Fabrication of Vortex Bladeless Windmill Power Generation Model

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Abstract

Today, India is top amongst the list of developing countries in terms of economic development. Hence the energy requirement is increasing rapidly. To meet these energy requirements non-renewable energy sources are used excessively but due to limited storage of this sources there is a need for generation of clean energy through renewable energy sources. India is having fifth largest installed wind power capacity in the world. As the region of high speed wind is limited and also the area required for installation of conventional windmill is high, bladeless windmill based on vortex induced vibrations can provide the solution for these disadvantages of the conventional windmill. Bladeless windmill basically works on the vortex shedding effect. Generally structures are designed to avoid vortex induced vibrations in order to minimize the mechanical failures. But here, we try to increase the vibrations to increase the generation of electricity.

Keywords: Bladeless, Vortex Induced Vibrations, Vortex Shedding, Clean Energy

I. INTRODUCTION

In the process of wind power generation there are mainly two methods are considered, Rotational wind harvesting and Oscillation wind harvesting. Though both allow the transfer of mechanical energy to electric energy there is major difference in the mechanical system of transmission of energy from one form to another.

Rotational wind harvesting is the basic principle used in the conventional windmill. In this type the spinning turbine blades are connected along a center shaft to gearbox. This gearbox transmits the mechanical energy obtained from the rotation of the blades by the flowing wind to the generator which intern translates the mechanical energy of rotation of blades into usable form of electricity.

Oscillation wind harvesting is the less common method used amongst the both methods. To understand the reason behind it we have to understand the working of it. This device works on the vortex induced vibrations (VIV). VIV are the motions induced on the body due to the interaction with the external fluid flow, produced by periodic irregularities in the flow. Basically VIV is the vibration in the perpendicular direction induced when a fluid is passed over an object. In the oscillation wind harvesting the most geometrically appropriate airfoil shape is cylindrical. The cylinder optimizes the effects of VIV because of its symmetry along its center axis. As a fluid flows past a cylinder placed vertically it starts to oscillate in the horizontal direction proportionate to air speed suspended by a spring. This oscillation can be compared to the rotation of turbine blades in the sense that both are mechanical motions caused by wind flow that must then be transferred to electrical energy. In the case of the oscillation wind harvesting device, the transformation is most commonly done through the use of a magnetic field. As the cylinder oscillates up and down, coils attached to either end move in tandem around magnets. The motion of the coils through the magnetic field generates current, causing voltage, which is then harnessed as electrical energy. This process varies greatly in efficiency based on device scale, spring tension, and the strength of the magnetic field being used to generate electricity.

A. Study of Vortex Induced Vibrations

1) VIV Theory
VIV is a result of vortex shedding phenomenon which generally occurs nearly on any bluff body when submerged into fluid flow. Normally, irregular vortex shedding will occur. Flow behind the body resulting in the fluctuating pressure differential which produces lift force perpendicular to the direction of the flow. The oscillating motion on the body is due to alternating lift forces.

2) Reynolds Number
In general, flow parameter that affects the behavior of vortex shedding has been observed to be the Reynolds number of flow as

\[ \text{Re} = \frac{U D}{\nu} \]
U is the free-stream velocity, D is the cylinder diameter and ν is the fluid kinematic viscosity. The regime that is targeted in this project is known as the “fully turbulent vortex street”, with Reynolds number in the range of (300<Re<3x10^5).

3) Strouhal Number:

The Strouhal Number, St is a non-dimensional parameter that describes the vortex shedding frequency to the oscillating flow mechanism.

\[ St = \frac{(fs D)}{U} \]

Where, fs is vortex shedding frequency.

Strouhal number will be used as a constant value in this project as the Reynolds number falls in the middle of constant Strouhal number region which is 0.2 for subcritical flow.

4) Lock In Phenomenon:

A phenomenon known as “lock in” is a condition when the vortex shedding frequency becomes close to the natural frequency of the body. It has the potential to enlarge the amplitudes of bodies’ oscillation which is similar to linear resonance.

II. LITERATURE REVIEW

This paper deals with the study of the vortex induced vibrations for harvesting energy in which the various methods of the wind power harvesting are discussed. The various phenomenon and concepts that are used in the wind power harvesting. Also the various problems which are related with the conventional wind power harvesting are discussed. The possible solution of using a piezoelectric material in the oscillation wind power harvesting type model is also discussed. [1]

This paper deals with the study of the bladeless wind power generation in which various aspects of bladeless wind power generation. In this paper the other type of thread attached mast model is discussed. The history of the bladeless wind power generation is also discussed. The various applications of the bladeless windmill and its future is discussed. [2]

This paper deals with the study of the influence of the taper ratio on vortex-induced vibration of tapered cylinders in which a series of tests are conducted and the effect of the various taper ratios is studied. For linearly tapered cylinders wider range of lock-in ranges were observed as compared to the uniform cylinders. The tests are carried out on small taper ratios. [3]

III. PROBLEM DEFINITION

- Conventional windmill requires high wind speed. For such air speed the places are limited. Hence windmills working on lesser wind speeds are need of the hour.
- The cost of the different parts of conventional windmill is very high. A typical windmill will cost $2500-$7500 per kilowatt.
- Designing of windmill blades is complicated.
- The area required for working windmill is high. The conventional windmills blades swept volume is more.
- Area of installation is 60 acres per megawatt of capacity of wind farms. Also they prove fatal to birds.
- They produce low frequency sound which is not good for human health.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Conventional Windmill</th>
<th>Bladeless Windmill</th>
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<tbody>
<tr>
<td>Mode of operation</td>
<td>It generates electrical power with blades.</td>
<td>It generates electrical power without blades.</td>
</tr>
</tbody>
</table>
Mode of generation | It captures wind energy using Rotational motion of the blades. | It captures wind energy using “Vorticity”
--- | --- | ---
Acoustics | It’s operation is noisy, as it produces noise above 20 Hz. | It is silent in operation as it oscillate at a frequency that doesn’t produce audible noise (below 20Hz).
Structure | The design is sturdy & there is high wear & tear. | The design is sturdy & there is minimal wear.
Safety | It is not safer for birds, that often suffer from collision with blades. | It is also safer for birds, that often suffer from collision with blades.
Maintenance | It is not feasible to maintain, as it has higher maintenance cost. | It is easy to maintain due to 80% reduction in maintenance cost.
Construction | It requires more no. of moving parts. | It requires less moving part & less material to produce same amount of electricity.
Economics | The manufacturing cost is higher. | The manufacturing saving is at around 53% of usual production cost.
Efficiency | It has higher efficiency (About 60%). | It has lower efficiency of energy conversion (About 30%).
Space Consideration | The area required for installation is more. | We can put more vortex in the same area to produce electricity

IV. Suggested solution

The problems that are associated with the conventional windmills are very much solved in the oscillation type wind power harvesting. Bladeless windmill is less costly and require less maintenance than the conventional windmill. The bladeless windmill has less moving parts than the conventional windmill. It requires less area and wind speed for its area. The bladeless windmill works on a principle of vortex shedding effect. The vortex shedding is the effect which set the object in oscillations when a fluid flow is passed over an object. Instead of capturing energy through rotational moment the energy is generated through oscillations through a piezoelectric material.

![Fig. 1: Proposed Model](image1.png)

V. Methodology

In this we have studied the design of the mast in which we designed and analyzed it for the maximum output frequency for the lock in frequency. For the calculations of the design the following procedure is carried out.

![Fig. 2: Analysis of Mast Model](image2.png)
A. Vortex Induced Vibration

Let’s consider a structure called Tapered Oscillation Cylinder.

Fig. 3: Vortex Induced Vibration

Considering the notations as,

\[ \begin{align*}
    d_0 &= D_{\text{max}}, \\
    d_1 &= D_{\text{min}}, \\
    D &= (D_{\text{max}} + D_{\text{min}})/2
\end{align*} \]

\[ H = L, \]
\[ U = \text{Air velocity}, \]
\[ \nu = \text{Kinematic viscosity}, \]
\[ f_s = \text{Oscillation frequency}, \]

Now, we know Reynolds Number (Re)

\[ \text{Re} = \frac{UD}{\nu} \]

And Strouhal Number (St)

\[ \text{St} = \frac{(f_s D)}{L} \]

Area of tapered cylinder,

\[ A_p = \frac{\pi}{2}(D_{\text{max}} + D_{\text{min}}) \cdot L \]

Reynolds Number distinguishes the flow of fluid as Laminar or turbulent. So we are targeting Re values \(300<\text{Re}<3\times10^5\) for better frequency of vibration. Now for Reynolds number to be \(300<\text{Re}<3\times10^5\), Strouhal Number should be 0.2 or 0.198 (from graph)

\[ \text{St} = 0.198 \]

Now all the parameters are known except Mean diameter (D). To find mean diameter, we have to do trial and error. By comparing our value of D with L/D ratio of other such Experiment.

Let’s fix length as L=2m total length so from previous research paper and past study we take L/D=10

Now,
\[ 2000/D=10 \]
\[ D_{\text{max}}=200\text{mm} \]

Now from different Research paper we found the taper ratio lies between 14-19 so selecting 16 as a taper ratio \(r=16\)
\[ r=L/D_{\text{max}}-D_{\text{min}} \]
\[ 16=2000/200-D_{\text{min}} \]
\[ D_{\text{min}}=75\text{mm} = 80 \text{ mm Approx for smooth taper} \]

\[ R_t = \text{Taper Ratio} = L/(D_{\text{max}} + D_{\text{min}}) \]

B. Natural Frequency

We know that from Theory of torsion of shaft

We have

\[ k_r = \frac{T}{\theta} - \frac{C_4}{J} \]

So \( W_\Pi = \sqrt{(T / I)} \)

T-torque of rotating member

I- Moment of inertia
now from CAD drwaing software and selecting material as pp polypropylene and Determining Thier mass Proerties considering wall thickness as 2mm we calculated mass=1.8kg and also found the position od centre of gravity. Z= 859.18mm from top mas Now natural freq fn= 1/2[1]*\sqrt{(KL^2-2mgL)/4/I} putting the values in the formula

\[ I=1/3mL^2 \]
\[ I=2.4 \text{ kg-m}^2 \]

Now as we know strouhal frequency should be close to natural frequency
So we know St=0.2
Putting the value in strouhal formula

\[ St = \frac{fsD}{U} \]

fs= 3 Hz
This should be equal to natural frequency
So by putting fn=3
We get K=834.2 N/m
Value of spring stifness .
This much force is provided to sustain the Air thrust

Fig. 4: High efficiency at large range of flow velocities.

VI. CONCLUSION

Bladeless wind powered harvesting is convenient, requires less investment and also less area than the convenient wind powered harvesting. The highly efficient energy is generated through the bladeless windmill. As the wind speed required is very low the future of the wind power harvesting is very much depend upon bladeless windmill concept. The device produces renewable clean energy which will provide alternate option for exhausting non-renewable energy sources in future.

REFERENCES