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Design and Fabrication of a Hybrid Savonius-Darrieus Vertical Axis Wind Turbine to Achieve Efficient Low Speed Wind Energy Harvesting

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Abstract: The growing need to have sustainable and decentralized energy systems has pushed the study of wind energy systems that can effectively perform at the low wind speed. The VAWTs are especially the right choice under such conditions because of their omnidirectional wind acceptance and simple structural design. Nevertheless, traditional Savonius and Darrieus turbines are limited in nature when they are used in isolation. The design and construction of a hybrid Savonius-Darrieus VAWT with the ability to Self Start like the Savonius rotor and high efficiency-based performances of the Darrieus rotor is presented in this paper. The turbine itself is made of low-cost materials, including sheets of metal blades and L-angles of shelter in mild steel. There is a spur gear mechanism that increases the speed of the shaft rotation so that it may allow effective coupling with the dynamo that runs on DC. Generation of this electrical power is proved by using DC LED light as a proof of concept. Low-speed under wind conditions provide experimental performance from low wind conditions, which prove stable operation and dependable energy production. The presented hybrid turbine will be a cost-effective and environmental-friendly solution that might be applied to domestic, rural and off-grid renewable energy sources.

Keywords: Vertical Axis Wind Turbine, Savonius, Darrieus, Hybrid Wind Turbine, Low-Speed Wind Energy, Renewable Energy.

I. INTRODUCTION

Because fossil fuels are running out, the world needs more energy, and people are worried about the environment, we are under more pressure to find ways to get power that we can use over the long term and that can be replaced naturally. The wind power has become one of the most possible source of renewable energy because of its cleanliness, broad distribution and minimal environmental consequences. Nonetheless, an effective use of wind power in areas with low and extremely intermittent wind velocities is a significant engineering issue.

The use of Horizontal Axis Wind Turbines (HAWTs) in conventional wind energy generation is predominant owing to the high efficiency they have in the continuous steady and high wind conditions. Although this is an advantaged feature, HAWTs need complicated yaw-in-order systems, accurate wind-direct orientation, high elevation during installation, and high maintenance, which restricts the usage of the technology in cities, rural, and off-grid areas, where wind is disordered and slow-speed [1]. Consequently, there has been a growing interest in research on Vertical Axis Wind Turbines (VAWTs) that are capable of functioning without the wind direction and are better adapted to decentralized generation of power.

The Savonius and Darrieus turbines were the most analyzed types of VAWT. The Savonius turbine generates energy by means of drag and is highly praised as having a great self starting property at low wind speeds, but it is poorly aerodynamically efficient and has a low power output [6], [10]. Conversely, the Darrieus turbine has been designed with the principle of aerodynamic lift and, therefore, allows higher rotational speeds and higher efficiency, though this turbine has a poor self-starting behavior, especially when the wind is weak [12], [14].

In order to overcome the personal drawbacks of these types of turbines, hybrid Savonius-Darrieus designs have been suggested, which will incorporate the strengths of the drag-based and lift-based rotors. A number of experiments have been done to prove that hybrid turbines are incredibly beneficial in increasing the starting torque without reducing

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performance at operating speeds [1], [3], [7]. Tripathi et al. [1] have also found significant increases in torque and power coefficients through optimization of parameters in hybrid rotor, whereas Maldar et al. [3] have pointed out the efficiency of hybrid set up in cross flow energy systems.

The current studies have been devoted to the enhancement of aerodynamic characteristics of hybrid turbines by using computational fluid dynamics (CFD), geometric optimization and further models development. To reduce the aerodynamic interference between the Savonius and Darrieus rotor, Ghafoorian et al. [2] proposed a dual-shaft hybrid design, which resulted in large changes in the power coefficient in both the low and high tip speed ratio (TSR) regimes. Likewise, Arrieta-Gomez et al. [4] used regression modeling and design of experiments to maximize the hybrid turbine parameters showing a significant improvement in their efficiency. The research on aerodynamic interaction also demonstrates that inappropriate rotor coupling may influence the performance adversely, and it is essential to optimize the hybrid integration [5], [13].

Besides the numerical optimization, some modern innovations are the application of artificial intelligence methods to predict the performance of turbines. Noman et al. [6] proved that ANN-based virtual clones have the capability of forecasting the Savonius turbine performance with less computational work and is a promising design optimalization tool. Observations using experimental fabrication-based studies have also revealed that mechanically simple and low-cost hybrid turbines can be successfully introduced to small-scale power generation [7], [8].

Although much research has been conducted with numbers and using experiments, little has been done on simple and low-cost hybrid wind turbines specifically designed to serve domestic, rural, and off-grid power. Most of the current designs are based on complicated aerodynamic shapes, or superior production processes, limiting their use in third world communities.

In this paper, the design and construction of a hybrid Savonius-Darrieus Vertical Axis Wind Turbine is optimised to low-speed wind energy collection are described. The turbine itself is made of mild steel L-angle supports and sheet metal blades making it cheap, durable, and simple to produce. A spur gear system is used to drive the turbine shaft faster to allow the efficient production of electrical power to a DC dynamo. Experimentally, the proposed system can be seen to be feasible by powering a DC LED lamp, and thus the system can be used in small-scale renewable energy generation, like rural electrification, domestic power supply, and off-grid energy systems.

II. SYSTEM DESIGN & METHODOLOGY

A. Overall System Architecture

The proposed system includes a hybrid Savonius-Darrieus Vertical Axis Wind Turbine (VAWT) that is mechanically driven connected to a DC power generating unit by a speed amplification system. The main aim of the system is to tap into low-speed wind conditions in an efficient way and has their structural simplicity and low cost of fabrication. The hybrid turbine combines the drag-based Savonius rotor with enhanced self-Starting and lift-based Darrieus rotor with enhanced power output at the higher rotational speeds.

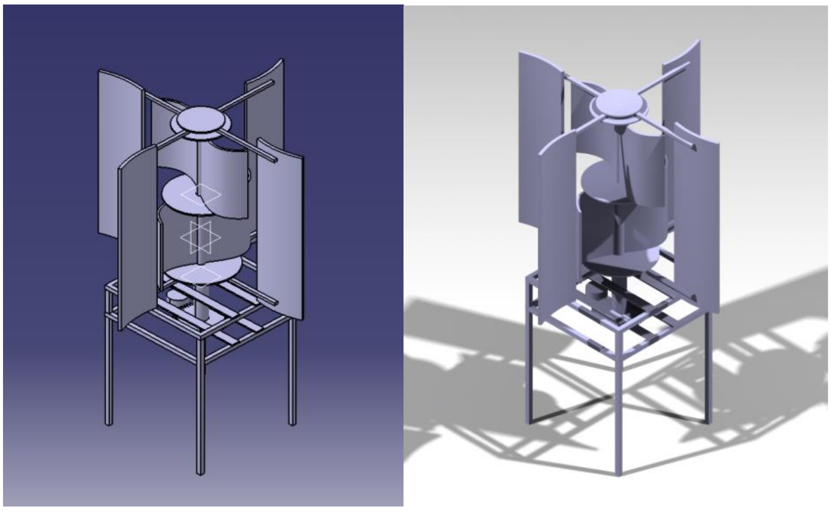

Fig 1. Model of hybrid Savonius–Darrieus Vertical Axis Wind Turbine

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The rotational energy of the propeller shaft is carried on to spur gear system to accelerate the shaft speed and power is supplied to a DC dynamo. The resulting electrical output is used to drive a DC LED load, proving the ability of the system to be used in practice in the small scale (i.e., rural lights and off-grid energy systems).

B. Hybrid Rotor Design

1) Savonius Rotor Design

The Savonius rotor will be a design with semi-cylindrical sheet metal blades in an overlapping arrangement. This rotor works on the principle of differentiating drag and it has high starting torque even in low wind velocities. The most important design factors are the blade curvature, the ratio of overlap, and the rotor diameter which have a great impact on the starting torque and the efficiency of the system.

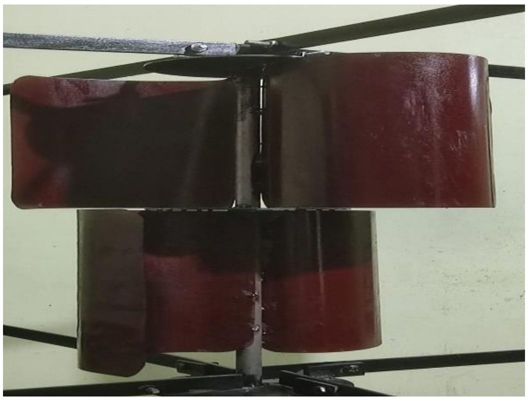

Fig 2. Savonius Rotor Design

The choice of sheet metal in the fabrication of blades is due to the fact that it is lightweight, corrosive resistant and easy to shape, thus is affordable to manufacture. The Savonius rotor is attached to the middle part of the shaft so that to provide equal torque generation in the initial stage of the start.

2) Darrieus Rotor Design

The Darrieus rotor is made up of straight vertical arranged blades that are symmetrical with each other and are arranged around a Savonius rotor. Contrary to conventional curved Darrieus blades, straight blades are taken up to make fabrication easier and manufacturing less complex. The lift is produced by these blades at a greater proportion of tip speed, and helps to increase the power production as soon as the turbine has attained operating speed.

Fig 3. Darrieus Rotor Design

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L-angle supports fix the Darrieus blades on the main shaft to guarantee structural stability and vibration resilience. The hybrid set-up facilitates successful aerodynamic interplay between the drag and the lift forces leading to enhanced overall performance.

C. Shaft and Structural Frame Design

The turbine shaft is made of mild steel, which is high in strength, durability and is available. The shaft also supports Savonius rotor and Darrieus rotor, and is also mounted on ball bearings to reduce the losses due to friction. Adequate alignment is done to minimize mechanical vibrations and improve safety of operations.

The structural frame is made of mild steel L-angles and makes up a stiffened support structure that can resist the loads caused by wind. L-angles allow ease of assembly, cost-effectiveness and adequate mechanical strength and the design is suitable to be used in the field.

D. Speed Amplification Using Spur Gear Mechanism

A spur gear system was used to accelerate the speed of the shaft prior to electrical conversion since the speed of its rotation is usually low (vertical axis turbines). The gear ratio will be chosen to present an equilibrium between the transmission of the torque and the improvement of rotational speed without any undue mechanical losses.

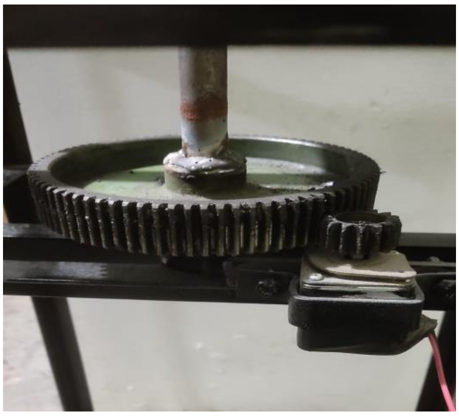

Fig 4. Spur Gear Mechanism

The key gear is placed on the turbine shaft and the secondary gear is attached to the dynamo DC shaft. The installation guarantees smooth transmission of power and it enhances the performance of generators during low wind speeds.

E. Electrical Power Generation System

Mechanical energy is transformed into electrical energy with the help of a DC dynamo. The DC generator allows this to be made easy since the system does not require any elaborate power conditioning circuits. The resulting DC output is directly linked to a DC LED lamp which is a visual indicator of power output and system operation.

The electrical subsystem proves that the proposed hybrid turbine has the potential of being used in low-power applications, such as outdoor lighting, sensor nodes, and small electronic loads.

III. EXPERIMENTAL SETUP AND TESTING

A. Experimental Setup

The experimental setup was designed to test self-starting action, the rotational performance and the electrical power generation capacity of the new hybrid Savonius-Darrieus VAWT at low and variable wind speed. The turbine was then attached on a stiff mild steel frame to allow it to be stable mechanically when standing in operation.

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Fig 5. Experimental Setup

The hybrid rotor was mounted on a mild steel shaft with the vertical axis and cushioned on ball bearings to reduce the amount of frictional losses. A speed-increasing mechanism was used between the turbine shaft and the DC dynamo shaft that was in the form of a spur gear. The DC dynamo DC outlets ran directly to a DC LED strip that was used as the electrical load and performance indicator.

The whole system was made to be under open atmosphere conditions in a natural setting so that the turbine could run using natural wind flows without creating its own air flows. This methodology is used to offer realistic performance analysis to small wind energy applications.

B. Instrumentation and Measurement

The experimental testing involved the following instruments and components:

- Anemometer is used to measure the speed of the ambient wind.
- Output voltage of the DC dynamo are measured with the help of the digital multi-meter.
- DC LED strip is used as a load and performance indicator.

The measurements of wind speed were carried out at the height of the turbine to ascertain the accuracy. The parameters of electrical output were recorded across the LED terminals.

C. Testing Procedure

The test process was conducted in a systematically organized manner as follows:

- The turbine was placed in an open space where there were no obstructions to ensure that the wind was exposed equally.
- An anemometer was used to record the initial wind speed.
- It was monitored that the turbine started itself at low wind speed.
- Electrical output voltage were obtained at varying wind speeds.
- In order to monitor the power generation, the power of the DC LED was monitored visually.
- Measurements were also done several times to achieve consistency and reliability of results.

IV. RESULTS AND DISCUSSION

The fabricated hybrid Savonius-Darrieu Vertical Axis Wind Turbine (VAWT) was experimentally tested in low wind speed conditions to test its electrical performance. The major parameters that were chosen to evaluate the effectiveness of the hybrid configuration in the utilisation of wind energy were the speed of the wind and the output voltage.

Experimental Results

A handheld anemometer was used to measure wind speed and DC dynamo produced an output voltage which was

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measured using a digital multimeter. The turbine showed good performance during low wind speeds and voltage was measured as soon as the rotor was started.

Table 1: Wind Speed vs Output Voltage

Wind Speed (m/s)	Output Voltage (V)
1.8	1.6
2.2	2.3
2.6	3.0
3.0	4.1
3.4	5.2
3.8	6.2

These findings are clear to point out that the hybrid Savonius-Darrieus VAWT can produce electrical energy at extremely low wind velocities with measurable voltage produced at a speed of about 1.8 m/s. This validates the high self-initiating nature of the Savonius rotor that is an important aspect during the start-up of the turbine.

With the increase in wind speed, there was an almost linear increase in the output voltage. This action is credited to the effect of the Darrieus rotor that increases the speed of rotation by the lift forces when the turbine is flowing. The interaction of both drag-based and lift-based rotor leads to a better conversion of energy than a single Savonius turbine.

The highest output voltage measured 6.2 V in the wind speed of 3.8 m/s which was enough to propel a DC LED load. The findings reveal that the system has the capability to generate constant voltage levels without experiencing sudden drops in voltage despite the changing wind conditions, which shows a stable mechanical state and good connection between the rotor, spur gear system and DC dynamo.

The results of the performance patterns, especially low cut-in wind speed and slow rise in voltage with wind velocity, are similar to those reported in earlier hybrid VAWT studies [1], [3], [7]. Although the absolute voltage output is confined by the small-scale prototype and generator rating, the findings confirm the usefulness of the hybrid concept in small-power and decentralized use.

The experimental evidence proves that the offered hybrid Savonius-Darrieus VAWT is effective to combine the low-speed initializing ability and the enhanced electrical performance. The turbine is efficient in low and variable wind conditions, and thus it can serve as a good solution to domestic lighting, rural electrification, and educational renewable energy systems.

V. CONCLUSION

The present study successfully demonstrates a hybrid Savonius-Darrieus Vertical Axis Wind Turbine (VAWT) can be designed, fabricated, and tested to be optimal in harvesting low-speed wind energy. The turbine has the advantage of a drag-based Savonius rotor coupled with a lift-based Darrieus rotor to achieve a self-starting property and efficiency in rotating the turbines. As experimental evidence has shown, the turbine begins operating as soon as the wind reaches 1.8 m/s, which proves the effectiveness of Savonius rotor to begin rotating at the slightest wind power. The DC dynamo and a spur gear device were able to turn mechanical energy into electricity that was used to drive a small DC LED as a demonstration of concept. The hybrid design has been shown to be stable in voltage production with changing low wind velocities, which verifies that it is applicable to small-scale, decentralized applications, including domestic lighting, rural electrification, and educational demonstration projects. Affordability, structural robustness and easy production of the system has been achieved by using low-cost materials such as mild steel L-angle and sheet metal blades, which are lightweight and easy to make, and useful in off-grid and constrained resource settings

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