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Experimental Test of Combined Wind Turbine in Wind Tunnel

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Abstract: In order to explore the enhancement in the coefficient of performance (C_p) of a three SB-Darrieus VAWT, an experimental test using a subsonic wind tunnel was carried out in this study.

In the center of the three SB-Darrieus (NACA 0012 Airfoil) VAWT, a 3-blades vane-kind VAWT with three moving vanes in each blade were placed, and both of the two types were set up on the same rotor shaft. To create the combined WT, two VAWTs were manufactured and assembled on the same rotating shaft. The first one is a Darrieus VAWT, has three SB (NACA 0012 airfoil) and the second one is a vane-type VAWT, has 3-blades with three movable vanes. A subsonic wind tunnel was used to test the combined WT at range of wind speeds varies from 2 to 12 m/s. The test in the wind tunnel, showed that the maximum value of the coefficient of performance (C_p) for the combined WT is (0.399), at speed of 5 m/s for the wind. It is considered greater than the value of (C_p) for the conventional Darrieus WT.

Keywords: Enhancement. experimental test. Darrieus, combined VAWT, power coefficient, movable vanes.

Abbreviations		**Notation**	
WT	Wind Turbine	V	Wind speed
HAWT	Horizontal Axis Wind Turbine	A	Swept area
VAWT	Vertical Axis Wind Turbine	C_p	Power coefficient
SB	Straight Bladed	C_d	Drag coefficient
TSR	Tip Speed Ratio	$W_{gen.}$	Generated power
RPM	Revolution Per Minute	ρ	Air density
AR	Aspect ratio		
AC	Alternating Current		
2D	Two Dimensional		

1. Introduction

In order to design a WT system that has the ability to generate power with high efficiency, a comprehensive perception of the aerodynamics and structural dynamics principles' for the rotor system is required. Variety of WTs mechanisms' are proposed to harness and mutate the wind's kinetic energy.

Two main kinds of WTs are available, the first one is the HAWT and the second one is the VAWT. WT machines' of horizontal pivot, considered much evolved and are used these days in the wind farms [1].

Each design has its own characteristics, which differs than the rest of designs. The most common type for using in applications of large-scale is the propeller type WT, which constitutes approximately all of the universal commercial turbines' whereas the VAWTs are commonly used more in medium as well as small-scale applications [2-3].

By analyzing these WTs, it was found that these turbines' design is not ideal and the power of the wind cannot be used entirely, as a result to many geometric issues.

To design a new type of the VAWTs without having drawbacks and has the ability to be used in wide range of application, the new type should be firstly use the kinetic energy of the wind and take the Betz limit as a maximum [4].

Design of the VAWT type with movable vanes is unpretentious in construction, production, and uses the force of drag by active area of the working elements. The maximum theoretical power coefficient of any WT design that runs in an open atmosphere is (0.59 or 16/27), which is known as the Betz Limit [4-5]. The global real limit for the coefficient of performance (C_p) is less than the Betz Limit, with range of values between 0.35 and 0.45 and these values are applicable even in the case of the WTs that have the best design. It is necessary to know that there are other losses in energy for a complete system of WT and approximately only (10-30%) of the wind's power is transformed into electricity.

Recent time studies are finding that HAWTs (designed on lift force), have theoretically higher efficiency than VAWTs (designed on drag force).

However, in spite of its lower efficiency, VAWTs have the ability to produce more electricity in cases where the wind is in turbulent condition and wind direction is not stable.

It is important to know that the power product of a WT's generator is proportionate to the acting area of WTs, as well as knowing that the power product of a WT's generator is proportionate to the cubic value of wind velocity. These features have to be taken into considerations as major factors of the power production for designing a new kind of WTs. The main aim of the new kind of Wind turbines is to increase the coefficient (C). Mainly, drag factor (C_d) is function of Reynolds number, element geometry of the WT, and Froude number.

Concerning the propeller WT, (A) is the swept area of the rotating blades, it should be mentioned that the actual area of blades four to five times less than (A). The wind between propellers goes by in a free way without obstructions and does not affect the blades. The actual output power of the propeller WT is four to five times less than the theoretical power of the turbine.

Results obtained from the tests that has been carried out using a cylindrical structure (Flettner rotor), demonstrated that the drag coefficient (C_d) could be enhanced by adding disks at the structure's top and bottom, this increment in (C_d) reaches about (60 to 90 %). The disks efficaciously convert the finite cylinder into an infinite one (less viscous lack close to the disks), through ensuring 2D influx style. For the proposed converter of wind power, it can be anticipated that shutting off the rotor by a disk (which shows up along the exterior verge of the rotor) at both top and bottom, will increase the value of the drag coefficient from $C_d = 1.2$ to $C_d = 2$ [6].

For a flat plate of (AR) value less than (5:1), the maximum efficiency gets to only about 18% (without taking effect of kinetic wind's pressure that acts on more than one rotor blade). This is sort of a low efficiency, almost the reason to reject the VAWT's resistance converter as an inactive notion [7].

Ying et al. [8] studied the optimal design and normal implementation of the coasting H-kind vertical axis WT of (5 Megawatt). The coasting construction used to be a truss resist type. The double current tube's status is used as well, to reckon the streamlined piles, which appear on the WT with taking the motion of the construction drifting into account. The obtained results showed that the type, which consists of H-kind turbine, has a better and higher development and implementation.

Qasim et al. [9] designed VAWT with movable vanes as an alternative for being immovable to limit the unfavorable torque on the turbine's structure (against the wind's direction). Generally, vanes of the edge open regardless the wind's direction and without impedance. This idea has been proposed by designing three vanes that are all even, and in other way in by designing three vertical vanes in a solo design, as illustrated in "Fig.1".

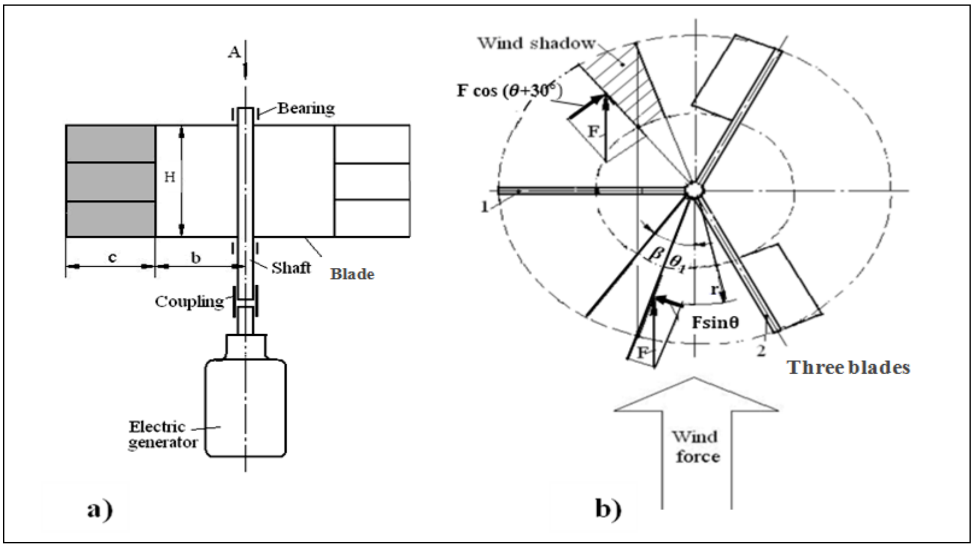

Figure 1 Vane-type three blades VAWT (a) Front view blades (b) Top view blades

Khammas et al. [10] examined the effect of specified parameters to evaluate the implementation ability and the performance of the straight-bladed vertical axis WTs. It was found from this examination that the vertical axis WTs has a higher ability to extract more power from wind compared to the horizontal axis WTs. The straight-bladed vertical axis WTs owns number of effective parameters such as tip speed ratio (TSR), edges' number, pitch point, solidity, and optimal design for the edge. "Fig.2" illustrates the three SB-Darrieus WT.

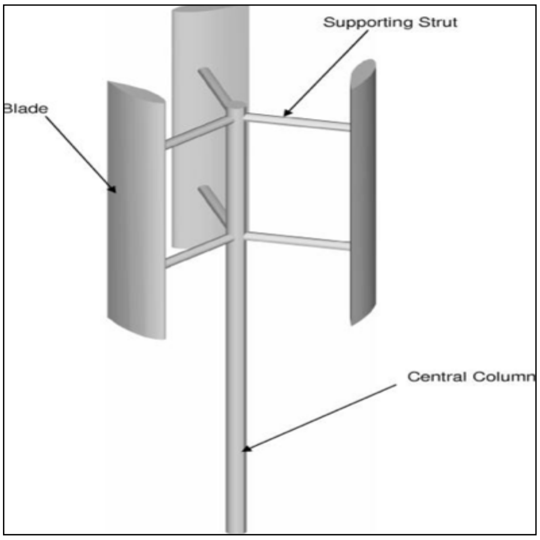

Figure 2 Three straight-blades Darrieus wind turbine

To enhance the self-beginning ability and the power coefficient (C_p) for the wind turbine, a vane-kind with moving vanes is installed with the H-Darrieus rotor. The combined wind turbine is made of 3-blades and each one of these blades have a three rotating vanes, when these vanes shut, they make cavities shape with the upper and lower board. The cavities of the blades improves the drag variance, to extend the torque and the power product of the combined WT. When the turbine is rotating in a direction opposite to the wind direction, the vanes are opened and this means the wind goes freely through it without resistance, which reduce the magnitude of negative torque for combined WT. “Fig.3” illustrated the combined WT rotor.

Figure 3 Combined three blades wind turbine rotor

2. Wind Tunnel Setup

An experimental test using a subsonic wind tunnel is carried out, to check the performance of the combined wind turbine design, acquire reliable info, compare the actual results with the theoretical results, and analyze the efficiency of the combined design.

The subsonic wind tunnel that is illustrated in “Fig.4” has a cross-segment with test area of measurements (30x30) cm^2. The Darrieus-vane type VAWT model is being placed in the center of the working area of the wind tunnel.

Figure 4 Subsonic wind tunnel

3. Experimental Setup in the Wind Tunnel

A hybrid combined WT contains three edges vane-type VAWT. The beat and foot sheets have summarized the use of the rotor distance across and rotor tallness of 0.085 m and H= 0.11 m, as shown in “Fig.5a”. The 3-edges vane-type has been placed in the middle of the three SB-Darrieus (NACA 0012 airfoil) with a width of 20 cm, height of 11 cm, and a line estimate of 0.035m, as illustrated in “Fig.5a and 5b”.

The three SB-Darrieus with movable vanes combined WT, is set up in the middle of the subsonic wind tunnel testing area. There are some of the useful tools that have been used in the experimental test such as the generator, the generator’s type that has been utilized in this test is an AC dynamo motor of (1–30 volt), despite the fact that the major function of it is a motor, but the motor has a structure similar to the generator. This sort of generators is utilized in this experiment, as the combined WT has no large torque; the large torque in turn requires a superior generator.

Experimental tests are carried out for several wind speeds and the product power is measured whenever the (RPM) and the wind condition is steady for the turbine. Digital anemometer has been used to measure the wind speed. Wattmeter has been used to measure the output power; it has an inaccuracy of 1%.

The speed of the wind tunnel is being adjusted through variation the frequency of its inverter, and the output power is being measured for each wind speed by using a wattmeter.

The wind turbines’ power coefficient (C_p) can be calculated using the following equation:

$$Cp = \frac{W_{gen.}}{0.5\, \rho\, A\, V^3}$$

Where: C_p - Power coefficient, $W_{gen.}$ - Generated power (Watt), A - Swept area (m2), V - Wind speed (m/s).

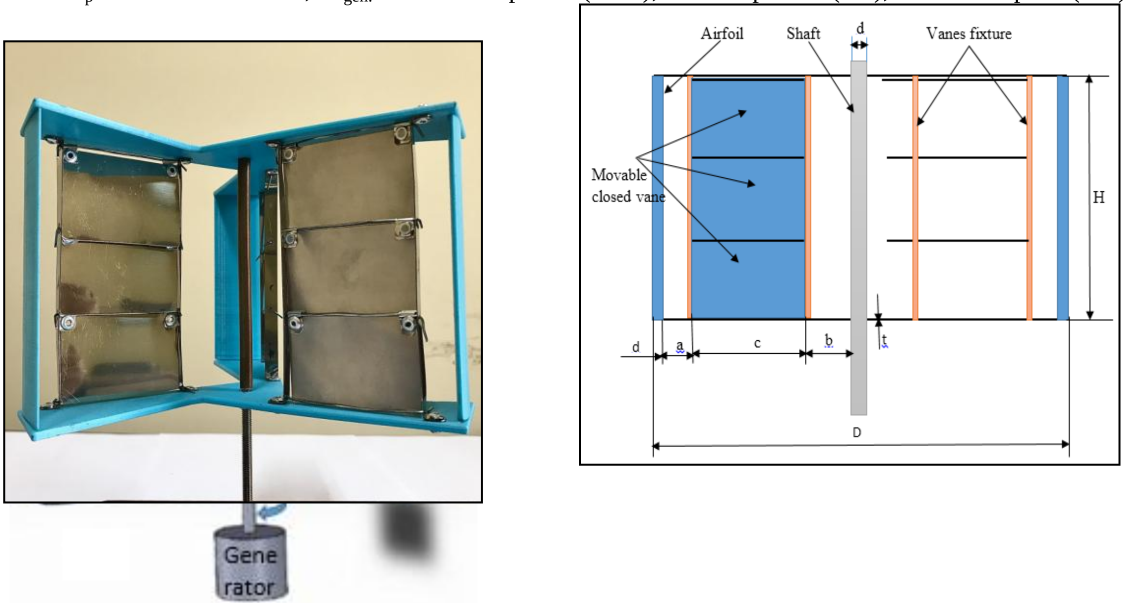

Figure 5 **a**) Front view for the hybrid WT b) Hybrid WT of vane-type in the middle of the H-rotor

4. Results and Discussions

Results of the number of revolutions per minute (RPM) for the combined Darrieus-vane model WT with different wind velocities, is illustrated in “Fig. 6”, the maximum RPM for this combined model is (1410) at wind velocity 12 m/s.

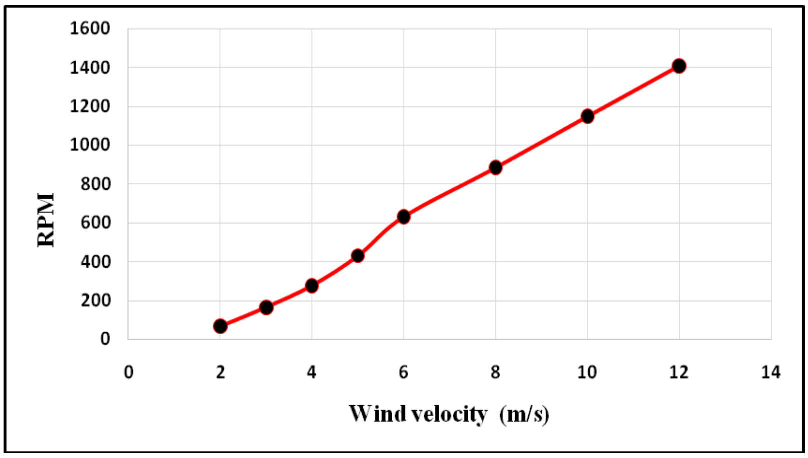

Figure 6 Number of revolutions of the combined model versus wind velocity

The subsonic wind tunnel Power generation against wind velocity results’ of the combined WT, are illustrated in “Fig.7”. The combined Darrieus-vane type WT model starts generation of power quicker than the H-Darrieus rotor. It can be noticed from the figure that when the vane-kind with moving vanes is in the middle of the H-Darrieus rotor, then the amount of the generated power becomes more significant (7.366 watt at wind speed 12 m/s). As anticipated, combining the H-Darrieus rotor with the vane-type rotor has enhanced the self-starting ability of the H-Darrieus rotor and in addition, the combined turbine generates electricity better than H-Darrieus by its own.

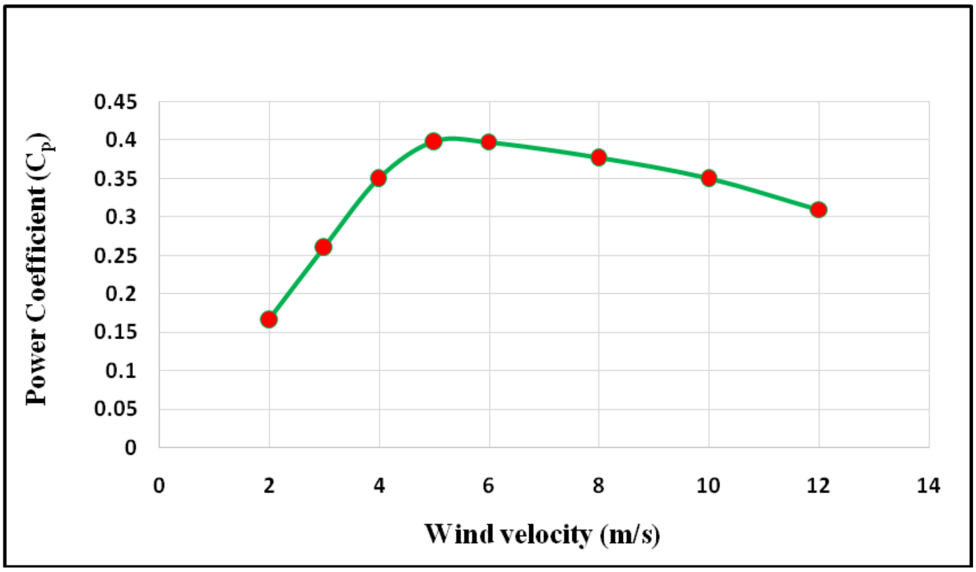

Figure 7 Experimental output power for three blades combined model versus different wind velocity.

“Fig.8” shows the power coefficient (C_p) of the combined WT. The Hybrid Darrieus-vane kind design with moving vanes in the centre of the H-Darrieus rotor, has a power coefficient of ($C_p = 0.399$) which is much better when compared to other commercial Darrieus WTs. When the wind celocity increases to 5 m/s, the value of coefficient of performance (C_p) for the combined WT increases as well. The main reason for this increment is the drag pressure addition without the elevate and vortex flows’ positive impact in empty areas of the H-Darrieus rotor and converging of the rotor with the wind direction. Then, when the value of wind velocity becomes more than 5m/s, a decrement in the power coefficient (C_p) can be noticed when the wind velocity increased, as illustrated in “Fig.8”.

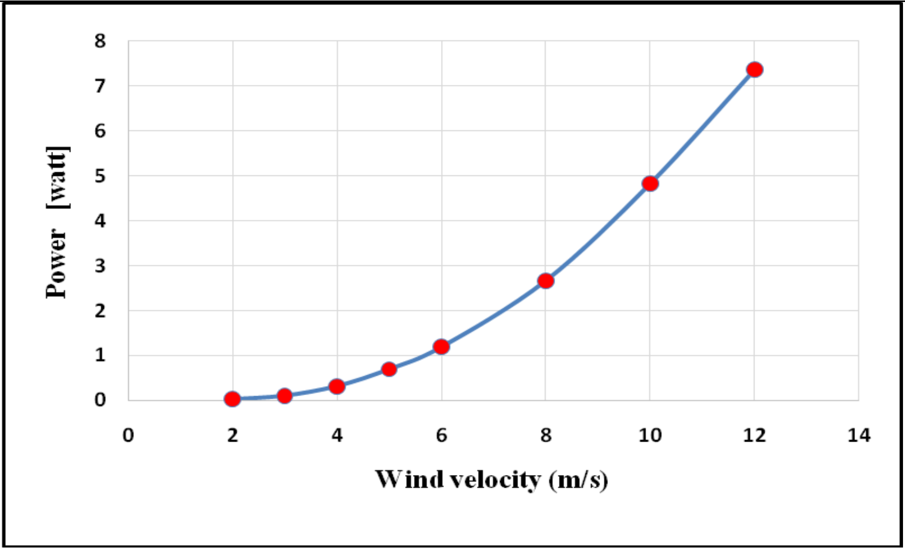

Figure 8 Power coefficient for three blades combined model versus different wind velocity

5. Conclusion

The results obtained from the experimental test that has been conducted in a subsonic wind tunnel, showed an improvement in the value of power coefficient (C_p) for the combined Darrieus WT. The experimental test has been conducted in a range of wind speeds varies from 2 to 12 m/s.

For the combined SB-Darrieus with movable vanes, placing the vane type rotor with movable vanes in the middle of the Darrieus rotor makes the self-starting ability better, the power coefficient (Cp) higher, and consequently having an efficient WT. In addition, it was found that when the turbine is rotating in a direction opposite to the wind direction, the vanes are opened and this means the wind goes freely through it without resistance, which reduce the magnitude of negative torque for combined WT.

The various values of power coefficient (C_p) for a specific wind velocities is shown in "Fig.8", It is observed that the maximum power coefficient (C_p) of (0.399) for the combined WT is higher when comparing to the value of power coefficient for commercial Darrieus WTs. This means the Hybrid combined WT is more efficient than the commercial Darrieus WTs.

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