Improving the Value of the Power Coefficient for Three Straight-Blades Darrieus Wind Turbine

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Abstract. In this study, an experimental test was carried out using a subsonic wind tunnel to study the improvement of the power coefficient of the three straight-blade Darrieus vertical axis wind turbine. A three-blade vane type vertical axis wind turbine with three movable vanes in each of the blades was fitted in the middle of the three straight-blade Darrieus (0012 Airfoil) vertical axis wind turbine, and they are installed on the same rotor shaft. For this purpose, two vertical axis wind turbine, the first one has three straight-blades Darrieus of type 0012 Airfoil and the second also has three straight-blade Darrieus but of type 0012 Airfoil with a three-blade vane type vertical axis wind turbine with three movable vanes were manufactured. Both turbines were tested using a subsonic wind tunnel at different wind speeds ranging from (4-28) m/s. The consequences showed that in the second turbine test, a power coefficient of $C_p=0.39$ was obtained, which is greater than the power coefficient of the first turbine ($C_p=0.184$) after the turbines were tested in a wind tunnel under identical conditions at a wind speed of 6 m/s. Therefore, the second wind turbine produces greater electrical power than the first wind turbine.

Keywords. Darrieus wind turbine, Straight-blade, Movable vanes, Power coefficient, Wind tunnel.

Introduction
The selection for the charm of renewable power has been creating due to the truth of the driving forward with oil catastrophe and natural contamination, and one of these sources is wind vitality. The overview carried out in the USA, and Europe showed that around 12% of the world's vitality era would be substituted with wind control by implies of 2020 (http://www.spiedl.org/2015).

Wind vitality is the most significant achievable renewable vitality valuable asset and moo rate in qualification with conventional fossil assets. Wind control can help in bringing down the reliance on fossil fuel. Numerous universal areas realized the greatness of wind vitality as a fundamental control asset. Important measures are being taken up worldwide to tackle most vitality from wind, and it is brilliant to utilize in the vitality era. It has been anticipated that around 10 million MW of wind vitality ceaselessly convenient on the floor of the soil [1]. WTs, which includes a for the most part HA kind and vertical pivot kind, can change over wind control into mechanical vitality. Although the even pivot wind turbine (HAWT) is the foremost common kind, the request for a VAWT has been developed within the world, especially the straight-bladed vertical hub wind turbine (SB-VAWT) due to the reality of its benefits such as moo in the coast, simple setup and redesign and numerous more. Nevertheless, the usefulness of self-
beginning of the SB-VAWT is very low, which is one of its drawbacks. In contrast, the Savonius and level plate rotor, which are a drag-type VAWT, have excellent starting execution. Subsequently, the Savonius and level plate rotors can be utilized as a tenderfoot for the SB-VAWT to amplify the start torque at moo turn and moo wind speed. The Darrieus wind rotor could be a VAWT at the starting concocted by implies of Darrieus [2]. It has two or three bent edges with airfoil cross-section of steady chord length. Both closes of the edges are connected to a vertical shaft (Figure 1).

![Darrieus rotor (egg-beater type).](image)

The DWT has moo opening torque in any case; it allows great effectivity at the intemperate rotational speed [3]. That is why the DW rotor cannot be utilized alone as anelectic. It is also considered that Savonius, at the same time with Darrieus, can compromise each other, blending with Darrieus upgrades each other blending the over the top beginning torque of the Savonius and the effectivity of the Darrieus machines at over the top rotational speeds. Gavalda et al.[4] considered the exhibitions of a self-adapting Savonius–Darrieus having two-frame Savonius and two-bladed aerofoil Darrieus rotor. The maximum control coefficient of 0.35 utilized to be once detailed at a cover proportion of 1/ 6. Gupta et al. [5] examined tentatively the by and large execution of a mixed Savonius–Darrieus wind rotor having a two-bucket Savonius rotor and 3-bladed Darrieus rotor in a subsonic wind. The foremost $C_p$ was gotten to be 0.25 at a 20% cover and 0.32 tip-speed proportion.

Wakui et al. [6] carried out a comparative comparison of the exhibitions of two astounding crossbreed setups of Savonius–Darrieus wind machine; one having two, two-bucket Savonius rotor, as the starter for a single two-bladed Darrieus rotor with the Savonius one inner of the Darrieus rotor and the other, same setup of Savonius rotor at that point once more set up beneath the Darrieus rotor. They decided that the 2d sort delivered a most extreme $C_p$ of 0.18 is the way better. Farhan Ahmed K.et. al. [7] considered a comparative study to find out approximately a drag drive for a level plate edge and a blended straight bladed Darrieus– Level plate edge. Based on wind burrow assessment information, the commencing torque generally, execution, and drag coefficient in general execution have been analyzed, and the achievability of the combination was once said. The plan proposed in 1925 using the French design Darrieus, in specific, has been seen as a promising thought for modern-day wind turbine (VAWT) thoughts are that their basic chart comprises of the plausibility of lodging mechanical and electrical components, gearbox, and generator at floor confirmation which there is no yaw contraption. Typically countered with the valuable asset of threats such as moo tip-speed ratio, lack of capacity to self-start, and inability to control power yield or speed by utilizing pitching the rotor edges. The Darrieus rotor's variation is the so-called
H-rotor (Figure 2 Endeavors were made extraordinarily within the UK, within the US, and Germany to develop this graph to undertaking development. On the other hand, of bent rotor edges, straight edges related to the rotor shaft by way of the struts’ capacity are utilized. H-rotors of a primarily straightforward structure, with the completely energized generator built-in at as before long as into the rotor structure excepting broker gear-box, have been created with a German maker’s help up till the opening of the nineties [8-11].

![Figure 2. Schematic of H-rotor wind turbine.](image)

Ying et al. [12] considered the optimal design and ordinary movement execution of the coasting of a 5 MW H-type VAWT. The coasting establishment utilized to be a truss fight sort is besides studded. The double-multiple-stream tube statute is also utilized to calculate the streamlined piles, which show up on the wind turbine considering the movements of the drifting establishment. The results of that comprise of an H-type turbine were given distant better; a much better; a higher; a stronger; an improve a much better development execution. Qasim et al. [13] planned vertical pivot wind turbine mobile level vanes pivoting as a substitute for being steady to constrain the loathsome torque on the structure of non-work (against the course of the wind). Usually, the edge vanes open and disregard the wind by means of the edge unreservedly without resistance to the discussion. To begin with, this thought has been put forward by planning three vanes being even in everyone and 2nd by planning three vertical vanes in a single outline. Khammas et al. [14] explored the effect of remarkable organize parameters for the general execution of the evaluation of SB-VAWTs. Amid this examination, they find that the VAWT contains a higher capability to extricate more vitality from moo wind than HAWT. SB-VAWT had significant parameters like edge optimal design, robustness, pitch point, the number of edges, and TSR on execution.

In this paper, a vane-type rotor with movable vanes in accordance with its high beginning torque is built-in with an H-rotor in order to expand the self-starting and performance coefficient of the WT. The proposed WT is outlined with three blades that have three rotating vanes in each blade, which makes cavities form with the upper and lower board when shut. The frames’ cavities enhance the building of the drag variable for the combined turbines to prolong the torque and the output power capability of the blended turbine. In opposite side reductions, the wind is resisted by the blades, which rotates in the opposite course of the wind by opening the moving vanes, thereby resisting the wind. This makes the negative torque to decrease.

**Wind tunnel setup**

The wind turbine test's target is to verify the power performance of the proposed design, hold real information, contrast the real information and the theoretical outcomes, and analyze the efficiency of product testing. The wind tunnel, as shown in Figure 3, has a cross-segment zone with measurements of 300x300 $mm^2$. The endorse combined model is set up in the middle of the working area of the turbine.
The range of the wind speed utilized is between 3.8 m/s to 28 m/s. The wind velocity is measured via recorded stress drop from a Pitot tube ($\Delta P$), and utilized Bernoulli formula (1):

$$P_1 + \frac{1}{2} \rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2} \rho V_2^2 + \rho g h_2$$

To estimate the wind velocity, the following formula can be used:

$$V = \sqrt{\frac{2 \times \Delta P}{\rho}}$$

Where $P$ is the pressure and $g$ is the gravitational force.

The tachometer shows minimal Instrument Advent Tach-post device used to determine the revolution velocity of the wind turbine shaft with the assistance of a contact of white paper attached to it that reflects light.

![Figure 3. Subsonic low-speed wind tunnel.](image)

**Experimental setup**

A hybrid wind turbine comprises three edges vane kind vertical pivot wind turbine. The beat and foot sheets have outlined the utilization of the rotor distance across and rotor tallness of 0.085 m and $H=0.11$ m, separately as appeared in (Figure 4a). The three edges vane sort has put the center of the three straight bladed Darrieus [0012 airfoils] with a breadth of 0.2m, the tallness of 0.11m, and a line estimate of 0.035m, as shown in Figure 4 (a and b). The combined three blades wind turbine fixed in the center testing place of wind tunnel and the essential tools used in the experimental test under the action of versus wind speed. The type of generator chosen to be used in this mission is an AC dynamo motor of (1–30) volt. Even though the original use of it is a motor, the motor has equal construction as the generator. This kind of generator is used in this project because the mixed wind turbine does now not have massive torque, which will be required to turn a better generator. Experiments are conducted in different wind velocities, and the output energy is acquired when the wind condition and turbine rotational speed is steady. The wind speed has been measured with the use of a digital anemometer. The output electrical power is measured via a Lutron DW-6060 wattmeter with an accuracy of 1%. The wind tunnel speed has been modified by changing the frequency of its inverter, and in every wind speed, the output power is measured based on analyzing the wattmeter. Then the power coefficient of the wind turbine is calculated based on the following formula:

$$C_p = \frac{W_{gen}}{0.5 \rho AV^3}$$
Where in Equation 3, $C_p$ is the power coefficient, $W_{\text{gen}}$ is output electrical power (Watt), $A$ is the swept area ($m^2$), $V$ is the wind velocity (m/s).

**Results and discussions**

The results of energy generation with $a$ versus wind velocity of every wind turbine using a subsonic wind tunnel are illustrated in Figure 5 and Figure 6. The comparative study between the outputs powers of every WT is shown in Figure 7. The hybrid turbine starts its power generation faster than the H-rotor. It is clear from the figure that, in the position vane type with movable vanes is middle the H-rotor; more significant amounts of power are generated (21.12 watt at wind velocity of 28 m/s). As expected, H-rotor's combination with vane-type rotor improved the H-rotor's self-starting capacity, and the mixed turbine starts electricity generation than H-rotor.

**Figure 4.** a) Front view for the hybrid wind turbine. b) Hybrid wind turbine of a vane-type in the middle of the H-rotor.

**Figure 5.** Experimental Electrical output power versus wind velocity for H-rotor wind turbine.
Figure 6. Experimental electrical output power versus wind velocity for vane type middle of H-rotor wind turbine.

Figure 7. Experimental electrical output power of each wind turbine at different wind velocities.

The Power coefficient $C_p$ of each turbine is plotted in Figure 8, the Hybrid turbine with vane type with movable vanes in the middle of H-rotor position has the very best power coefficient ($C_p = 0.395$) in compare with the H-rotor ($C_p = 0.184$). The power coefficient $C_p$ of each turbine increases as the wind speed increases to 6 m/s. The leading cause for this extends, adding the drag pressure without the elevate and positive impact of vortex flows in empty areas of H-rotor and converging the wind direction with the rotor. Then, after wind speed gets 6 m/s, each turbine's power coefficient decreases with increased wind speed, as shown in Figure 8.

Figure 8. Power coefficient of each wind turbine at different wind velocity.
Conclusion
The experimental findings showed enhancement in the power coefficient for three straight-blades Darrieus wind turbine, aerodynamic overall performance effects of Hybrid and H-rotor acquired from experimental tests in a subsonic wind tunnel at different wind speeds ranging from 4-28 m/s. In the model vane type with movable vanes rotor in middle of H-rotor, results show that built-in each vane type with movable vanes and H-rotor with other makes an efficient wind turbine that has better self- beginning capability besides higher power coefficient and in opposite side reductions, the wind is resisted through the blade which rotates in the opposite direction of the wind through opening the moving vanes thereby resisting the wind. This makes the negative torque to decrease. Figure 8 shows the variant of power coefficients at distinctive wind velocity. It is seen from the graph that the most power coefficient of \(C_p=0.395\) for Hybrid wind turbine which is higher than H-rotor \(C_p=0.184\). In any case, whereas comparing the control coefficients \(C_p\) for H-rotor Darrieus wind turbine with that of the blended setup of vane sort with mobile vanes-Darrieus H-rotor, it is decided that there is a particular change within the control coefficient for the Crossbreed vane sort–H-rotor that, provided an effectivity of 0.395 which, is higher than the effectiveness of the H-rotors rotor \(C_p=0.184\) at the conditions of the same test of wind speed 6m/s.

References
[1] Shrikant G Gawade and Prof Patil 2015 Comparative Study of a Single Stage Savonius with a combined Savonius-Three Bladed Darrieus (International Journal for Technological Research in Engineering) vol 2 no 6
[2] Darrieus GJM 1931 Turbines Having its Rotating Shaft Transverse to the Flow of the Current (US patent) no 1 835 018
[3] Shankar PN 1979 Development of Vertical Axis Wind Turbine (Proc Indian Acad Sci) C2) vol 1 pp 49–66
[4] Gavalda Jna, et al 1990 Experimental Study on a Self-Adapting Darrieus– Savonius Wind Machines (J Sol Wind Technol) vol 7 no 4 pp 457–61
[5] Gupta R, Das R and Sharma KK 2006 Experimental Study of a Savonius– Darrieus Wind Machine (In: Proceedings of the international conference on renewable energy for developing country)
[6] Wakui T, et al (Member Waseda University: twakui@aoni.waseda.jp) 2005 Hybrid Configuration of Darrieus & Savonius Rotors for Stand-Alone Wind Turbine-Generator System.
[7] Farhan Ahmed K et al 2017 Comparative Study of a Drag Force for Flat Plate Frame and a Combined Straight Bladed Darrieus- Flat Plate Frame (Journal of Telecommunication, Electronic and Computer Engineering) e-ISSN: 2289-8131 vol 10 no 1–14
[8] Paraschivoiu, I 2002 Wind Turbine Design: with Emphasis on Darrieus Concept (Canada: Presses Internationales Polytechnique)
[9] Kaltschmitt, M, W Streicher and A Wiese 2007 Renewable Energy, Technology and Environment Economics (Berlin, Heidelberg: Springer-Verlag)
[10] Antheaume, S, T Maitre and J Achard 2008 Hydraulic Darrieus Turbines Efficiency for Free Fluid Flow Conditions Versus Power Farms Conditions (Renewable Energy) vol 33 no 10 2186e98
[11] Hwang, I S, Y H Lee and S J Kim 2009 Optimization of Cycloidal Water Turbine and the Performance Improvement by Individual Blade Control (Applied Energy) vol 86 no 9 1532e40
[12] Ying G, Liqin L, Xifeng G and Wanhai X 2018 Aerodynamics and Motion Performance of the H Type Floating Vertical Axis Wind Turban (Appl. Sci.) vol 8 p 262
[13] Qasim A Y, Usubamatov R and Zain Z M 2011 Design of Vertical Axis Wind Turbine with Movable Vanes (Australian Journal of Basic and Applied Sciences) vol 5 pp 896–902
[14] Khammas A F, Mustaffa M T, Usubamatov R, Askar K H, Qasim A Y and Guadir G A 2015 Investigate the Effect of Difference Design Parameter on Performance Evaluation of Straight Blade Vertical Axis Wind Turbine (Sh-Vawt) (International Journal of Engineering Technologies
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