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To cite this article: Kalakanda Alfred Sunny et al 2018 J. Phys.: Conf. Ser. 1139 012040

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Airfoil selection and computational study on the torque performance of 4-blade vertical axis wind turbine

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Abstract. This paper contains numerically simulated data for a 4-blade Darrieus rotor type vertical axis wind turbine (VAWT). NACA0012, NACA0015, NACA0018 and NACA0021 airfoil types were analysed for the tangential force they create at different angle of attack. Based on the maximum tangential force generated by the airfoil for one full revolution, an airfoil series is selected for designing the 4-blade VAWT in simulation bed using Solid Works and then it is meshed, and cell zones are created over it in ANSYS tool. Then CFD analysis is carried out for different rotational speeds. Considering the overall torque produced during one full revolution, optimal rotational speed is arrived at. Finally, this study is aimed to study the torque performance of 4-blade Darrieus rotor type VAWT. This study is useful for designing the small scale VAWT for meeting the low energy demands at the load centres itself.

1. Introduction
Progress in harnessing wind energy is becoming popular in the present days. Reason for this is the free availability of wind resource, and other reason would be the ease of harnessing energy using wind turbine systems [1]. Wind energy harvesters are those generating electricity from the wind’s kinetic energy using wind turbines coupled with electrical alternators [2]. These are classified to be in various types, however the most seen wind turbines are horizontal axis wind turbines (HAWT), vertical axis wind turbine (VAWT), convergent type, divergent type, etc. [3,4]. In recent years, the possibility of harnessing wind energy has seen a new-dimensions like Invelox type which can generate excess electricity with same available wind speeds when compared to the conventional HAWTs or VAWTs [5,6]. However, for small scale power generation applications, VAWTs are most favorable when compared to HAWT, see the possible benefits of VAWT in [7]. In this regard, evaluating the torque at available wind speeds and rotational angle is an essential to quantify the power availability at the wind turbine system. A study was conducted on the two blade VAWT to evaluate the torque generation possibility and in identifying the best airfoil selection for VAWT [8]. Similarly, a study was conducted in a similar way to assess the torque generation possibility at different rotational speed for three blade VAWT [9].

Objective of this paper is to identify the best suitable airfoil series for developing the vertical axis wind turbine. Here, a 4-blade VAWT design is opted and its torque performance is studied at different rotational velocities. For this a computational modelling and CFD analysis is performed.
Paper is organized in following sections: applied methodology for airfoil selection, 4-blade VAWT design and its computational modelling is described in section-2. In section-3, the CFD analysis is carried out and results obtained from the study are discussed. Section-4 concludes the paper highlighting the significance of the work carried out in this paper.

2. Methodology
2.1. Airfoil Selection Based on Tangential Force
Symmetric airfoils such as NACA 0012, NACA 0015, NACA 0018, and NACA 0021 were selected as study airfoils. Among these selected airfoils one is picked as best performing airfoil based lift to drag ratio (here, lift being the key driving force and the lift to drag ratio should be higher). For evaluating the maximum tangential force, there is a requirement in studying the airfoil characteristics (typically at for various angle of attacks starting from 0° to 180°) which are taken from the available literature [10-14]. The value of CD and CL for angle of attack 0° to 180° and forces generated (neglecting the rotation effect and interference due to other blades).

Tangential forces calculations formula [8,9]:

\[ F = F_y' - F_x' \]
\[ = F_y(\cos\theta) - F_x(\sin\theta) \]

Where, \( F_x \) = Horizontal component of force; \( F_y \) = Vertical component of force; \( F_x' \) = Tangential component of \( F_x \); \( F_y' \) = Tangential component of \( F_y \).

After calculating tangential forces, graphical representation is made between total forces generated and rotation angle for each airfoil, shown in Figure 1.

In Figure 2, all the selected airfoils are made (tangential force vs angle of attack plot) to pick the best performing airfoil as per the required condition of generating maximum tangential force. Among all
the studied airfoils NACA 0015 is found to have maximum tangential force over one complete cycle. Hence, NACA 0015 is selected for designing four blade vertical axis wind turbine (4-blade VAWT) and for this, its cross section is needed, see in Figure. 3.

![Figure 2. Force vs. rotational angle](image)

**Figure 2.** Force vs. rotational angle

![Figure 3. Cross section of NACA 0015 airfoil](image)

**Figure 3.** Cross section of NACA 0015 airfoil

2.2. **Computational Modelling**

For computational modelling and analysis, the of NACA 0015 airfoil is made as per the dimension shown in Figure. 4. Using Solid Works, 4-blade VAWT is designed and the same is shown in Figure. 5. The designed cell zones in Solid Works were exported to ANSYS Workbench for computational analysis. “Triangular meshing is used for the geometry. Edge sizing of the blades are given regarding some divisions, and the mesh grows by a factor of 1.015” [8]. As, shown in Table 1, three meshes of different grid sizes with a different number of elements were used, see Figure. 6. Corresponding forces (x-force, and y-force) on the four blades were analyzed and showed in Table 2.
3. Results and Discussion
Computational analysis was performed at wind velocity of 10 m/s with different rotational velocities of 4 rad/s (38 RPM), 8 rad/s (76 RPM) and 16 rad/s (152 RPM). For these three conditions, velocity...
contours and corresponding torque generation are evaluated for each degree of airfoil rotation. From the x-component and y-component forces obtained, the tangential forces generated by each blade at different angle of rotation were calculated. Further the total torque produced by the turbine was determined. The analysis was performed from 0° to 80° and the results are repeated for four times to complete one full rotation. Results are obtained from computational studies by varying the angle in the steps of 10° from 0° to 360° to complete one full rotation of the turbine. For all the four blades X-force and Y-force, tangential force and torque are calculated. Analysis at a rotational velocity 4 rad/s indicating the contours of velocity are shown in Figure 7. Blades are tested at a zero-degree angle of attack for rotational velocity of 4 rad/sec with stagnation point at approximately 90°. Due to flow separation, the leading edge of blade 1 has the highest flow velocity. The blade 3 is in the wake of blade 1 experiences comparatively lesser force. Figure. 7. shows the velocity contours at 4 rad/sec for the four blade VAWT and Figure. 10. shows the respective total torque produced by the blades for the various angle of rotation. There will be a certain point where the turbine rotational speed neutralizes the flow velocity. Thus, the net torque at that instant will be zero due to the absence of tangential force.

The results are analyzed for rotational velocity 8 rad/sec and 16 rad/sec and were shown as velocity contour in Figure. 8., and Figure. 9. respectively. The generated torque in the 4-blade VAWT for 8 rad/sec and 16 rad/sec rotational velocities were shown in Figure. 11., and Figure. 12 respectively. Upon calculating the area under the curve, it is found that the turbine would probably have the maximum efficiency for rotation velocity of 8 rad/sec. This depicts that the VAWT works better at higher RPM. However, the rotational speed will be governed by the torque produced, a moment of inertia of blade assembly and friction at the axis of rotation.
In Figure 13, comparison is made to understand the effect of rotational velocities on the generated torques for the selected airfoil. It is observed that, at 8 rad/sec the torque generated is high when compared to 4 rad/sec, and 16 rad/sec. The performance of wind turbine is dependent on rotational speed of the turbine shaft. Finally, this study showed that, the torque generated depends on two factors such as relative velocity of the wind and change of the relative angle of attack [8,9].

4. Conclusion
In this paper, a computational analysis of a four blade vertical axis wind turbine is carried out. Turbines with maximum torque generation will usually yield better energy for any modelled wind turbine. From the studies made it is understood that there are two parameters which effect the torque generation of the turbine. One is force in the airfoil and the other one is velocity of the wind at which direction it is attacking the blade. So, the study was made to have clear understanding of variation of torque with respect to the rotational angle of the blades and wind velocity. From the computational study made and results obtained it is evident that increase in rotational velocity first increases the torque and later it reduces by further increase of rotational velocity. It is understood that two factors affect the torque generation, one is relative velocity of the wind with respect to moving turbine blades and the other is relative angle of attack due to rotation of the turbine blades. At a rotational velocity, the torque produced will be negligible. This rotational velocity will be the maximum for a given wind velocity. Ideally, this will be the RPM at which the torque produced will be zero. However, practically it might not be the case. There are some factors to be considered such as inertia of the wind turbine,
friction in the shaft and unsteady flow. So, to overcome these factors, some positive torque value is required.

References
[1] Ahmet Duran Sahin 2004 Progress and recent trends in wind energy. *Progress in Energy and Combustion Science* **30** pp 501–543
[2] Carolin Mabel M and Fernandez E 2008 Growth and future trends of wind energy in India. *Renewable and Sustainable Energy Reviews* **12** (6) pp 1745–1757
[3] Chen L, Ponta F L and Lago L I 2011 Perspectives on innovative concepts in wind-power generation. *Energy for Sustainable Development* **15** pp 398-410
[4] Cota O D and Kumar N M 2016 Experimental design of wind turbine with an airfoil embedded multiple generators *International Journal of Applied Engineering Research* **11**(3) pp 767-769 (Special Issue)
[5] Daryoush Allaei and Yiannis Andreopoulos 2014 INVELOX: Description of a new concept in wind power and its performance evaluation. *Energy* **69** pp 336-344
[6] Kumar N M Subathra M S P and Cota O D 2015 Design and Wind Tunnel Testing of Funnel Based Wind Energy Harvesting System. *Procedia Technology* **21** pp 33-40
[7] Sunny K A, Kumar N M 2016 Vertical axis wind turbine: aerodynamic modelling and its testing in wind tunnel *Procedia Computer Science* **3** pp 1017-1023
[8] Kalakanda Alfred Sunny, Pradeep Kumar, Nallapaneni Manoj Kumar, A. Veena, Adheena G J 2018 Two blade vertical axis wind turbine: Investigations on the torque generation at different rotational velocities *IOP Conf. Ser.: Material Science and Engineering* (Article in Press).
[9] Sunny K A, Kumar P, Kumar N M and Priscilla S 2018 Computational analysis of three blade vertical axis wind turbine *Progress in Industrial Ecology – An International Journal*. (Article in Press).
[10] NACA Airfoil Series 2006 URL: [http://www.aerospaceweb.org/question/airfoils/q0041.shtml](http://www.aerospaceweb.org/question/airfoils/q0041.shtml)
[11] Sheldahl R E and Klimas P C 1981 Aerodynamic characteristics of seven symmetrical airfoil sections through 180-degree angle of attack for use in aerodynamic analysis of vertical axis wind turbines (No. SAND-80-2114) *Sandia National Labs* NM (USA).
[12] Anderson J 2001 Fundamentals of Aerodynamics 3rd Edition *Mc. Graw Hill* Singapore
[13] Kalakanda Alfred Sunny, Pradeep Kumar, Priscilla S and Nallapaneni Manoj Kumar 2017 CFD analysis of three blade vertical axis wind turbine *Proceedings of 1st International Conference in Recent Advances in Mechanical Engineering (ICRAME-2017)* pp 6-8, Kingston Engineering College Vellore, India
[14] Ira Herbert Abbott and Albert Edward Von Doenhoff 1959 Theory of Wing Sections-Including a Summary of Airfoil Data *Courier Corporation* pp 693