

Performance Characteristics of Vortex Wind Turbines with The Computational Fluid Dynamics (CFD) Aided Simulation

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Abstract. The purpose of this paper present research on vortex wind turbines that is referred to as wind turbines without propellers or bladeless. The innovation of the vortex lies in its unique shape and the way it harnesses energy through oscillating motion. The mast column oscillates with the wind, harnessing the von Karman vortices generated as the fluid passes through the column structure. This paper presents the results of computational fluid dynamics (CFD) simulations of a vortex wind turbine with 6 and 7 inch diameter cylinders at various wind speeds. The voltage generated by a vortex wind turbine with a cylinder diameter of 6 inches was measured under realistic conditions to evaluate the wind turbine's performance in terms of output power generator due to vortex generation. The result of the research show wind speeds as low as 5 m/s that the vortex wind turbines may already exhibit generator-induced oscillations. Vibrations can be obtained using either CFD simulations or measurement results in actual conditions that the vibrations can generate a generator to produce electric voltage.

1 Introduction

Vortex wind power plants is called wind turbines without propellers or bladeless wind turbines [1][2][3]. A vortex wind turbine is a wind power plant that operates based on oscillating resonances caused by wind vortices due to eddy currents [4]. This is in contrast to wind turbines, which operate by the rotation of a propeller. The phenomenon of vortex flow can change the apparent elastic constant of a cantilever bar moving at a certain frequency. Vortex turbines are wind turbines powered by the vibrational resonance caused by the vortex [5]. It is different from horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT), which rotate by the movement of a propeller [6]. The vortex's innovation comes from its unique shape and the way it harnesses energy through vibratory motion [7]. A composite or polymer rod-shaped column reinforced with carbon fiber vibrates in the wind, harnessing the von Kármán vortices that are generated as the fluid moves through the vertical

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columnar structure [8]. Inside the composite bar column is a generator, which is driven to generate electricity without contacting any moving parts.

Vortex innovation lies in its unique shape and the way it harnesses wind energy through vibration [9]. The mast column oscillates with the wind, harnessing the Von Karman vortices generated as the fluid passes through the column structure [10]. The mast column is a vertical, elongated, cylindrical device consisting of two main parts: a fixed part attached to an anchor and a flexible pole used as a cantilever rod. The cantilever interacts more freely with the cylinder, which interacts with the moving fluid. The oscillating cantilever rod drives a linear generator to generate electricity [11]. This paper presents the results of a computer fluid dynamics (CFD) simulation of a vortex wind turbine with cylinder diameters of 6 and 7 inches at different wind speeds. The performance of this wind turbine is also evaluated by measuring the voltage generated by the 6 inch and 7 inch cylinder diameter vortex wind turbines under real conditions. The objective presented in this paper is to determine the performance of the vortex turbine wind turbine system structure.

1.1 Von Karman Vortices

Vortex flow is the behavior of a fluid passing through an obstacle and is determined by the Reynolds number/Re, a dimensionless parameter that includes kinematic viscosity [8]. Cylindrical structures are stable when Re is about 50 or less, vortex paths appear at $102 < \sim Re < \sim 105$, and turbulent flow occurs as Re becomes larger. This suggests that viscosity plays an important role in the formation of vortex flow in fluids. Vortex flow forms only in a certain range of flow velocities determined by the range of Reynolds number (Re) [12] [13]. Von Karman vortices form almost everywhere when the fluid flow is disturbed by an object [14] [15]. In Figure 1, a circular object is shown that disturbs the fluid flow, thereby changing the direction of the fluid flow into a vortex. This figure shows how the path of the von Karman vortex develops behind the cylinder moving through the object. The size of the vortex depends on the Reynolds number of the fluid impinging on the object [15]. Figure 1 shows the type of flow with different Reynolds numbers on the cylinder.

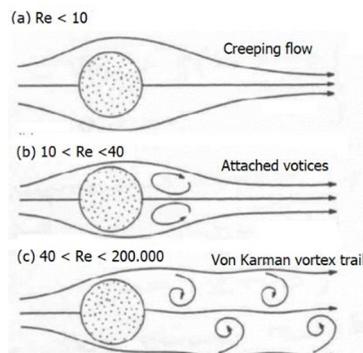


Fig. 1. Flow past an infinitely long cylinder for flow ($Re < 10$) flow lines are smoothly connected behind the cylinder. $10 < Re < 40$ two vortices are formed that rotate in opposite directions. Re continues to increase to the $Re > 40$ region, the symmetric formation breaks and two asymmetric vortices are formed, known as the Von Karman Vortex street [12].

1.2 Cantilever Elastic Rod

In Newtonian mechanics the equation of motion, which is a second-order linear ordinary differential equation with constant coefficients that can be obtained using equation. Simple harmonic motion is one dimension using Newton's second law and Hooke's law of spring elasticity [16]. Elasticity E is the ability of a material to return to its original shape in size and position when pushed, pulled or subjected to some other deformation force. If a linear spring is subjected to a force F , the stiffness of the spring is k and the spring will deflect. If the stiffness of the cantilever beam (Figure 2) is x , a linear relationship applies as in equation (1).

$$k = \frac{E.A}{L_0} \quad (1)$$

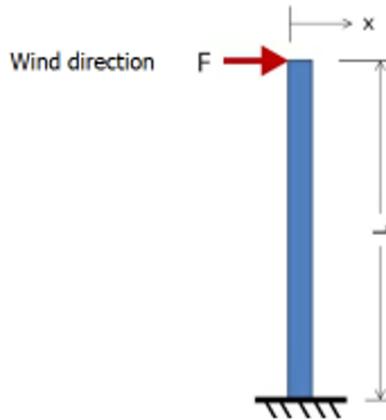


Fig. 2. Illustration of a cantilever bar subjected to wind force

A cantilever bar subjected to a force is a Newtonian motion phenomenon of a moving mass represented by equation (2). On the other hand, the cantilever bar is represented as a rigid spring and is expressed by equation (3).

$$F_g = m \frac{d^2x}{dt^2} \quad (2)$$

$$F_p = kx \quad (3)$$

Since the spring force F_p and the spring force are equal to the Newtonian motion F_g , they are expressed in equation (4).

$$m \frac{d^2x}{dt^2} + kx = 0 \quad (4)$$

Mathematically, this equation is a homogeneous second-order linear differential equation and its solution is written as follows

$$x(t) = e^{+\sqrt{\frac{k}{m}}ti} + e^{-\sqrt{\frac{k}{m}}ti}, \quad \text{whre } \omega = \sqrt{\frac{k}{m}}$$

Then $x(t) = e^{+\omega ti} + e^{-\omega ti}$ is equal to equation (5)

$$x(t) = \cos \omega t + \sin \omega t \quad (5)$$

ω is the angular speed, if the wave has an initial phase speed φ then equation (3) is written as equation (6). The equation is simple harmonic motion that can be served as a mathematical model for a variety of motions.

$$x(t) = A \sin(\omega t + \varphi) \quad (6)$$

1.3 Wind Energy

There are various ways to extract energy from the wind, but the traditional one is to connect the center shaft of a wind turbine to a generator. This conversion has energy losses, which can be avoided by switching to bladeless wind turbines that utilize the vibrations caused by the vortex. Vortex wind turbines require less material for construction compared to rotary wind turbines of the same height. Bladeless wind turbines require less maintenance than conventional wind turbines because they have fewer moving parts [17]. The installation of wind turbines requires a feasibility study investigation of wind speeds at the location. Therefore, it is important to monitor wind speeds to determine whether it is feasible to build a wind turbine at that location [9]. The relationship between wind speed (v) and energy generated is very important in planning the development of a site where a wind turbine will be built. The relationship between wind speed and wind energy is shown in the following formulas. Power output P is the energy per unit time expressed in equation (7)

$$P = \frac{1}{2} \rho A v^3 \quad (7)$$

Where A is the area determined by the height (h) multiple to the diameter (d) of the cylinder and ρ is the fluid density.

2 Materials and Methods

Vortex turbines are vertical, long, cylindrical devices. The turbine consists of two main parts a fixed base fixed to an anchor and a flexible pole that acts as a cantilever and interacts more freely with the fluid in oscillating motion. The turbine does not need bearings, shafts, gears or the presence of moving parts in contact with it and therefore does not require lubrication as rotating machines [14]. The operation of this equipment requires very little maintenance and operating costs [9]. Electricity is generated by a linear generator that converts mechanical energy into electricity. The generator uses neodymium magnets in translational motion and the stator is located inside the mover [18]. The schematic diagram of a vortex wind turbine is shown in Figure 3.

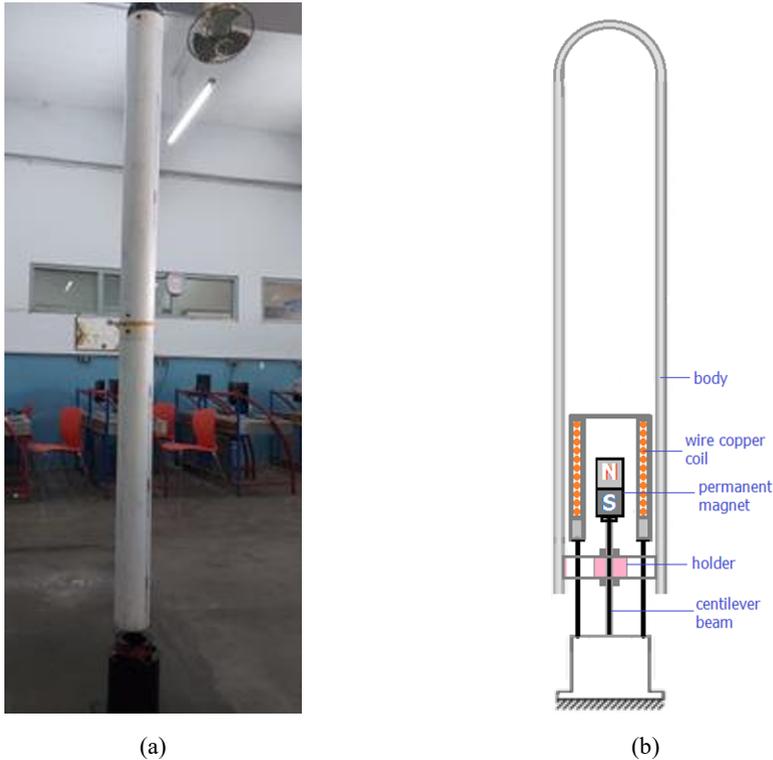


Fig. 3. (a) vortex wind turbine or bladeless wind turbine and (b) schematic of the vortex turbine components

The wind turbine component consists of cylindrical cylinders with diameters of 6 and 7 inches and a height of 2 meters. The 12 mm diameter steel centilever rods have an effective length of 120 cm and the power plant is a neodymium permanent magnet linear generator. Test results were observed in the form of CFD simulations to determine lift and drag coefficients [19], fluid motion simulations and field tests to generate electricity.

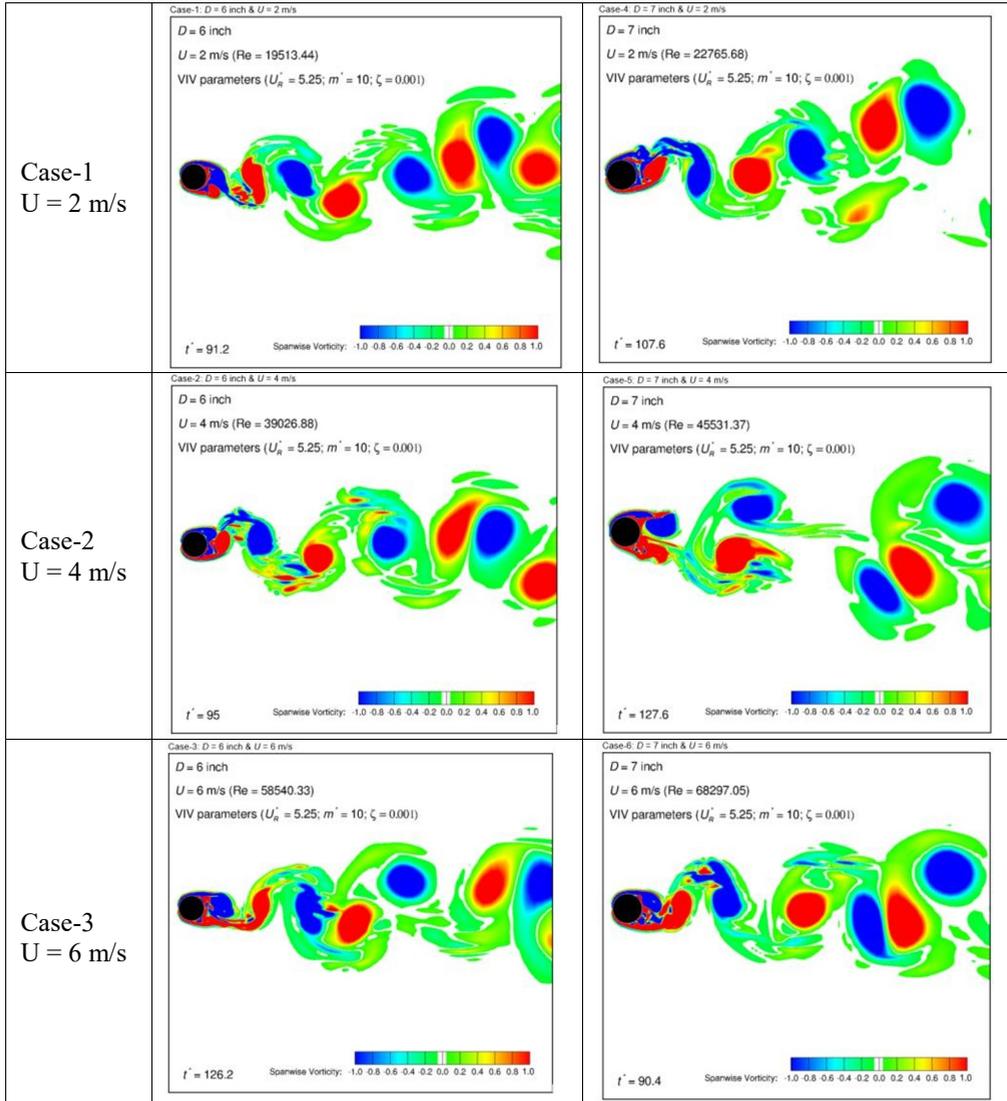
3 Results and Discussion

The results of the Computational Fluid Dynamics (CFD) computer simulation study are presented in Tables 1 and 2. The cylinder diameter and wind speed affect the frequency and deflection/width of the wind-generated oscillations due to vortex symptom formation.

Table 1 shows the simulated motion of the fluid after passing through the cylinder. Von Karman vortex paths provide information about fluid flow or objects obstructing fluid flow based on the patterns formed in the vortex paths [20]. Therefore, the patterns seen in some of the images in Table 2 are of great importance as they are the patterns under investigation.

Table 1. Variation of the cylinder diameter and wind speed with respect to the oscillating motion of the cylinder

Wind Speed	D = 6 inch	D = 7 inch
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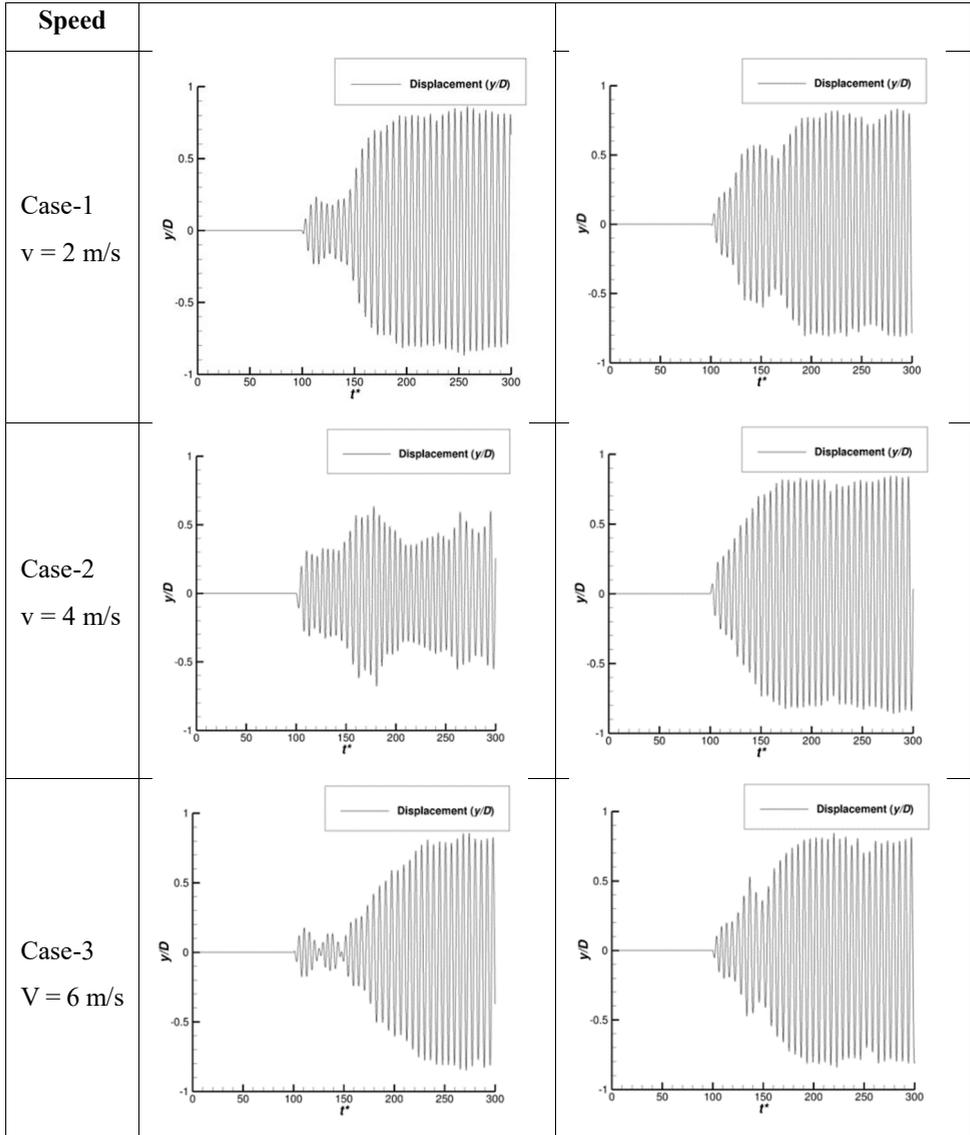


The time required to create a stable Karman vortex path can be deduced from the values in Table 1. The vortex exit events were observed after 100 s at each wind speed, but the exit occurred at 4.0 m/s for the 7 inch cylinder, indicating the stability of the oscillations. The vibration frequencies obtained were relatively low for each wind speed. The oscillation frequency tended to increase with increasing wind speed, in agreement with the results of Ajay Kumar Kaviti, 2021 [17].

Table 2 shows the simulation results for displacement of vibration on the 6 and 7 inch cylinder variants. From CFD can be obtain the lift coefficient that indicates the capacity of the fluid to move from a fixed position relative to the cylinder.

Table 2. Variation of cylinder diameter and wind speed on drag and lift coefficients

Wind	D = 6 inch	D = 7 inch
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The results of CFD simulations with wind speeds ranging 2, 4, and 6 m/s can be shown by plotting the effect of wind speed on cylinder diameter as shown in Figure 6.

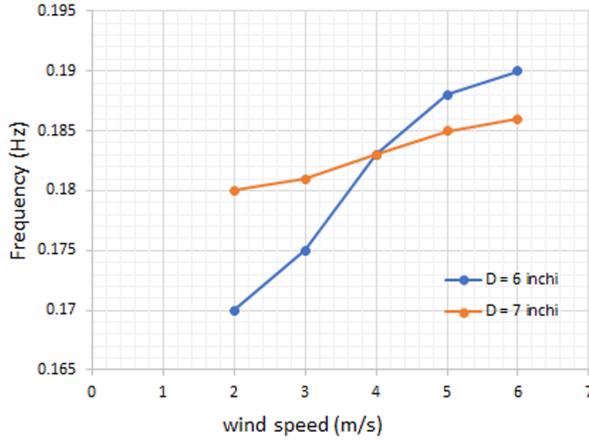


Fig. 6. Effect of wind speed on the frequencies of 6 and 7 inch diameter cylinders.

The effect of wind speeds from 2 to 6 m/s on the frequency shows a linear increase. However, for cylinders with a diameter of 7 inch, the effect of the increase is more sloped than for cylinders with a diameter of 6 inch. This may be due to the fact that the 7 inch diameter cylinder is heavier and requires more energy to vibrate. Figure 7 shows the test results for a 6 inch diameter vortex cylinder showing the effect of wind speed on the generated voltage.

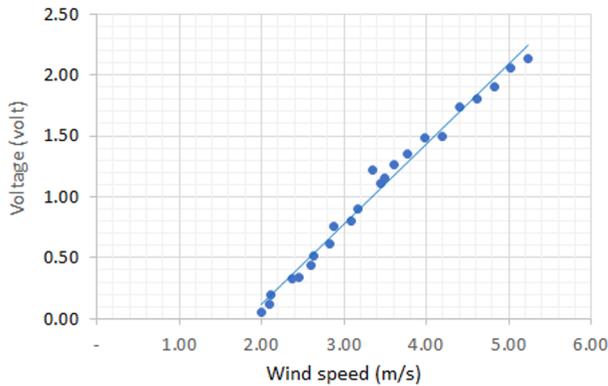


Fig. 7. Effect of wind speed on the electrical voltage produced by a vortex wind turbine

A kentilever rod attached to a cylinder becomes an object when placed in a fluid flow. The cylindrical object creates a vortex flow in the fluid. The cylinder of the object is connected to an elastic cantilever rod that can resonate with the fluid flow, causing the cantilever rod to vibrate. The vibration of the rod is caused by an external force, for example a blowing wind. This symptom is an external force-induced vibration, mathematically known as force vibration undamped.

The natural frequency produced by the turbine's kentilever bar must be such that it resonates with the frequency of the vortex flow through the column. Mathematically, this is an undamped vibration phenomenon. Extending equation (4) to equation (8) gives

$$m \frac{d^2x}{dt^2} + kx = F_0 \sin \omega_0 t \tag{8}$$

The fixed component (centimeter rod rod) increases in vibration amplitude due to vibration energy (eddy currents), and the vibration amplitude is fixed under certain conditions (steady-state vibration response). In general, the vibration equation is expressed by equation (9).

$$x(t) = (1 - e^{-At}) \sin \omega t \quad (9)$$

Where $x(t)$ is a function of the vibration displacement with respect to time, A and B are constants as a function of the vibration coefficient and t is time. Simulations of the undamped oscillatory motion of a vortex train due to fluid flow are shown in Figure 8. Where displacement is ratio $x(t)/A$ (Amplitudo).

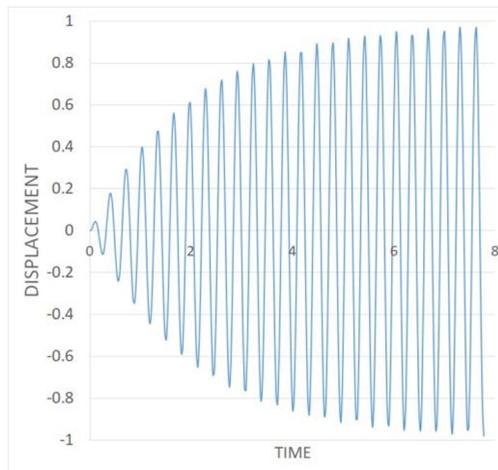


Fig. 8. Simulation of vibration movement in a column from a mathematical equation function as a function of vibration amplitude versus time from equation 10.

Under vibration conditions with stable amplitude and frequency, the vibration mechanism due to vortices can function well with respect to the expected motion. This stable vibration in the vortex turbine functions to drive the linear generator so that the output of electrical energy is also stable.

4 Conclusion

At low wind speeds below 5 m/s that vortex wind turbines can already exhibit generator induced oscillations. The effect of wind speed on the generated voltage also increases linearly with wind speeds between 2 and 5 m/s. The effect of wind speed from 2 to 6 m/s on the oscillation frequency increases linearly.

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