Review of the Hybrid H-Savonius Rotor's Design and Performance

D. Sarkar, A. R. Sengupta, P. Bhadra, S. Alam, and B. Debnath

Abstract In recent times, the progress and activities on renewable energy sources are growing exponentially. Amongst the various kinds of renewable resources, wind energy is one of the most preferable due to its abundant availability, lesser cost, zero emission compared to other sources. Amongst the various kind of vertical axis wind turbines (VAWT), H-Darrieus rotor is more popular in the built environment for their simple constructions and higher power coefficient which also suffers from poor self-starting features. Again, the Savonius rotor is having the good self-starting ability but possess lesser power coefficient. To address all such limitations, existing investigations of hybrid H-Savonius rotor have been reported here in terms of the design, various parameters and aerodynamic performances which are used to improve their self-starting and efficiency. From this study, it is seen that the coaxial arrangement of the H-Savonius rotor is capable to exhibit higher efficiency and better self-starting characteristics than the staging assembly or the individual Savonius or H-rotor. Again, a newly designed hybrid H-Savonius rotor exhibits the maximum power coefficient of 0.414 at TSR2.5. Modification of the Savoniusblade and thicker H-rotor airfoil blade helps to increase the efficiency of the hybrid rotor. This present paper offers an overall idea on the research growth to improve the design and performance of the hybrid H-Darrieus rotor.

Keywords Hybrid H-Savonius rotor · Self-starting · Power coefficient · Torque coefficient · Computational fluid dynamics

1 Introduction

Energy is a key element for social and economic development and growth of a country. The world demands energy in the form of low cost. Since the beginning of the elevation, human society has been depending upon the conventional energy resources. The conventional fossils fuels are depleting so fast day by day, as it has limited resources.

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Burning these fuels affects the environment critically by emitting greenhouse gases, which is the cause of global warming. The energy demand in the form of electricity is exponentially increasing very rapidly. Scientist and researchers are trying to meet the demands by using alternative renewable energy resources to power generation. This is why it motivates towards the development of wind energy in 1973 due to the high price of oil and limited fossils fuel resources [1]. Mankind has been using wind power for agriculture development, irrigation, to simplify mechanical work, navigation purposes, etc. In the past few decades, the researches and development activities in the field of renewable energy have been increased. Amongst various renewable energy sources, wind energy has got great attention as an alternative resource to coal, petroleum and nuclear energy which is more abundant, renewable, widely distributed, economically affordable, and most importantly, it has zero emission. To reduce the global energy-related carbon emission require a high growth rate of wind energy as a source of clean renewable energy.

1.1 Wind Turbine and Its Classification

Amongst the renewable energy sources, wind energy is one of the options for green, well-economic energy generation. The wind turbine is a device which converts the wind energy for power generation. Depending upon the axis of rotation, wind turbines are generally classified into two categories: horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). HAWTs are well known for their comparatively high efficiency over VAWTs, and it has been used for medium- to large-scale power generation. Again, VAWTs have advantages over the HAWTs such as lower installation and cost, compact design, easy to assemble, good self-starting ability, low cut-in speed, create less noise and omni-directional. VAWTs can be also classified into two types: Darrieus and Savonius turbines or rotor. H-Darrieus rotor is a variant of the curved-bladed Darrieus rotor, which has straight vertical blades [2]. In Fig. 1,

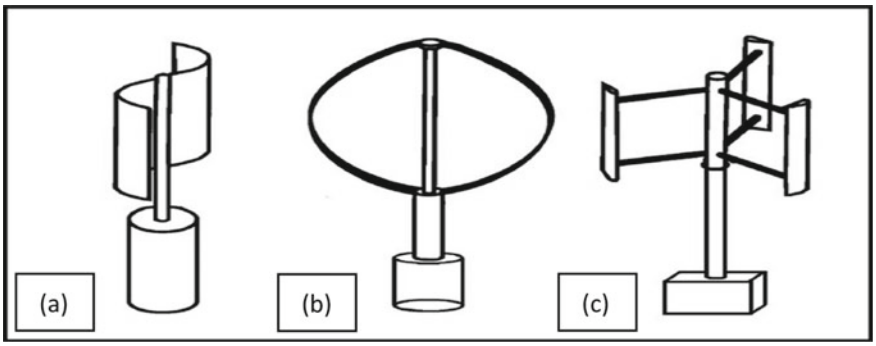

Fig. 1 **a** Savonius rotor, **b** Darrieus rotor and **c** H-Darrieus rotor

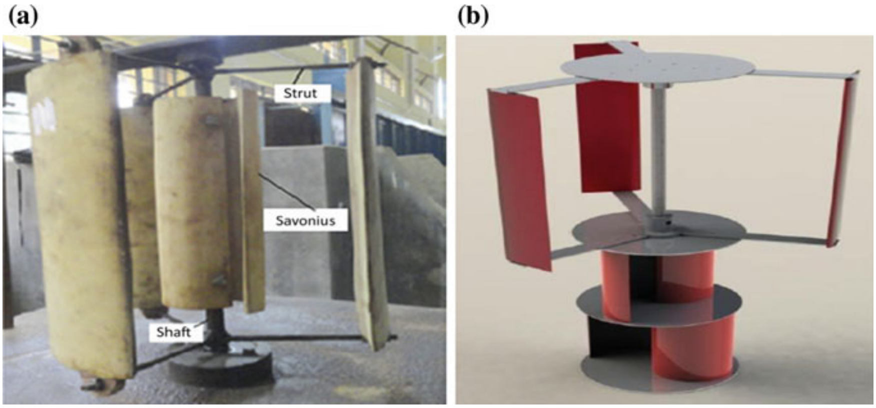

Fig. 2 **a** Single-stage hybrid H-Savonius rotor and **b** multi-stage hybrid H-Savonius rotor

the classification of the wind turbines is reproduced from the available literature [3].

H-Darrieus rotors are lift force-based device. The energy is taken out from wind by the component of lift force working in the direction of rotation. Such turbines have the highest efficiency amongst the VAWTs, but it suffers from its poor starting torque. The Savonius rotors are drag forced-based device. The main advantages of such a rotor are its ability to self-staring in contrast to the other VAWTs. In Fig. 2, there are two diagram; one is single-stage hybrid H-Savonius rotor [4], and another is multi-stage hybrid H-Savonius rotor [5] which are presented in the classification of staging of hybrid rotor.

There is aspecial kind of hybrid rotor known as hybrid H-Savonius rotor, where both the lift and drag mechanisms are useful for the self-starting and performance improvement of such hybrid rotor [6]. The combined rotor is a combination of two different rotors (Darrieus and Savonius) which are mounted on the same shaft. Hybrid rotors are generally a combination of H-Darrieus and Savonius rotors. It is seen that a hybrid design of Darrieus with Savonius can make it fully self-starting, along with higher aerodynamic performances compared to any of the single rotor [7].

1.2 Purpose of the Present Study

Since the past few decades, the experimental and theoretical researches and applications on improving the design and overall performance of the VAWTs have been increased rapidly. Most of the works have been performed on either Darrieus or Savonius rotor, but only a few studies are there regarding the theoretical and experimental investigations of the hybrid H-Savonius rotor. In order to utilize the properties of both lift- and drag-type rotors, hybrid H-Savonius rotor came into the picture. The present review has covered most of the research works done on the design and performance improvement of hybrid H-Savonius rotor.

2 Experimental Study on the Hybrid Rotor

Compared to a Savonius rotor, one of the greatest advantages of the Darrieus rotor is its higher power coefficient (Cp). However, the Darrieus rotor suffers from its poor self-starting features. In order to use the advantages of both the rotors, the hybrid rotors came into existence to overcome the self-starting problem as well as to enhance their aerodynamic performances.

Bhuyan and Biswas [4] have experimentally investigated and found the results of three S818 unsymmetrical-bladed hybrid rotor having maximum Cp of 0.34 at tip speed ratio (TSR) 2.29 and Reynolds number of 1.92×10^5 for the optimum 0.15 overlap of the inner Savonius, followed by maximum Cp of 0.28 at TSR 2.42 and at same Reynolds number for the simple H-rotor. Mousavi et al. [8] studied experimentally the performance of a coaxial hybrid vertical axis wind turbine having DUW200 airfoils for the H-rotor. The performance has been compared with another hybrid turbine having a multi-staging arrangement and with simple H-rotor having same airfoils. The results showed that the coaxial system exhibits self-starting features and higher power coefficient compared to the others. Gawade and Patil [9] attempted an experimental study to measure the performance of individual Savonius and coaxial H-Savonius rotor. The maximum power coefficient for Savonius was obtained as 0.16, while for coaxial H-Savonius rotor, the maximum Cp of 0.39 was obtained. Here, the combined rotor showed the self-starting ability at wind speed of 3 m/s.

Abid et al. [10]concluded from their experimental study that a combination of NACA 0030 blade H-Savonius rotor showed the starting characteristics at low wind speed. Here, the three-bucket Savonius was mounted on top of the three-bladed H-rotor. The H-rotor blades with NACA 0030 airfoil has a higher thickness which resulted in an increase in the self-start capability of the rotor. Sahim et al. [11] studied on the hybrid H-Savonius rotor and showed how the radius ratio of the hybrid rotor affects the torque coefficient and power coefficient. It was observed that the higher radius ratio (RL = radius of Savonius/radius of Darrieus) resulted in lower power coefficient and higher torque coefficient. Siddiqui et al. [12] have experimentally analysed the performance of the five different arrangements of VAWT, viz. individual Savonius, Darrieus, two-stage Savonius in the middle of the H-rotor, two-stage Savonius on the top of the H-rotor and lastly Savonius below the H-rotor. It was found that the coaxial system showed the highest efficiency than the rest four. The highest power coefficient of about 0.41 was achieved at TSR of 1.6. Therefore, from the above experimental studies, it was found that coaxially placed H-Savonius rotor is the most efficient rotor system compared to the individual Savonius, individual Darrieus, H-Savonius rotor of multistage arrangements of such rotors.

3 Computational Fluid Dynamics (CFD) Analysis on the Hybrid Rotor

On this hybrid H-Savonius rotor, researchers have performed CFD simulations based on various design parameters and system arrangements to enhance their self-starting features and power performances. Some notable and important findings are briefly described below.

Hosseini and Goudarzi [13] have performed a CFD study on the design of an innovative hybrid H-Savonius rotor for obtaining an extended operative range and enhancing the self-starting capabilities. This hybrid rotor consisted of two buckets modified Savonius Bach-type rotor and three-bladed Darrieus rotor while the whole arrangement included setup of these two rotors in two stage. The result showed that the maximum value of Cp is 0.414 at TSR of 2.5. This design of the hybrid rotor being suitable for low and high wind speed also improved its self-starting ability and operating range. Gupta et al. [14] have studied the performance of a combination of three-bucket Savonius and three-bladed Darrieus rotor arrangement with the Savonius placed at the top over the Darrieus. It has been seen from this study that with the increase of overlap, the power coefficient started to decrease. The highest power coefficient obtained was 0.51 at TSR 0.61 without overlap, which is higher than the efficiency of the Savonius rotor at any overlap positions under the same test conditions. Letcher [15] has carried out an experiment in three different directions which are: CFD modelling, generator design and materials/manufacturing process. From the data, it was concluded that the power output of the combined setup is higher than the single Savonius and single Darrieus rotor. Some notable results of CFD analysis along with a comparison of various hybrid rotor systems have been discussed in Table 1.

In Fig. 3, Cpvs TSR graph of various designed hybrid rotors have been plotted. From this figure, it has been noticed that two-stage two buckets modified Savonius Bach-type rotor-combined three-bladed Darrieus rotor setup has the maximum Cp value of 0.414 at TSR 2.5.

Sharma et al. [16] also investigated on the hybrid three-bladed Darrieus–Savonius rotor, where Darrieus mounted on the top of the Savonius for overlap variation from

Table 1 Notable results of CFD analysis along with a comparison of various hybrid rotor systems

Turbine	Optimum TSR	Maximum Cp	Minimum TSR	Maximum TSR
Bhyuan et al. (with Savonius overlap 0) [6]	2.29	0.19	–	~3
Bhyuan et al. (with Savonius overlap 0.15) [6]	2.29	0.34	–	~3
Hosseini et al. [15] (hybrid rotor)	2.5	0.414	Self-starting	4.5
Sun et al. [19]	1.8	0.33	1.25	2.25
Liu et al. [20]	2.24	0.41	0.4	2.58

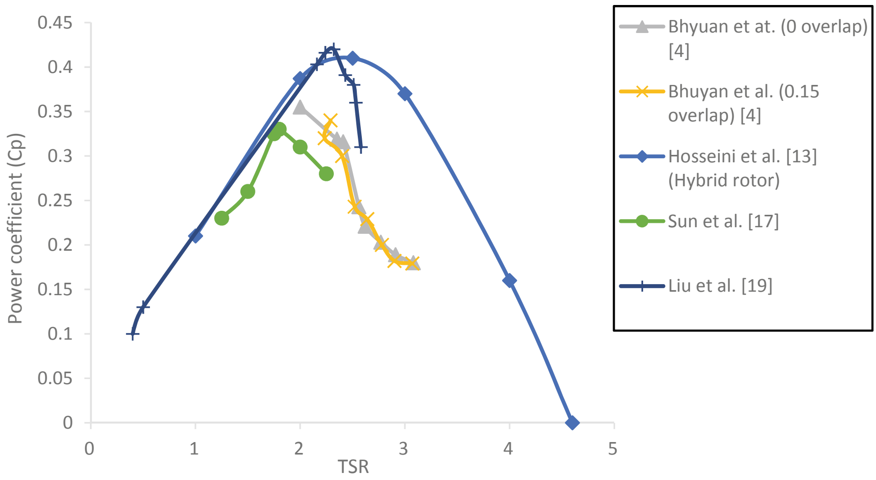

Fig. 3 Cp versus TSR curve for various designs

10.8% to 25.8%. The maximum Cp of 0.53 was obtained at 0.604 TSR for an optimum overlap position of 16.8%. It was observed that Cp increases with the increase of overlap. However, there is an optimum value of overlap for which Cp is maximum, and beyond this, Cp started to decrease. The similar results are observed for Ct as well. Sun et al. [17] performed numerical analysis on the performance of the hybrid H-Savonius rotor with four different hybrid models; the numerical result indicated that the power coefficient (Cp) of the hybrid H-Savonius rotor is dropped down when the distance between its centre axis and the Savonius blades, whereas the starting torque can be significantly improved. The comparison of power coefficient amongst all the simulated turbines, the optimum TSR of four hybrid turbines that having maximum power coefficient is around 1.75. Amongst all four turbines, the Cp is highest of their hybrid turbine 1 (with zero distance in between the rotation axis and Savonius blade), the value of the highest obtained Cp is around 0.33 at TSR 1.80. Roshan et al. [18] investigated on the effects of non-dimensional parameters like initial overlap ratio (ε), arc angle (Ø) and curvature (α) of the Savonius blades on the performance of the 18 hybrid H-Savonius models at 7 different TSRs. From the result of CFD simulation, it has been observed that model 12 having the maximum power coefficient (Cp) of 0.195 at TSR of 3 amongst all 18 models. Liu et al. [19]investigated that the larger modified Savonius (MS) rotor has a better self-starting capability. However, the power coefficient of hybrid Darrieus-modified Savonius (HDMS) VAWTs decreases when the size of MS rotor increased. An appropriate size of an MS rotor can maintain the power efficiency of HDMS compared to the Darrieus. The maximum power coefficient of the HDMS-1Xi VAWT is 0.41 which is 13% higher than the MS VAWT. Abdolahifar and Karimian [20] were done CFD analysis on the hybrid H-Savonius VAWT with the suitable wall and proper Savonius blade. In the comparison of the normal straight blade Darrieus rotor to the hybrid H-Savonius rotor, the hybridone produced 2.3% more average moment along with 40% less moment fluctuation at TSR 0.9.

4 Conclusions

To improve the overall efficiency and self-starting characteristics, hybrid H-Savonius rotor is being analysed by researchers which have shown the better result on low cut-in speed, wide operational range and especially in self-starting capability. From the present literature review, some important findings are listed below.

- Experimental study reveals that the coaxial arrangement of the H-Savonius rotor can exhibit higher efficiency and better self-starting features than the staging assembly or the individual Savonius or H-rotor.
- From the CFD result, the highest of power coefficient of 0.53 is obtained for an overlap position 16.8% of Savonius blade at TSR 0.604. The use of the modified Savonius rotor generated higher torque coefficient which helps to achieve self-starting characteristics of hybrid H-Savonius rotor.
- From the numerical analysis of an innovative new design of hybrid H-Savonius rotor, the maximum power coefficient of 0.414 at TSR 2.5 is achieved.
- The HDMS produced maximum Cp of 0.41 which is very closer to the new innovative-designed hybrid H-Savonius rotor, whereas the HDMS hybrid rotor produced 0.4% a lesser amount of power coefficient.

The present study gathered most of the investigations regarding the performances and designs of the hybrid H-Savonius rotor. It can act as a platform for future research in the field of Hybrid H-Savonius rotor.

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