A Numerical Study to Choose the Best Model for a Bladeless Wind Turbine

Mohammed Amein Alnounou and Sikata Samantaray

Abstract A new type of wind turbine has been created called the bladeless turbine, which uses a completely new type to capture wind energy, as it works with a minimum of moving parts to generate electric current using the vibration produced by the wind. In this chapter, numerical modeling of airflow around a two-dimensional cylinder was made and compared with the reference values to ensure the correctness of the program used, and then the three-dimensional cylinder was studied and the numerical study expanded to include several cases. Where the study was conducted on five different shapes of the mast by changing the angles of inclination of the cylinder under boundary conditions $T = 288.16$ K, $P = 1$ atm, $V = 0.0003$ m/s and studying the effect of model dimensions on the results of the modeling process by comparing the pressure diagrams around the studied shapes in order to ensure that the results are within the least relative error. The results also showed that with increasing the angle of inclination of the cylinder, a lower pressure drop was obtained. Numerical modeling of the airflow around the bladeless wind turbine was also made according to two cases: the first case when the same boundary conditions $V = 0.0003$ m/s, $T = 288.16$ K, $P = 1$ atm, the second case at reference boundary conditions $V = 3$ m/s, $T = 300$ K, $P = 1$ atm, Using a regular mesh and hexahedron, the density of the used mesh has been modeled, and then reviewing the effect of the used perturbative model on the results, choosing the perturbative model best suited to the studied case, and comparing it with the reference case.

Keywords Vortex-induced vibrations · Bladeless windmill · Vortex shedding · Numerical modeling

1 Introduction

Pipe curvatures are the most accurate and important part of increase in requirements of living life; the search for a large and stable source of energy that secures the needs

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P. Pradhan et al. (eds.), *Recent Advances in Mechanical Engineering*,
Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-16-9057-0_38

of these large gatherings has become obsessed by scientists, and finally, electric energy was the best type of energies due to the ease of transferring it and converting it to other forms of energy where all countries of the world today depend entirely on electricity and its progress is measured by the amount its consumption of this energy; therefore, it was necessary to find the means and methods that lead to the production and utilization of this energy.

One of these methods was wind turbines where there are two main classes of wind turbines called the first horizontal axis while the second is called vertical axis, but these turbines were suffering from some problems, the most prominent of which is (loud noise—requiring high wind speeds)—containing mechanical parts that are exposed to wear due to friction and impact on wildlife—high operating and maintenance costs.

Therefore, a new type of profitable turbine has been devised called the blade-free turbine that uses a radical new approach to capture wind energy, as it works through the phenomenon of nonlinear resonance, which is known as vibration resulting from eddies (VIV). This phenomenon is of great importance in many branches of mechanical engineering.

For example, it can be found in marine structures or heat exchanger tubes, as well as in urban structures such as slender chimneys, tall buildings, power lines, and bridges.

During the past years, many studies have been conducted on this phenomenon; usually, this phenomenon is considered an undesirable effect because it may affect the structural integrity or reliability of performance, but now this phenomenon can be used in extracting clean energy [1].

1.1 Bladeless Turbine Parts

This turbine consists of one structural component, as it consists of the following parts:

(1) The lower section fixed to the ground: the upper section which is a hollow conical cylinder made of lightweight materials and is subject to vibration when exposed to the wind.

(2) The mast: It is a cylinder that connects the upper and lower sections, where the lower part of it is fixed in the ground, while the upper part supports the upper part of the turbine in increasing its oscillations, and it also reduces the mechanical pressure on the lower section.

(3) The magnetic generator: It consists of two rings of magnets between the upper section of the vibrating and the fixed axis fixed from the ground. Due to its simplicity to manufacture, it has distinct advantages such as transportation, storage, and assembly.

1.2 Turbine Working Principle

The turbine captures wind energy by means of a nonlinear resonance phenomenon known as vortex-induced vibrations (VIV). It is an aerodynamic effect experienced by engineers, when the wind exceeds the structure of the turbine, the flow changes The air generates a periodic pattern of vortices, and as soon as these forces are strong enough, the fixed structure begins to oscillate, and this vibration causes a convergence between the rings of the two magnets, then the value of the forces of repulsion between them increases and the divergence occurs and the wind returns to affect the moving mast and thus the process of convergence and divergence between the two magnets continues and is done power generation, and research continues to determine the best way to generate power from this technology [1] (Fig. 1; Table 1).

Fig. 1 A bladeless wind turbine

Table 1 A comparison between bladeless wind turbines and blade wind turbines

	Bladeless wind turbine	Blades wind turbines
Blades	You don't need	You need
Wind velocity	It operates at different and relatively low wind velocity	They operate at high wind velocity
Noise	Don't make noise	Make noise
Construction and maintenance cost	Low cost	High costs
Movable rotating parts	It does not contain rotating parts	Rotating parts contain
Payoff	Relatively low payoff	Higher payoff
Size	Small size	Big size
Steering blades	No steering blades needed	Need guide blades
Its impact on wildlife	It does not affect wildlife	Affect wildlife

2 Literature Review

2.1 Phenomenon of Vibration Caused by the Vortex (VIV)

In 2012, researchers Santiago Gil Barrero Antonio Avila, Pindado Sergio were introduced A study focused on the phenomenon of vibration caused by the vortex (VIV) by considering a circular cylinder to be analyzed as a potential source for obtaining energy and determining the effect of some parameters on the energy conversion factor, such as the mass ratio $*m$ (the ratio of the body density to the density of the surrounding fluid) or the mechanical damping factor. The study concluded that there is an ideal value of the damping factor by which the highest energy conversion factor r/M can be obtained, and that increasing the Reynolds number can achieve higher values of the energy conversion factor [2].

In 2014, researchers Robert Correa, Eric Cremer presented a study dealing with the development of a compact device capable of harvesting wind energy and converting it into electrical energy through the phenomenon of nonlinear resonance, where a small model was constructed and tested in an air tunnel, and the results showed the possibility of vortexing, which in turn causes vibration and harvesting. Wind energy and electricity generation, but it will be difficult because of the low air density compared to other fluids such as water that have proven effective in this device, and Fig. 2 shows how to vortex-induced vibration [3].

And In 2018, the Keystone School of Engineering, Pune, Maharashtra, India, published A study focused on the phenomenon of nonlinear resonance known as vibration caused by the turbine, which is of great importance in energy extraction, and the Alya code was developed in order to simulate the problems of fluid–structure interaction, which is the phenomenon of the mutual effect between a fluid and a solid body (fluid–structure interaction) FSI and conduct several experiments for graded models of turbine and a comparison of numerical and experimental results with an error rate of less than 10% [4].

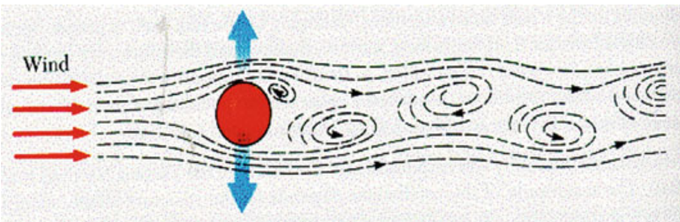

Fig. 2 Vortex-induced vibration

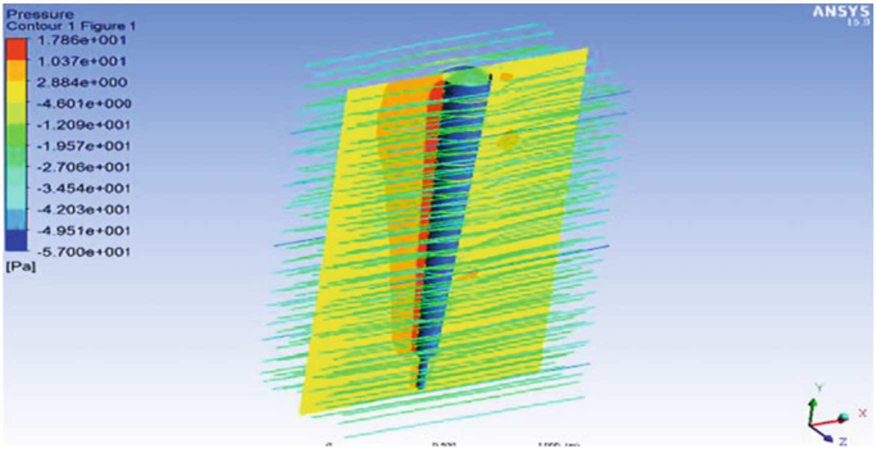

Fig. 3 Pressure field resulting from the study

2.2 Models of Turbines Approved in the Studies

In 2019, researchers Onkar D. Kshirsagar, Amol B. Gaikwad presented a numerical study of the shape of the turbine and reached the following conclusions:

The pressure distribution in the shape of the turbine ranges from Pa [−57 to 17.8], the maximum turbine deformation was 5.4318 mm and minimum 0 mm as in Fig. 3, and the study concluded that fiberglass is the most suitable material for the manufacture of the shape because it gives maximum deformation [5]. And in 2016, researchers Saurav Jadhav Bobde, Sameer presented a study on methods of generating electricity through a linear generator (magnetic generator) instead of a linear motor, so there is no need for an arm that converts reciprocating motion into rotational motion, which had failed in this project during its experiment on a model small, well study and design of the mast and its analysis for maximum vibration [6].

In a journal study [7], several tests on tapered cylinders are carried out to investigate the effects of taper ratios. In comparison with uniform cylinders, tapered cylinders have a far wider variety of lock in ranges.

3 Numerical Solution Approach and Performance Parameters

3.1 Study of Airflow Around a Cylinder

The airflow around a two-dimensional cylinder is considered one of the simplest flows, but studying this flow here is an essential step, to compare the results with previous studies, and thus ensure the mastery of the programs used as well as obtain some of the necessary data as initial values, which are used later when modeling the flow around the turbine. The two-dimensional and three-dimensional flux has been studied.

3.2 Two-Dimensional Flow Study

The studied shape is drawn with the size of the observation, as in Fig. 4, but before starting this step, the type of study must be determined 2D, given that the study is a primary study, so we choose 2D and enter the boundary conditions, which are: the entry area and the outlet area.

Based on the reference studies that were conducted on the studied form and compared with the values which resulted from our study of the same figure shows the following: *Cd* values for the reference study were $Ci = 3.88$, and for the studied model, $Co = 3.94$ (Figs. 5 and 6).

Where the uncertainty percentage was 1.5%, thus making sure of the correct work of the program used and testing the accuracy of the results (Fig. 7).

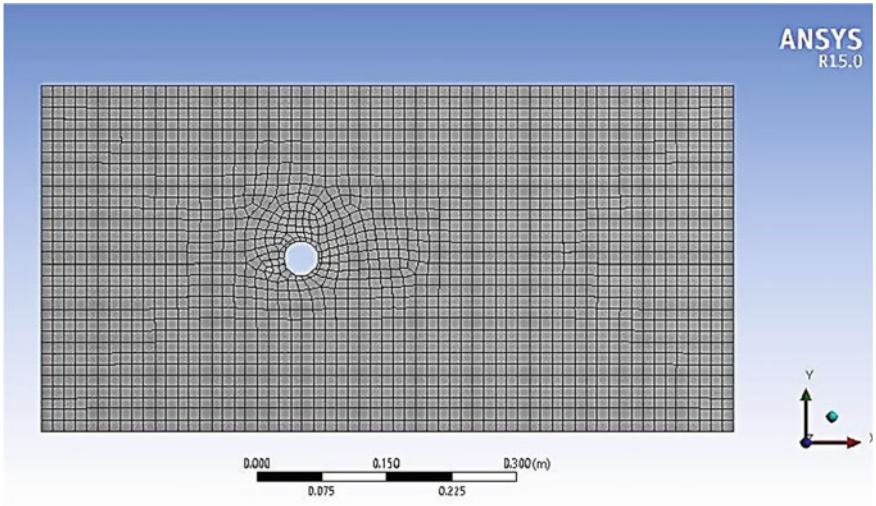

Fig. 4 Drawn shape with mesh in two-dimensional case

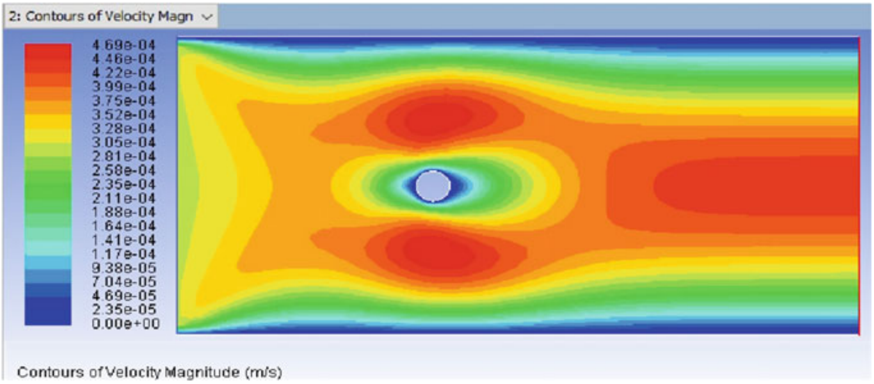

Fig. 5 Velocity distribution diagram around the studied shape

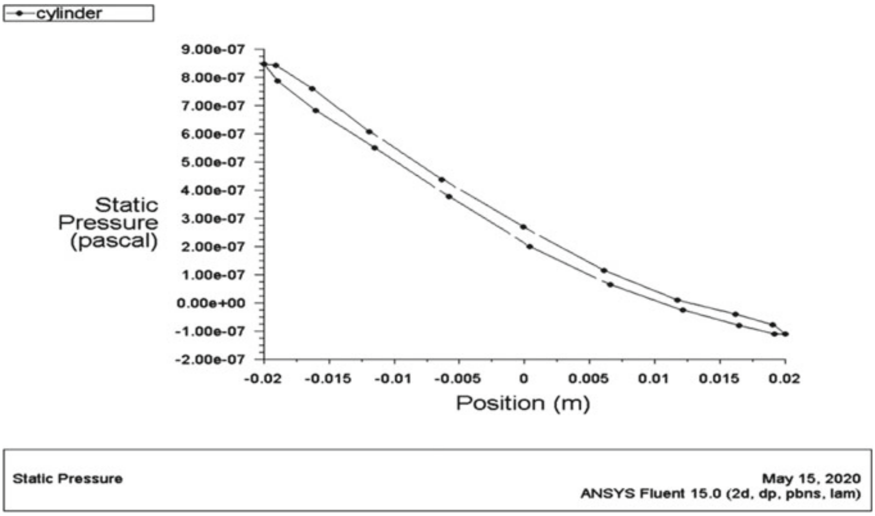

Fig. 6 Pressure distribution diagram around the first studied model is shown

3.3 Three-Dimensional Flux Study

A three-dimensional flow was studied around a fixed diameter cylinder having the same boundary conditions used in the case of two-dimensional flow. This study was carried out with the same boundary conditions and we reached the following results: Fig. 8 shows the pressure distribution diagram around the model (1) (Table 2).

By adopting the same previous conditions, the three-dimensional study was expanded. Several studies were conducted on different shapes by changing the angle of inclination of the cylinder until reaching the desired turbine shape as in Fig. 9.

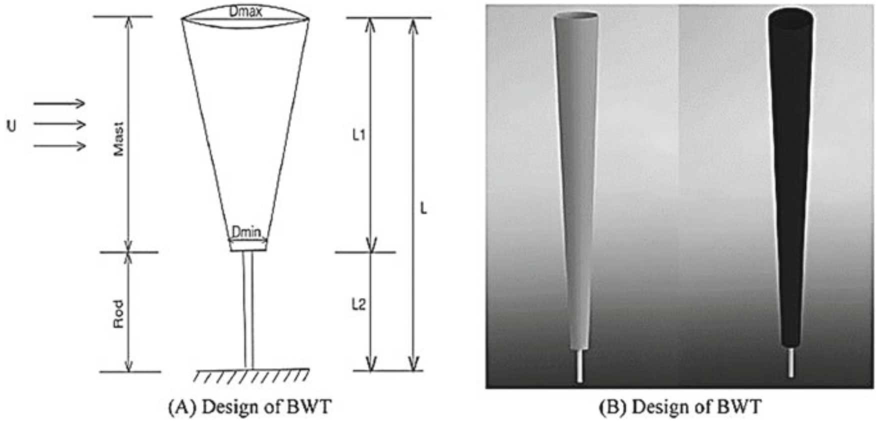

Fig. 7 **a** Vortex turbine size and components. **b** Vortex bladeless wind turbine solid model

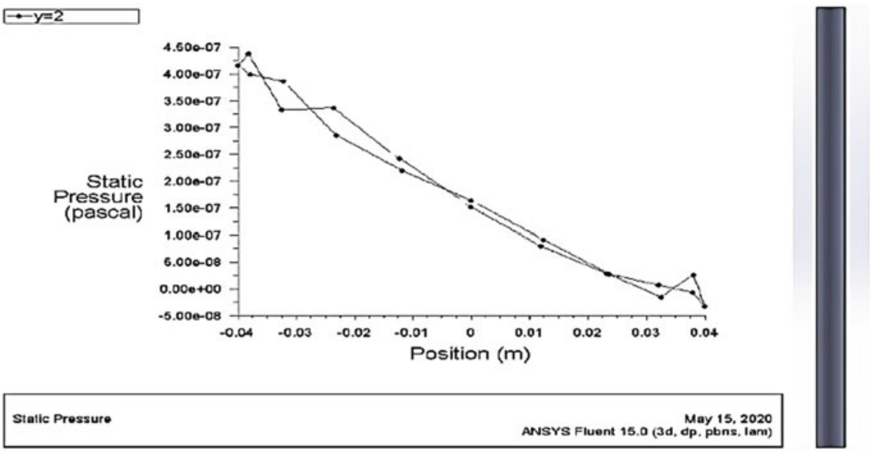

Fig. 8 A diagram of the pressure distribution around the model

Table 2 Varied dimensions of five distinct turbine types

Sl. No.	Parameters	Dimensions (mm)				
		1	2	3	4	5
1	Dmax	200	210	220	225	225
2	Dmin	175	150	150	140	125
3	d	0	0	0	0	20
4	L1	2000	2000	2000	2000	1800
5	L2	0	0	0	0	600
6	L	2000	2000	2000	2000	2400

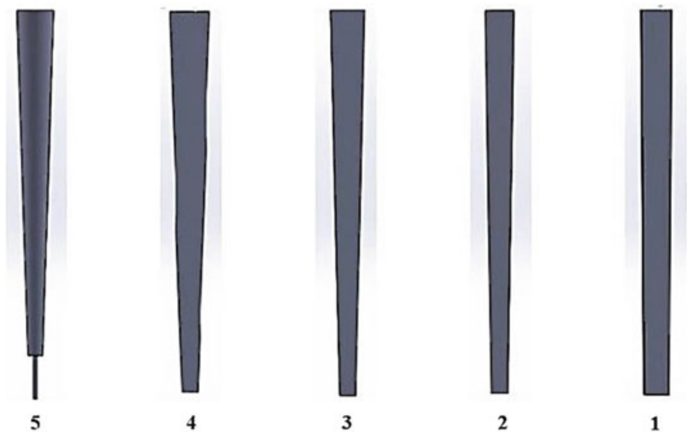

Fig. 9 Gradient of the studied shapes of the turbine shape

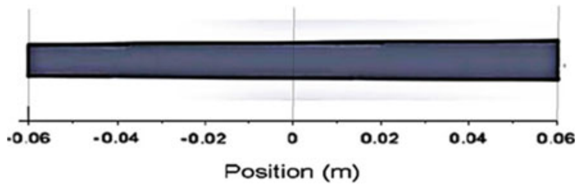

Fig. 10 Turbine position division

Figure 10 shows how the position of the turbine was divided into the study of pressure on the turbine in both directions (Figs. 11 and 12).

4 Conclusion

With an increase in the angle of inclination of the cylinder (mast), we notice a decrease in pressure caused by wind and vibration. In the numerical study of the airflow around the shape of the turbine chosen for the study, we note that the velocity distribution pattern is proportional to the pressure distribution pattern around the mast. Further study into optimizing VIV phenomena will be conducted in order to improve energy extraction rate dependent on cylinder geometries. Different VIV device designs would be numerically and experimentally investigated in order to induce more stringent vortex shedding operations, thus the energy production. VIV can also be combined with other clean energy technology such as solar, wind, and tidal.

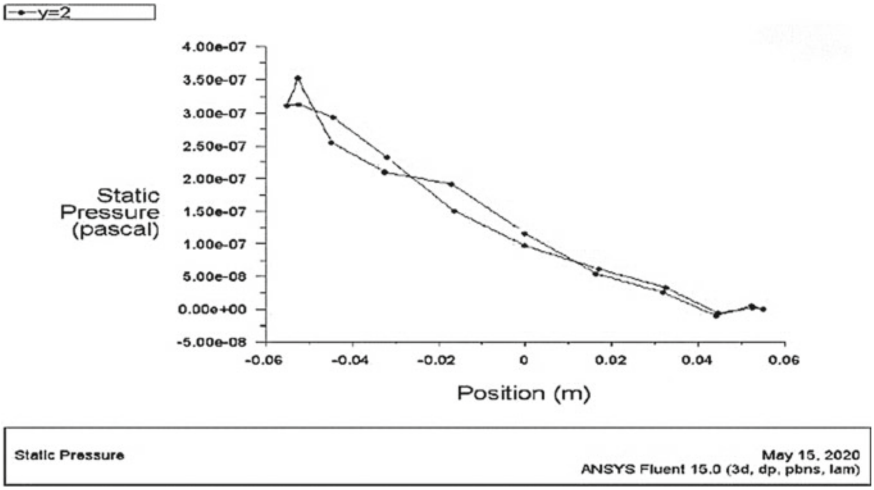

Fig. 11 Pressure distribution diagram around the model (1)

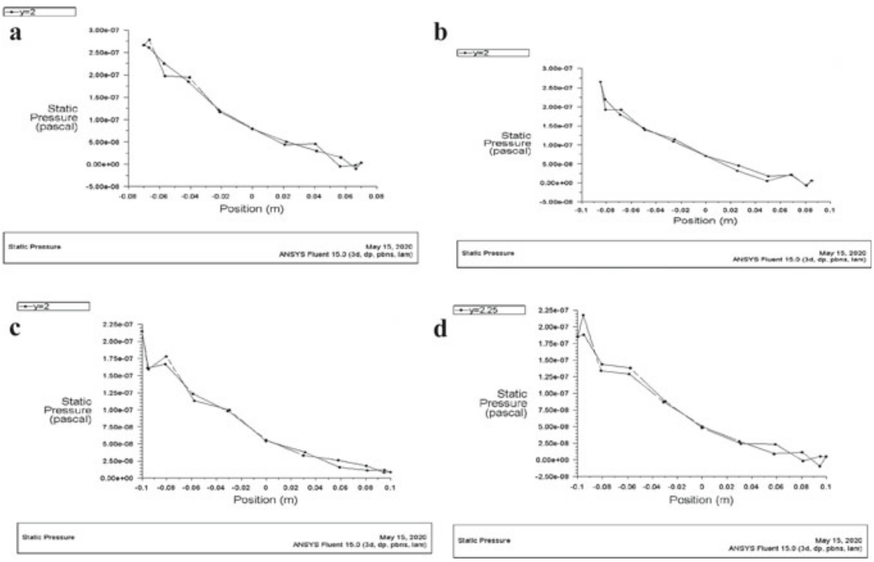

Fig. 12 Pressure distribution diagram **a**, **b**, **c**, **d** around models 2, 3, 4, 5, respectively

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