

# Comparative Analysis of Modelling for Piezoelectric Energy Harvesting Solutions

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## Abstract

Due to the global energy crisis and environmental degradation, largely as a result of the increased usage of non-renewable energy sources, researchers have become more interested in exploring alternative energy systems, which may harvest energy from natural sources. This research article provides a comparison between various modeling of piezoelectric elements in terms of power generation for energy harvesting solutions. The energy harvesting can be computed and calculated based on piezoelectric materials and modeling for the specific application. The most common type of environmental energy that may be collected and transformed into electricity for several purposes is Piezoelectric transduction, which is more effective, compared to other mechanical energy harvesting techniques, including electrostatic, electromagnetic, and triboelectric transduction, due to their high electromechanical connection factor and piezoelectric coefficients. As a result of this research, scientists are highly interested in piezoelectric energy collection.

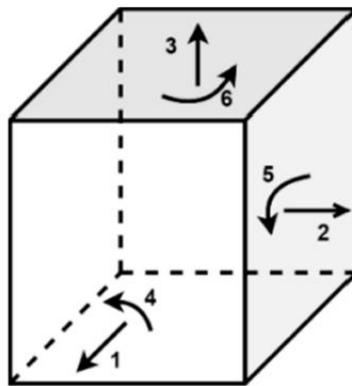
**Keywords:** Piezo-electric effect, energy harvesting

## 1. Introduction

The recent research trends in the development of electronic devices indicate a downward tendency in the overall trend with numerous functions, portability, flexibility, high processing capacity, and low-performance communication [1, 2]. It is possible that, the use of energy in vivo, such as mechanical vibration, heat, water flows, electromagnetic light, and radio wave radiation, and electricity will provide clean power for the operation of a variety of electronic devices [3, 4]. These devices include wireless, mobile, and implanted biomedical sensors. Traditionally, electrochemical batteries have been used to power these types of devices. On the other hand, the battery has a limited lifespan, which is often less than the lifespan of electronic gadgets. This entails an additional charge or additional cost for replacement. For biomedical equipment, additional battery replacement operations are required, increasing the risk of infection and morbidity, as well as the cost of providing healthcare facilities for patients [5]. Another downside of batteries is that they are large and frequently regulate the weight and size of electronics, making it difficult to miniaturize the mobile gadgets [6, 7]. Taking all of these disadvantages into account, a considerable amount of research and development was invested to create energy-saving solutions for a wide variety of electronic wireless devices that might be used as a source for self-power. It would be preferable, rather than using a traditional battery as a source of energy, to collect parasitic energy from the environment around the electronic gadget [8, 9]. Figure 1 shows a general cubic structure of polarized axis based piezoelectric material.

Many research efforts have been directed towards the use of smart materials in the construction of engineering structures. Smart materials have particular characteristics, which can be altered by external stimuli such as temperature, stress, and electric or magnetic fields in a controlled environment [10, 11]. The memory alloys and piezoelectric materials are two of the well-known examples of intelligent materials that are often used in a variety of applications. The latter is distinguished by a one-of-a-kind characteristic known as the electro-mechanical effect.

According to the literature [12], this characteristic is related to the interplay between the electrical and mechanical characteristics of a particular material. In recent years, piezoelectric materials have been developed as a breakthrough for energy collection, owing to their exceptional capacity to produce electricity from low-frequency electronic vibrations. In response to the growing need for cutting-edge driving assistance systems, scientists have created a pneumatic pressure monitoring system, which can wirelessly transmit data to the pneumatic driver [13-15]. However, the batteries present in a monitoring system cannot be replaced or recharged and it is necessary to design an efficient energy harvesting system [16]. Figure 2 shows the application of energy harvesting through some excited energy.



**Figure 1.** Structure of Polarized Axis based Piezoelectric Material



**Figure 2.** Application of Energy Harvesting from Excited Energy

The development of a piezoelectric moving power harvester has recently received a lot of research attention, with many papers focusing on the practical testing of on-road noise stimulation to improve harvest efficiency by using stochastic resonance. Wireless technology and microelectronics have enabled the manufacture of wearable equipment, such as clothes and accessories, via the use of battery or energy collecting devices in the recent decades [17]. These methods are coupled with the notion of Internet of Things (IoT), which makes significant use of wireless sensor networks. The Internet of Things has enabled the deployment of intelligent devices in distant regions or locations, where battery charging is difficult or impossible to achieve (e.g., health care devices placed inside the human body, and smart buildings). The energy density of chemical batteries must be improved despite the advancements in low-power integrated circuit technology [9, 11] since it is difficult to meet the power needs of these applications despite the advancements. As a result, new energy-collection technologies must be developed in order to maintain such self-powered gadgets operational. Renewable energy harvesting is critical not only to the long-term viability of self-powered systems as a competitive and cost-effective alternative to batteries but also to the reduction of greenhouse gas emissions and the preservation of environment [18]. Typically, an energy collection system is composed of three components, namely:

1. Dynamism input
2. Harvesting devices
3. Output load

Generally, it is the energy from which the power is scooped and this energy may be environmental friendly or external [11]. It comprises of a framework, which transforms environmental energy into electrical energy. Finally, the sink absorbs or stores the power supply.

## 2. Organization of the Research

The organization of this study paper comprises several parts: Section 3 offers current research on the solution to collect piezoelectric energy. Section 4 covers many recent harvesting techniques. Section 5 provides test findings for piezoelectric energy collection devices. Section 6 ends our research study.

## 3. Preliminaries

Advanced research and development on micro, nano-scale piezoelectric materials and techniques has broadened the use of piezoelectric technology. Many new piezoelectric materials have been developed in recent years. These materials include ceramics and polymers, as well as chemicals and biomaterials in a range of nanostructures and thin films with suitable physical characteristics such as a high piezoelectric rating, as well as flexibility, extendibility, and durability [18]. It is recommended that, they may be used in developing areas like wireless network technologies, Internet of Things, wearable electronics, and remarkable materials. As a consequence, the research interest in piezoelectric energy collection has increased significantly. Nonlinear energy harvesters are being constructed based on a variety of novel concepts. Unlike the non-linear energy harvester discussed earlier, which can only collect vibrational energy in one direction, Su et al. created two-panel PEH magnets with two degrees of freedom that can collect vibrational energy in both directions (2DOF). It is constructed by using exterior and interior beams that are magnetically linked. The magnets exert a nonlinear force on the structure between the two beams, preventing them from being accepted. During testing, the device shows broadband characteristics as well as the existence of two voltage peaks within a certain stimulation frequency range [19].

Arrieta and colleagues proposed using a composite platform to collect bistable energy. This bistable plate is made possible via a unique heat treatment process that enables it to resist high pressures. It is critical to highlight that high-level stimulation is needed in this configuration to generate high-energy interwave oscillations [20].

Betts and colleagues devised a bi-stable composite optimization technique that enables improved power output by identifying the optimal device-static pairings [21].

Gao et al developed a new type of PZT ceramics with a higher coupling factor than conventional PZT ceramics. While piezoelectric pottery is inexpensive and of excellent quality, it is also delicate and prone to thick inconsistencies. As piezoelectric ceramics are increasingly used in micro electromechanical systems (MEMS), [22] PZT thin films with small-scale flexibility have been created for the fabrication of cord-texturizing and epitaxial thin films on the coupling substrate.

Erturk and Inman also classified piezoelectric materials like hard and soft single crystals, ceramics, and other ceramic-based materials. Hard single crystals and ceramics have less mechanical damping than their predecessors, but they produce more power [23].

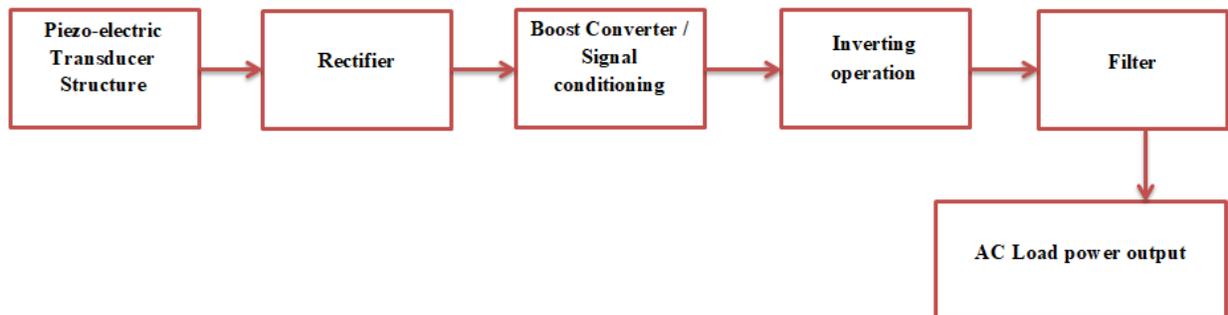
Kim et al examined the potential to produce electricity from existing coastal structures using piezoelectric transducers. The authors have also addressed recent developments in the generators of ocean waves. In a hydraulic model experiment, hydrographic analysis was conducted on a 2D wave flume. The results show that, the higher wave produces maximum voltages over a longer period [24].

Yi et al proposed that, thin piezo-electric films be used as a substratum for the double, flexible polymer buckled PEH Bridge. The proposed technique produces a constant quantity of high energy for the energy harvester per chip surface. The result was improved by the low stiffness

clamping, which benefits from the bending of the bridge by resulting in substantial deformation [25].

#### 4. Methodologies

The most omnipresent and adaptable energy accessible in the ambient environment is mechanical energy. In the ambient world, mechanical energy is the most ubiquitous and flexible type of energy available in the market. Mechanical-to-electrical transduction may be used to gather the motion, flux, and vibration of sources and convert them into electrical power [26]. Inertial energy harvesting is the most widely used electromechanical energy harvesting method, and it is based on the mass resistance to acceleration, which is considered as a source of energy harvesting. Vibration energy harvesting has been extensively investigated in the literature, and the most basic configurations of an inertial energy harvester that represents the spring-mass damping system has been developed [27]. This section analyzes some piezoelectric device models. Figure 3 shows general block diagram of energy harvesting using piezo-electric transducer.



**Figure 3.** General block diagram of energy harvesting using piezo-electric transducer

#### **4.1 Piezoelectric Coulomb's Friction Modeling**

For multi-domain BEM, a model for the friction of Coulomb has been proposed by including the formulation of the border integration technique for in-plane electrostatically and extended plane strain elasticity assumptions, as well as the formulation of the border integration technique for extended plane strain elasticity assumptions. In order to succeed briefly, the main equations of the problem are not provided in current study but they are found in many research articles. The global equation system for the whole structure gathered is then achieved by applying compatibility and consistency requirements to all sub-sectional boundaries (crossing point).

#### **4.2 Piezoelectric Sensor Modeling**

Piezoelectric materials have regulatory equations that describe reduced electrical field sensing objectives. Modeling of the sensors is a component of these equations, which is detecting for lower electrical fields. This sentence is used to measure or monitor equipment, whether it works well or broken. This led to a re-drawing of a sample study from previous research to explore sensor modeling. For the beam supported, the sensor is a strain gauge on either side of the third buckling model with four samples:  $x = 3$  and  $2L/3$  for the beam supported, and  $x = 5$  and  $3L/5$  for the beam supported. A total of four strain gauge sensors are used for each of the two occurrences. The installation of sensor modeling requires a third mode with its multiples, whereas for the first three models of beam buckling, the modal control is achieved: the first, the second, the third, and the five beam buckling models. Therefore, the use of strain measurement data to assess beam performance was recognized as a technique for assessing beam performance. The output sensor vectors for a two-beam model should be calculated (both supported and cantilevered).

### 4.3 Piezoelectric Finite Element Modeling

It is critical to understand the piezoelectric material equations for FE modeling. Due to the anisotropic nature of the PZT transducer, the derivative terms used to evaluate sensor and action reasons for FE analysis are critical [28]. The dynamic Euler-Bernoulli beam bend equation was investigated in this study when subjected to a lateral bending force and a progressively rising axial compressive stress ( $p$ ).

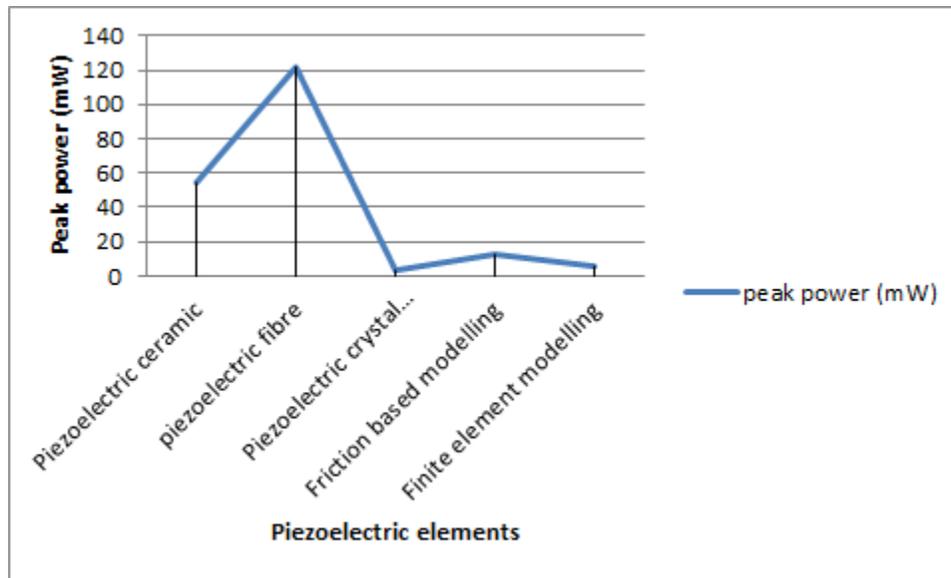
## 5. Results and Discussion

The direct piezoelectric effect and some current developments and methods in piezoelectric power collectors (PEHs) were addressed in this part. PEHs are often divided into two sections, which are as follows:

1. The transducer produces electrical energy,
2. The circuit transforms and rectifies the electrical energy produced and the circuit that regulates the electrical energy generated.

Figure 4 shows the obtained peak power in results based on piezo electric elements. A PEH's capability remains dependent on the performance of both the transducer and circuitry. In general, the PEH is divided into three stages, which are as follows:

1. Mechanical to mechanical energy conversion
2. Mechanical to electrical energy conversion
3. Electrical to electrical energy conversion



**Figure 4.** Peak power in results based on piezo electric

**Table 1.** Peak Power Generation by Piezoelectric Material through Modelling

Piezoelectric material / Modelling	Peak power (mW)	Volume	Frequency (Hz)
Piezoelectric ceramic	54	1.44 cm <sup>3</sup>	100
Piezoelectric fibre	121.5	2.12 cm <sup>3</sup>	-
Single crystal based Piezoelectric	3.5	15 x 6 x 0.25 mm	102
Friction based modelling by piezo-electric	12.3	20 x 4 x 1.5 mm	100
Piezoelectric finite element modelling	5.9	70 x 10 x 0.5 mm	100

PEHs may be constructed from a variety of piezoelectric materials. Piezoelectric materials through modelling are shown in Table 1 by the peak power they produce. These materials include PVDF, piezoelectric ceramic, piezoelectric fiber, PMN-piezoelectric single crystal, and PMN-PT single crystal. The piezoelectric transducer is available in a variety of forms, including cantilever beam, cymbal type circular diaphragm, and stack type topologies [29].

## 6. Conclusion

In summary, this study provides various modeling for piezo electric elements and suggestions for scientists who are interested in using piezoelectric energy harvesters in conjunction with various structural devices. They identify, detect, and assess the critical literature on piezoelectric energy harvesters' applications, and they provide suggestions for further research. With this classification, you may get a good idea of what areas of research are being done on piezoelectric power harvesters. Piezoelectric generators, according to study results, may be used to effectively monitor the health of patients and to stimulate neural and bone tissue regeneration in both wearable and implanted equipment and medical devices. To further their medicinal application, more study should be carried out on piezoelectric generators, on the other hand. In the electronics industry, the current tendency is to decrease device sizes, reduce energy consumption and enhance device flexibility and integration. Piezoelectric generators, on the other hand, due to advances in materials and manufacturing processes, have been micro and nano-made, enabling greater flexibility, capacity integration, and power density. As a consequence, the bulk of wireless electronic devices may soon be powered by piezoelectric generators.

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