Comparative Study of a Drag Force for Flat Plate Frame and a Combined Straight Bladed Darrieus-Flat Plate Frame

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***Abstract*—In this paper, experimental investigations were carried out to evaluate the drag forces of a flat plate frame with movable vanes and a combined Straight-Bladed Darrieus - flat plate frame by. For this purpose, two models were developed, one flat plate frame with movable vanes and another one straight-bladed combined with a Darrieus-flat plate frame. For the combined Straight-Bladed Darrieus - flat plate frame, having one flat plate constructed by three movable vanes. A straight-bladed Darrieus NACA0012 airfoil is attached at the tip of the model structure. The design increases the torque of the model on the side which rotates to wind direction hence increasing the drag coefficient C_d and reduces the negative torque on another side of the frame that rotates opposite to the wind. The results indicated that the maximum drag force for flat plate frame is 1.64 N under wind speed V=28 m/s and at azimuth angle θ = 90°, and the maximum drag force for the combined model is 6 N under the same condition.**

***Index Terms*—Flat Plate; Drag Force; Movable Vanes; Combined; Straight Bladed.**

I. Introduction

The need for the development of renewable energy has been increasing because of the continuing oil crisis and environmental pollution, and one of these resources is wind energy. The survey carried out in the USA and Europe showed that about 12% of the global power generation would be substituted with wind power by 2020 (http://www.spiedl.org/ 2015). Wind energy is the most potential renewable energy resource and low cost compared with conventional fossil resources. Wind energy can help in reducing the dependency on fossil fuel. Many countries realized the importance of wind energy as an important power resource. Necessary measures are being taken up across the world to harness maximum power from wind and its effective utilization in power production. It has been predicted that roughly 10 million MW of wind energy continuously available on the surface of the earth [1].

Wind turbine, which has a mainly horizontal axis type and vertical axis type, can convert wind energy into mechanical energy. Although the horizontal axis wind turbine (HAWT) is the most common type, the demand for a vertical axis wind turbine (VAWT) has been increasing in the world, especially the straight-bladed vertical axis wind turbine (SB-VAWT) because of its advantages such as low in price, easy installation and maintenance and many more. However, the capability of self-starting of the SB-VAWT is very low, which is one of its disadvantages. On the contrary, the Savonius rotor, which is a drag-type VAWT, has good starting performance. Therefore, the Savonius rotor can be used as a starter for the SB-VAWT to increase the start torque at low rotation and low wind speed.

Takao et al. [2] worked on improving the performance parameters with the addition of guide vane row around the turbine. As a result, they observed an increase in power coefficient to 0.215, which is 1.8 times higher than that of the original turbine without any guide vane row.

Wilhelm et. al. [3] presented circulation control methods for the performance improvement, thereby increasing power coefficient and improving self-starting characteristics through ‘lift augmentation’.

Howell et. al. [4] performed an aerodynamic analysis by using fluid flow simulations as well as wind tunnel testing. The results indicate that the power coefficient increases until the tip speed ratio (TSR) ‘2’ and afterwards a declining trend is observed. Combining the rotor is one way to optimize and overcome the problem of low starting torque on Darrieus wind turbines. Although the Savonius rotor has a lower power coefficient than the Darrieus rotor, it has useful characteristics of high starting torque and self-starting at low tip speed ratio. It has been presented that a large starting torque can be produced from the Savonius rotor, with a condition of operation by Darrieus rotor at a higher tip speed ratio [5].

Combining both designs in one was suggested by Debnath et. al. [5], Gavalda et. al. [6] and Gupta et. al. [7]. It was found that the power coefficient can be as high as 0.35 for different overlap percentages. Moreover, a high torque coefficient was obtained which showed the ability of self-start at low wind velocity.

Wakui et. al. [8] studied the generator systems for the turbine type as well through dynamic simulations and presented their conclusion that a custom design should be arranged according to the compatibility of each turbine configurations and wind flow conditions.

Debnath et al. [5] plotted the variation, of the power coefficient (CP), with a tip speed ratio. It was observed that when TSR reach 0.36, power coefficient increases to 0.33, later, the power coefficient starts to decrease with the increase in TSR.

Gupta et. al. [9] studied a combined Savonius–Darrieus type vertical axis wind rotor, which has got many advantages over individual Savonius or individual Darrieus wind rotor, such as better efficiency than the Savonius rotor and high starting torque than the Darrieus rotor. Two types of models, one simple Savonius and the other combined Savonius–Darrieus wind rotors were designed and fabricated. The Savonius rotor was a three-bucket system having provisions for overlap variations. The Savonius–Darrieus rotor was a combination of three-bucket Savonius and three-bladed Darrieus rotors with the Savonius placed on top of the Darrieus rotor.

In this study, a combined frame turbine model with an SB-VAWT and flat plate frame with movable vanes was designed. Based on wind tunnel tests data, the starting torque performance and drag coefficient performance were analyzed, and the feasibility of the combination was discussed. Beforehand, the performance on flat plate rotor was also measured for comparison. The performance has been conducted in an open circuit subsonic wind tunnel to measure drag coefficient of the combined and flat plate with movable vanes frame. A combined frame is proposed to be used with a vertical axis wind turbine especially with a Straight- Bladed Vertical Axis Wind Turbine (SB-VAWT). This shape of the combing frame is aimed to improve self-starting torque performance at low speed and drag coefficient of Darrieus wind turbine.

II. Methodology

The paper presents two designs of wind turbines which are measured by drag force and drag coefficient for each model in order to evaluate the proposed designs. Each model consisting of movable guide vanes and a shaft. Installation of airfoils was made for model 2 to increase the performance of model 1.

A. Flat Vane Type Frame (Model 1)

Model 1 is fabricated with 3 sections of horizontal movable vanes which attached to a frame. The frame is connected at its end to a shaft as illustrated in Figure 1. These movable vanes are able to open or close perfectly depends on wind direction. Performance of model 1 is to be evaluated based on its drag force. Therefore, the frame has been designed based on the consideration to get high values of the drag factor. The dimensions of this vane type wind turbine model are, width c=5.6 cm, height H=11 cm, thickness t = 1mm.

The wind tunnel uses stationary turbofan engines that suck air through a duct, equipped with a viewing port and instrumentation where model on the shaft are mounted for experimental work.

Drag coefficient, C_d for each model can be calculated as:

$$C_d = F_d/(0.5\rho A V^2) \tag{1}$$

where F_d = Drag force
ρ = Air density
A = Projected area
V = Wind velocity

B. Combined Straight Bladed Darrieus with Flat Plate Frame (Model 2)

The shape of a combined frame vertical axis wind turbine under test has constructed from mild steel (only NACA 0012 airfoil constructed from PLA thermoplastic), with vane dimensions, c = 5.6 cm, H=11 cm, t =1 mm, as drag device and the Darrieus wind turbine dimensions for NACA 0012 airfoil was selected considering its thickness and aerodynamic performance. The chord length C = 0.035 m, airfoil thickness t =0.12C = 0.0042 m as a lift device. The specific designed combined structure is shown in Figure 2.

The tests were carried out using the wind tunnel in a laboratory. The experiment setup of combined design in wind tunnel is shown in Figure 3. The operating range of wind velocity is 4-28 m/s. The results later will be measured under wind velocity variations for comparative study of both designs.

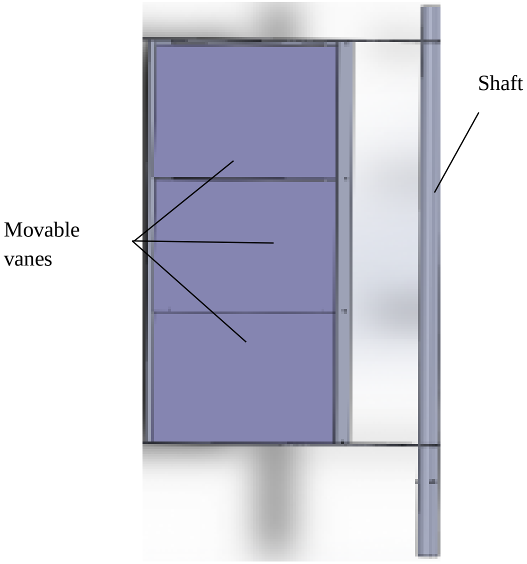

Figure 1: Flat plate movable vanes frame (Model 1)

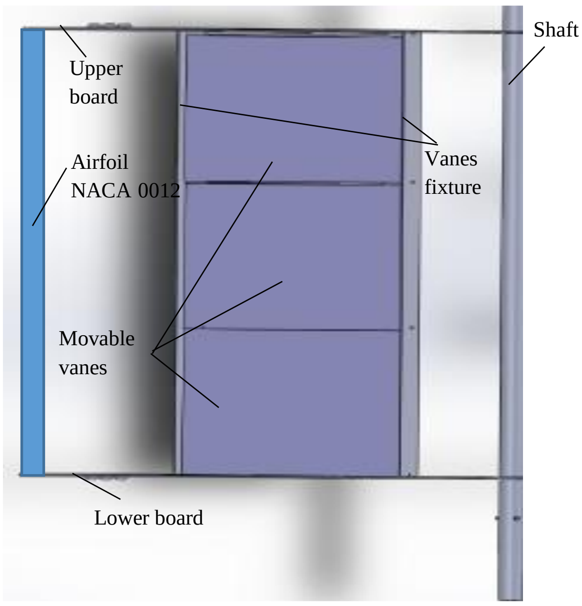

Figure 2: Front view for combined frame (Model 2)

Figure 3: Experiment Setup of Combined Frame in Wind Tunnel

III. Results and Discussion

The shaft was placed in the middle of wind tunnel and the frame was subjected to the wind that was travelled up to a maximum velocity of 28 m/s. As the wind velocity increases, the frame rotates faster resulting in the increase in drag force as shown in Figure 4. It indicates that Model 2 has shown a significant increase in drag force with the increase of wind velocity. The maximum drag force for Model 1 and Model 2 are 1.65 N and 7.9 N, respectively at wind speed 28 m/s.

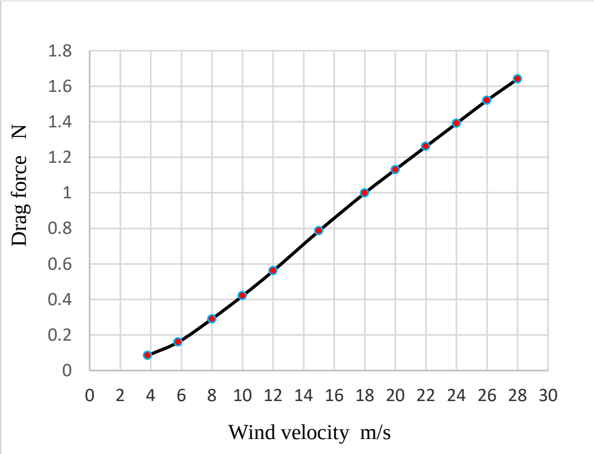

Figure 4(a): Experimental drag force for flat plate frame (Model 1) under different wind velocity

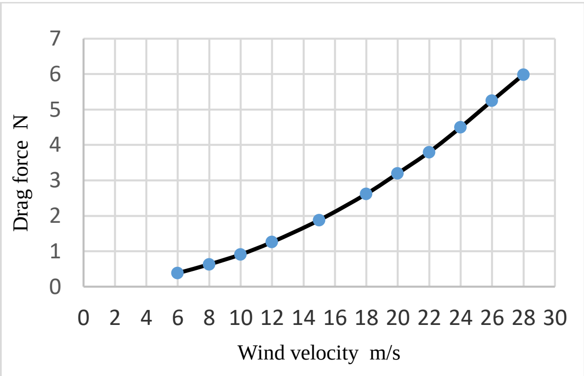

Figure 4(b): Experimental drag force for combined frame (Model 2) under different wind velocity

From experiment results for the drag force in the wind tunnel and Equation (1), the drag coefficient can be determined and is plotted against wind velocity as shown in Figure 5. Figure 5(a) indicates the drag coefficients drop until 0.5 as the wind velocity increases. Figure 5(b) shows that combined frame was able to keep the drag coefficients above 1 even at maximum wind velocity of 28 m/s.

Continuous wind force that acts to model causing drag force to form scoop vanes when the wind velocity is $V = 28$ m/s with different azimuth angles θ, as shown in Figure 6(a). The highest drag force, 1.64 N was reached when azimuth angle $\theta = 90°$. Figure 6(b) shows the result of drag coefficient for combined model has reached 7.07 N at its peak when azimuth angle $\theta = 90°$.

Figure 7 shows the relation between drag coefficients for combined frame with azimuth angles. The maximum drag coefficients for each model are 1.4 (Model 1) and 1.85 (Model 2) when azimuth angle is 90° at wind velocity of 5.8 m/s.

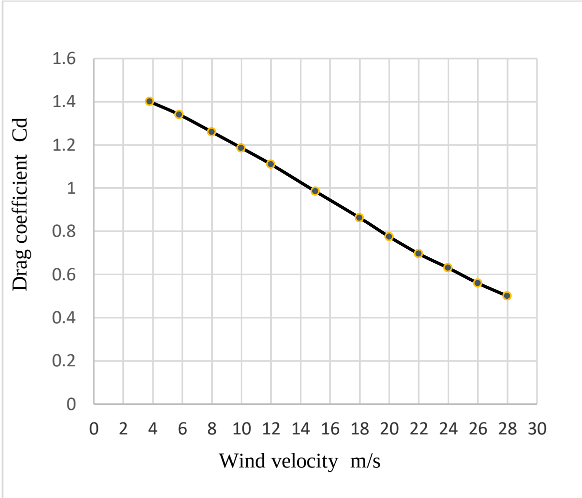

Figure 5(a): Experimental drag coefficient for flat plate frame (Model 1) under different wind velocity

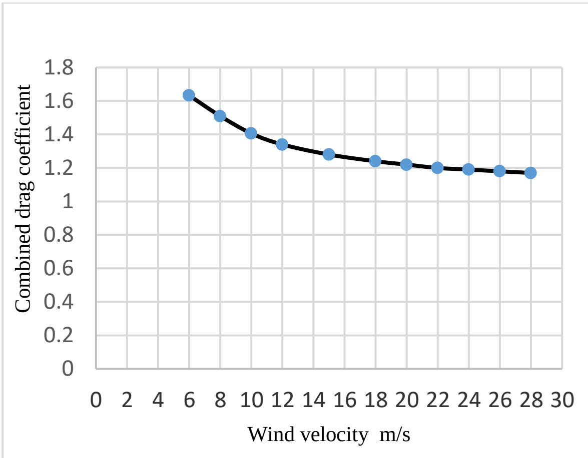

Figure 5(b): Experimental drag coefficient for combined frame (Model 2) under different wind velocity

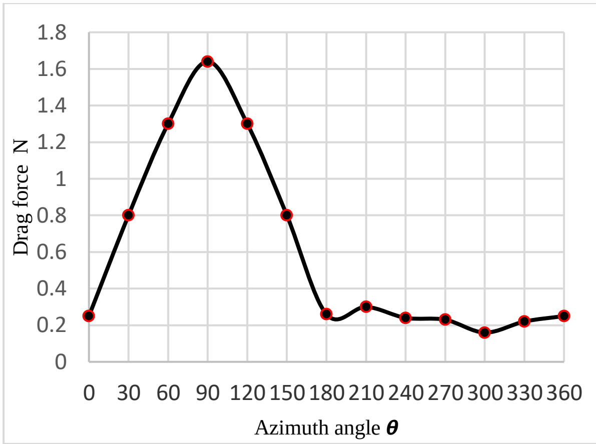

Figure 6(a): Experimental drag force for flat plate frame (Model 1) versus azimuth angles ($V_{wind} = 28$ m/s)

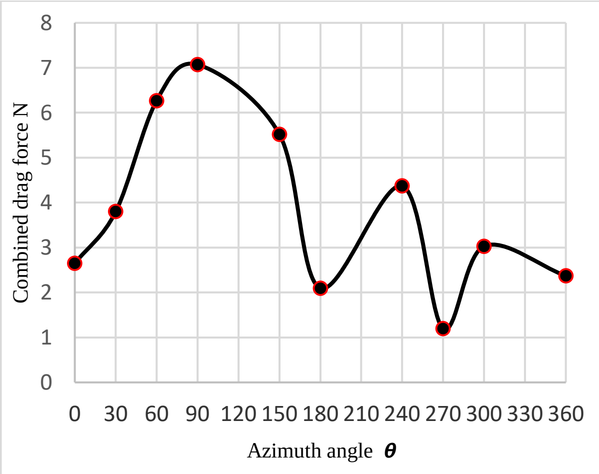

Figure 6(b): Experimental drag force for combined frame (Model 2) versus azimuth angles (V_{wind} = 28 m/s)

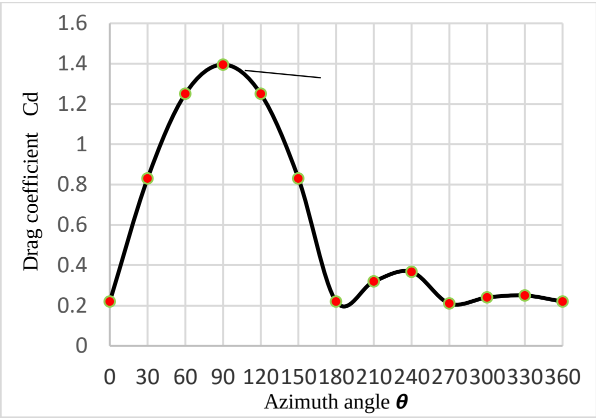

Figure 7(a): Experimental drag force for flat plate frame (Model 1) versus azimuth angles (V_{wind} = 5.8 m/s)

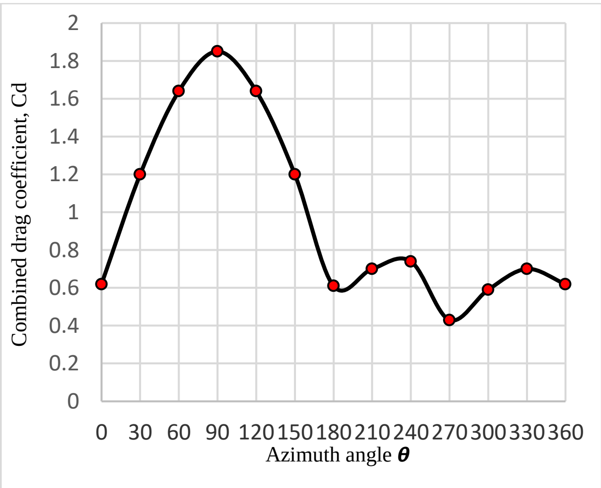

Figure 7(b): Experimental drag force for combined frame (Model 2) versus azimuth angles (V_{wind} = 5.8 m/s)

IV. Conclusion

In this paper, an attempt was made to measure the performance flat plate frame and a combined straight bladed darrieus - flat plate frame. The following conclusions are summarized from the study.

- Combined model has shown a significant increase in drag force and drag coefficient as a result when tested with wind velocity variations. The design enables the wind turbine to capture high wind energy, hence generating higher torque.
- The scoop condition of frame enable higher positive torque, higher angular speed of a rotating shaft by using straight bladed Darrieus NACA 0012 airfoil attached to the frame which produces better lift force and high angular velocity
- The movable vanes act to produce maximum positive torque while reducing the negative torque as it is opened when in the opposite direction of the wind.

The present combined frame can be used with the Darrieus-type vertical axis wind turbine as its producing higher starting torque and a higher number of revolutions (RPM) by minimizing the disadvantage of Darrieus-type when starting at a low wind speed condition.

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