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Technical Note

Design, Development and Testing of a Combined Savonius and Darrieus Vertical Axis Wind Turbine

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ABSTRACT

With a growing focus on renewable energy, interest in design of wind turbines has also been expanding. In today's market, the horizontal axis (windmill) turbine is the most common type in use; but, vertical axis (Darrieus) turbines have certain advantages. Darrieus turbines, which are lift-driven, have a higher power potential than the horizontal, or drag-driven turbines. The main flaw with their design is their inability to self-start. Darrieus turbines require an external energy source to bring the device to a minimum rotational speed. This paper presents design, construction and testing of a vertical axias (Darrieus) wind turbine with 3 blades, starting solely from the low energy of the wind. A separate drag device (Savonius type turbine) on the top of an existing Darrieus turbine was mounted to make the turbine self start at low wind speed. The cut-in speed of the turbine was 3 m/s, cut-off speed was 20 m/s and power obtained was 50 Watts at wind velocity of 6 m/s. The testing with primiarly available permanent magnetic generator sponsored by industry resulted in 35 Watts at 9m/s.

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INTRODUCTION

Wind power is one of the most important part of renewable energy resources [1]. Wind power (*P*) depends on wind speed (*v*), density of air (ϱ), for a turbine intercepting a cross-section (*A*) and efficiency factor (*C*) as given in Eq. 1. At the same time particular construction of the wind turbines contribute to the wind power through efficiency factor.

$$P = CA\,\varrho v^3/2 \qquad (1)$$

A vareity of turbines have been designed for the generation of electric power using wind energy [1-6]. For the small-scale wind energy, a portable turbine with efficiency of 21% and output electrical power of 9.8 W at wind speed of 10 m/s [2] was fabricated and is considered as one of the most efficient small power wind turbine. Sometimes the same kind of turbines were designed and used for wind and water power conversion into electric power. A vertical axis water turbine was also designed to supply energy for underwater mooring platform [3]. The combination of Darrieus-Savonius turbine was used in an irrigation canal [4]. It was observed that due to Savonius rotor the torque was increased at a lower speed; however at the same time, power coefficient was decreased. The performance of a hybrid vertical axis wind turbine comprised of Savonius wind turbine, combined with a three bucket H-rotor wind turbines with DUW200 airfoils was investigated [5]. It was concluded that when H-rotor and Savonius were combined, a higher performance was obtained as compared to the H-rotor only. The performance of a three-bladed combined Darrieus-Savonius rotor was investigated with Darrieus mounted on top of Savonius rotor, for overlap variations from 10.8 to 25.8% [6].

The importance of vertical axis wind turbines has been encouraged by the quick development of wind

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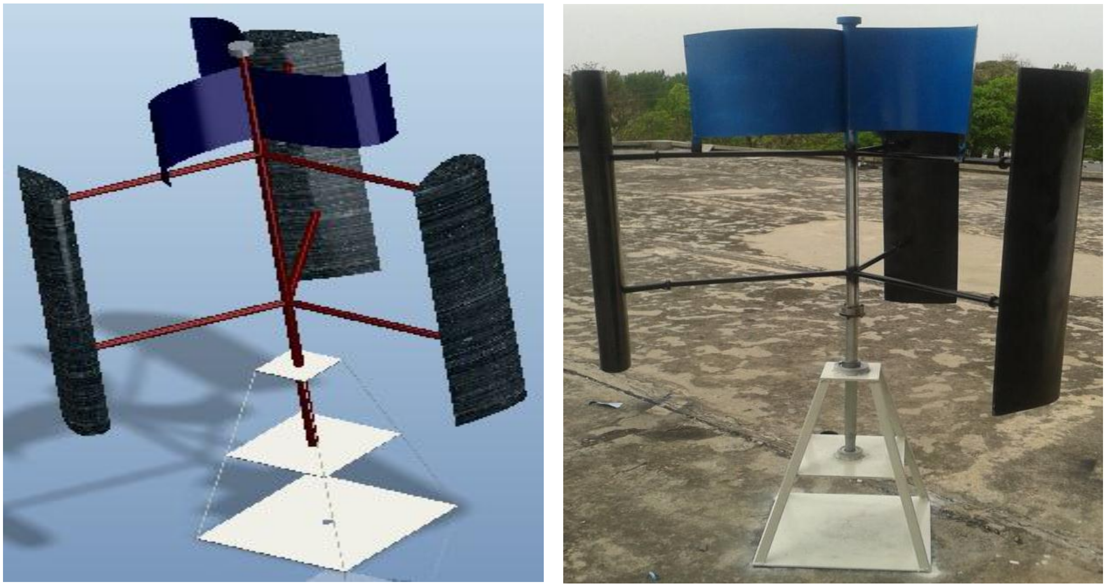
power generation and by the need for a smarter electrical grid with a decentralized energy generation, especially in the urban areas. The lift type vertical axis wind turbines (Darrieus wind turbine) performance prediction is a very complex task, since its blades move around the rotor axis in a three dimensional aerodynamic environment that lead to several flow phenomena, such as, dynamic stall [7], flow separation, flow wake deformations [8] and their natural inability to self-start. These issues can be overcome with the use of several more or less complex solutions, being one of them the development of a blade profile capable of making the wind turbines self-start [9].This paper focuses on presenting a methodology for the development of self-start capable Darrieus wind turbines with the improvement in the blade design and the integration of savonius device [10, 11].

With a 3-bladed vertical-axis wind turbine (VAWT), there are no in-plane and out-of-plane rotor vibrational modes which is observed in 2-bladed and 4-bladed configurations [12]. The symmetrical loading of a 2-bladed VAWT rotor can be eliminated entirely by the inclusion of a third blade. In addition to an increase in the dynamic structural stability of the rotor, the third blade reduces torque ripple in the rotor's torque output, thus reducing the compliance that must be built into the drive train of a 2-bladed VAWT. It was found that the thicker the blades the higher the drag contribution to the forward movement of the wind turbine blades [13]. In the NACA0025 airfoil the drag forces contributing to the tangential force are 110% higher than in NACA0012, and in the NACA0030 the forces are 150%higher than in NACA0012.The thicker blades are able to provide the wind turbine the self-start capabilities, while the thinner blade wind turbines are observed most likely unable to self-start [14, 15].The NACA0030 present 26% better performance than NACA0012 [13].

Design, construction and testing

Based on detailed study and calculation, the diameter of the turbine calculated is almost 1.5m with 50~100 Watts of power, at wind speed of 5~7 m/s. Structure was made of fiber glass, aluminum and cast iron to ensure high strength to weight ratios and durability. The base made from cast iron with proper supports keeps it stable. Two roller bearings were used in the base to support the shaft. A Savonius-type drag device was made from aluminum sheet and mounted to the main shaft. The VAWT developed is shown in Figure 1. All the tests on the turbines were performed in the sub-sonic wind tunnel laboratory as shown in Figure 2. Digital Anemometer and tachometer were used to measure the wind speed and revolutions per minute of the turbine. The turbine attained about 60 rpm at 3m/s, which was further reduced to 2.5 m/s after attaching the Savonious blades (see Figure 3). The cut off velocity of VAWT is 20 m/s. Theoretically, the calculated power of the generator is around 50 Watts at the rated wind velocity of 6m/s (see Table 1).



(a) (b)

Figure 1. Vertical axis wind turbine developed, (a) Image, (b) Photo

In order to generate electric power primarily an available customized generator that works on the principle of magnetic flux was used with the turbine. This generator had a cut in velocity of 3.5 m/s; this means that the turbine will start at 2.5 m/s but the generator will start taking the load when the wind velocity reaches 3.5m/s. The startupwind speed was found to be 4m/s. The turbine produced the maximum power of 35 watts at about 9 m/s.The turbine took the load at about 5m/s.As the generator was 10 years old, therefore a reasonable difference was observed between experimental and theoretical results. Experimental results are given in Figure 4. The assembly was directly connected to the generator which reduced the manufacturing complexity. The mounting mechanism improved the stability without having any effect on the cut in speed.

Figure 2. Testing of vertical-axis wind turbine

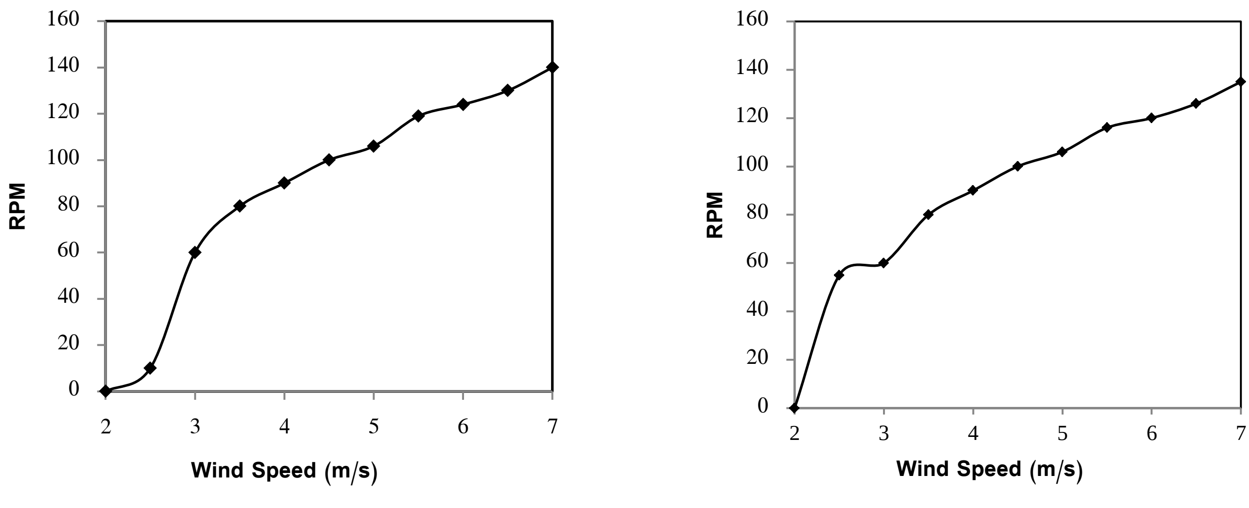


Figure 3. RPM Vs starting wind speed: (a) Without Savonius blades, (b) with Savonius blades

TABLE 1. Theoretical power calculations [16]

Parameters	Wind Densit = 1.243 kg/m^3 Diameter = 1.25 m Length = 0.9m Sweep Area = Dia x Length = 1.125 m^2 V_{avg} = 6m/s Generator Efficiency = 80% Turbine Efficiency = 42%
Wind Power = P_{max}	P_{max} = (1/2)pAv^3= 151 Watts
Attainable Power = P	P = 0.8 x0.42 xP_{max}= 50 Watts

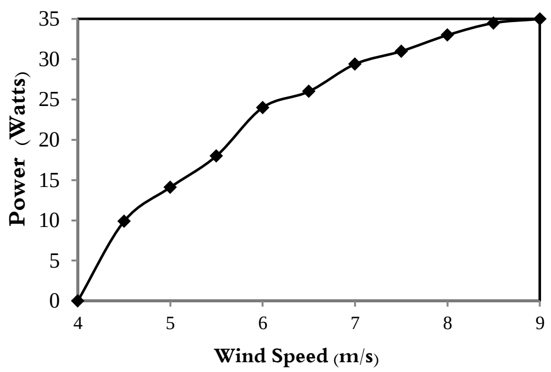


Figure 4. Experimentally calculated power using available permanent generator from industry

CONCLUSIONS

The Darrieus VAWTdesigned, fabricated and tested proved to function as a self-starter. The combination of NACA 0030 airfoil and Savonius device provided the functions required for a starting mechanism. It was also concluded that 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.

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Persian Abstract

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چکیده

با تمرکزی رو به رشد بر انرژی های تجدید پذیر، علاقه به طراحی توربین های بادی نیز در حال گسترش است. در بازار امروز، توربین با محور افقی (آسیاب بادی) رایج ترین نوع مورد استفاده می باشد. اما، توربین های محور عمودی (Darrieus) دارای مزایای خاص می باشند. توربینDarrieus ، که هدایت از طریق بالا برنده می باشند، دارای توان بالقوه ی بالاتری از توربین های افقی یا هدایت از طریق کشیده شدن می باشند. نقص اصلی طراحی آنها ناتوانی در شروع خود به خودی آنها است. توربین های Darrieus به یک منبع انرژی خارجی به دستگاه برای حداقل سرعت چرخش نیاز دارند. این مقاله طراحی، ساخت و آزمایش یک توربین بادیمحورعمودی (Darrieus) با ۳ تیغه، صرفا شروع با انرژی کم از باد را نشان می دهد. دستگاه کشیدن جداگانه (توربین نوع Savonius)در بالای توربین Darrieus موجود، سوار شده تا توربین در سرعت باد کم شروع به کار نماید. سرعت شکافتن توربین ۳m/sو، سرعت برشm/s ۲۰ و توان به دست آمده ۵۰ وات در سرعت باد از۶m/s بود. تست باژنراتور ابتدایی مغناطیسی دائم در دسترس با حمایت مالی صنعت منجر به ۳۵ وات در۹m/sشد.