IJSRD - International Journal for Scientific Research & Development| Vol. 6, Issue 04, 2018 | ISSN (online): 2321-0613

A Review on the Selection Parameters of H-rotor Darrieus VAWT

Rucha Bhalerao[1] Ashwin Bhalerao[2] Ashishkumar Maurya[3] Prof. Priyanka Chavan[4]
[1,2,3]Student [4]Assistant Professor
[1,2,3,4]Department of Mechanical Engineering
[1,2,3,4]Pimpri Chinchwad College of Engineering & Research, Ravet, Pune-412101, India

Abstract— Around the globe the demand for energy resources is increasing day by day. As the conventional resources are depleting, the focus is now shifted to the non-conventional resources in order to fulfill the rising need. Wind energy can be easily harnessed as it is readily available in nature & can be a feasible option in this regard as they provide a promising solution. H-Darrieus are earning great popularity in the wind energy market. In the paper the author provides you with the benefits of vertical axis wind turbine over horizontal axis wind turbine. This paper presents a review on various design parameters of H- Rotor Darrieus Vertical Axis Wind Turbine along with its aerodynamics & an optimum design procedure.

Key words: H- Rotor Darrieus, Vertical Axis Wind Turbine (VAWT)

I. INTRODUCTION

In the recent years the Renewable energy resources are gaining popularity mainly the wind energy as the remains of Non-Renewable are decreasing day-today with rising need. Wind energy can be harnessed through wind turbine to generate mechanical power. Here kinematic energy of wind is converted to mechanical energy. Currently there are only 2 main categories of wind turbine based on the alignment of the axis i.e HAWT & VAWT. The prime advantage of the H-rotor Darrieus VAWT is its only moving part i.e the rotor so that yaw mechanisms are not required. Moreover, as the blades are straight its design & fabrication is very simple unlike the blades of HAWT. Furthermost, as the all the components of VAWT are mounted on ground there is ease of maintenance [1]. The figure below shows the graph of coefficient of performance vs TSR for various turbines [3].

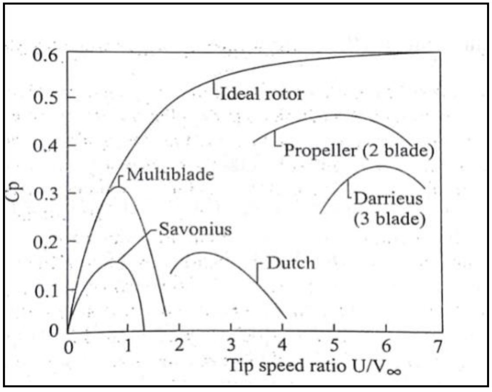

Fig. 1: Coefficient of performance (Cp) vs Tip speed ratio (TSR) graph

The very first windmill was built in Scotland in July 1887 for the commercial purpose of electricity generation [2]. The development of wind power in India began in 1986 with the first wind farms being set up in coastal areas of Maharashtra (Ratnagiri), Gujarat and Tamil Nadu (Tirunelveli) with 55 kW Vestas wind turbines. Wind energy systems have been used for centuries as a source of energy for mankind.

These demonstration projects were supported by the Ministry of New and Renewable Energy. The potential for wind farms in the country was first assessed in 2011 to be more than 2,000 GW by Prof. Jami Hossain of TERI University, New Delhi. By the end of 2015, India had the fourth largest installed wind power capacity in the world. The levelized tariff of wind power reached a record low of ₹2.43per kWh (without any direct or indirect subsidies) during auctions for wind projects in December 2017. Wind power generation capacity in India has significantly increased in recent years. As of the end of October 2017 the total installed wind power capacity was 32.72 GW, mainly spread across the South, West and North regions. The figure below gives the development potential of wind farms all over the world.

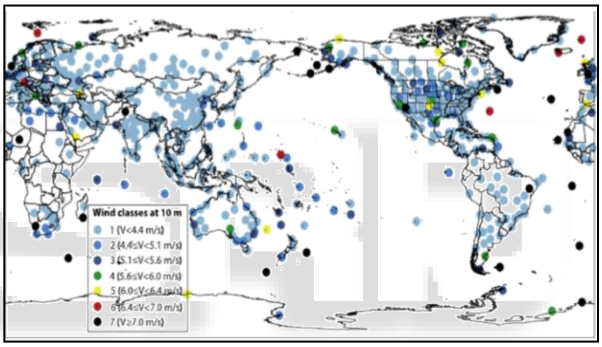

Fig. 2: Basic average wind speed across the world [1].

II. ABBREVIATIONS & ACRONYMS

VAWT	Vertical Axis Wind Turbine
HAWT	Horizontal Axis Wind Turbine
ρ	Density of the wind
A	Swept Area
$V_{\square}$	Inlet Velocity of wind
U	Induced Velocity
C_p	Coefficient of performance
$P_{turbine}$	Mechanical Power
P_{wind}	Power extracted from wind
Q	Torque
ω	Angular Velocity
V_o	Outlet Velocity
λ	Tip Speed Ratio
R	Rotor Radius
L	Length of Blade
N	Number of Blades
c	Chord length
V_c	Chordal velocity component
V_n	Normal velocity
θ	Azimuthal angle
α	Angle of Attack
C_t	Tangential force coefficient
C_n	Normal force coefficient

σ	Solidity
F_{ta}	Average tangential force
F_n	Normal force
F_t	Tangential force
H	Rotor Height

III. CLASSIFICATION OF VAWT

Based on the aerodynamic force used for extraction VAWT are classified into 3 types namely Lift type, drag type & combined lift & drag type [1]. They are further discussed as follows:

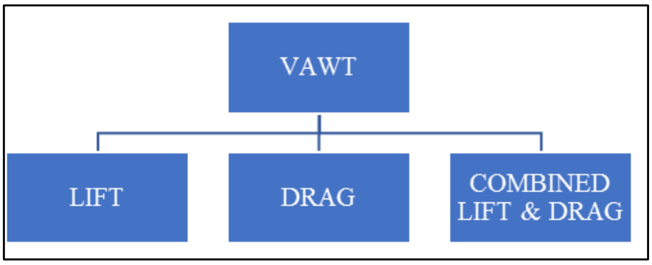

Fig. 3: Classification of wind turbine based on aerodynamics.

A. *Lift type*

These turbines are lift based turbine. The extraction force used to harness power from the wind is mainly the lift force; it is the driving force of the turbine. Lift based turbines mainly consist of HAWT & Darrieus VAWT. Basically, it a great choice for commercial application & they started gaining popularity in the later part of 20th century [1].

B. *Drag type*

These types of turbines utilize the drag force to generate power. They mainly consist of Savonius turbine. Here lift force opposes the motion hence, it is not desired. Although it has low efficiency as compared to others it is still used because, its simple to design & maintenance is low. Finnish engineer Sigurd Johannes Savonius in 1922 invented the Savonius vertical axis wind turbine. Seeing the rotor from above, it seems to be a two-scoop machine which looks like a “S” in cross section [4] [5] [6].

C. *Combined lift & drag type*

In this turbine both lift & drag force contribute in the power generation. Its design is a bit complex as compared to another Vertical axis wind turbine. This concept was suggested by Gavaldalet al, Gupta & Biswas & Debnath et al. High torque was observed at self-start low wind speed [7] [8] [9]

Darrieus vertical axis wind turbine was first patented in 1931 with all possible arrangements of vertical blades. It is one of the most efficient VAWT. The variants of Darrieus vertical axis wind turbine are discussed as follows:

1) *H-rotor Darrieus VAWT:*

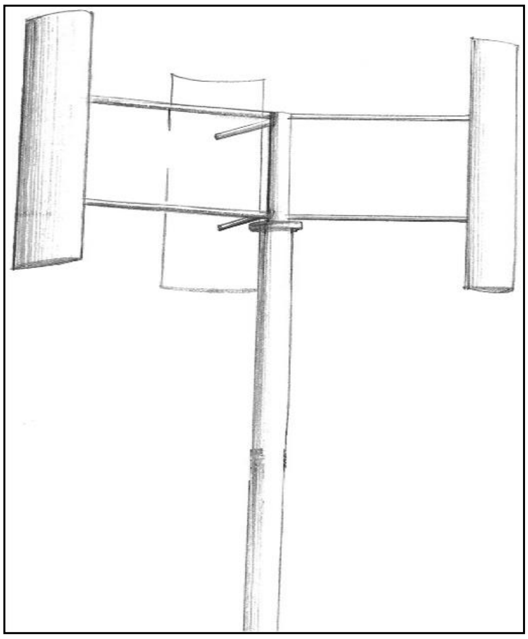

Fig. 4: H-rotor Darrieus Vertical axis wind turbine [1]

It is a straight blade, lift based vertical axis wind turbine. In this the aerofoil blades are directly connected to the rotor with the help of a strut. It appears like a “H” in shape. Thus, it is also termed as H-rotor or Giromill VAWT. It was developed in the late 90’s in UK. Mainly it consists of 2-3 blades [1] [10].

2) *Helical Darrieus VAWT*

Fig. 5: Helical Darrieus Vertical axis wind turbine [1]

The blades of Darrieus VAWT are tilted into a helix e.g. three blades and a helical twist of 60 degrees. The twisted 3 bladed Darrieus VAWT results in decreasing the flow separation This type of blade helps in self-starting the wind turbine at desired speed. The greatest disadvantage is the complications involved in fabrication of twisted blades [1].

3) Egg beater type VAWT

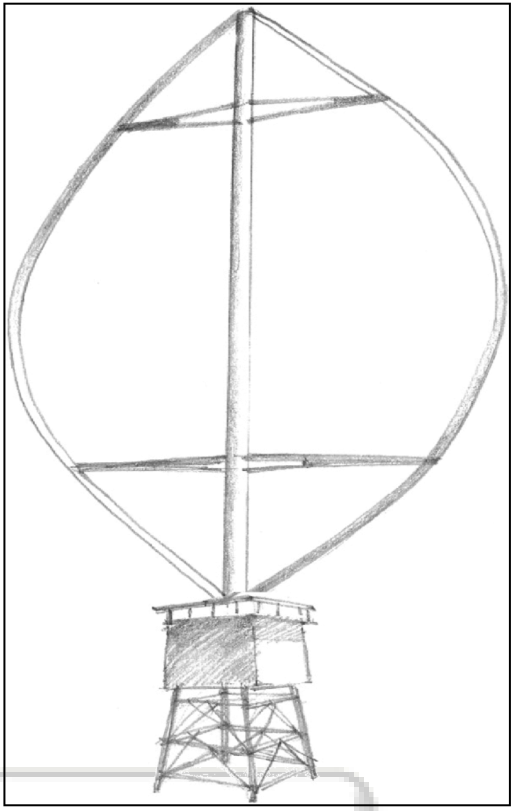

Fig. 6: Egg beater type Vertical axis wind turbine [1]

It possesses two or more blades arranged in the form of an egg beaters. Although it's design is complex it is the most efficient turbines in all the VAWT. Due to its complicated geometry its exerts minimum bending stress in the blades. It's being used on large scale & the liveliest example is the 3MW Egg beater Darrieus VAWT established in Canada [1] [11].

IV. BETZ LAW FOR VAWT

According to the Betz law, the power extracted from the wind is given by,

$$P_{wind} = \frac{1}{2}\rho A V_{\square}^{3} \qquad (1.1)$$

Where,

ρ = Density of wind in kg/m^3,

A = Swept Area in m^2 &

$V_{\square}$= Inlet Velocity of wind in m/s.

Coefficient of performance:

$$C_p = \frac{P_{turbine}}{P_{wind}}$$

$$= \frac{Q * \omega}{\frac{1}{2}\rho A V_{\square}^{3}} \qquad (1.2)$$

Where,

Q = Torque in Nm &

ω = Angular Velocity in rad/sec[10].

V. DESIGN PARAMETERS

A. Wind speed

In India the average wind speed is observed to be 4.4 - 7 m/s & above depending upon the region at an altitude of 10 m. This is the desirable wind speed for most VAWT. According to Betz law, for the coefficient of power to be maximum the ratio of inlet velocity to the outlet velocity should be 0.333333 [3] [10] [1].

$$\text{i. e } \frac{V\infty}{Vo} = \frac{1}{3}$$

B. Tip Speed ratio

The power coefficient is strongly dependent on tip speed ratio, defined as the ratio between the tangential speed at blade tip and the actual wind speed. TSR should range from 5 to 10.

$$\lambda = \frac{\text{Tangential Speed at blade tip}}{\text{Actual Speed}}$$

$$\lambda = \frac{R\omega}{V\infty} \qquad (1.3)$$

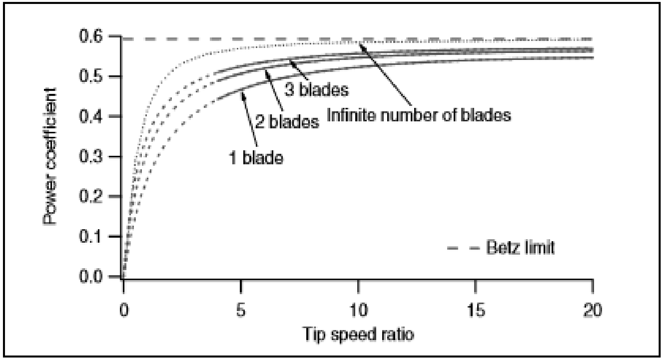

Fig. 7: Variation of C_p with respect to TSR [10]

C. Angle of attack:

Angle of attack is the angle between the body's reference line and the oncoming flow. In aerodynamics, angle of attack specifies the angle between the chord line of the wing and the vector representing the relative motion between the aircraft and the atmosphere. The angle of attack should be less than 16º. After 16º stalling effect starts.

D. Solidity:

The solidity σ is defined as the ratio between the total blade area and the projected turbine area. It is an important non-dimensional parameter which affects self-starting capabilities and for straight bladed VAWTs is calculated with,

$$\sigma = \frac{N\,c}{R} \qquad (1.4)$$

Where, N = Number of Blades,

c = Blade chord Length in m,

R = Radius of the rotor in m.

Solidity should around 0.1 to 0.3.

E. Aspect Ratio

Aspect ratio is the ratio of length of the blade to the radius of the rotor. It's nearly ranges from 0.5 to 2 depending upon the turbine & its application.

$$\text{Aspect Ratio (AR)} = \frac{L}{R} \qquad (1.5)$$

F. Material

In order to minimize the weight & according to feasibility of fabrication Aluminium, wood, composites & carbon fiber are preferable materials for the vertical axis wind turbine [10].

G. Number of Blades

The number of blades has a direct effect in the smoothness of rotor operation as they can compensate cycled aerodynamic loads. For easiness of building, four and three blades have been contemplated [10].

H. Aerofoil shape

Selecting an aerofoil is one of the most crucial task. As H-rotor Darrieus is a lift-based turbine, high lift coefficient is desired. Mostly symmetric NACA aerofoils with high lift coefficients are used. Though asymmetric have higher lift but, due to complex geometry their fabrication is difficult. Hence NACA 0018, NACA 0012, NACA 0015, etc. symmetric aerofoils are being used.

VI. AERODYNAMICS OF STRAIGHT BLADED DARRIEUS VAWT

Though the straight-bladed Darrieus-type VAWT is the simplest type of wind turbine, its aerodynamic analysis is quite complex. Before comparative analysis of the main aerodynamic models, the general mathematical expressions, which are common to most of the aerodynamic models, are described in this section[1].

The flow velocities in the inlet and outlet sides of the Darrieus-type VAWTs are not constant. The chordal velocity component V_c and the normal velocity component V_n are, respectively, obtained from the following expressions:

$$V_c = R\omega + V_a \cos\theta \qquad (1.7)$$

$$V_n = V_a \sin\theta \qquad (1.8)$$

where V_a is the axial flow velocity (i.e. induced velocity) through the rotor, ω is the rotational velocity, R is the radius of the rotor, and ɵ is the azimuthal angle. The angle of attack (a) can be expressed as,

$$\alpha = \tan^{-1}\left(\frac{Vn}{Vc}\right) \qquad (1.9)$$

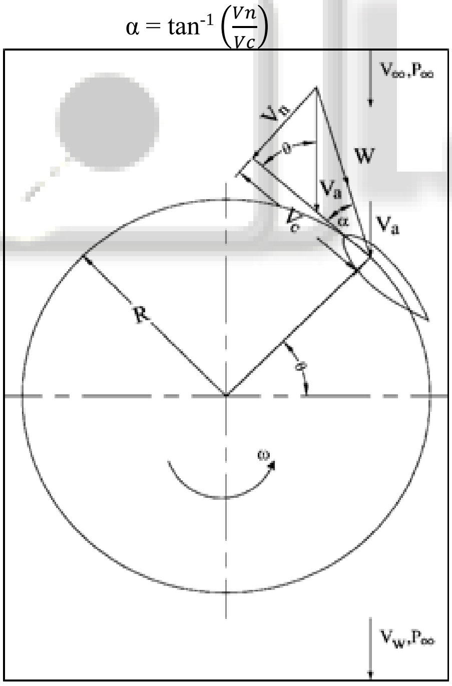

Fig. 8: Aerodynamics of Darrieus Vertical axis wind turbine [5]

Substituting the values of V_n and V_c and non-dimensionalizing,

$$\alpha = \tan^{-1}\left[\frac{\sin\theta}{(R\omega/V\infty)(Va/V\infty)+\cos\theta}\right] \qquad (2.0)$$

If we consider blade pitch,

$$\alpha = \tan^{-1}\left[\frac{\sin\theta}{(R\omega/V\infty)(Va/V\infty)+\cos\theta}\right] - \gamma \qquad (2.1)$$

where, γ = blade pitch angle

The relative flow velocity (W) can be obtained as,

$$W = \sqrt{Vc^2 + Vn^2} \qquad (2.2)$$

Variation of tangential and normal forces:

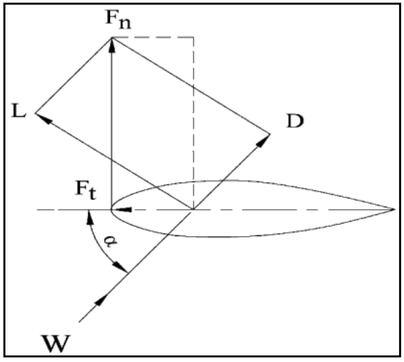

Fig. 9. Force Analysis of the rotor blade [5]

The directions of the lift and drag forces and their normal and tangential components are shown in Fig. The tangential force coefficient (C_t) is basically the difference between the tangential components of lift and drag forces. Similarly, the normal force coefficient (C_n) is the difference between the normal components of lift and drag forces. The expressions of C_t and C_n can be written as,

$$C_t = C_l \sin\propto - C_d \cos\propto \qquad (2.3)$$

$$C_n = C_l \cos\propto + C_d \sin\propto \qquad (2.4)$$

The net tangential and normal forces can be defined as:

$$F_t = C_t \frac{1}{2} \rho C H W^2 \qquad (2.5)$$

$$F_n = C_n \frac{1}{2} \rho C H W^2 \qquad (2.6)$$

Where, ρ is the air density,
C is the blade chord &
H is the height of the turbine.

Since, the tangential and normal forces represented by Equations are for any azimuthal position, so, they are considered as a function of azimuth angle θ. Average tangential force (F_{ta}) on one blade can be expressed as

$$F_{ta} = 1/2\pi \int_0^{2\pi} Ft(\theta)\, d\theta \qquad (2.7)$$

The total torque (Q) for the number of blades (N) is obtained as.

$$Q = N\, F_{ta}\, R \qquad (2.8)$$

The total power (P) can be obtained as

$$P = Q * \omega. \qquad (2.9)$$

VII. DESIGN PROCEDURE

- Power: Set the desire power output for the turbine
- Rated velocity: Select the rated velocity for a particular region.
- Calculation of Swept Area: Calculate the swept area by substituting power, density of air & rated inlet velocity in Betz equation.
- Aspect Ratio: Set the aspect ratio for the turbine.
- Calculation of Length of Blade & Rotor Diameter:
- Put the aspect ratio relation in swept area & calculate diameter of rotor and length of blade.
- Calculation of chord length: For calculation of chord length select the number of blades & solidity.
- Selection of TSR: Select the TSR & calculate angular velocity accordingly.
- Select aerofoil shape for the blade for maximum lift coefficient.

VIII. CONCLUSION

In this paper we studied the various vertical axis wind turbine out of which Darrieus vertical Axis wind Turbine proved to be the most efficient. Based on the design simplicity, high efficiency & easy fabrication H-rotor Darrieus VAWT is achieving great popularity. The factors influencing the H-rotor Darrieus VAWT such as wind speed, aspect ratio, solidity, tip speed ratio, aerofoil shape, number of blades, material & angle of attack are studied & it optimum range is specified. The design strategy for the rotor has also been mentioned. Hence, H-rotor Darrieus VAWT TSR should be between 5-6, Solidity should range between 0.1-0.3, NACA symmetric aerofoils should be utilized, Angle of attack should be less than 16º to avoid dynamic stalling effect on the rotor blade & optimum number of blades should be 3.

ACKNOWLEDGMENT

This research was supported by Pimpri Chinchwad College of Engineering & Research, Ravet. We thank our guide Ms. Priyanka Chavan who provided insight and expertise that greatly assisted the research. And also, for her assistance with blade design procedure. We would also like to show our gratitude to Mr. S. H. Mankar, Head of Mechanical Department, PCCOER, for sharing their pearls of wisdom with us during the course of this research.

REFERENCES

[1] Mazharul Islam, David S.-K. Ting, Amir Fartaj (18 December 2011). “Vertical axis wind turbine – A review of various configurations and design techniques”
[2] *Price, Trevor J (3 May 2005). "James Blyth – Britain's First Modern Wind Power Engineer". Wind Engineering.*
[3] P K Nag, “Power Plant Engineering”. Third edition
[4] Gorelov DN, Krivospitsky VP. Prospects for development of wind turbines with orthogonal rotor. Thermophysics and Aeromechanics 2008;15:153–7.
[5] Islam M, Ting DSK, Fartaj A. Aerodynamic models for Darrieus-type straightbladed vertical axis wind turbines. Renewable and Sustainable Energy Reviews 2008;12:1087–109.
[6] Siota T, Isaka T, Sano T, Seki K. Matching between straight-wing nonarticulated vertical axis wind turbine and a new wind turbine generator. Electrical Engineering in Japan 2011;174:26–35.
[7] Debnath BK, Biswas A, Gupta R. Computational fluid dynamics analysis of a combined three-bucket Savonius and three-bladed Darrieus rotor at various overlap. Journal of Renewable and Sustainable Energy 2009;1:1–13.
[8] Gavalda J, Massons J, Diaz F. Solar Wind Technology 1990;7:457.
[9] Gupta R, Biswas A. Computational fluid dynamics analysis of a twisted threebladed H-Darrieus rotor. Renewable and Sustainable Energy 2010;2:1–15.
[10] James F. Manwell, Jon G. McGowan, Anthony L. Rogers-“Wind Energy Explained_ Theory, Design and Application”, 2nd Edition -Wiley (2010)
[11] S. Brusca, R. Lanzafame, M. Messina. "Design of a vertical-axis wind turbine: how the aspect ratio affects the turbine’s performance". 2014.