Modeling and Simulation of Piezoelectric based Hybrid Energy Harvesting System

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Abstract

Piezoelectric energy harvester reliable, environment-friendly, and needs much less maintenance when compared to conventional systems which work mainly by converting normally wasted vibration energy in the environment to usable electric energy. Energy harvesting using vibration will become tremendous technology in which the conversion of mechanical vibration into electricity is much more useful for micro-devices and it also reduced the need for continuous battery change or power cables. This paper is focused on harvesting wind energy using piezoelectric transduction. The geometrical configuration of proposed model is a cantilever beam, whose one end is fixed and another end is a bluff-body cross-section (rectangular). Lift forces are generated which cause strain across the cantilever beam by the vortex-induced vibration phenomena, and so the electrical power generated is directly related to the cross-section of the bluff body, speed of the wind, and angle of attack of the wind concerning the bluff body. The proposed model is simulated on COMSOL MULTIPHYSICS to obtain the frequency response, electrical resistance (load) dependence relation.

Keywords: Energy Harvester, Piezoelectric, Vortex-Induced Vibration.

1. INTRODUCTION

Electricity generation from alternative sources of energy has become a recent topic, especially in connection to Industry applications. A large amount of electrical energy is extracted by the conversion of solar, water, or wind power. In general, the energy obtained in such a way is called "green energy [1]. Different types of energy harvesting systems have been developed to store energy dissipated over roads, and railway stations such as solar energy from sunlight and kinetic energy from traffic and movements [2]. Since wind is an inexhaustible source of energy and it is also an omnipresent, rich, and most important environment friendly so energy source we focus on is wind energy harvesting which generates energy for low energy electronics [3]. Conversion of wind sources to electrical power sources is done by using different kinds of mechanisms, i.e., electromagnetic induction, piezoelectric, and electrostatic effect [4]. All three piezoelectric transducers have the benefit of greater power density, greater energy conversion, and ease of assembly and

maintenance. Continuous vibration is produced on piezoelectric cantilever beam by aerodynamic effect; this effect is vortex-induced vibration and galloping [5,6].
Vortex-induced vibration happens because of continuous vortex shedding from a non-streamlined bluff body like a rectangle and triangle when the wind flows over the bluff body. Vortex-induced vibration causes uneven vortex shedding patterns with very large amplitude and unstable frequency.

1.1 Shape and working operation of Piezoelectric Wind Energy Harvester

Figure 1 shows, that the beam has a rigid tip body with a rectangle-shaped cross-section. Piezoelectric sheets are bonded on the upper and lower surface of the cantilever beam and as this beam is cantilever it is fixed at one end with proof mass mounted on another end. From fluid dynamic, as wind flows across the rectangular section, the continuous vortices shedding from the edges of the section are in a wide range of Reynolds numbers [5,7]. The generated vortices induce a periodic lift force on the rectangular section and thus it is subjected to a longitudinal vibration and the attached proof mass will be subjected to vibrate upward and downwards sinusoidal motion.

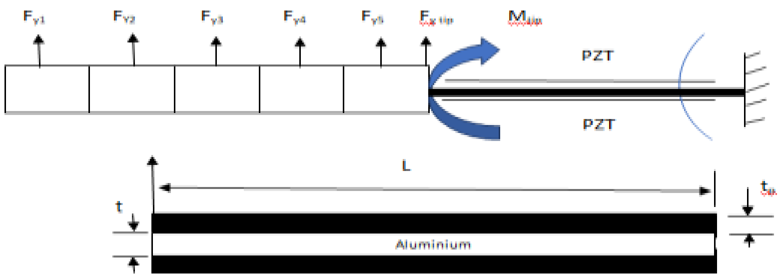

Figure 1. Schematic of the bean geometry[8]

Piezoelectric sheet elements (PZT) bonded to the top and bottom surface of the aluminum beam generate an alternating voltage in response to the bending induced by the upward and downward motion of the rectangular section [11-13]. Practically, electrical energy which is obtained from wind energy harvester will have two purposes it is either stored and power some devices, or the voltage obtained is discharged over a load resistance. For pure bending of the beam mechanical strain is given as

$$\in = -\frac{\partial^2 \omega}{\partial x^2}$$

The piezoelectric constitutive equations for uniaxial loading have the following form :

$$\begin{bmatrix} \in \\ D \end{bmatrix} = \begin{bmatrix} s^E & d \\ d^T & e^\sigma \end{bmatrix} \begin{bmatrix} \sigma \\ E \end{bmatrix}$$

Where $\in$ mechanical strain, electric displacement D, mechanical stress σ, electric field E, s^E is the compliance matrix, e^σ is the matrix of dielectric constants, and d is the piezoelectric coupling matrix[8].

2. METHODOLOGY

Simulation and Modeling- COMSOL Multiphysics 5.5 will be used to model the piezoelectric bimorph cantilever beam. Firstly, properties in solid mechanics like geometry, stress and boundary conditions should be given, and then in electrostatics properties, charge conservation, ground, and terminal voltage will be given. The following results were obtained.

- Frequency Response.
- Electrical Resistance (Load) dependence.
- Acceleration dependence.

2.1 Modeling and Simulation using COMSOL MULTIPHYSICS

The proposed model consists of two active layers of piezoelectric which are bonded on the upper and lower side of the base material. Given model is clamped on one side and at the free end, a cantilever mass is attached. This energy harvester using piezoelectric transduction is vibrated with the help of sinusoidal acceleration which generates electrical energy due to the direct effect of piezoelectric.

As this particular cantilever has two active layers (bimorph) in which the ground electrode is inserted withthe neutral plane and in this design there are two electrodes of the same voltage is situated at the exterior i.e.at the top and bottom of the cantilever despite that stress above the neutral plane is in compression and tension innature. Two piezoelectric sheets of the length of 21 mm, the width of 0.16 mm, and thickness of 0.06 mm are bonded on the upper and lower surfaces of aluminum sheets whose length and width are the same as piezoelectric but the thickness of 0.04 mm is selected as shown in Table 1.

Table 1. Materials and Geometry Specifications[9]

Material	Length (l) mm	Width (b) mm	Thickness (t) mm	Modulus of Elasticity (GPa)
PZT 5A	21	0.16	0.06	3
Aluminium	21	0.16	0.04	69

Figure 2. Major Components of Piezoelectric Bimorph.

3. RESULTS AND DISCUSSIONS

The mechanical performance of the energy harvester model is analyzed by obtaining three different graphs. The first resultshows a relationship between electrical power output with a frequency of vibration at a constant electrical load. In the second plot, a relationship between power output and electrical load impedance was obtained, and the last relationship between power output and acceleration is explored.

Results from figure 3 show that, at a fixed frequency of 80 Hz, which produces sinusoidal forces along thelength of the bimorph cantilever beam that shows the variation of Von-misses stress along the length of the bimorphcantilever beam.

And secondly, it is concluded that a ground boundary condition is provided which is a reference potential because of one electrode at the bottom and another at the top. Ground potential is provided at the bottom and another floating potential is to mimic a conducting material. Piezoelectric material is a dielectric material without any conductivity and there is a need to know the charge generation. So at a fixed frequency of 80 Hz the voltage generated across the bimorph cantilever beam energy harvester is obtained.

3.1 Effects of PZT 5A sensors utilizing the local variation in acceleration

1. The relationship between electrical voltage output, input mechanical power, and electrical power output obtained at a constant frequency of 70.5Hz as shown in Figure 4. It is concluded from this graph that voltage variation is linear and electrical power output is quadratic.

2. The Given results show the relationship between electrical power outputs and the voltage obtained concerning external load resistance as in Figure 5. From the obtained data it is clear that max output is at 6 kΩ obtained at a frequency of 70.5 Hz vibrating at 1g of acceleration.

3. This result shows the plot between input mechanical power, output electrical power, and the voltage induced on the piezoelectric beam to vibration frequency generated due to sinusoidal acceleration as shown in Figure 6. This result is computed at a fixed resistance load of 12 kΩ which also shows peak amplitude obtain at 70.5Hz which is near to the computed resonant frequency.

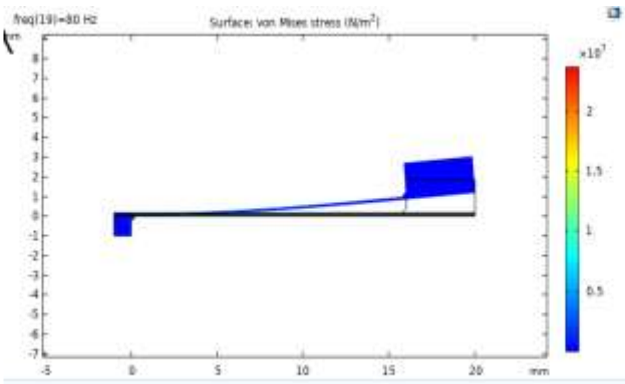

Figure 3. Von-misses stress generated along the length piezoelectric bimorph at Freq of 80 Hz

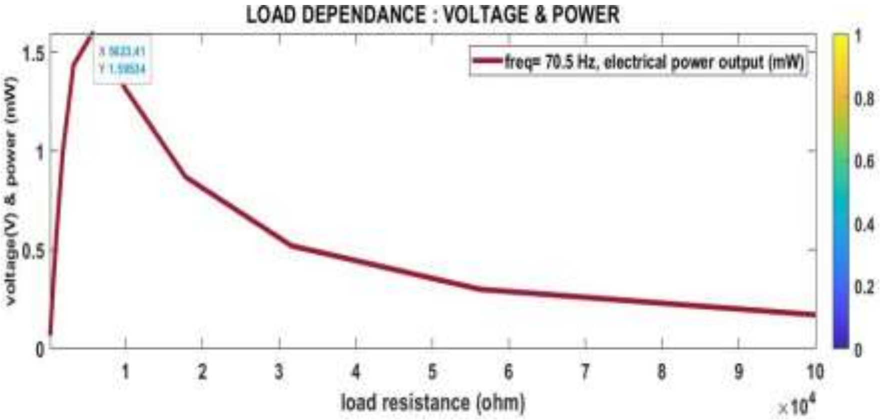

Figure 4. Effect of acceleration concerning dc voltage, mechanical and electrical power

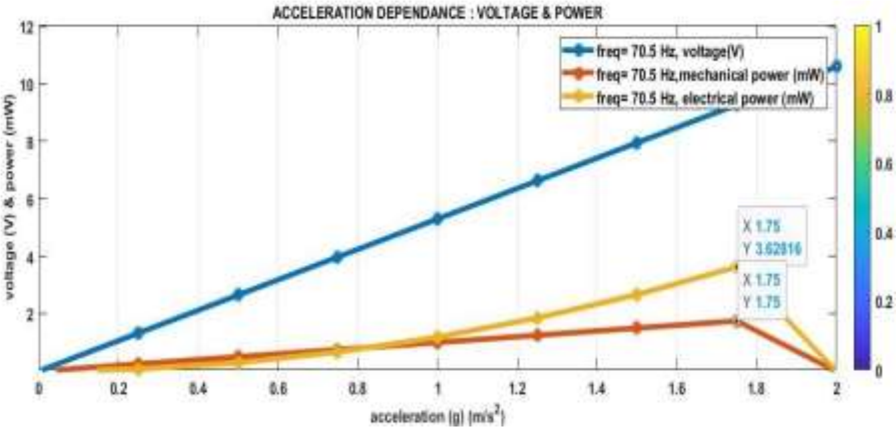

Figure 5. Relation between power output versus electrical load

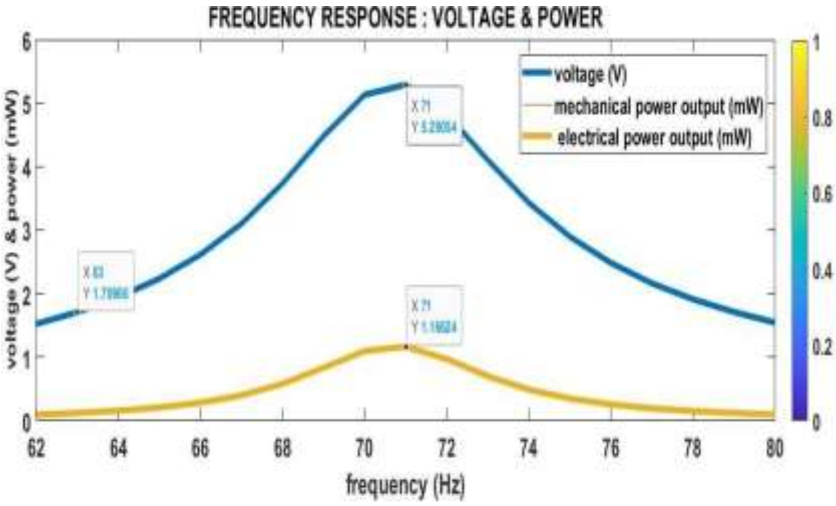

Figure 6. Relation between electrical power output versus excitation frequency

4. SUMMARY AND CONCLUSION

In this work, a device formed on vortex-induced vibration where a piezoelectric layer is established over a cantilever beam was developed which generates electrical power output from kinetic energy induced by wind and vibration induced by local variation in acceleration. The proposed model comprises two activelayers of piezoelectric which are bonded on the upper and lower side of the base material. Given model is clamped on one side and at a fixed end, a cantilever mass is attached.

A finite element solution using COMSOL MULTIPHYSICS of the device was performed. Three differenttypes of analysis were performed by this system which include Frequency Response, electrical load resistance dependence, and a function of acceleration. From the obtained data it is clear that max output electrical power is 1.145mW at 6 kΩ obtained at a frequency of 70.5 Hz vibrating at 1g of acceleration. To this end, although the power obtained was in mill watts but it is sufficient for many small power electronics, rechargeable batteries, and wireless communication.

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Biographies

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