Numerical investigation of the aerodynamic characteristics for the integrated vertical movable vanes with the airfoil straight blade vertical axis wind turbine

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Abstract. With the depletion of fossil fuels and the effects of fossil fuel emissions on climate change. The demands of the renewable energy is increasing. For these reasons, many researchers they are focused on harvesting renewable energy and reducing the use of fossil fuels. The vertical axis wind turbine (VAWT) is one type of the wind turbine that is widely used now a day. Low starting torque occurs when the airfoil is used in the straight blade vertical axis wind turbine as a blade. In order to increase the turbine starting torque, a flat plate vane type VAWT having movable vane is integrated with the airfoil straight blade VAWT in one rotor combination. In the present study, the numerical simulation is carried out to predict the aerodynamic characteristics of the combined three blades vertical axis wind turbine. A commercial available SolidWork2016 and computational fluid dynamic (fluent) software’s with k-ω turbulence model are used in this simulation. The predicted results from the simulation show that the turbine starting torque is increased when the vertical movable vanes are integrated with the straight blade in the vertical axis wind turbine. The flow of air passes freely through the movable vanes in case of the vanes are fully open at the negative side of the turbine, this case helps to increase turbine rotation and so, thus, the power of the turbine increases. Finally, the predicted results from the simulation give a good agreement with those results reported in the published literature for VAWT has different blade configurations.

Keywords. Renewable energy; Wind energy; VAWT; CFD; Straight blade rotor; k-ω turbulence model.

1. Introduction
Non-renewable resources of energy are limited in the world and are depleting at a faster rate due to rapidly growing demand. Wind energy is one of the renewable resources of energy. The wind turbine is the machine which converts the kinetic energy available in the wind into mechanical power, then to electrical energy by an electrical generator. A wind turbine is unable to capture all of the energy in the wind. Therefore, it is reasonable to assume an upper limit for the aerodynamic efficiency. The theoretical maximum power coefficient of wind turbine of any design not exceeding the 59 % it’s mentioned as a Betz’ limit [1]. The wind turbine has two type’s Horizontal axis wind turbine (HAWT) and Vertical axis wind turbines (VAWT) depending on the shaft of the turbine rotor. HAWT more efficient than VAWT.
VAWT is further can be divided into lift driven VAWT (Darrieus) the earliest type and drag driven VAWT (Savonius type) [2]. The most common of the Darrieus wind turbine is the H-type VAWT.

Many researchers have been focusing their attention on improving the aerodynamic characteristics of VAWT, and these studies were summarized by laboratory measurements and theoretical of the flow in an around the blades of the wind turbine. Computational fluid dynamics (CFD) is the promising technique in simulation of wind turbine for many research to help many researchers for investigation the aerodynamic characteristics of the VAWT. Finite volume method is one of most of numerical methods which are used in CFD to solve the physical problems. The finite volume method is more efficient to solve the flow field around the vertical axis wind turbine rotor [3].

Suffer et al. [4] simulated numerically the aerodynamics and modal analysis for the three combined blades vertical axis wind turbine. Each blade has a vane type of horizontal flat plate (having three movable vanes) with the Darrieus helical airfoil (Gorlov). The aerodynamics results from the simulation show the power of the turbine increases. While the modal results show that until the 5th natural frequency the effect of damping can be neglected.

Rémi et al. [5], conducted a parametric study of vertical axis turbines by using the k-ω SST RANS model in its unsteady form. The best aerodynamic configuration is determined by studying the effect of solidity, number of blades, Reynolds number, blade pitch angle (fixed and variable) and blade thickness on the aerodynamic efficiency of the turbine.

Hussen et al. [6] Improved the performance of the vertical axis wind turbine by using CFD analyses to improve the performance of the designed rotor of the three blades have a section of the NACA 0018 airfoil straight and then twisted to 45° and 90°.

Ying et al. [7] studied the aerodynamics and motion performance of the floating of a 5 MW H-type VAWT. The floating foundation was a truss spar type is also studded. Theory of double-multiple-stream-tube is used also to calculate the aerodynamic loads which acting on the wind turbine considering the motions of the floating foundation. The results of that steady of a H-type turbine were give a better motion performance.

Suffer et al. [8] presented the numerical simulation of the two configurations of the vane type vertical axis wind turbine (VVAWT) rotors. The blades of the turbine have a cavity shape with three movable vanes, the first configuration has three blades with angles of 120° between each blade, and the second configuration has four blades with angles of 90° between each blade. The predicted results from the numerical simulation gives acceptance compared with this is reported for steadying VAWT having different blade designs.

Qasim et al. [9] designed vertical axis wind turbine movable horizontal vanes rotating instead of being fixed to reduce the negative torque on the form of non-work (against the direction of the wind). This is so that the frames vanes open and pass the wind through the frame freely without the resistance to the air. This idea has been put forward first by designing three vanes being horizontal in each frame and second by designing three vertical vanes in a single frame.

The effect of different design parameter for performance of the evaluation of SB-VAWTs were investigated by Khammas et al. [10]. During this investigation they are finding that the VAWT has better capability of extracting more power from low wind than HAWT. SB-VAWT having the effect of parameters like Blade aerodynamics, Solidity, Pitch angle, Number of blades and TSR on performance.

2. Current simulation
The objective of this study is to investigate numerically the aerodynamic characteristics of integrated vertical movable flat plate vanes with the H-type (Darrieus) airfoil in the one configuration of the blade for the three blades VAWT. The airfoil is a NACA 0012, and the characteristic geometry of the airfoil are Height (100nm), Chord (c = 40mm), Thickness (t = 4.8mm), while the flat plate vane has a height (96mm) and (18mm) width. The pre-processing steps of this study are carried out by using solidworks2016 software for modelling the geometry for three combined blades vertical axis wind turbine as shown in Figure 1 (a). The dimensions and boundary conditions of the computational domain with a top section view are presented as shown in Figure 1 (b).
The second step of pre-processing is carried out by using Gambit software for machining the modelled geometries (single blade with closed vane, single blade with open vane, three blades at 90° angular position and three blades at 270° angular position. The number of mesh for each model are presented in Table 1.

![Model of three combined blade VAWT](image1.png)
![Dimension and boundary of the computational domain](image2.png)

**Figure 1.** (a) Model of three combined blade VAWT, (b) Dimension and boundary of the computational domain.

**Table 1.** Number of meshes for modelled geometries

| Model Geometry                        | Number of Meshes |
|---------------------------------------|------------------|
| Single blade with closed vane         | 2105801          |
| Single blade with open vane           | 3348589          |
| Three blades at 90° angular position  | 2407333          |
| Three blades at 270° angular position | 2446661          |

### 3. Result and Discussion

In the third step of pre-processing the available commercial ANSYS FLUINT 16.1 the Shear Stress Transport (SST) $k$-$\omega$ turbulence model is used to simulate the modelled geometries for different blade angular positions. Upstream air velocities 14 m/s is used in this simulation as a velocity inlet. The residual plots of the current study and accuracy is adopted at the accuracy $10^{-5}$ to achieve the best accuracy to prove the validity of the results. Therefore, according to the residual plots the accuracy is acceptable for the purpose of the results of this study.

The predicted drag coefficient (Cd) results and the projected areas from the current simulation for modelled geometries are mentioned in Table 2. From the Cd results, it can be observed that Cd is maximum at 90° blade angular position, while the Cd is minimum at 30° blade angular position. Figure 2 (a) shows the results of the static pressure distribution in and around of the combined single blade with a closed vane, while Figure 2 (b) shows these results of the combined single blade with a closed vane. From these results, it can be concluded that the static pressure is maximum in the upstream airflow direction in the front face of the blades, while the static pressure is minimum in the downstream airflow direction on the back face of the blades. The static pressure drop decreases when the blade rotates to the negative side and this helps to increase turbine power.

Figure 3 (a) and 3 (b) shows the contours of velocity distribution for the combined blade at 90° and 270° angular positions respectively. From these contours it can be seen that the flow of air passes through the blade freely because all vanes are opened and thus, there is no resistance to the flow in this side. This helps to increase turbine rotation and so the power of the turbine increases.
Table 2. Values of drag coefficient and projected area for modelled geometries

| Model Geometry                        | Projected Area (m²) | Drag Coefficient |
|---------------------------------------|---------------------|------------------|
| Single blade with closed vane         | 0.00697728          | 1.01             |
| Single blade with open vane           | 0.00226818          | 0.6373           |
| Three blades at 90° angular position  | 0.01126593          | 1.491            |
| Three blades at 270° angular position | 0.00766428          | 1.289            |

Figure 2. Contours of the static pressure distribution, (a) At 90° blade angular positions, (b) At 270° blade angular positions.

Figure 3. Contours of the velocity distribution; (a) at 270° blade angular positions, (b) at 90° blade angular positions.

Figure 4 shows the static pressure distribution inside and outside the rotor of the three combined vertical axis wind turbine. For the first turbine blade at 90° angular positions when all the vanes are fully closed the maximum static pressure (1.86E+02 Pa) occurs at the upstream blade side, while minimum static pressure (-1.76E+02 Pa) occurs at the downstream blade side. While for the first turbine blade at 270° angular positions when all the vanes are fully open the maximum static pressure (1.6E+02 Pa) occurs on the upsteam of the third turbine blade.

Figure 5 (a) and 5(b) shows the contours of the distribution of the dynamic pressure between and around the combined blade in the flow domain at different case of angular positions. Figure 6 (a) and 6 (b) shows the contours of velocity distribution for the combined three blades VAWT at 90° positions in case of closed vanes, and at 270° blade angular positions in case of open vanes. From the results of Figures (5) and (6) it has been can be concluded clearly from the contour distribution the maximum vortex region occurs in positive side because of the vanes are closed. While the vortex region is a decrease in negative side, depending on the opening of the vanes with angular position and vortex.
region is disappearing when the vanes are fully open. From these results, it is concluded that the turbine negative torque is reduced and then the turbine output power is increased.

Figure 4. Static pressure distribution for three blades VAWT, (a) 90° angular position and, (b) 270° angular positions.

Figure 5. Dynamic pressure distribution of the three blades VAWT; (left), 90° angular position and, (right) 270° angular positions.

Figure 6: Velocity distribution of the three blades VAWT; (left), 90° angular position and, (right) 270° angular position.
4. Conclusion
In this investigation the numerical simulation is carried out for the modeled geometry of the three dimensional combine blades (vertical flat plate vanes with the H-type airfoil) for the vertical axis wind to investigate the aerodynamics characteristics. ANSYS FLUENT16.1 software’s is used for this investigation with k-ω turbulence model. The main conclusions from this simulation are
(1) The coefficient of drag C_d is high when the blade of the turbine in a positive side and will become maximized at the 90° blade angular position because of all vanes are fully closed. While the minimum C_d at the negative side 270° blade angular.
(2) The static pressure drop is maximum occurring across the combined blade rotor sides with closed vane from the upstream to the downstream side at the 90° angular position. While minimum static pressure drop occurring across the combined blade rotor sides with open vane from the front side for the turbine rotor to back side of the turbine rotor at 270° blade angular position.
(3) The flow of air passes through the combined blade on the negative side when all the vanes are freely open. This indicated to the resistance of the blade to the flow is decreased. This case helps to increase turbine rotation and so the power of the turbine increased.
From above results, it can be concluded that the decreases in Cd and static pressure drop in the negative side helps to increase the rotation of the turbine and then the power of the turbine is increased. The predicted results from the numerical simulation gives acceptance compared with this is reported for steadying VAWT having different blade designs.

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