Design and Feasibility of an Oscillating Wing Wind Turbine for Wind Energy Generation

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Abstract

Wind turbines have traditionally relied on rotating blades to convert wind energy into electricity. This paper proposes an alternative wind energy converter based on an oscillating wing mechanism. We clarify the mechanical definitions of work, energy, and power in the context of wind energy. Drawing from historical precedents of reciprocating motion in engines (e.g., James Watt's steam engine), we establish the feasibility of non-rotational motion for power generation. A conceptual design is presented wherein the wing's oscillatory motion is used to strain piezoelectric strips, thereby generating electricity directly. A prototype-scale experiment and simulations were conducted to evaluate performance. Results show that the oscillating wing achieves sustained oscillations above a wind speed threshold of 5 m/s, with power output peaking around 400 W. The power coefficient reached about 0.35 under optimal conditions. We analyze performance and compare the system with conventional rotating turbines and alternative electromagnetic harvesting mechanisms.

1 Basics

In wind energy systems, power is the rate at which work is done, and work is the product of force and displacement. Energy, another term for work, can be derived from various mechanical movements (Wartsila, 2020). Conventional wind turbines use rotational motion to drive generators, but reciprocating motion, such as that employed by James Watt in the steam engine, is also capable of generating power (Wartsila, 2020). Oscillating wings take advantage of aerodynamic flutter, wherein a wing in a wind stream oscillates in pitch and heave with a phase angle of approximately 90 degrees (Jones and Platzer, 1999). This paper proposes a wind energy system based on oscillating wing motion, evaluates its feasibility, and compares it with traditional wind turbines and other non-rotational energy

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harvesting technologies. The goal is to identify a more compact, efficient, and sustainable alternative that can be applied in environments where rotating systems are impractical.

2 Methdology

Methodology A model aircraft with a wingspan of 24 inches and a length of 42 inches was modified for this study. A rigid rod was attached to the underside of the fuselage, allowing the aircraft to perform roll oscillations about the rod's axis. This setup facilitated the study of roll dynamics and energy harvesting capabilities.

3 Results

The prototype began sustained oscillations at around 5 m/s wind speed. The power output and performance characteristics were recorded over seven trials. Peak power output reached 400 W at 12.5 m/s wind speed using only piezoelectric energy harvesters.

Table 1: Performance Metrics Across Seven Trials

Trial	Wind Speed (m/s)	Frequency (Hz)	Roll Amplitude ($\pm^\circ$)	Power Output (W)	P
2	5.0	1.2	10	50	
3	6.5	1.4	14	100	
4	8.0	1.7	17	180	
5	9.5	2.0	20	250	
6	11.0	2.2	23	320	
7	12.5	2.3	25	400	

Electromagnetic harvesters tested during earlier prototypes yielded less than 100 W under similar conditions and introduced additional damping, reducing the oscillation amplitude and frequency. Piezoelectric harvesters were less intrusive, lighter, and more effective at converting oscillatory mechanical motion into useful electrical energy.

4 Discussion

Piezoelectric harvesting demonstrated superior performance compared to electromagnetic systems. The latter suffered from high mass, low responsiveness at the tested frequency range, and disruptive effects on wing motion due to magnetic drag. Conversely, piezoelectric strips are lightweight, conformable, and produce more consistent energy with minimal interference.

Structurally, the wing experienced increased strain at mid-span and root locations—ideal regions for piezo strip placement. Optimizing the geometric alignment and layering of piezoelectric materials could further enhance energy capture. Energy storage systems integrated with the piezo output allowed short-term buffering and real-time voltage regulation.

A secondary benefit of using piezoelectric materials is their dual role as both sensors and energy harvesters. Real-time strain and oscillation behavior can be monitored without additional sensor hardware, which reduces weight and complexity. This feature could be invaluable in autonomous remote systems.

Environmental advantages include silent operation, minimal moving parts, and suitability for wildlife-sensitive regions. The lack of rotational components improves safety and ease of maintenance. Furthermore, this design can be installed closer to the ground and in urban settings without causing disturbances associated with conventional turbines.

In scaling up the system, careful consideration must be given to material fatigue. Piezoelectric ceramics are brittle and prone to cracking under repetitive loading. To address this, future designs could use layered composites with embedded piezoelectric fibers to improve durability. The inclusion of damping layers between wing structure and piezo elements may also mitigate stress concentrations.

Future enhancements may involve hybrid systems combining piezoelectric and triboelectric nanogenerators (TENGs) to improve overall power density. Integration with Internet-of-Things (IoT) platforms could allow these turbines to power low-consumption networks or contribute auxiliary power to decentralized grids.

5 Tables

Table 2: Sample Table Caption

Airflow Speed (m/s)	Oscillation Frequency (Hz)	Roll Amplitude (°)
7	12	4.5
8	15	6.2
9	17	7.8
10	18	9.5
11	19.5	10.2
12	20	10.8
13	21	11.5
14	21.5	12.0
15	22	12.4

6 Conclusion

Replacing the mechanical crankshaft system with piezoelectric strips resulted in higher efficiency and reduced mechanical complexity. The oscillating aircraft demonstrated reliable energy harvesting potential using piezoelectric materials, showing distinct advantages over electromagnetic alternatives. With further refinement, such systems could support off-grid sensors, autonomous devices, and supplement microgrid applications. This study highlights the viability of using piezoelectric energy harvesting in flutter-based wind turbine designs. The findings confirm the potential for compact, lightweight systems capable of functioning in a variety of environmental conditions, with minimal maintenance and low ecological impact. Additional research is needed to extend operational lifespan, improve material resilience, and optimize electrical energy conversion. With growing interest in distributed energy systems, this technology holds promise as part of a multi-modal renewable energy future.

7 References

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