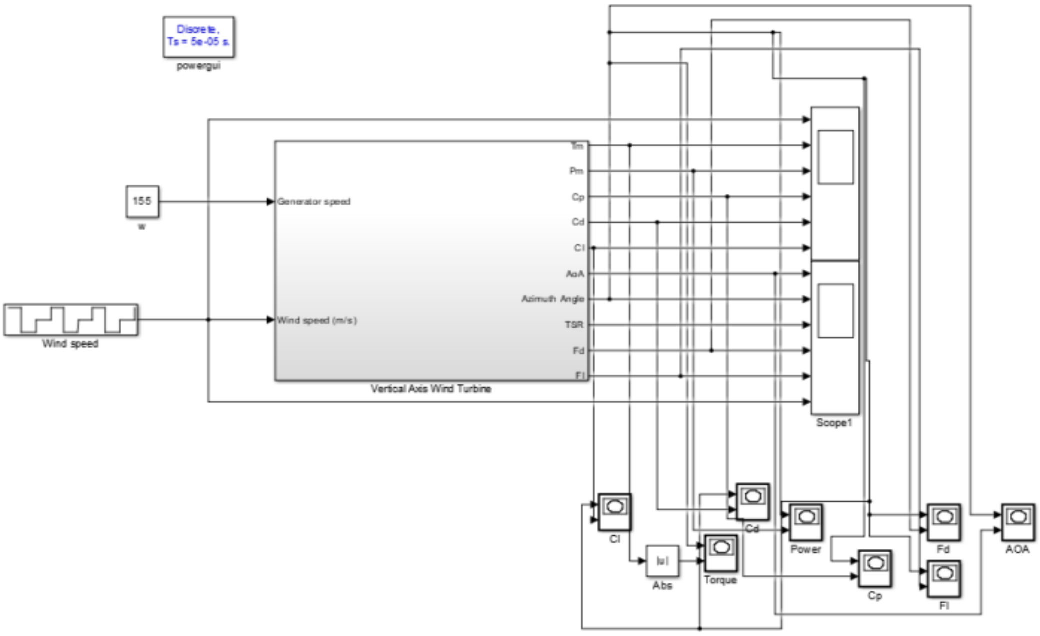

Fig.2.1 Simulation Blocks

Mathematical calculation is done in matlab for future later use in VAWT model simulation in simulink while the data plot and analysis is done in matlab editor.

The VAWT model is setup as a system with series of inputs, outputs and feedback loops. The equations 1-9 are fed into this simulation circuit. The inputs included those variables outside the system such as wind speed,generator speed The parameters of the system are constants of models like radius, airfoil etc..The static variables are the variables required to define the model dynamics such as torque and power and included with output integrals.

The generator speed is fed as 155 rad/sec and the wind speed is varied between 4 to 6m/sec. The radius of the turbine is taken as 0.4m. Simulation gives the main information about azimuth angle, angle of attack, torque and power. After the main parameter has been set the first loop starts to run covering the turbine rotation across the azimuth angle from 0 to 360 degrees, we get TSR. From TSR and azimuth angle, angle of attack is obtained which is the second loop. The system calculates the data in accordance with the previously described equations. In the third loop using lift force, drag force, tangential force torque is obtained from which we are getting our desired mechanical power output.

3. DESIGN

Generator speed and wind speed are given as input to VAWT. The generator speed is155 rad/sec and the wind speed is varied from 4 to 6m/s. torque, power, C_P, C_D, C_L, AOA, Azimuth angle, TSR, F_D,F_L are connected to scopes to see how these parameters varies by varying the azimuth angle from 0 to 360°.

All these formulas are fed to the simulation circuit to get the required torque and power.

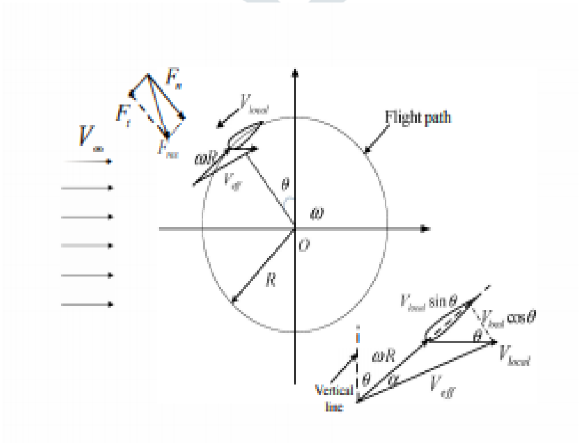

Fig.3.Impeller movement and force analysis.

Tip speed ratio can be expressed as,

$$\lambda = WR/V \qquad (1)$$

W = Generator speed

R = Radius of blade

V = Speed of wind

From Pythagoras theorem,
$(WR+V_{Local}\sin\theta)^2=(V_{Local})^2+(V_{Local}\cos\theta)^2$(2)

From the above formula we calculate Azimuth angle θ
The angle of attack(α) = $\tan^{-1}\frac{\sin\theta}{\lambda+\cos\theta}$(3)

Lift force coefficient C_L and drag coefficient C_D can be expressed as
$C_L = \frac{F_L}{½\rho V^2 cdh}$(4)

$C_D = \frac{F_D}{½\rho V^2 cdh}$(5)

Tangential force coefficient is basically the difference between the tangential component of lift and drag forces.
$C_T = C_L \sin\alpha - C_D \cos\alpha$(6)
In the formula, C_T is the Lilienthal aerodynamic coefficient parallel to the direction of the chord, and the force parallel to the direction of the chord is for wind turbine positive work force. If the chord length is c, dh is the length of wing in the vertical direction. This section of wing given instantaneous torque to the wind turbine in instantaneous can be calculated by the formula

dm = $\frac{1}{2}\rho V_{eff}^2 cC_T Rdh$(7)
where ρ=air density

$V_{eff} = WR+V_{Local}$(8)
c = chord length
C_T = Tangential force coefficient
R = Radius of blade
dh = length of the wing in vertical direction

In the instantaneous, the blade provides power for the impeller can be described as
dp = dm*W (9)

4. ADVANTAGES

- Cost required for simulation is less.
- Results obtained in simulation are acceptable.
- The values of lift coefficient, drag coefficient, power coefficient and angle of attack can be obtained from the simulation graphs.
- Virtual VAWT will be designed and analysed in mat lab before constructing actual VAWT.
- Torque and Power output can be easily analysed.
- For the required wind velocity the range of TSR can be obtained.

6. APPLICATIONS

- The values of TSR, angle of attack, power coefficient, lift coefficient, drag coefficient torque and output power can be obtained from simulation, can be used while constructing actual VAWT.
- This project can be used while constructing actual VAWT.

7. SIMULATED RESULTS

The azimuth angle varies from 0 to 360 degrees for different wind speeds and accordingly the power generated is varied. Similarly, the power of coefficient is varied from 0.45 to 0.5. The TSR varies from 1.4 to 1.7 which is caused by the change in wind speed of 4m/s to 6m/s. By varying the azimuth angle from 0 to 360 degrees, the change in parameters such as torque and power are provided.

SCOPE GRAPHS

The following graph provides the waveforms for wind speed, power, torque, coefficients of power, drag and lift is provided in Fig.4

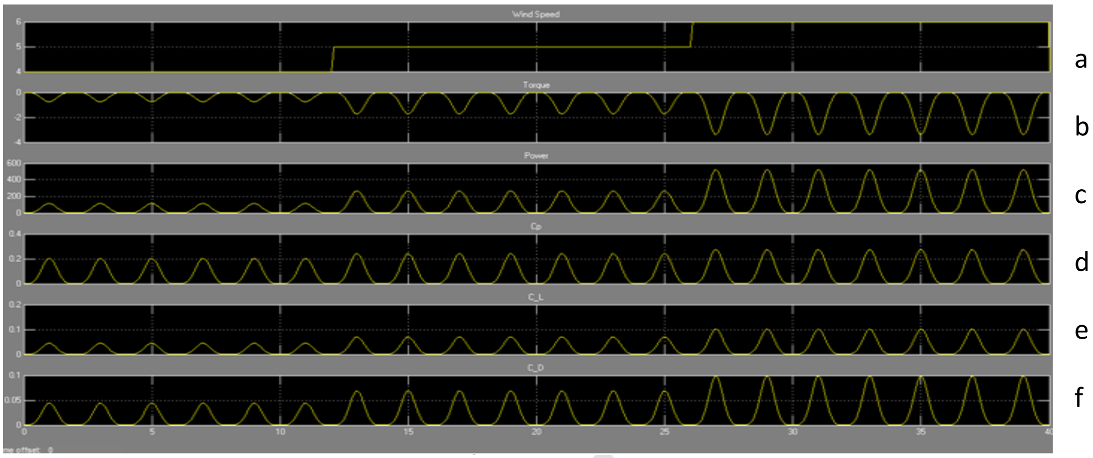

Fig.4. (a)Wind speed (b)Torque (c)Power (d)Power co-efficient (e)Lift force co-efficient (f)Drag force co-efficient

The graph for waveforms of angle of attack, azimuth angle and drag, lift forces are provided in Fig.5.

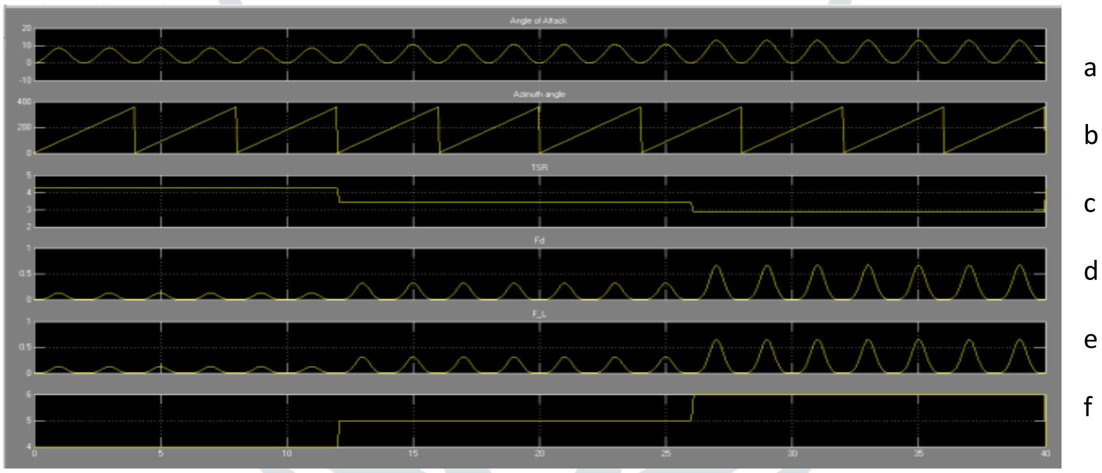

Fig.5. (a)Angle of attack (b)Azimuthal angle (c)Tip speed ratio (d)Drag force (e)Lift force (f)Wind speed

The variation of torque generated by the turbine for different azimuth angle is provided in Fig.6.

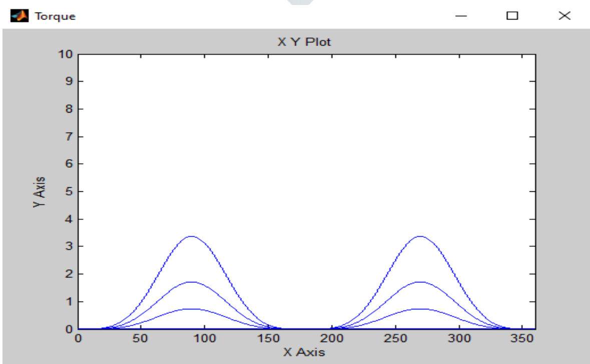

Fig.6. Torque v/s azimuth angle

The variation of power generated by the turbine for different azimuth angle is provided in Fig.7.

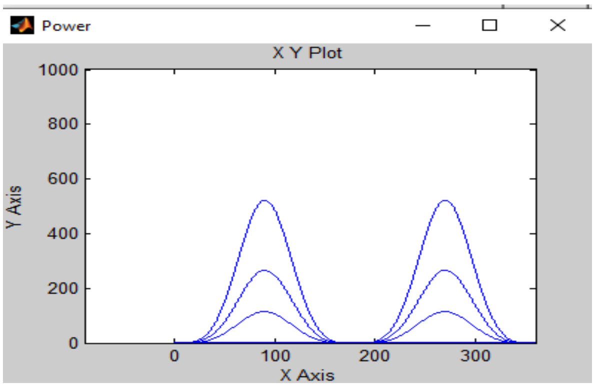

Fig.7. Power v/s azimuth angle

The variation of angle of attack generated by the turbine for different azimuth angle is provided in Fig.8.

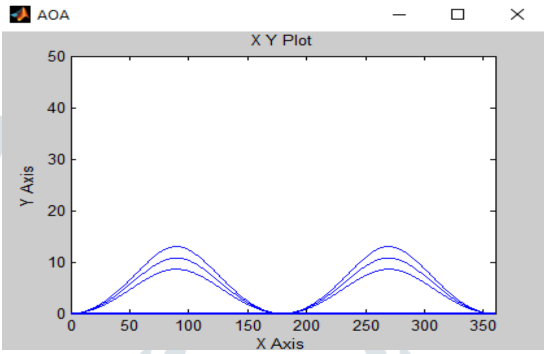

Fig.8. Angle of attack v/s azimuth angle

The graphs of lift and drag coefficients v/s azimuth angle is provided in Fig.9 and Fig.10.

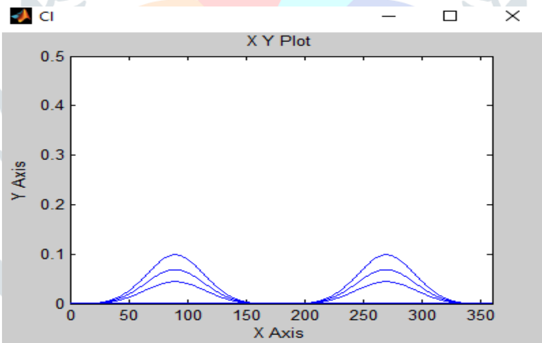

Fig.9.Lift coefficient v/s azimuth angle

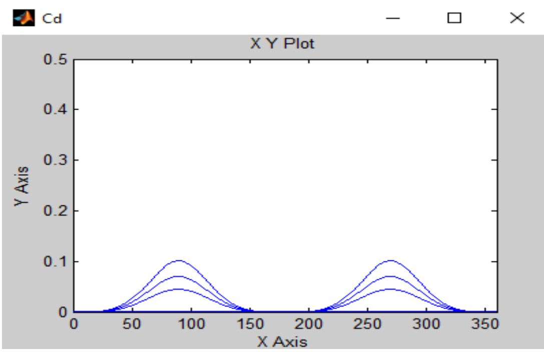

Fig.10.Drag coefficient v/s azimuth angle

The graphs of power coefficient and drag force v/s azimuth angle is provided in Fig.11 and Fig.12.

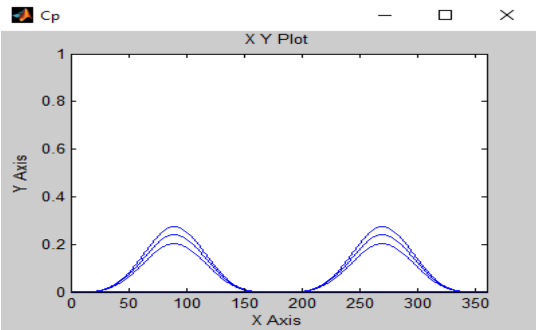

Fig.11. Power coefficient v/s azimuth angle

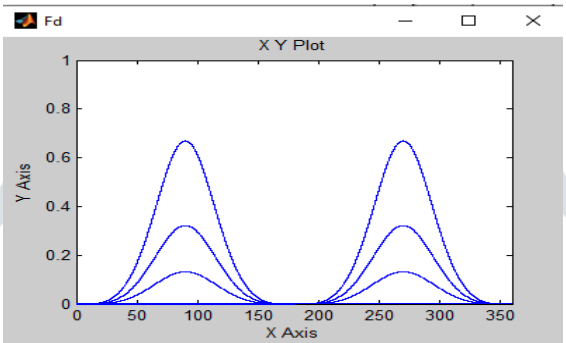

Fig.12. Drag force v/s azimuth angle

The graph of lift force v/s azimuth angle is provided in Fig.13.

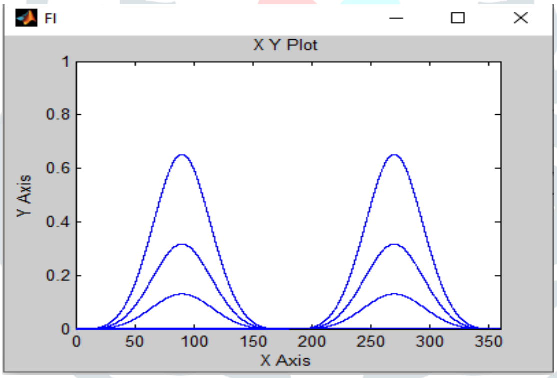

Fig.13.Lift force v/s azimuth angle

8.CONCLUSION

A vertical axis H-darrieus turbine works at low wind speed is modelled for its optimum operation for low wind speed conditions of 4 to 6 m/s and generator speed of 155 rad/sec to produce mechanical power output. The project Also gives the variation of power, torque, angle of attack, lift coefficient, drag coefficient, lift force and drag force V/s Azimuth angle from 0 to 360 degrees. The performance of wind turbine is observed by varying wind speeds and corresponding output is noted.It is observed that the proposed project gives the mechanical power output of 120W, 280W, and 520W for the wind speed of 4m/s, 5m/s and 6m/s respectively.

9. REFERENCES

[1]Hou-kun dai, zong-xiao yang, lei song,“Mathmatical modeling for H-type vertical axis wind turbine”,Proceedings of the 11th IEEE International Conference on Networking, Sensing and Control,April 2014

[2]Fang Feng, shengmao Li, Yan Li, Dan Xu,“Torque characteristics simulation on small scale combined type vertical axis wind turbine”, international conference on applied physics and industrial engineering,2012.

[3] Nitin A. Dhumne, SurbhiShrivasta, “A Novel Method Design of Vertical Axis Wind Turbine by using Magnetic Levitation”, Volume 4, issue 1, June 2017.

[4] S. Brusca, R. Lanzafame, M. Messina, “Design of a vertical-axis wind turbine: how the aspect ratio affects the turbine’s performance”, Int J Energy Environ Eng (2014).

[5] NitinGupta,Aashish Kumar, Sandeep Banerjee and SumirJha, "Magnetically Levitated V A WT with Closed Loop Wind Speed Conditioning Guide Vanes", 1st IEEE International Conference on Power Electronics. Intelligent Control and Energy Systems (ICPEICES-2016).
[6] ArunAdhikari, BipinKhadka, Subhash Chandra Shah, KeshavPriyadarshi, "Design and Fabrication of Magnetically Levitated VAWT", IJIRST, Volume 4, Issue 5, October 2017.
[7]ShubhamPatil, Pratik Kumbhar, OslaniyaSiddharth, PatilRohit, C S Waghle, "Magnetic Vertical Axis Wind Turbine", IRJET, Volume 4, Issue 5, May 2017.
[8]M, Islam,V. Esfahanian, D. S-K. Ting, A. Fartaj, "Applications of Vertical Axis Wind Turbines for Remote Areas", Proceedings of 5th Iran National Energy Conference,2005.
[9] Felix Farret, M Godoy Simos "Integration Of Alternative Sources Of Energy" Wiley Publications,April 2006.
[10] MagdiRagheb and Adam M. Ragheb, "Fundamental and advanced topics in windpower", july 5th 2011.