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Strategies in Harvesting Wind Energy from Flow-Induced Vibration for IoT Applications

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ABSTRACT

By linking common things to the internet and enabling them to interact and carry out diverse tasks, the Internet of Things (IoT) is revolutionizing the globe. A huge rise in data has resulted from this connectedness, and the need for energy to power these gadgets is also rising. As the number of IoT devices continues to rise, it is essential to find effective and sustainable ways to power them. By transforming ambient energy into usable electricity, energy harvesting provides a workable answer to the energy dilemma. It is possible to consume the captured energy right now or to store it for later. The practice of capturing minute amounts of renewable energy that would otherwise be lost is known as energy scavenging and it includes a variety of energy sources, including thermal, kinetic, and photovoltaic energy. A two-dimensional numerical simulation investigates the potential of harvesting energy from flow-induced vibrations using different geometrical configurations and harvester dimensions. The Ansys program is utilized to model the flow, combining the shear stress transport model with the unsteady Reynolds-averaged Navier-Stokes equation. The simulation involves TENG to describe the V-Q-x relationship, while piezoelectric transducers employ Euler Bernoulli beam theory. Three tests are conducted for each strategy, utilizing a rectangular prism-shaped bluff body. Results from the numerical simulation, conducted using MATLAB, reveal that the piezoelectric transducer produces a total output power of 84.5 mW, the electromagnetic transducer yields 92.8 mW, and the TENG performs the best, reaching a total output power of 107.0 mW. These findings showcase the potential of energy harvesting techniques for powering IoT devices in a sustainable and efficient manner.

1. Introduction

There has been an increasing trend towards renewable energy as a response to the energy issue. It is derived from renewable natural resources or processes, hence the name "clean energy." For instance, wind power uses the constant flow of wind to turn turbine blades, which then use an electric generator to produce electricity. According to the Energy Information Administration (EIA),

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12% of the primary energy used in the United States in 2021 came from renewable sources. Wind energy accounted for 27% of all renewable energy sources [1].

When a fluid, such air or water, passes over a structure, the resultant vibration causes the structure to tremble [2]. This is referred to as vibration caused by flow. These things can occur when the fluid flow is turbulent or the structure is in an unstable posture. Pipes, vessels, and bridges are just a few examples of the diverse types of constructions that may experience this kind of vibration. In natural systems like rivers and streams, it can also happen. For instance, the bridge may shake as the wind travels over its surface if the wind is powerful enough and the bridge is not constructed to handle the forces of the wind. The generated vibration can be captured and converted into energy.

Vibration caused by fluid flow is referred to as "flow-induced vibration" in objects or structures. There are both transient and steady-state flow-induced vibrations. Stable-state vibration occurs when both the fluid flow and the vibration are constant. Transient vibration occurs when the fluid flow or vibration varies over time. Vortex shedding, vortex-induced vibrations, galloping, and turbulence-induced vibrations are a few of the things to blame. Vortex shedding is the alternating shedding of vortices from an object's downstream side. Vortex-induced vibrations are produced when an object interacts with the vortices it emits [2,4].

A transducer is a device that converts one type of energy into another. In the context of an electro- mechanical connection, a transducer can be used to convert mechanical energy into electrical energy or electrical energy into mechanical energy. One common type of transducer used for electro- mechanical coupling is the electric motor. In order to run a fan or a pump, it converts electrical energy into mechanical energy. Alternatively, a generator converts mechanical energy into electrical energy [3] in a form of piezoelectric transducers, TENG transducers and electromagnetic transducers.

2. Methodology

ANSYS, the software for computational fluid dynamics is used in this study. This CFD program offers codes that are made up of numerical algorithm to address fluid flow issues. Ansys Fluent is made up of parts for designing geometry, mesh creation, solving problems and doing post-processing.

The creation of the bluff body is the first step in the preprocessing procedure, which is then followed by the setup of the computational domain and boundary conditions as shown in Figure 1.

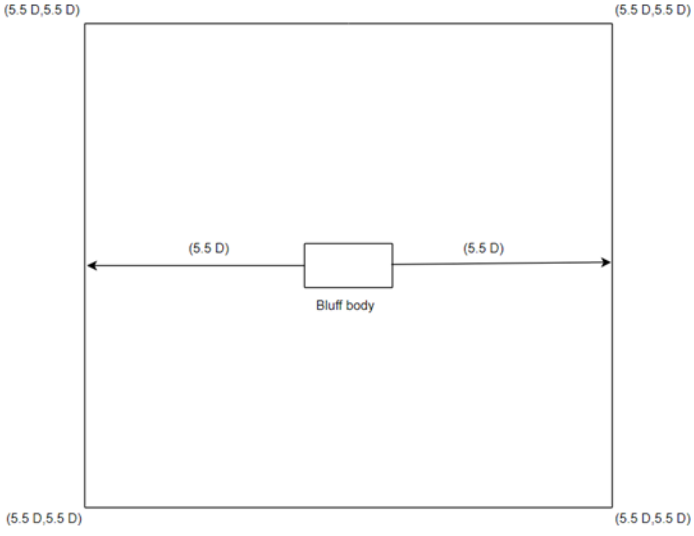


Fig. 1. The design of bluff body in a computational domain

The solver settings are set during the solving phase. The simulation is then carried out by resolving the equations related to a specific flow problem. After the problem has been solved, numerical analysis and graph plotting are carried out using MATLAB software. ANSYS Fluent software is being used to analyze the flow visualization in the meantime.

In this study, the collected power is estimated using a simple mathematical representation of a vibrating system. The calculated power is in charge of calculating the power obtained from the flow-induced vibration of the bluff body's four various geometric shapes. The power harvesting equation of piezoelectric, triboelectric nanogenerators and electromagnetic respectively to the corresponding sequence is displayed below:

$$P_e rms = \sqrt{\frac{\Delta t}{2(T-\Delta t)} \sum_{i=2}^{j} ([P_e(t_i)]^2 + [P_e(t_{i-1})]^2} \quad (1)$$

$$P_{fluid} = \frac{1}{T} \int_0^T (m\ddot{y} + c\dot{y} + ky)\dot{y}dt \quad (2)$$

$$P_{normal} = 8\pi^2 m(\zeta f n) \quad (3)$$

In order to ensure that the numerical simulation can be carried out precisely and consistently, the grid convergence study has also been carried out in this study. At a chosen reduced velocity, UR=7, three distinct grid resolutions—coarse, medium, and fine—are evaluated for this validation research. Three versions of the stabilized amplitude waveform are used to test the stability of the signal. Three flow-induced vibration energy transducers' dynamic responses and vibration-induced features. The results, including the vibration's amplitude, frequency, frequency at which vortices shed their energy, and power spectrum density, are noted and analyzed. The MATLAB program is used to plot the graph. A key component of this work that clarifies the flow pattern around the rectangular prism and determines the dynamic zone for flow-induced vibration is flow visualization evaluation. The vibrating rectangular prism-created vortex shedding patterns are included in the visualization of the flow as shown in Figure 2.

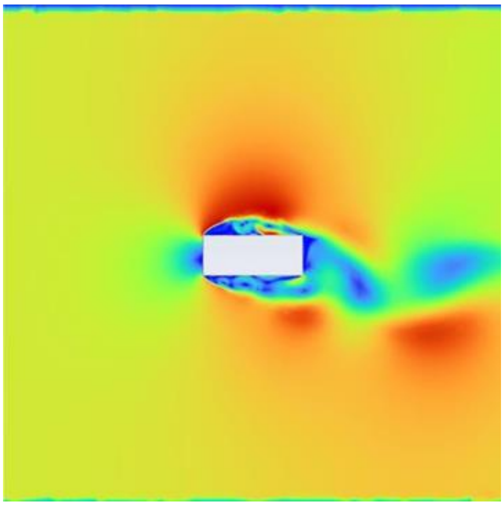
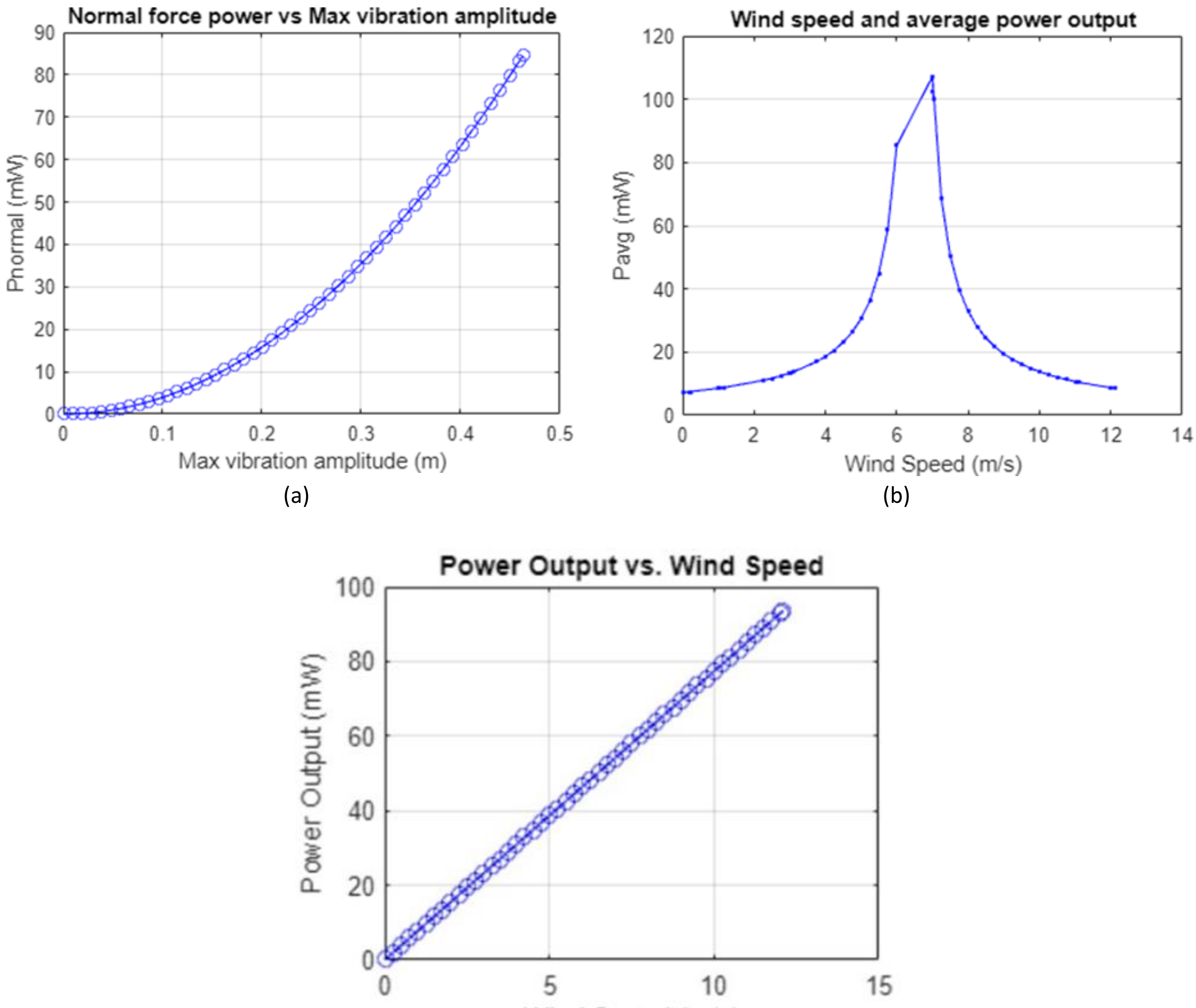


Fig. 2. Contour of fluid flow path over a bluff body in a computational domain

3. Results

Figure 3 presents the numerical simulation of three FIV energy harvesters using a mathematical software MATLAB. The relationship in between each Figure 3 can be seen correlating to outputting power in mW with respective factor to the power calculation. According to the numerical analysis conducted, TENG, one of the three transducers shown in the table, generated the most power, 107.0 mW. As far as energy conversion efficiency goes, this makes it the most effective transducer. The TENG performed better than the piezoelectric and electromagnetic transducers by generating more power output. The TENG's 107.0 mW output clearly outperforms both the piezoelectric and electromagnetic transducers, which both had output powers of 84.5 mW and 92.8 mW, respectively.



(a) (b)

(c)

Fig. 3. Simulation results for (a) piezoelectric transducer, (b) TENG transducer, (c) electromagnetic transducer

On the other hand, the summary of power output (mW) of different flow induced vibration energy transducers based on the simulation results are shown in Table 1.

Table 1
Summary of power output (mW) between flow induced vibration energy transducers

Flow induced vibration energy transducers	Power output (mW)
Piezoelectric	84.5
Triboelectric Nanogenerators (TENG)	107.0
Electromagnetic	92.8

4. Conclusions

To harvest FIV from energy transducers, numerous researches has been conducted in proposing their ideas to create a small renewable energy like transducers to harvest small amount of energy to power IoT applications. Although, each and every research is uniquely to their own, three general types of transducers can be seen used to harness energy from FIV which are piezoelectric, TENG and electromagnetic transducers. Piezoelectric and electromagnetic are similarly close to each other as they require piezoelectric sheet to collect energy however, electromagnetic uses magnetic flux to induced the vibration as well. TENG in other hand, uses several materials such as PTFE, aluminum, copper and more to collect energy by contact friction. Based on the numerical simulation conducted, TENG produced the most output power with 107.0 mW over other transducers with piezoelectric produces 84.5 mW and electromagnetic gained 92.8 mW respectively by conducting a simulation procedure of a wind flow passing through a rectangular prism.

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