STUDY AND ANALYSIS OF PIEZO BENDER FOR ENERGY HARVESTING APPLICATION USING MATLAB SIMULINK

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "Study and Analysis of Piezo Bender for Energy Harvesting Application Using MATLAB Simulink". I also declare that is has not been previously submitted for the award of any degree or diploma other similar title of this for any other examining body or University.

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Date: 24/7/2022

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيم

In The Name of Allah, Most Gracious and Most Merciful

First and foremost, Alhamdulillah, I would like to express my gratitude to Allah S.W.T for providing me wisdom and grace to complete this valuable piece of work in a successful manner.

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PEH	PIEZOELECTRCIC ENERGY HARVESTER

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ABSTRAK

Penjanaan tenaga piezoelektrik (PEH) ialah peranti yang digunakan untuk menukar tenaga getaran atau tenaga mekanikal daripada persekitaran kepada tenaga elektrik. PEH boleh dipersembahkan dalam beberapa konfigurasi atau struktur seperti rasuk julur, simbal dan jenis tindanan. Dalam kertas kerja ini, tumpuan utama adalah untuk mengkaji dan menganalisis PEH rasuk julur bimorph menggunakan MATLAB Simulink. Konfigurasi rasuk julur bimorph piezoelektrik boleh diwakili oleh model blok "Piezo bender" yang terdapat dalam pakej perisian Simulink dan MATLAB. Kuasa keluaran dan voltan yang dijana oleh peranti piezo yang membengkok dengan dua sumber getaran berasingan dianalisis dan disimulasikan dalam skop kajian khusus ini. Punca getaran bagi satu varian mempunyai frekuensi tetap, manakala sumber bagi varian kedua mempunyai frekuensi yang semakin meningkat. Tenaga yang diperoleh daripada sistem getaran dikumpul oleh bender piezo, yang kemudian mengubahnya menjadi tenaga elektrik. Tenaga terkumpul digunakan untuk menggerakkan beban berterusan dan mengecas bateri simpanan. Penemuan menunjukkan bahawa kuasa output yang dijana piezo bender apabila menggunakan frekuensi malar adalah lebih baik, datang pada 67.0288 mW, berbanding kuasa output apabila meningkatkan frekuensi, iaitu hanya 0.67493 mW. Ini kerana sumber getaran dengan frekuensi malar jauh lebih dekat dengan frekuensi resonans berbanding dengan frekuensi bukan malar. Daripada hasil dan kajian simulasi penemuan ini, ia mungkin digunakan untuk membangunkan system peranti PEH menjadi realiti.

STUDY AND ANALYSIS OF PIEZO BENDER FOR ENERGY HARVESTING APPLICATION USING MATLAB SIMULINK

ABSTRACT

Piezoelectric energy harvesting (PEH) is a device used to convert vibration energy or mechanical energy from the environment into electrical energy. PEH can be presented in a few configurations or structures such as cantilever beam, cymbal, and stack type. In this paper, the primary focus is to study and analysis PEH of bimorph cantilever beam using MATLAB Simulink. A piezoelectric bimorph cantilever beam configuration can be represented by a "Piezo bender" block model found in the Simulink and MATLAB software packages. The electromechanical effect like output power and voltage generated by a piezo bender with two separate vibration sources are analysed and simulated within this particular research piece's scope. The vibrating source of one variant has a constant frequency, while the source of the second variant has an increasing frequency. The energy obtained from the vibration system is collected by a piezo bender, which then transforms it into electrical energy. The collected energy is used to power a continuous load and charge a storage battery. The findings indicate that the output power of the piezo bender when utilising a constant frequency is more excellent, coming in at 67.0288 mW, compared to the output power when increasing the frequency, which is just 0.67493 mW. This is because a vibration source with a constant frequency is far closer to the resonant frequency compared to non-constant frequency. From these findings simulation results and studies, it might be used as a reference to develop a PEH devices into reality.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

1.1.1 OVERVIEW OF PIEZOELECTRIC ENERGY HARVESTER

Piezoelectric energy harvester, also known as a PEH, is one of the most prevalent methods or mechanisms used in energy harvesting technology. It can transform mechanical vibratory energy into electrical energy power sources by using piezoelectric material. The four different shape configurations may be found in PEH transducer mechanisms, the cantilever beam, circular diaphragm, cymbal type, and stack. The vibration in the piezoelectric harvester allows for the collection of vibratory energy and transfers it into electrical energy.[1]

In this study, we will concentrate on PEH via a cantilever beam. The active piezoelectric material layer that is pasted on top of the passive substrate beam is the definition of the piezoelectric cantilever beam arrangement. Due to its easy manufacture and modelling and straightforward design, it is frequently utilised.[1] The most frequent configuration of cantilevered laminated beams is either a unimorph or bimorph. A bimorph cantilever beam configuration consists of two layers of piezoelectric material that are poled along the substrate in the middle. In contrast, the composition of a unimorph cantilever beam consists of only one layer of piezoelectric material that is bonded with the substrate, as shown in Figure 1.1.

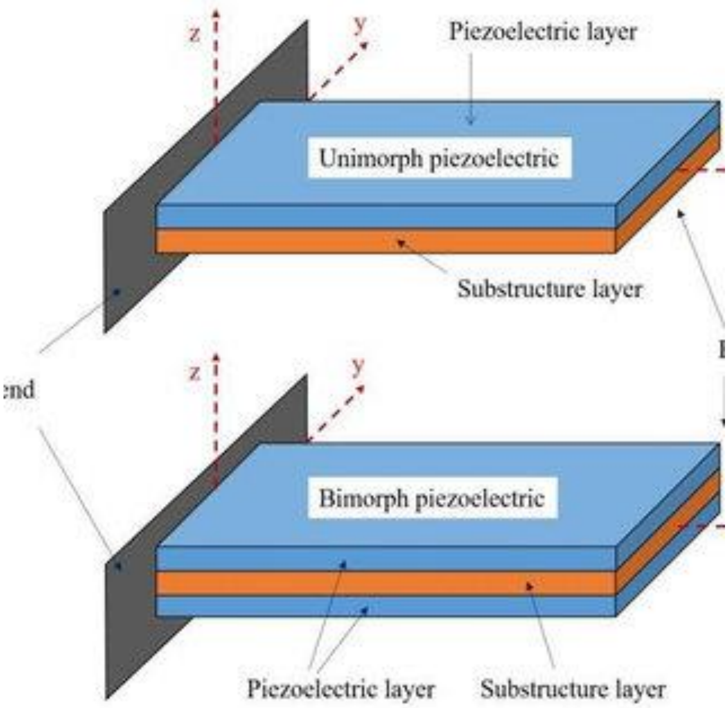


Figure 1.1 Unimorph and Bimorph Piezoelectric Cantilevered Beam Configuration

When PEH is triggered at the frequency that corresponds to their resonance, piezoelectric beams can produce a significant amount of power. To clarify, the resonant frequency is the frequency at which the medium vibrates most strongly in its natural state. Beam harvesters frequently have an inertial mass added to the tip of the device to reduce or optimise the system's resonance frequency and increase mechanical responsiveness and output power in low amplitude excitations. This is done so that the device can more effectively harvest energy from low-amplitude excitations [2].

1.1.2 OVERVIEW OF SIMULINK MODEL USING MATLAB

Simulink is a MATLAB software that allows us to simulate a model using the graphical programming language. It consists of a Simulink library browser for us to choose the blocks needed, such as the piezo bender block in our case. The Figure 1.2 shows the blocks provided in Simulink library browsers. A system or a model can be developed by selecting the blocks needed.

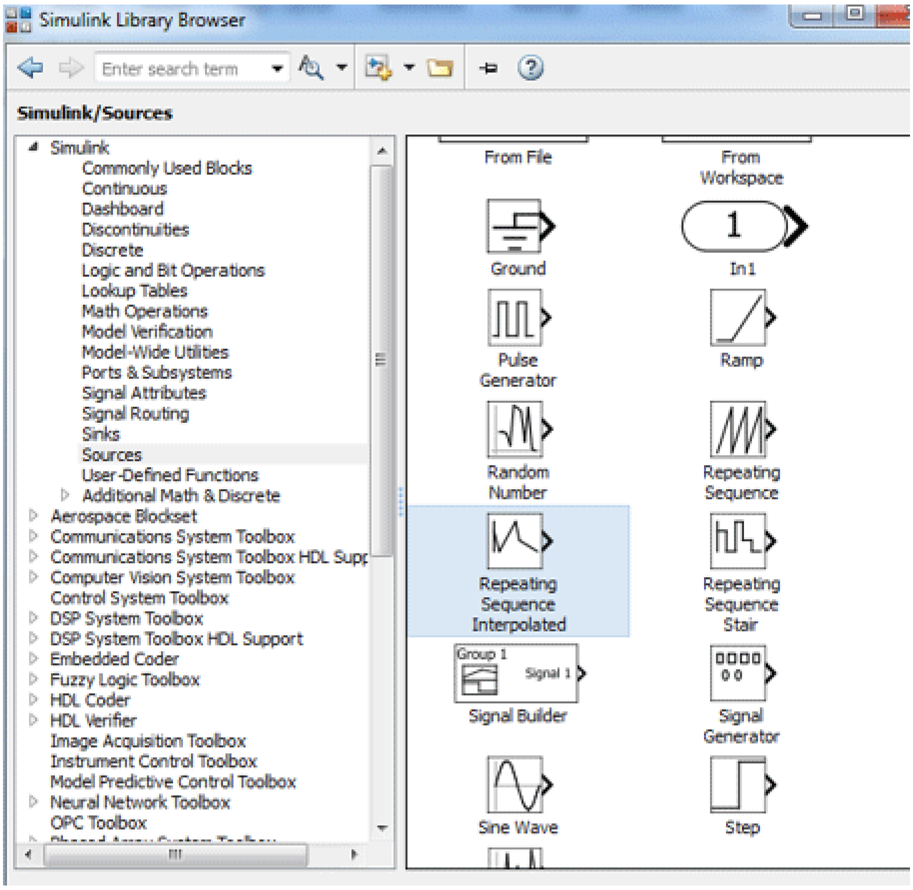


Figure 1.2 Simulink MATLAB Library Browser

1.2 PROBLEM STATEMENT

Earlier research in this area focused on developing a nonlinear piezoelectric model for piezoelectric energy harvesters (PEH). Analytical and numerical studies of nonlinear PEH power output have been examined recently [3]. Despite the fact that cantilever beams have been employed in several applications and that a substantial amount of literature is accessible outlining their operational principles and uses, it has been discovered. However, there aren't any comprehensive investigations of the electromechanical interaction in PEH or analyses of the PEH sensing performance [4]. Therefore, it is essential to research the electromechanical effect like output voltage and power generated in piezoelectric structures like cantilever beams. By simulating an electromechanical equivalent piezoelectric vibrational energy harvester, it is crucial to study this issue in light of concerns about energy security.

1.3 OBJECTIVES

There are two main objectives of this study:

- To study the behaviour or electromechanical effect of Piezo Bender in energy harvesting applications by developing a Piezo-Bender electromechanical equivalent model in Simulink/MATLAB.
- To study the output power of Piezo Bender subjected to different vibration sources.

1.4 SCOPE OF WORK

In this project, a mathematical model programming of the electromechanical interaction within a piezoelectric energy harvester will be simulated using MATLAB Simulink software to describe the model process. The model for a piezoelectric energy harvester is a bimorph cantilevered beam, also known as a piezo bender block. Two vibration sources are used as mechanical input to bend the piezo bender and harvest energy. From the simulation, the output power generated by PEH can be measured to charge a battery and power a constant load.

1.5 THESIS ORGANISATION

Chapter 1 contains the general outline and the introduction of the research. Besides, the objectives and problem statement are stated in this chapter. Chapter 2 reviews the literature review and related published research works such as the history of PEH, the theory and recent works. Chapter 3 describes the research methodology and the details of block parameters on designing the piezo bender for energy harvesting system by using Simulink MATLAB. Chapter 4 present and discuss the result of output power generated by the piezo bender with two different vibration sources. This chapter also contains the interpretation of the data and results obtained from a battery charged. In Chapter 5, the results and contributions of the studies are summarized. This is done whether or not the main objective of the project has been met.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY OF PIEZOELECTRIC

In 1880, two French physicists, Jacques Curie and Pierre Curie, often known as the Curie brothers, began demonstrating an experiment that focused on the formation of crystals. Since then, the piezoelectric theory has seen a rise in popularity that has lasted for more than a decade. They were particularly interested in the pyroelectric phenomenon, which occurs when the temperature of a crystalline substance fluctuates and generates an electric potential. Carl Linnaeus and Franz Aepinue previously investigated this phenomenon. It piqued their attention. The brothers' Curie was the first to hypothesize that there was a direct connection between the potential caused by temperature variations and the mechanical strain that was the origin of piezoelectricity. They hypothesized that certain types of crystal asymmetries in materials would lead to the development of a piezoelectric action. They conducted research using a variety of crystals, such as quartz, topaz, cane sugar, Rochelle salt, and tourmaline. Consequently, the Curies realized that the mechanical strain caused by the crushing of such materials resulted in electric potential. The piezoelectric effects induced by quartz and Rochelle salt were the most pronounced [5].

2.2 THEORY OF PIEZOELECTRIC ENERGY HARVESTER

In order to harvest piezoelectric energy, three stages need to be completed [6] as shown in Figure 2.1.

Stage I. Mechanical-mechanical energy transfer:

The material component of the piezoelectric device that is responsible for receiving mechanical energy from the surrounding environment should have the appropriate levels of mechanical impedance, mechanical strength, and damping factor to ensure that the mechanical energy (vibration) is transferred into the device correctly and with no loss.

Stage II. Mechanical-electrical energy transfer:

It considers the electromechanical coupling factor of the piezoelectric energy harvester structure and the piezoelectric coefficients.

Stage III. Electrical-electrical energy transfer:

Piezoelectric materials convert mechanical energy into electrical energy at a very high voltage, suggesting that these materials' output impedance is relatively large.

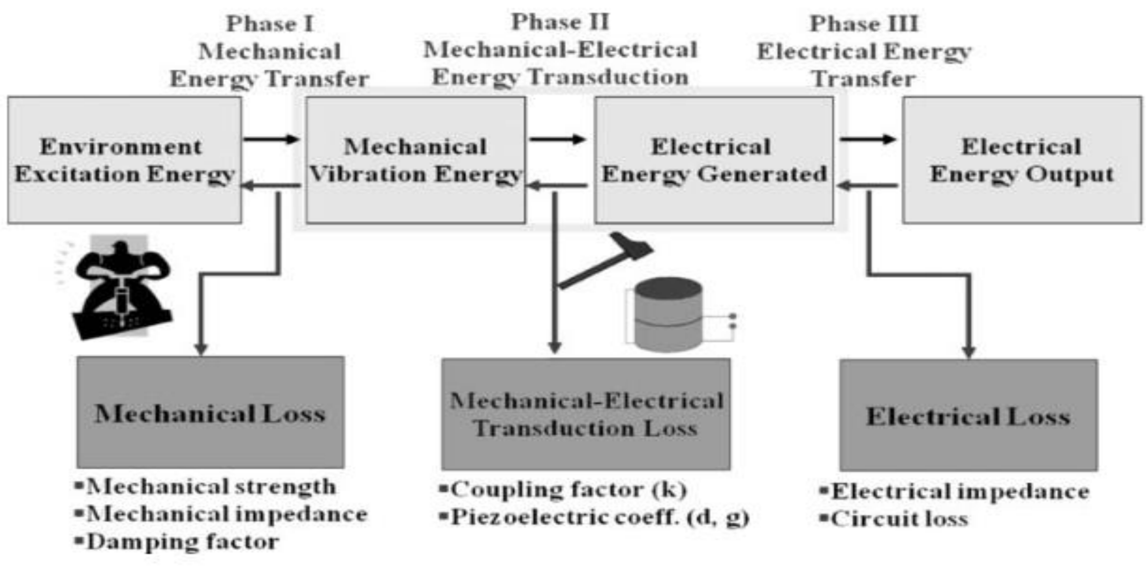


Figure 2.1 The three stages involved with piezoelectric energy harvesting [6]

2.3 PIEZOELECTRIC EFFECT

The piezoelectric effect exists in two forms which are direct and converse piezoelectric effect. (Figure 2.2) The ability of a material to convert mechanical strain into electrical charge is referred to as the direct piezoelectric effect. The piezoelectric effect also exists in a second form, known as the converse effect, which describes the ability of a material to convert an applied electrical potential into the energy of mechanical strain. The ability of the material to serve as a sensor is a result of the direct piezoelectric effect, and the ability of the material to work as an actuator is a result of the converse piezoelectric effect. A substance is said to be piezoelectric if it can change the form of energy it receives from an electrical source into energy generated by mechanical strain and vice versa [7].

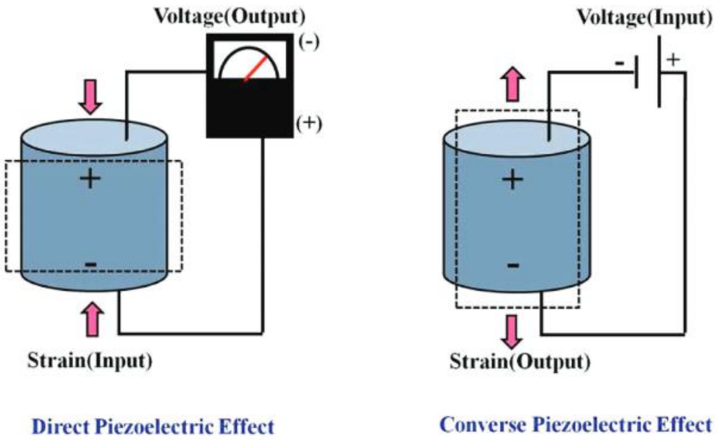


Figure 2.2 Direct and Converse Piezoelectric Effect [8]

The following piezoelectric constitutive equations [9] are responsible for governing both the direct and the reverse piezoelectric effects:

$$T_1^p = Y_p(S_1^p - d_{31}E_3) \quad (1)$$

$$D_3 = d_{31}T_1^p + \varepsilon_{33}^T E_3 \quad (2)$$

$$T_1^s = Y_s S_1^s \quad (3)$$

Where T=Stress, S= Strain, Y= Young modulus, d= piezoelectric constant, ε_{33}^T= permittivity at constant stress, E= electric field, D= electric displacement.

2.4 PIEZOELECTRIC MATERIAL

PZT, also known as Lead Zirconate Titanate (PZT), is one of the most common piezoelectric materials. This is mainly attributable to its outstanding electromechanical coupling properties in single crystals [10]. Because it can convert up to 80 per cent of mechanical energy into electrical energy, PZT material is in high demand. This is one of the reasons why [11]. The following figure illustrates the piezoelectric properties of the substance in question**.**

Material and form	d_{31}(pm/V) piezoelectric coupling coefficient	$\epsilon 33/\epsilon_o{}^a$ permittivity	k31 electromechanical coupling factor	$T_e(^{o}C)^b$ temperature
Quartz (single crystal)	2.3	4.4	–	–
BTO (polycrystalline)	−79	1900	0.21	120
PZT (polycrystalline)	−190~-320	1800-3800	0.32~0.44	230~350
PVDF (film)	23	12~13	0.12	80~100
PZT (sol-gel thin film)	190-250	800-1100	–	–
PZT (sputtered thin film)	100		–	–
ZnO (sputtered thin film)	10.5-11.5	10.8-11	–	–
AIN (thin film)	–	8.6	–	–

Figure 2.3 Properties of Piezoelectric Material [10]

2.5 STRUCTURAL CONFIGURATION OF PEH

There is a wide variety of structural options available for PEH devices, such as the cantilever beam design, circular diaphragm configuration, the cymbal type structure, and the stack configuration, as shown in Figure 2.4 [8], in which the cantilever beam kind of structure is the one that is utilised the most frequently due to the simplicity of its structural geometry and the development of the most significant amount of strain for a given degree of mechanical vibration.

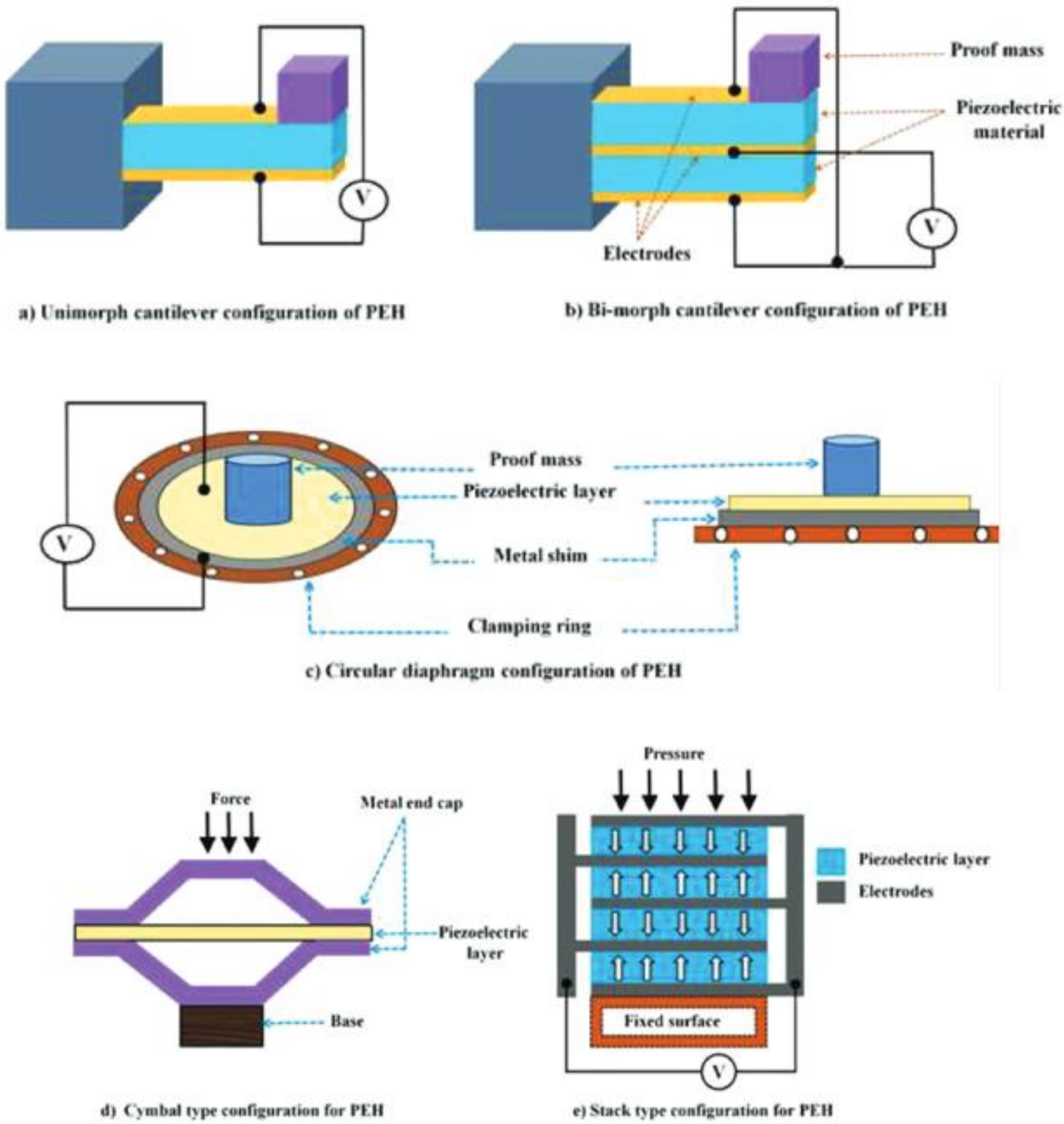


Figure 2.4 Structural Configuration of PEH [8]

2.5.1 BIMPORH CANTILEVER BEAM

Cantilever structures are often used in piezoelectric energy harvesters (PEH) because piezoelectric materials can be subjected to high mechanical strain during vibration. The bimorph cantilevered beam receives an application of piezoelectric material. When the piezoceramic layer is stressed dynamically, an alternating voltage is produced across the electrodes that cover the piezoceramic layer. This voltage is used to control the piezoelectric effect (s) [2]. More significantly, the resonant frequency of basic bimorph cantilever configuration modes is much lower than other structural configurations.

As seen in Figure 2.5 (a), the direction in which an electric field can be applied to piezoelectric material can result in two different PEH topologies. These are the 31-mode and the 33-mode configurations. In the -33 mode, the electric field is applied in the "3" direction, and the material is strained in the poling or "3" direction. On the other hand, in the -31 mode, the electric field is applied in the "3" direction, and the material is strained in the "1" direction or in a direction that is perpendicular to the poling direction. These two modes of operation are especially significant when it comes to defining the electromechanical coupling coefficient, which manifests itself in two different forms: the first is the actuation term d, and the second is the sensor term g. Both of these terms are used to refer to the same thing, which is the electromechanical coupling coefficient. The term g13 is the sensing coefficient for a bending element that is poled in the direction of "3" and is strained along "1” [12].

The most common form of 31-mode bimorph cantilever is one built from two piezoelectric sheets connected to one another via a shim located in the middle of the structure. The construction is meant to operate in the bending mode, in which the top layer of the elements is in tension while the bottom layer is in compression or vice versa. It generates an electric charge by using the piezoelectric effect. In order to induce accumulated current or voltage by each layer, the top and bottom layers are poled either in the same direction or in the opposite direction. This process is known as parallel or series poling, and it can be used to induce either type of accumulated current or voltage [13]. The layers can be poled in parallel or series to achieve this result. It is feasible to manufacture the piezoelectric elements on a bending cantilever using multiple layers, with the required electrodes and wiring positioned in-between each layer. This construction method is described further in the following sentence. The power conversion potential is the same in every scenario; the number of layers and the poling direction are the only elements that, in theory, should change anything other than the voltage to current ratio. The power conversion potential is constant [7].

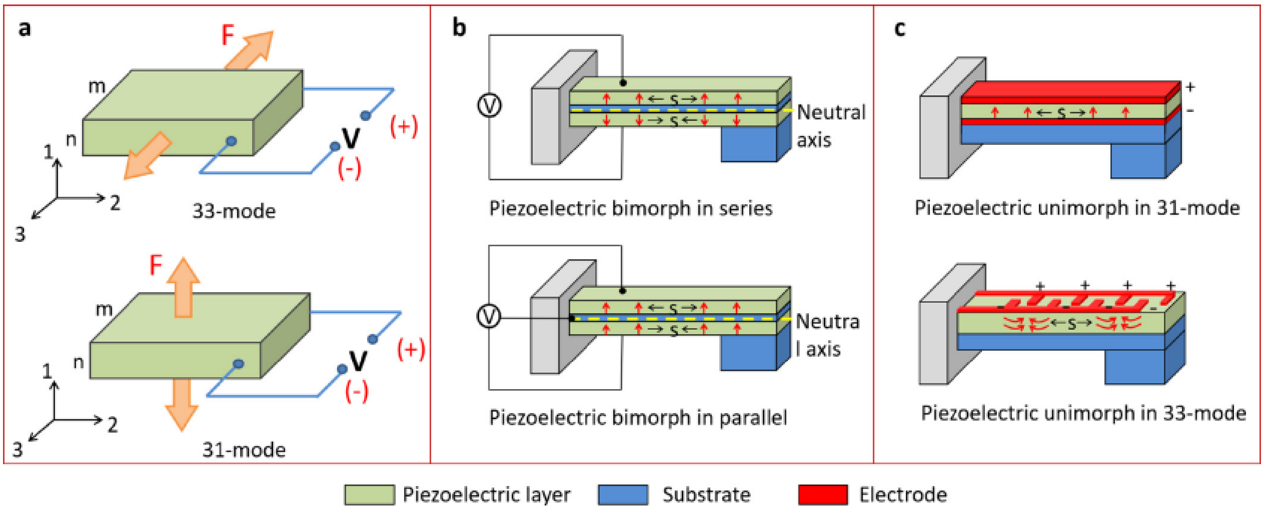


Figure 2.5 Structural Configuration of Bimorph and Unimorph Beam [12]

2.6 PREVIOUS MATHEMATICAL MODELLING OF CANTILEVERED PEH

In the past, researchers had examined the modelling of electromechanical power generators [14-15] to build or model a cantilevered PEH. Below are the previous mathematical models developed:

1. Lumped Parameter Model

   A lumped parameter model, also known as a single degree-of-freedom (SDOF) model, was created to investigate the electromechanical coupling effect of cantilevered PEH [16]. It is by analysing the cantilevered beam as a mass-spring-damper system (Figure 2.6), which is very helpful for connecting the mechanical component of the harvester to a short electrical harvesting circuit. SDOF modelling does provide an initial understanding of the problem by allowing simple closed-form expressions; however, it is only a rough approximation that is limited to a single vibration mode and ignores several critical aspects of the physical system, such as the dynamic mode shape and accurate strain distribution along the bender. This is even though SDOF modelling does allow for simple closed-form expressions [17].

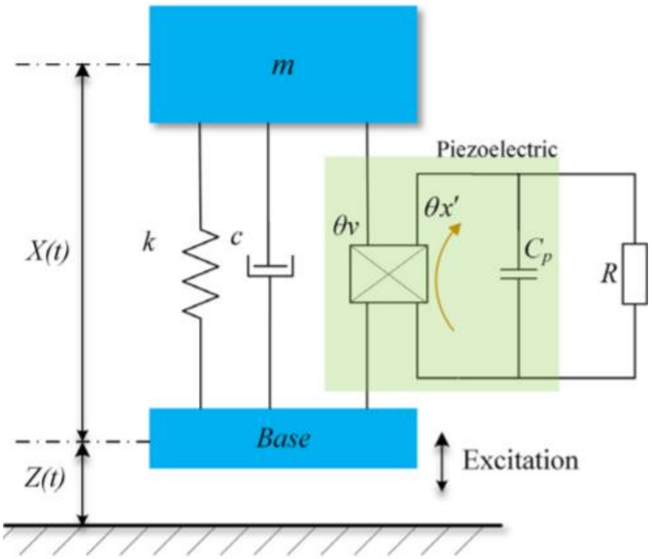


Figure 2.6 SDOF Model

2. <u>Euler-Bernoulli Beam</u>

To improve the model, Erturk and Inman [18] pointed out flaws in current cantilevered PEH models. They suggested completely coupled distributed parameter models for cantilevered piezoelectric energy harvesters that considered both unimorph [19] and bimorph [20] structures based on Euler-Bernoulli beam assumptions. They were able to obtain the coupled voltage response across the resistive load as well as the coupled vibration response of the harvester explicitly for harmonic base excitations [19]. These excitations came in the form of translation with slight rotation. Recently, Erturk and Inman [21] have presented an analytical distributed parameter modelling of cantilevered PEH based on three different beam theories: Euler-Bernoulli, Rayleigh-Ritz, and Timoshenko models.

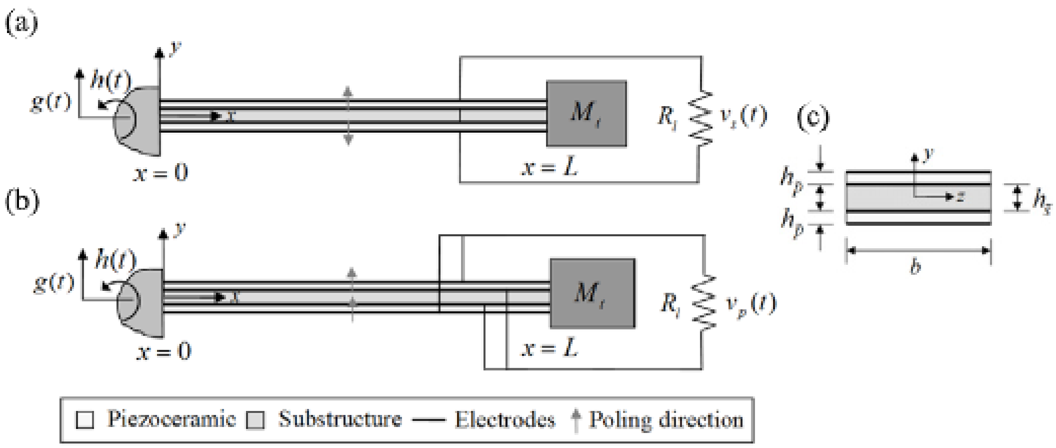


Figure 2.7 Erturk and Inman Model of Bimorph Cantilever Beam with (a) series connection, (b) parallel connection (c) cross-sectional view of a bimorph cantilever [18]

	Piezoceramic (PZT-5H)
Length (mm)	24.53
Width (mm)	6.4
Thickness (mm)	0.265 (each)
Mass density (kg/m^3)	7500
Elastic modulus (GPa)	60.6
Effective piezoelectric constant (C/m^2)	−16.6
Permittivity constant (nF/m)	25.55

Figure 2.8 Geometric and Properties Used by Erturk and Inman Model [21]

2.7 INTRODUCTION PIEZO BENDER

Piezo Bender (Figure 7) is a block model in the Simulink programming environment. Its purpose is to represent a piezoelectric bimorph beam with a rectangular cross-section. The piezoelectric device known as a piezo bender will bend in response to applying an electrical field between the plates that make up the device. On the other hand, a piezo bender generates an electrical potential whenever it is bent because of the piezoelectric effect. The piezo bender is constructed out of several distinct rectangular layers of piezoelectric material, each of which has its polarity and is oriented in a direction that is perpendicular to the stack. This polarisation is flipped in a different direction over every layer [22].

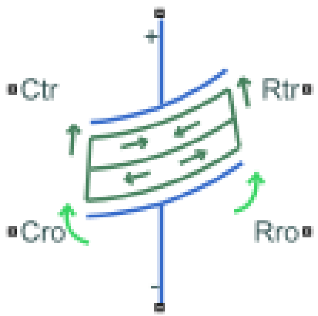
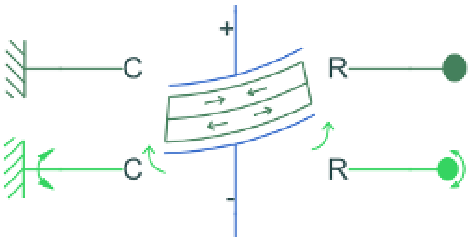
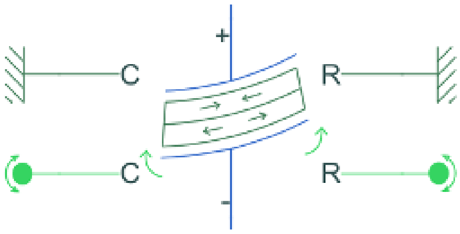
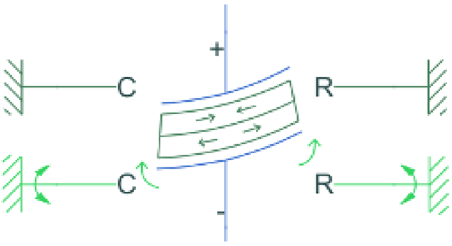


Figure 2.9 Piezo Bender Block Models

2.7.1 PIEZO BENDER BOUNDARY CONDITIONS

Piezo benders consist of a rectangular beam with two sides, left and right ends. The piezo bender has three standard boundary configurations: free, supported and clamped, as shown in Table 1.

Table 1 Piezo Bender Block Models Configurations

Configuration	Model	Description
Clamped-Free		When the configuration is said to have a clamped free state, the displacement and rotation are equal to any value.
Supported-Supported		The displacement is equal to zero when the configuration is said to have both sides supported.
Clamped-Clamped		When the configuration is said to have both sides been clamped, it indicates that displacement and rotation are equal to zero.

2.8 APPLICATION OF PIEZOELECTRIC ENERGY HARVESTING SYSTEM

The piezoelectric device is widely used as an energy harvesting system for numerous applications. The example of piezoelectric for energy harvesting applications in real life are given below:

1. Charging Batteries

   This paper studied the energy harvesting application in charging a battery. The battery is charged through the direct effect of piezoelectric, where mechanical energy is converted to electrical energy.

2. Road Pavement

   The piezoelectric transducer is placed in the road pavement [23] to harvest renewable clean energy from the vibration energy generated from the vehicles passing through the pavement. It is used for other sensors available on the road, such as traffic lights, information boards and more. By practising this application, energy saving can be achieved.

2.9 SUMMARY OF THE CHAPTER

The theory mentioned in the literature review are current theory that are already being recognize. The input knowledge gained from the journals in the literature review has essential effect in terms of the study to the research. Therefore, the development model of the piezo bender energy harvesting system has been design using Simulink MATLAB software to study the electromechanical effect in more details by applying different type of mechanical input. To model the system, Euler-Bernoulli beam assumption is used as a reference such as the geometric and material properties.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter provides an in-depth discussion on the progression of the research process and how it works. To illustrate the research of a piezo bender in an energy harvesting application from a vibrating object, the methodology and the block diagram will be employed.

3.2 BLOCK DIAGRAM

Below is a simple block diagram of piezoelectric for energy harvesting systems in general shown in Figure 3.1. This thesis developed the piezoelectric energy harvesting system through MATLAB Simulink software.

Figure 3.1 Block Diagram of Piezo Bender for Energy Harvesting System in General

The description of the block diagram is given below:

1. **Vibration Energy:** To harvest energy from the piezo device, it required vibration energy as an input to simulate. The vibration energy is usually transferred or generated from the surrounding environment as a mechanical force.
2. **Piezo Device:** In piezoelectric energy harvesting, piezoelectric material or device is essential to convert vibration or mechanical energy into electrical energy at a very high voltage.
3. **Rectifier:** The electrical energy produced by the piezo device is in alternating current (AC), which works alternately in a reversed direction. So, the rectifier converts the AC to direct current (DC), which works in only one direction.
4. **DC-DC Converter:** It functions in converting DC input voltage or current to another output.
5. **Sensor/Actuator:** The device that receives the output generated to power it.

3.3 MODELLING PIEZOELECTRIC ENERGY HARVESTING SYSTEM USING PIEZO BENDER IN SIMULINK MATLAB

3.3.1 SIMULINK MODEL

Figure 3.2 shows the model of piezo bender for energy harvesting system that have been designed and developed to study the electromechanical effect.

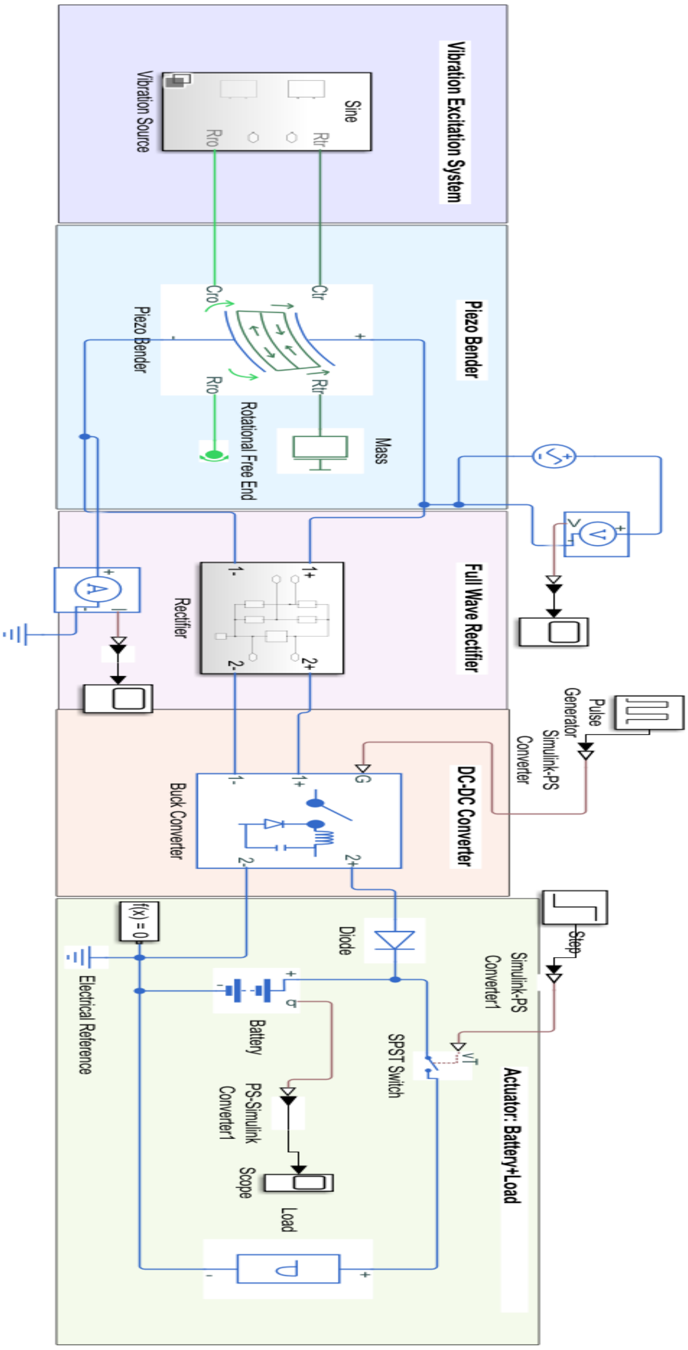


Figure 3.2 Simulink Model of Piezo Bender for Energy Harvesting Application

3.3.2 VIBRATION SYSTEM

In a previous study, the vibration energy in the harvesting system consists of two parts which are the mechanical and electrical parts. The mechanical part provides energy from the surrounding environment that is transferred into the piezo device to vibrate the input and harvest energy. As the first course of action, the piezo bender block model is connected to a vibration system which is the mechanical part to simulate the piezo bender input. The vibration sources in this system can be categorised into two variants: Sinusoidal and Chirp signals, as shown in Figure 3.3. The Chirp signal is a vibration source for engines that vary their speed, whereas the Sinusoidal signal is used for engines that rotate at a constant speed. Chirp signals are utilised in engines that ramp up and down in speed. Either of these two sources is going to result in the production of mechanical vibrations.

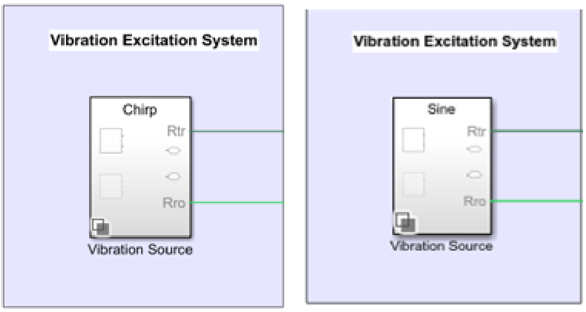


Figure 3.3 Vibration Excitation System Block Diagram

Figure 3.4 shows the vibration source subsystem of the Sinusoidal variant in the simulation model. A Sinusoidal vibration source consists of a sine wave signal that connects to an ideal translational velocity source to produce a constant speed. The frequency of the sine wave is set to 185 Hz. Besides, the Chirp signal vibration source subsystem is shown in Figure 3.6.

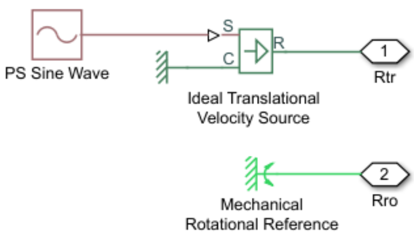


Figure 3.4 Sinusoidal Vibration Sources Subsystem

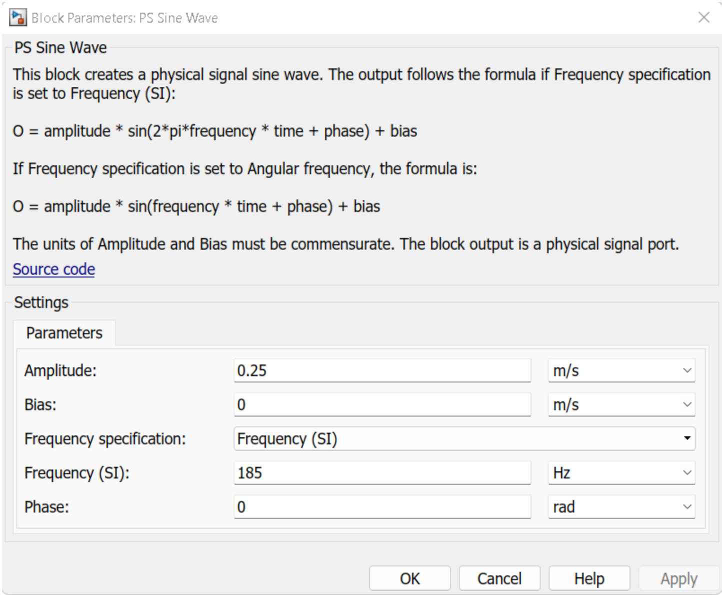


Figure 3.5 Sinusoidal Vibration Sources Parameters

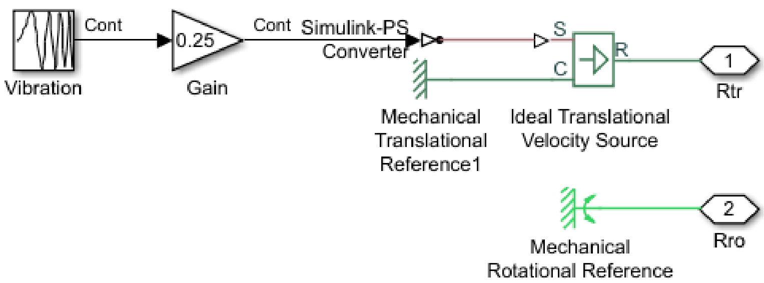


Figure 3.6 Chirp Signal Vibration Sources Subsystem

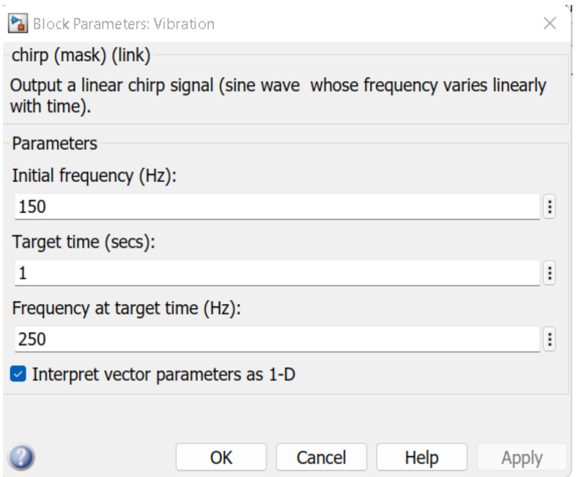


Figure 3.7 Chirp Signal Parameters

3.3.3 PIEZO BENDER BLOCK

A piezo bender block model (Figure 3.8) is used as a piezoelectric transducer or device in an energy harvesting system. The piezo bender represents the piezoelectric bimorph cantilever beam device, whose parameters are shown in Figure 3.9. The device will bend and generate an electrical potential by applying vibration energy. Besides, the piezo bender is connected to a tip mass and rotational free end on the right side. The tip mass is added to lower the system's resonance frequency or make it work better, as well as to improve the system's mechanical responsiveness and output power during low-amplitude vibrations. The external force will cause mass movement, which will cause the deformation of the connected piezo element. The deformations produce a charge and voltage across the electrical terminals of the piezo bender that are harvested into power.

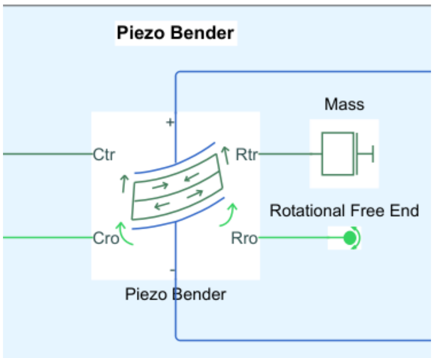


Figure 3.8 Piezo Bender Block Connected with Mass and Rotational Free End

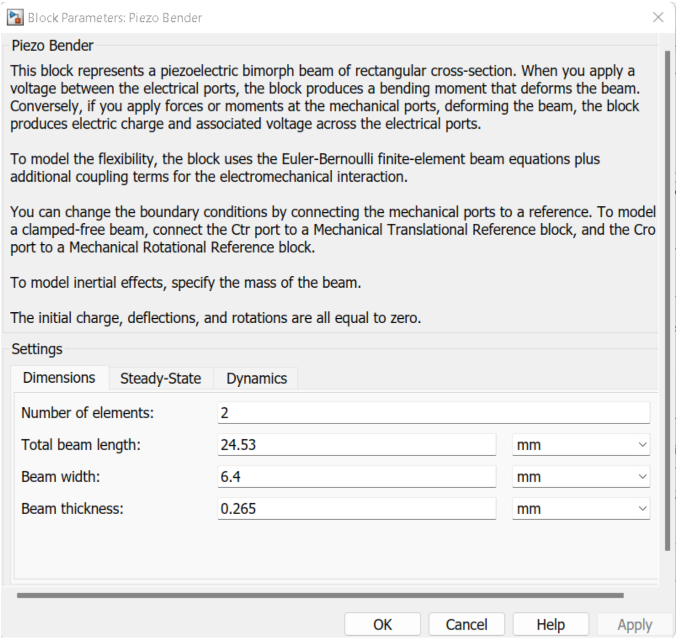


Figure 3.9 Piezo Bender Block Parameters

3.3.4 RECTIFIER

The full-wave bridge rectifier is connected to a piezo bender to convert the alternate current or voltage (AC) generated from the bending of the device into direct current (DC). It converts the sinusoidally varying ac input from the piezo element into pulsating DC voltage. The rectifier consists of four diodes and a capacitor that acts as a filter to smooth the DC voltage, as shown in Figure 3.11. This pulsating dc output voltage from the rectifier is then passed through a capacitive filter to reduce distortions.

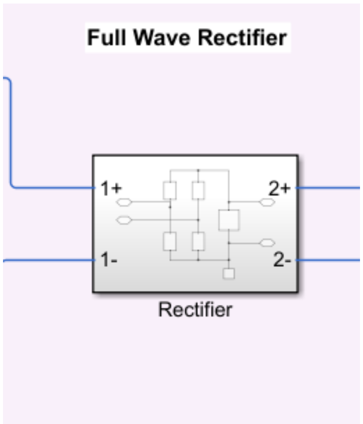


Figure 3.10 Full-wave bridge Rectifier Block

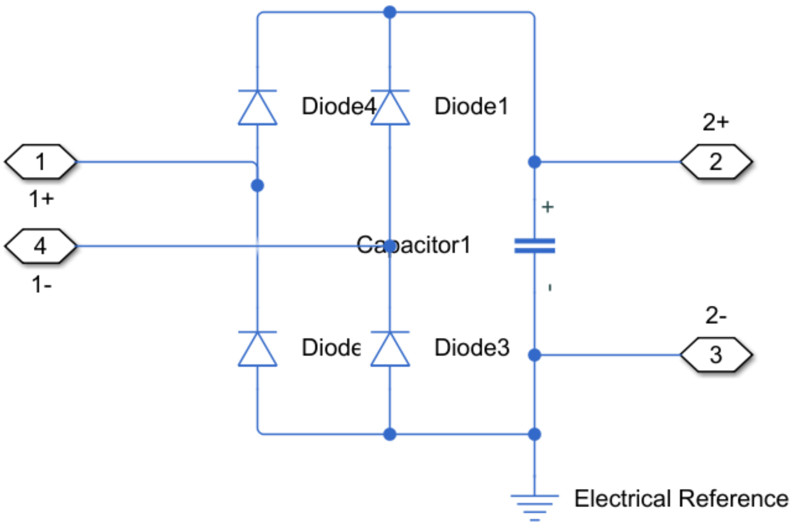


Figure 3.11 Full-Wave Rectifier Bridge Subsystem consists of 4 Diode and 1 Capacitor

3.3.5 DC-DC CONVERTER

To represent the DC-DC converter, the buck converter block is used in Figure 3.12 as a converter that, when operated by an associated controller and gate-signal generator, reduces the output voltage. Buck converters are sometimes called step-down voltage regulators because they reduce the overall voltage magnitude. It works as a voltage controller. Buck converter consists of switching devices, resistor, diode and

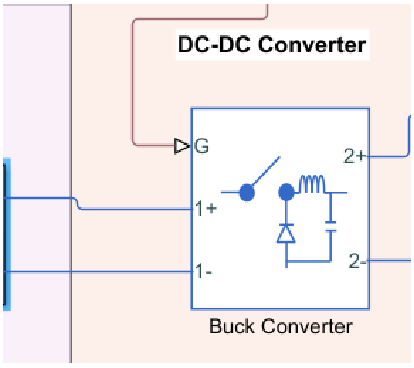


Figure 3.12 Simscape-Buck Converter Block

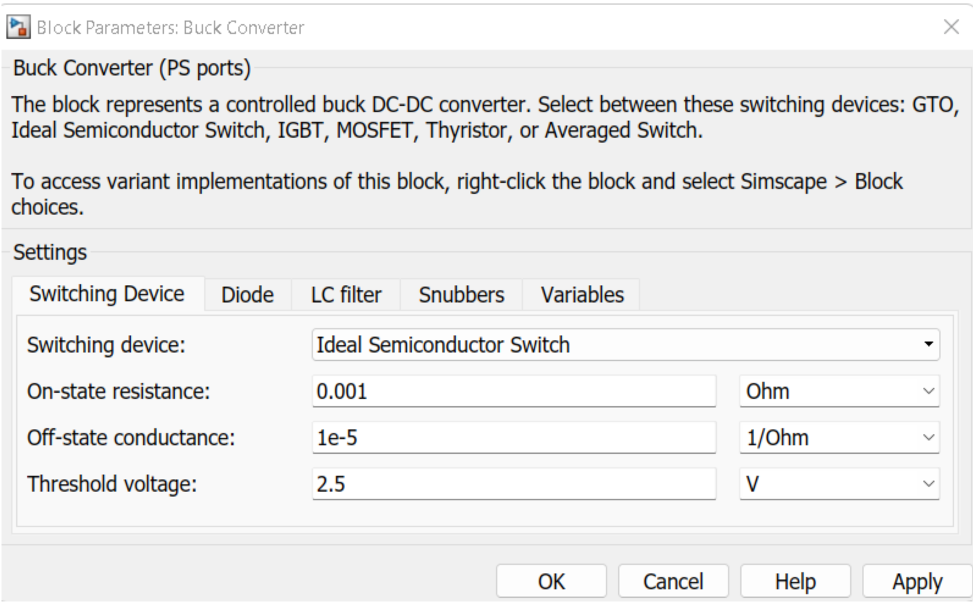


Figure 3.13 Simscape-Buck Converter Block Parameters

3.3.6 ACTUATOR

The DC voltage generated is applied to power a battery and a load. Figure 3.14 shows the circuit of the connected battery with load. Initially, the piezo bender energy harvester system designed will charge a battery.

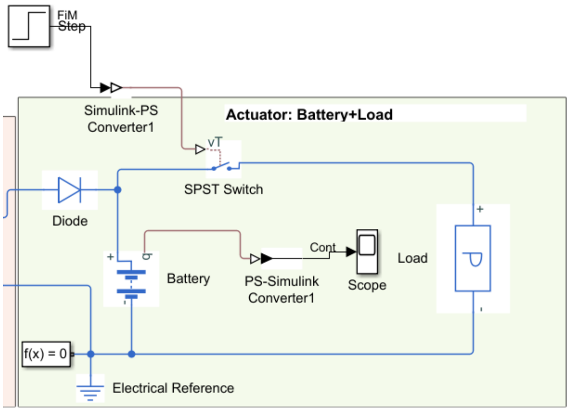


Figure 3.14 Actuator Circuit of Battery and Load

The battery cannot hold a charge since it has a voltage source that varies with the amount of charge and resistance connected in series. The source battery's output will be precisely or very close to 3 volts if the internal resistance is adjusted to 2 ohms and the nominal voltage is 3 volts. This is the case since the nominal voltage is also 3 volts.

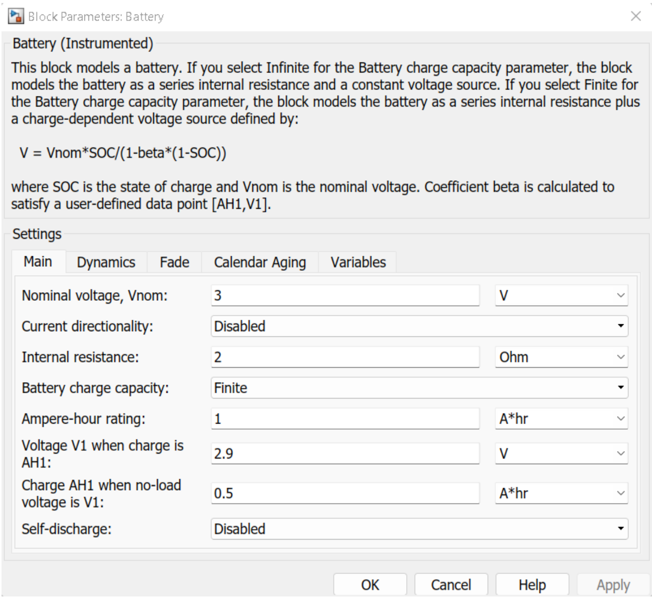


Figure 3.15 Battery Parameters