Pharos Engineering Science Journal (PES)

ISSN: 3009-6197 Vol. 1, No. 1, 2024

Design and fabrication of linear generator for vortex bladeless wind turbine

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***Abstract*— This paper presents the design and manufacture of a linear generator that leverages wind-induced vortex movement to generate electrical power. This innovative technology represents a significant advancement in turbine performance, providing a cost-effective, environmentally friendly, and reliable alternative to conventional wind turbines. Unlike traditional designs that utilize rotating blades, this bladeless turbine employs a conical structure positioned along a shaft, responding dynamically to varying air currents. This unique configuration not only enhances aerodynamic efficiency but also drastically reduces the turbine's environmental footprint. The design incorporates only one moving part, minimizing mechanical vibrations and maintenance requirements. As a result, the proposed turbine addresses many challenges faced by traditional wind energy systems, including noise pollution and wildlife disruption. By promoting sustainable energy generation, this bladeless turbine design has the potential to lead a new era in renewable energy technology, aligning with global efforts to reduce carbon emissions and transition to cleaner energy sources.**

***Keywords*— Bladeless, linear generator, Vortex.**

I. Introduction

The world is suffering severely from an energy crisis due to climate change, global warming, and depletion of oil reserves. According to British Petroleum, at current extraction rates, the world's oil reserves are estimated to last until 2072 [1]. Renewable energy technologies are essential for the advancement of nations globally. Among these, wind power significantly contributes to the reduction of greenhouse gas emissions and the fight against climate change, which is vital for the well-being of humans, wildlife, and ecosystems [2]. Wind energy is one of the fastest-growing forms of renewable energy, providing a sustainable alternative to fossil fuels [3]. However, current wind turbines, while effective in harnessing renewable energy, have notable drawbacks. Traditional turbines have been linked to high bird mortality rates due to collisions with the blades, leading to numerous bird carcasses in their vicinity [4]. This issue raises concerns about the ecological impacts of wind farms, as the loss of avian species can disrupt local ecosystems [5]. Additionally, the noise generated by these turbines can be disruptive for nearby residents, contributing to discomfort and potential health issues [6]. Moreover, wind turbines are susceptible to malfunctions, which can lead to hazardous debris being ejected during failures, posing risks to both human safety and the environment [7]. The maintenance of these turbines requires substantial resources, including parts, funding, and ongoing upkeep, which can strain local economies and resources [8]. In response to these challenges, the concept of bladeless wind turbines has gained attention in recent years. This paper explores the development of a bladeless wind turbine that operates using a cylindrical design that moves perpendicular to the wind. This mechanism utilizes oscillation to produce energy, which is then stored in a battery bank. By eliminating traditional blades, this innovative approach aims to reduce bird fatalities and minimize noise pollution while maintaining efficient energy production.

II. Literature Reviewe

A. Linear Generator

To construct a linear generator for the bladeless wind turbine, it's essential to first grasp the fundamental principles and history of linear generators. A linear generator is an electromechanical energy converter driven by a prime mover, transforming mechanical energy into electrical energy through reciprocating motion. Its operation resembles that of a rotary generator but includes an endpoint effect. In a linear generator, the moving component travels in a straight line until it reaches a terminal point, at which it halts and changes direction. In contrast, a rotary generator continues its motion without reaching an endpoint. This endpoint effect can lead to notable issues, such as cogging force.

B. Selection of moving part

The size of the magnet required to create the magnetic field in a moving coil machine is significantly larger than that of a moving magnet generator with the same output and efficiency. Because magnets are the most costly component in these systems, moving coil applications are typically suited for scenarios where cost is less of a concern. One advantage of the moving coil design is the elimination of radial forces, open-circuit axial forces, and torque affecting the moving coil, which are critical considerations in linear machines. Radial forces can overpower gas or oil bearings, potentially leading to operational failure. Additionally, moving iron can be rotationally unstable within its air gap; if tilted, it tends to further tilt and close the gap, behaving like a negative torsion spring with such a high spring constant that it undermines efforts to achieve stabilization through improved alignment

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and greater mechanical rigidity. In contrast, moving magnets offer higher efficiency. Therefore, in this design, the magnets in the linear generator will be moved rather than the coil or core, taking practical considerations into account.

C. Selection of Generator type

The functioning mechanisms of various wind energy conversion types, including linear and rotary generators, are illustrated in Fig. 1. A linear generator is a device that transforms mechanical energy into electrical energy, moving or sliding in a single direction along either the x-axis or y-axis. There are multiple types of linear generators available for converting wind energy. To provide a clear comparison between these generators, refer to Fig. 2.

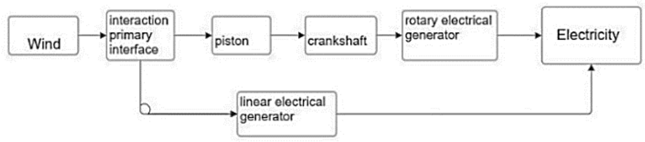

Fig. 1. Linear or rotary.

Linear generator type	Advantage	Disadvantage
Induction generator	• The design of an AC generator is simpler than a DC generator, and hence it becomes easy to understand its working principle. • operate silently, low maintenance and lowest cost.	• It is not sturdy as a DC generator. • additional insulation due to the generation of large currents.
Synchronous Generator	• high efficiency at low speed • can operate at any speed.	• brushes required. • needs DC excitation from external source.
DC Generator	• It is relatively straightforward to understand. • consists of simple parts. • reliable for off-grid.	• incompatible with a transformer. • Its efficiency and durability are low. • Copper loss, Iron loss, magnetic loss, or core loss.
Permanent Magnet Generator	• electricity is not required to magnetize. • higher power and torque density. • suitable for low load application.	• magnet installation is expensive. • weight increases with size.

Fig. 2. Linear generator type.

III. Added Value of the Paper

Our novel bladeless wind turbine design and fabrication that have special linear generator have an added value of:

- Providing a safer environment for wildlife or people, as the bladeless turbines do not have rotating blades, which reduces the risk of injury.
- Excellent market competitiveness and cost control capability.
- Improving the power output and the weight of our bladeless wind turbine.
- Minimizing need for maintenance.

IV. Methodology

The proposed system includes various components: permanent ring magnets, copper coils, a spring, diodes for the rectifier bridge, a capacitor and resistor for smoothing the DC voltage, battery banks, a cylindrical object or mast, and a switch to adjust based on wind direction. The cylindrical pole or mast serves as the mechanism for generating electricity from wind energy, harnessing the wind's momentum to produce power. The oscillation of this mast is referred to as vortex shedding, generating energy that varies with the object's shape and size. The spring stabilizes the mast to the base, facilitating the movement of the device. The linear alternator converts the mechanical energy from the wind into electrical output, functioning similarly to Faraday’s flashlight.

The rectifier is an assembly of capacitors, resistors, diodes, and inductors, converting AC power from the linear alternator into DC power for charging the battery bank. This bank stores the produced energy and acts as a safeguard against excessive voltage. The mast or cone is attached to the spring, which connects to the base, while the linear alternator, comprising copper wire and a permanent magnet, is housed within the mast. The alternator connects to a switch, leading to a bridge rectifier, and finally to the battery bank for energy storage.

The initial project step involved creating small prototypes to compare air-core and iron-core designs. Two prototypes were developed to identify the most suitable generator. The first prototype was an air-core generator with 660 turns of wire wound around a cylindrical mold. However, it produced only a minimal voltage due to a larger air gap between the rotors and stator, which distorted the magnetic flux. In contrast, the iron core yielded better results, generating 12V. This was achieved by wrapping the coil around E-shaped lamination sheets to simulate a magnetic circuit, minimizing eddy current and hysteresis losses, while the metal helped retain more magnetic flux. Consequently, the iron core was selected as the final model for the prototype.

The permanent magnet moves horizontally to induce magnetic flux for power generation. The number of turns in the windings depends on two factors: the strength of the magnet and the required voltage. The strong magnet reduces the necessary number of turns. However, the thin copper wire yielded only about 0.35 milliamps, which is insufficient for the desired power output. A thicker copper wire is needed to achieve the expected performance from the linear alternator, resulting in a higher current and increased amperage. The mast was constructed from polycarbonate to form the cone, as it is lightweight and easily shaped. Finally, it was glued to the spring. The mast was tested using a leaf blower, conducted without the linear alternator to evaluate its movement, and the test was successful.

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V. Analysis

A. Maxwell's Equations

Maxwell's equations are fundamental principles in electromagnetism that provide a mathematical framework for understanding the behavior of electric and magnetic fields. In the context of linear generators like the inner-translator FSPMLG, these equations elucidate the process by which mechanical energy is converted into electrical energy. Here's how Maxwell's equations relate to electricity generation in linear generators:

1) Maxwell's First Equation (Gauss's Law for Electricity): This equation relates the divergence of the electric field (∇·E) to the charge density (ρ) and the permittivity of free space (ϵ0).

$$\nabla \cdot E = \frac{\rho}{\epsilon_0} \tag{1}$$

In linear generators, such as the inner-translator FSPMLG, electric charges are induced or present due to the relative motion between the magnetic field and the conductive elements. Maxwell's first equation describes how these charges create an electric field.

2) Maxwell's Second Equation (Gauss's Law for Magnetism): This equation relates the divergence of the magnetic field (∇·B) to the magnetic charge density (ρm) and the permeability of free space (μ0).

$$\nabla \cdot B = 0 \tag{2}$$

While the presence of magnetic charge density is rare, the magnetic field in linear generators is primarily generated by electric currents flowing through conductive elements. Maxwell's second equation describes how magnetic fields behave and their relationship to electric currents.

3) Maxwell's Third Equation (Faraday's Law of Induction): This equation describes how a changing magnetic field induces an electric field. It relates the curl of the electric field (∇×E) to the rate of change of the magnetic field (∂B/∂t).

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{3}$$

In linear generators like the inner-translator FSPMLG, Faraday's law explains how the relative motion between the magnetic field and the conductive elements induces an electric field and subsequently an electromotive force (EMF).

4) Maxwell's Fourth Equation (Ampere-Maxwell Law): This equation relates the curl of the magnetic field (∇×B) to the electric current density (J) and the rate of change of the electric field (∂E/∂t).

$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t} \tag{4}$$

In linear generators, the interaction between the induced electric field and the conductive elements produces electric currents, which in turn generate a magnetic field. Maxwell's fourth equation captures this relationship.

By incorporating Maxwell's equations into the analysis of linear generators, we gain a deeper understanding of the underlying principles governing electricity generation. These equations highlight the intricate interplay between electric and magnetic fields, providing insights into the conversion of mechanical energy into electrical energy in systems like the inner-translator FSPMLG.

B. Theoretical Analysis

1) Calculation of the Rate of Change of Magnetic Flux ((dΦ.B)/dt) with givens:

Vibration frequency 5 Hz, Amplitude of motion 4 cm upward and 4 cm downward, Number of coil turns 2000 turns, Flux density 0.25 T, length of the wire 0.02 m.

$$v_{\max} = 2\pi f A \tag{5}$$

$$v_{\max} = 0.4\pi \text{m/s} \tag{6}$$

Using this maximum velocity, we can then calculate the rate of change of magnetic flux ($\frac{d\Phi_B}{dt}$).

2) Application of Faraday's Law for a Single Wire : The induced voltage (E) in the linear generator can be calculated using the equation:

$$E = -Blv \tag{7}$$

Substituting the given values in (7)

$$E \quad = -(0.25).(0.02).(0.4\pi) = 0.00628\, V/coil \tag{8}$$

$$E_{\text{total}} = (0.00628\,) * (2000\, Turn) = 12.56\, Volt \tag{9}$$

C. Theoretical Results

Utilizing Maxwell's equations and fundamental electromagnetic principles, we estimated the voltage generated by the linear generator. By substituting into the relevant laws, the expected voltage value was calculated to be 12.56 volts. This calculation is based on the principle of electromagnetic induction, which states that the voltage induced in a coil is directly proportional to the rate of change of magnetic flux through it.

D. Simulation Results

In the COMSOL simulation, the linear generator was designed considering all the mentioned parameters, including vibratory motion and the characteristics of the coil and magnet. The simulation yielded a generated voltage value of 11.8 volts as shown in Fig.3 and Fig.4 .

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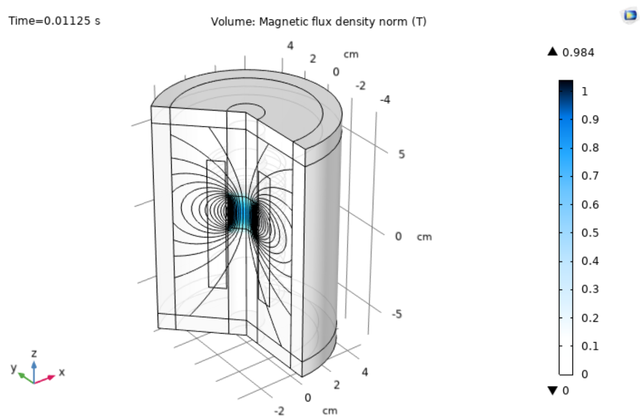

Fig. 3. Linear oscillation

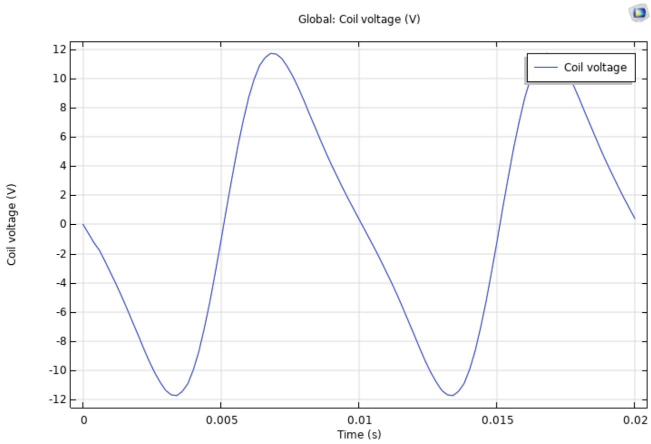

Fig. 4. Graphical results

E. Analysis of Discrepancies

The difference between theoretical results and simulation outcomes can be attributed to several factors. Firstly, theories and laws assume ideal conditions, such as no internal resistance in the coil and perfect magnet efficiency. However, in practical reality and simulation, these factors affect performance.

Secondly, the accuracy of modeling in COMSOL and its sensitivity to boundary conditions and material properties might contribute to the differences observed between expected and simulated results. For example, edge effects and end effects may not be accurately accounted for in theoretical modeling.

Lastly, experimental error and estimations in measuring physical variables (such as vibratory motion and magnetic strength) can also contribute to the discrepancy between theoretical results and simulation outcomes.

Understanding these differences allows us to improve the designs of linear generators and simulation strategies to achieve more accurate and representative results of practical conditions.

VI. Conclusion

Bladeless wind turbines are a new approach to generating energy from wind without the use of traditional blades. This innovation benefits the environment and minimizes the risk of harm to both humans and wildlife. This option will be cheaper and will require fewer components. This project has demonstrated that the concept is effective and can be productive in certain situations. The design model was also analyzed using COMSOL Multiphysics to study the power generation and efficiency of the model, in order to compare it with existing linear generators available on the market. The power output may be low, but power is still generated nonetheless. This project has been a successful in terms of the concept behind the idea. This technology could be used in the future by individuals and businesses seeking a cheaper and efficient wind power generator. The specific design can be enhanced and optimized to improve the performance of the linear generator.

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