

# A Review on Combined Vertical Axis Wind Turbine

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**ABSTRACT:** Energy procurable in two types first is non renewable energy and second is renewable energy. Wind energy is most available pure energy in form of renewable energy. Wind power is a primary source of sustainable energy and can be harvested using both horizontal axis wind turbine and vertical axis wind turbine. In this paper involves study of combined vertical axis wind turbine (CVAWT). In past few years more research works are carried out to increase efficiency of combined rotor. Review of all research paper shows the experiments are conducted only on aspect ratio, tip speed ratio, velocity, other geometrical parameter and different airfoil of combined rotor to increase the performance. They also conducted to increase the power and efficiency improvability. The development of this design include optimizing combined rotor blade both structure and flow performance requirements of newly design blades. The combination of both rotor increase the total power of turbine in low wind speeds. This concept also help full to overcome the problem of cost, land availability and high equipment cost.

**KEYWORDS:** Savonius rotor, Darrieus rotor, Power co-efficient, Tip speed ratio, Overlap ratio, Velocity, Combined vertical axis wind turbine, Blade angle.

## I. INTRODUCTION

Wind energy is one of the most cleanly and reliable source of renewable energy. Wind is natural resource and can be used as an alternative energy. A wind turbine is a machine that transfers wind energy in to mechanical energy with the use of blades and shaft and convert that form of energy in to electricity with use of generator[12]. Energy is the key to modern life and provides the basis necessary for sustained economic development. . The emission of CO<sub>2</sub> into the atmosphere contributes to the global climate change, particularly global warming. To tackle this problem, many of the developed nations are continuing to invest heavily in renewable energy sources. The demand for the power around the world is continuously increasing very rapidly, as the stock of conventional sources of energy (i.e. fossil fuels) is limited and decreasing very fast and the earth's ecological balance is being damaged beyond its sustainable limit [9].

**WIND ENERGY:** Wind energy is the most potential renewable energy resource low cost compared with convention fossil resources. Wind energy can help in reducing the dependency on fossil fuel. Wind energy can be utilized to windmills, which in turn drive a generator to produce electricity. It is expected that wind being a non-polluting and non-toxic energy source, will go a long way in solving our energy requirements. Many countries including India realized the importance of wind energy as important power resources. It has been predicted that roughly 10 million MW of wind energy continuously available on surface of earth. India's wind power potential is 45000MW [5].

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It is accepted that vertical axis wind turbine represent a suitable alternative for wind power extraction in many developing countries. The reason for this is mainly because of highly efficient rotors and there advantage over the horizontal axis wind turbine such as:

- (1) Simple construction
- (2) Extremely cost effective
- (3) Acceptance of wind flow from any direction without orientation.[7]

**H-DARRIEUS ROTOR:** The energy is taken from the wind by a component of the lift force working in the direction of rotation. Lift force is perpendicular to the resultant of two velocity component of wind velocity and relative velocity of airfoil to the shaft. These types of turbines have highest values of efficiency among VAWTs and the tip speed ratio can be much higher resulting in a much higher rpm. But generally suffer from problems of low starting torque and poor building integration.

H-Darrieus-Rotor

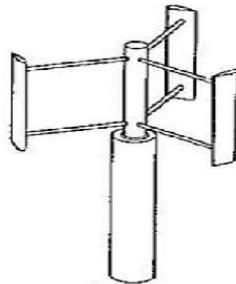


Fig-1: H-Darrieus Rotor

**SAVONIUS ROTOR:** The operation of Savonius rotor work on the difference of drag force when the wind strikes the concave and convex part of the semi-spherical blades. The flow energy utilization of Savonius rotor is lower than that of Darrieus rotor. So, this type of turbine is generally used for low-power applications and usually used for wind velocimetry applications. The greatest advantage of a Savonius rotor is its ability to self-start in contrast to other 'Lift type' VAWTs. Recently, some generators with high torque at low rotational speed, suitable for small-scale [2].

Savonius-Rotor

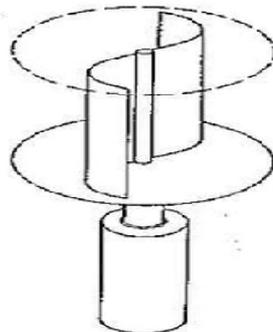


Fig-2: Savonius Rotor

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**COMBINED ROTOR:** Combined rotors are the combination of two different rotor (Savonius and H-Darrieus) mounted on the same shaft. Mostly combined wind or water rotors are available in the vertical axis configuration. Combined rotors generally combine Darrieus and Savonius type wind rotors. However, many other configurations might be available for designing of combined rotors. A combined rotor overcomes the shortcomings of the one fold airfoil turbine rotors and takes advantage of another turbine rotor. Since the Darrieus rotor is not self-starting, a blended design with Savonius blade can make the combined which can make it self-starting and more power efficient and high torque co-efficient than any of the single rotor [11].



Fig-3: Combined Rotor[5]

## II. WIND TURBINE DESIGN PARAMETERS

The various parameters involved in the performance testing of the vehicle is listed below[3]:

1. Swept area.
2. Power and power co-efficient.
3. Tip speed ratio.
4. Blade chord
5. No. of blades.
6. Solidity.
7. Initial angle of attack.

**1. Swept area:**

The swept area is the section of air that encloses the turbine in its movement,  
 $A_s = H.D$

**2. Power and power co-efficient:**

The power the turbine takes from wind is calculated using the power coefficient.

$$C_p = \frac{\text{Capture mechanical power by blades}}{\text{Power available in wind}}$$

**3. Tip speed ratio:**

It is defined as the ratio between the tangential speed at blade tip and the actual wind speed

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$$\lambda = \frac{\text{Tangential speed at the blade tip}}{\text{actual wind speed}}$$

**4. Blade chord:**

The chord is the length between leading edge and trailing edge of the blade profile.

**5. No. of blades:**

The number of blades has a direct effect in the smoothness of rotor operation. From various references it is concluded that two or three blades are more suitable for vertical axis wind turbine.

**6. Solidity:**

It is defined as the ratio between the total blade area and the projected turbine area.

**7. Initial angle of attack:**

The initial angle of attack is the angle the blade has regarding its trajectory, considering negative the angle that locates the blade's leading edge inside the circumference described by the blade path.

### III. NUMERICAL CALCULATION

There are few studies that have been carried out for analytical design and performance parameters of hybrid turbine. A design equation for 3-bladed Darrieus and two stage Savonius rotor has been found and given as Eq. (1) and (2) for power output and TSR (Tip speed ratio) respectively.

$$P = 0.5 \cdot \rho \cdot V^3 (A_s C_{P_s} + A_d - A_s \cdot C_{P_d}) \quad (1)$$

$$\lambda = \omega R V \quad (2)$$

Where,

- $A_s$  = Swept area by Savonius rotor in m<sup>2</sup>;
- $A_d$  = Swept area by Darrieus rotor in m<sup>2</sup>;
- $C_{P_s}$  = Power coefficient of Savonius rotor;
- $C_{P_d}$  = Power coefficient of Darrieus rotor;
- $\rho$  = Air density in kg/m<sup>3</sup>;
- $\omega$  = Shaft speed in rad/s;
- $\lambda$  = TSR of hybrid turbine;
- $R$  ( $R_d$ ) = Maximum rotational radius;

A torque and power equations has been studied for three bladed Darrieus and single stage Savonius rotor given as follows:

$$Q_T = Q_s + Q_D \quad (3)$$

Where,

- $Q_T$  is the torque of the combined machine;
- $Q_s$  is the torque of the Savonius rotor;
- $Q_D$  is the torque of the Darrieus rotor

Total torque of combined machine mathematically as following

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$$QT=12\rho ATRTCQr \quad (4)$$

And CQr can be calculated as follows:

$$CQr= (CQsAsDsATRT) + (CQDADRDATRT) \quad (5)$$

Where,

RD is the equatorial radius Darrieus turbine;

AD is the swept area of Darrieus turbine;

DS is the diameter of Savonius rotor;

RT is the radius of the combined machine;

AT is the swept area of the combined machine.

The power coefficient of combined machine has been evaluated as:

$$CPR = \lambda CQr \quad (6)$$

Where,

CPR is the Power coefficient of the combined rotor[11]

## IV. LITERATURE REVIEW

**Mohammed Hadi Ali [1]:**Has carried out experimental comparison and investigation of performance between two and three blades Savonius wind turbine. Due to this purpose, two models of two and three semi-cylindrical blades were designed and fabricated from Aluminum sheet, with having an Aspect ratio of (  $As = H/D = 1$ ), the dimension is (  $H = 200$  mm height and diameter  $D = 200$  mm). These two models were assembled to have overlap zero ( $e = 0$ ) and a separation gap zero ( $e' = 0$ ). Subsonic wind tunnel is used to investigate these two models under low wind speed condition, which shows that maximum performance at ( $\lambda = TSR = 1$ ) and a high starting torque at low wind speed, and also gives reason for three bladed rotors is more efficient than the two blades, that by increasing the number of blades will increase the drag surfaces against the wind air flow and causes to increase the reverse torque and leads to decrease the net torque working on the blades of Savonius wind turbine.

**N.H. Mahmoud [2]:** Has conducted an experimental analysis by using, wind tunnel experimental setup, the experimental results shows that -Three bladed Savonius rotors are more efficient than the three and four bladed Savonius rotors. The rotor with end plates gives higher efficiency than the without end plates. Blades having overlap ratios are better than the blades with without overlap ratios. By increasing Aspect Ratio Coefficient of performance ( $C_p$ ) will also increase.

**Javier Castillo [3]:**Has carried out that, three-bladed design is more efficient than a four-bladed rotor; a low solidity ( $\sigma \geq 4$ ) wind turbine may present self-starting problems as rotor efficiency.  $C_p$  also decrease at low tip speed ratio, so optimum tip speed ratio is 2.5-3 for H-rotor. He also conclude that Larger radius turbines are more efficient than small turbines at same rotational speed as the tangential airspeed increase leads to smaller angles of attack, bigger Reynolds numbers and thus bigger blade lift coefficients.

**U.K.Saha,S.Thotla, D.Maity [4]:**Has conducted that, power coefficient  $C_p$  of Savonius rotor depends on number of stages. When number of stages increased from one to two, the rotor shows better performance characteristics, however the performance get degraded when the number of stages become three. These may be increased in inertia of rotor. So

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the optimum number of stages for Savonius rotor is two. It also concludes from the experimental evidence that a two-blade system gives optimum performance. For two blade two stage  $C_p$  is about 30%,  $V=6-8$  m/s.

**T.Letcher[5]:** Has carried out experiment in three separate directions Computation Fluid Dynamics (CFD) modelling, generator design and materials/manufacturing process. With the experimental data collected during this project, It was concluded that the power output of combined setup is higher than the single Savonius and Darrieus rotor.

**M.Abid,K.S.Karimov[6]:** Experimental study concluded that, combination of NACA 0030 airfoil and Savonius rotor provided the functions required for a starting mechanism. The Savonius and Darrieus blades should have different assemblies to perform effectively. Savonius and Darrieus blades were observed responsible for the low start up speed and high rpm, respectively. Furthermore, the blades with NACA 0030 airfoil provided the high thickness which resulted in an increase in the self-start capability of the turbine. The power output of turbine is around 14 Watt at 5 m/s velocity.

**S.M.Rassoulinejad-Mousavi,M. Jamil [7]:** In this paper attempt was made to measure performance of individual H-Darrieus and combined Savonius-H-Darrieus rotor for three different conditions. Conclusion has been summarized from the experimental study that, Combined H-Darrieus and Savonius rotor shows self-starting ability at low wind speed 3m/s. When H-rotor placed at top of S-rotor than, power output (24 Watt) is maximum compare to S-rotor at middle of H-rotor (20 Watt).It has been found that in the case that the two turbines (H-rotor and savonius) are combined, higher performance is acquire in compare with H-rotor. The authors concluded that Combining both savonius and H-rotor with each other makes an effective wind turbine which has better self-starting ability besides higher power coefficient.

**ShrikantG.Gawade,D.S.Patil[8]:** Has conducted comparative study of a single stage Savonius with combined Savonius- 3 blade Darrieus. For maximum power output NACA0021 blade profile for H-rotor is taken in to consideration. From experimental study it was concluded, the maximum power co-efficient for Savonius is around 16% while for combined Savonius- H rotor maximum power co-efficient is 39% which is much more improved towards power production.

**R.Gupta,K.K. Sharma [9]:**Has studied about the performance of a two-stage two-bladed configuration of the Savonius rotor. Experiments were conducted in a subsonic wind tunnel. The parameters studied are overlap, tip speed ratio, power coefficient ( $C_p$ ) and torque coefficient ( $C_t$ ). Optimized Overlap ratio was used to generate maximum performance of the rotor. The study showed that maximum  $C_p$  of 0.25 was obtained at 20% overlap condition. Similarly power and torque coefficients decrease with the increase of overlap from 0% to 16.2%.

**S.Brusca,R.Lanzafame[10]:** This experiment work looks at designing a vertical-axis wind turbine to maximize its power coefficient. It has been seen that the power coefficient of a wind turbine increases as the blade's Reynolds number rises. By experimental study it was found that the ratio between blade height and rotor radius (aspect ratio) influences the Reynolds number and as a consequence the power coefficient. It has been highlighted that a turbine with a lower aspect ratio has several advantages over one with a higher value. The advantages of a turbine with a lower aspect ratio are: higher power coefficients, a structural advantage by having a thicker blade (less height and greater chord) and greater in-service stability from the greater inertia moment of the turbine rotor.

**Richard m. keslo et al. [13]:** Conducted that performance variation of leading edge for distinct airfoil profiles. Anexperimental screening has been undertaken to determine the impact of sinusoidal leading-edge protrusions on the performance of two NACA airfoils with different aerodynamic characteristics. Force measurements on full-span airfoils with manifold combinations of tubercle amplitude and wavelength expose that when compared to the unmodified equivalent, tubercles are more beneficial for the NACA 65-021 airfoil than the NACA 0021 airfoil. The authors concluded that NACA 0021, which has maximum thickness at 30% of the chord, increased lift performance in the post stall domain.

**Franklyn Kanyako et al. [14]:** Has carried out that highlighted the progress made in the development of aerodynamic models for forecasting the performance of straight-bladed, fixed-pitch vertical axis wind turbine blade profiles. An improved blade element momentum algorithm using a hybrid database was built to survey the solidity of the turbine, by

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analysing the effect of blade chord, radius, and number blades at different tip speed ratios. The authors have done 2-D numerical investigation to compare the performance prediction scope of the CFD and mathematical model. The authors concluded that negative and/or minimum  $C_p$  and torque are generated at lower tip speed ratios, which indicate that NACA 0015, NACA 0018, and NACA 0021 airfoils are not self-starting. Nevertheless, NACA0021 has shown to have better starting performance than the other two airfoils due to its intimate section.

**MicolChigliaro [15]:** The authors concluded that a nominal reduction of overall rotor performance with the enlargement of its shaft diameter. From this study, concludes that aerodynamic blade profile NACA 0012, NACA 0015, NACA 0018, NACA 0021, NACA 0025, NACA 0063 are advisable for Darrieus rotor. Many researchers have used these blade profiles for wind applications using other solidities and other models. It has been also observed from literature survey that blade profile NACA 0021 has better starting function due to its thickness. It has been also observed that Combining both savonius and H-rotor with each other makes an effective wind turbine which has better self-starting ability besides higher power coefficient.

## V. CONCLUSION

By summarizing above literatures, we obtain following conclusions:

- From the above literature survey, it is evident that the power output of vertical axis wind turbine for two blade two stage is maximum. It is also observed that when H rotor is placed above S rotor then power output increases with respect velocity of wind and in H-Darrieus rotor NACA0021 has better self-starting performance and gives higher  $C_p$  than other airfoils.
- Efficiency of turbine depends upon the velocity of wind and geographical climatic condition. It is concluded from above study that Power Output of Combine Setup is higher than Single Savonius and Darrieus rotor.
- By analysing the factor, it was found that the aspect ratio influences the Reynolds number and power coefficient. Lower aspect ratio gives higher power coefficient of turbine. For savonius turbine optimum tip speed ratio is about 0.8-0.85 and according to that  $C_p=0.17$  to  $0.20$  as well as zero overlap ratio is increase power coefficient higher. Where darrieus rotor have maximum power coefficient =  $0.35$  to  $0.40$  on tip speed ratio  $2.5-3$ . So combination of both rotors will give better result.

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