BUS STAND LAMP USING PIEZOELECTRIC ENERGY

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A report is submitted in partial fulfillment of the requirement for the degree of Bachelor in Electrical Engineering

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JUNE 2014

I declare that this report entitle "Bus stand lamp using piezoelectric energy" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : ....

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ABSTRACT

The development of piezoelectric energy harvester has quickened up in last few years mainly due to semiconductor improvements. Harvesting ambient vibration energy through piezoelectric element is increasing lately due to the technology growing more to use free energy source. The prototype development of bus stand lamp using piezoelectric energy was developed to show the concept of the harvester system. This product overcomes the problem of lacking lighting system for bus stand at rural place. The piezoelectric disc was place on the floor to gain energy from people walking across this area. The location to place this piezoelectric disc is determined in order to maximize the harvesting output power from people step on it. Power that harvested will be stored in the supercapacitor or battery before delivered to the load. This product used light emitting diode (LED) to light the bus stand as energy efficiency of LED is high compared to the traditional lighting. This bus stand is using LDR sensor to make it only turns on light when at night. In this project, two experiments were conducted to determine the maximum output of this piezoelectric harvesting base that can generate. From the experimental results, it show that the piezoelectric energy harvester base can generate a significant output that can charge the battery.

ABSTRAK

Pembangunan penjanaan tenaga piezoelektrik semakin pesat dalam beberapa tahun kebelakangan ini disebabkan oleh peningkatan dalam bidang semikonduktor. Penjanaan tenaga getaran melalui bahan piezoelektrik semakin meningkat akhir-akhir ini kerana teknologi sekarang lebih kepada menggunakan sumber tenaga bersih. Prototaip pembangunan perhentian bas menggunakan tenaga piezoelektrik telah dibina untuk menunjukkan konsep sistem penjanaan ini. Produk ini dapat mengatasi masalah kekurangan sistem lampu pada perhentian bas khususnya di kawasan luar bandar. Piring piezoelektrik ditempatkan di atas lantai untuk megumpul tenaga daripada orang berjalan di kawasan tertentu. Lokasi untuk meletakkan piring piezoelektrik ini ditentukan terlebih dahulu untuk memaksimumkan keluaran kuasa dari orang yg memijak di atasnya. Kuasa yang dijana akan disimpan di dalam superkapasitor atau bateri sebelum dihantar ke beban yang lain. Produk ini mengunakan diod pemancar cahaya (LED) untuk menyalakan perhentian bas itu kerana kecekapan lampu LED adalah tinggi berbanding dengan lampu tradisional. Perhentian bas ini menggunakan sensor LDR untuk menghidupkan lampu (LED) apabila pada waktu malam. Dalam projek ini, dua eksperimen telah dijalankan untuk menentukan keluaran maksimum dari sistem penjanaan piezoelektrik ini. Daripada keputusan eksperimen, ia menunjukkan bahawa keluaran voltan dan arus dari penjana tenaga piezoelektrik boleh menjana output yang boleh mengecas bateri.

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LED	light emitting diode
AC	alternating current
DC	direct current
LDR	light dependent resistor
PZT	lead zirconate-titanate
PVDF	polyvinylidene fluoride

CHAPTER 1

INTRODUCTION

1.1. Introduction

Research for an alternative energy source that can provide power supply is increasing greatly with time as our technology is moving more to free energy source. The concept of implementing piezoelectric materials into the environment to provide a sustainable power source is drawing a lot of attention to the scientific community [1]. The ability of this material to harvest energy from vibration attracts people to do more research about the capability of this material to generate more energy.

The focus of this project is to develop a piezoelectric energy harvesting system, where the main design is to harness the vibration energy from walking people at bus stand and turn that wasted energy into electricity to power light emitting diode (LED) at that bus stand. Piezoelectric material can provide a solution to this design constrains because of their mechanical properties of being small, lightweight and their versatility in an endless array of applications [2].

1.2. Project Background

This project focuses on designing a piezoelectric energy harvesting system that can power up bus stand lamp. A product designed is environmentally friendly systems because it generates electricity by using wasted energy from the vibrations produced by people walking on the floor. It uses piezoelectric effect to generate voltage and then charge the battery to power up bus stand lamp at night. Piezoelectric elements are integrated in the floor at the bus stand to change the pressure and vibration into electrical power. This system provides control circuit that will turn on the lamps at night.

1.3. Problem Statement

In Malaysia, many incidents reported occur at bus stand especially at night. Usually this happens when they do not have adequate facilities such as lighting systems at the bus stop. In urban areas, bus stand normally is provided with lighting system, but in rural place, such things are not provided. Usually this occurs when the TNB pole is far from the bus stop so it is difficult to connect the supply to the bus stand. Nowadays in Malaysia, the increase in numbers of public transport users caused the bus stand always full with peoples. By taking advantages of this condition, wasted energy can be harness from foot step on the floor of the bus stand and ultimately manipulating the energy into something useful and beneficial to transport users.

1.4. Objective

The objectives of this project are:

- To analyze electrical performance of piezo energy.
- To develop a model of piezoelectric energy harvester system for bus stand lamp.
- To verify the reliability of bus stand model and energy harvester base.

1.5. Scope

This project focuses on designing energy harvesting system using piezoelectric ceramics disc. This project uses piezoelectric ceramics disk as an energy harvester that harvest energy from vibrations of people walking on the floor. It use super capacitor size 0.47 Farad 5.4Volt as energy storage element. This project also uses four diode functions as full bridge rectifier to convert AC voltage from piezo disc to DC voltage. Zener diode is used as a protection for super capacitor. For the lighting system, it uses light emitting diode (LED) and light dependent resistor (LDR) sensor for night detection system. The reliability of the system will be verified from the experiments by considering the output voltage and current.

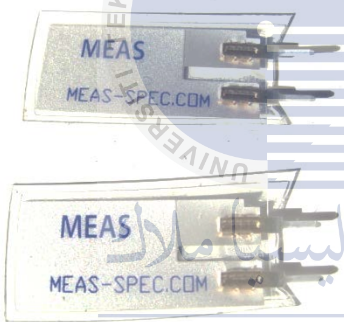
CHAPTER 2

LITERATURE REVIEW

2.1. Piezoelectric

Piezoelectric is an effect of the electromechanical relationship that allows certain materials such as crystals and synthetic ceramics to produce an output voltage power that come from mechanical stress or vibration. Piezoelectric elements are widely used in many applications such as acoustic transducers, mechanical actuator and for electric energy harvesting system. Ceramics such as lead zirconate-titanate or PZT and bimorph such as polyvinylidene fluoride or PVDF are common type of piezoelectric materials. Material type bimorph element has its own advantages like being soft and flexible, but they have lower dielectric and piezoelectric constant than ceramics [3]. Most efficient materials are quite expensive. For this project, cheaper materials such as ceramics disc that are much less efficient, but will still work to demonstrate the concept of piezoelectric energy harvesting will be used. Table 2.1 shows the different type of piezoelectric material that normally used in the energy harvesting system.

Table 2.1 Different type of piezo material

Type of material	Explanation
Ceramic disc 	Piezoelectric ceramics is referred to polycrystalline made by maxed oxide (zirconia, lead oxide, titanate, etc.)which experienced by high sintering and solid state reaction, then through high-voltage direct current polarized, so it have the general term of the piezoelectric effect of ferroelectric ceramics[4].
PVDF film 	Piezoelectric PVDF polymer is a long chain, semi crystalline polymer having the repeat unit (CH_2-CF_2). It is approximately 55% crystalline and has a molecular weight of typically 4 x 10^5.Piezoelectric PVDF polymer due to its perfect elastic properties and high piezoelectric constant can be good applicant for energy harvester [5].

2.1.1. Lead zirconate-titanate (PZT)

Lead zirconate-titanate (PZT) is the most commonly used piezoelectric materials for power generation. PZT ceramic is suitable for energy harvesting systems since the efficiency of conversion from mechanical to electrical energy controlled by the piezoelectric constants d and g and PZT ceramics have a high piezoelectric constant and the quality factor [6]. PZT form a tetragonal structure with a small atom in the center as shown in Figure 2.1. When the crystal is strained, the center atom displaces from its lattice site and creates a potential [7].For this project, the displacement at the center atom caused from pressure from people walking on the floor will allow energy harvesting process occurs.

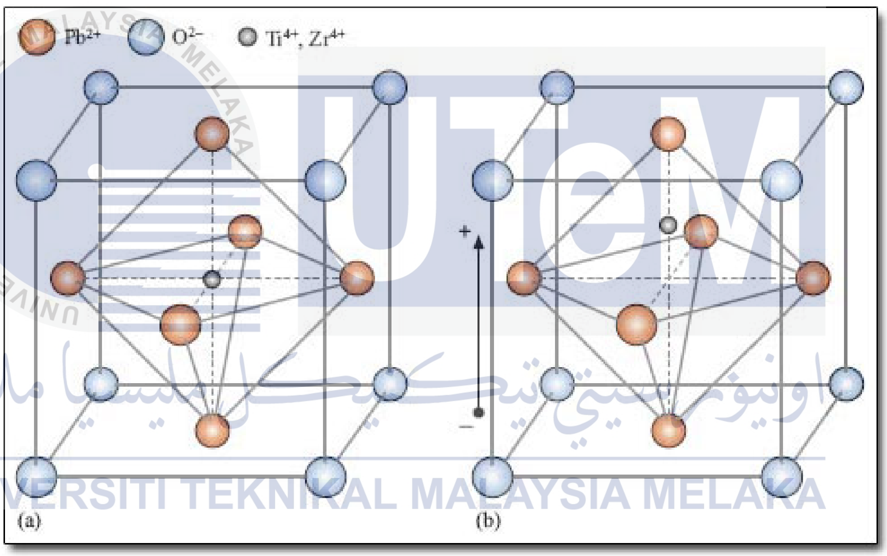


Figure 2.1 Lead zirconate-titanate crystal structures [7]

2.2. Application of piezoelectric

Piezoelectric ceramics are important high-tech materials, the laser information technology, electronics technology, sensor technology, measurement technology, precision machining technology, communications, biotechnology, medicine, navigation, automatic control, ultrasound and sound of water, fire and explosion in the army, commercial and public areas have been widely used [4].

Such as ultrasonic motors, it uses the inverse piezoelectric effect piezoelectric material to change the power to the elastic energy of mechanical vibration. Through friction between the stator and the mover to drive actuators perform rotary or linear motion; this is a new electric machine. Ultrasonic motor performance is dependent on the effective strain energy transmitted to the piezoelectric ceramic oscillator. Different locations in the piezoelectric ceramic oscillator vibration can stimulate different levels vibrator. So the optimum design and application of piezoelectric ceramic in ultrasonic motor is important [4].

Most conventional speakers are not designed to be thin, because the magnetic transducer driven requires additional depth to enhance low-frequency sound [8]. By using piezo disc, the vibration of that disc can transform it into a speaker.

In automotive, application of piezoelectric can be such as in air bag sensor and seat belt buzzer. In daily use, application of piezoelectric can be seen in cigarette lighter, musical instruments and also in depth finder device.

2.3. Piezoelectric Energy Harvester Circuit

Equivalent circuit of the piezoelectric harvester [9] can be represented as a spring mass system mechanically coupled to the electrical domain as shown in Figure 2.2. Here, L_M represents the mechanical mass, C_M the mechanical stiffness and R_M takes into account the mechanical losses. Domain mechanically coupled to the electrical domain through a transformer that converts the pressure to current. On the electrical side, C_P represents the plate capacitance of the piezoelectric material. At or close to resonance, the whole circuit can be transformed into electrical domain, in which the piezoelectric element when excited with sinusoidal vibrations can be modeled as a sinusoidal current source in parallel with a capacitance C_P and resistance R_P [10].

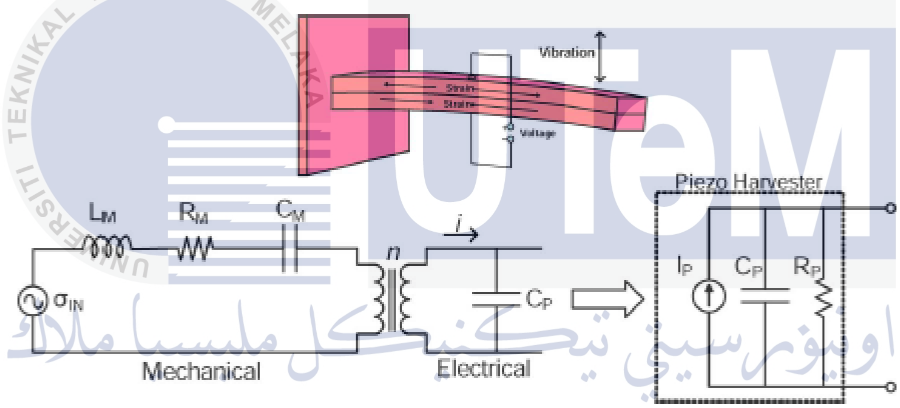


Figure 2.2 Equivalent circuit of a piezoelectric energy harvester showing the mechanical and electrical sides of the device [9]

Energy harvesting systems nowadays normally consists from four main important parts. It consists of energy source, full bridge rectifier circuit, energy storage and load. For energy source, piezoelectric element that harvest energy from footstep walking people on floor will be used. Component like piezoelectric element will produce an output in AC form. Full bridge rectifier circuit will be used to convert this AC form into suitable DC form. For energy storage, super capacitor will be used to store energy and transfer it to the light emitting diode (LED) as the load.

2.3.1. Full Bridge Rectifier circuit

Full bridge rectifier is usually used as a rectifier circuit to convert the AC output voltage of the piezoelectric harvester to DC voltage [10]. Common implementation of this rectifier circuit is shown in Figure 2.3. Capacitors C_{RECT} on the output rectifier are considered as large compared to C_P and thus holds the rectifier output voltage (V_{RECT}) is essentially constant in the cycle to cycle. With this assumption, the voltage and current waveforms associated with the circuit is shown in Figure 2.3[10].

The non-idealities of the diodes are represented using a single parameter V_D which is the voltage drop across the diode when current from the piezoelectric harvester flows through it. Every half cycle of the input current wave can be divided into two areas. For the full-bridge rectifier, in the period between $t=t_0$ and the $t=t_{OFF}$, piezoelectric current I_P flows into C_P to charge or discharge it. During this period, all the diode is reverse biased and no current flows into the output capacitor C_{RECT}.

This situation continued until the voltage across the capacitor C_P labeled as V_{BR} in Figure 2.3 is equal to $V_{RECT} + 2V_D$ in magnitude. When this happens, one set of diodes turn ON and the current starts flowing into the output. This is the interval between $t=t_{OFF}$ and in $t=t\pi$. This interval will last until the current I_P changes direction. The shaded part of the current waveform shows the amount of the charge is not transfer to the output of every half cycle. At low values of V_{RECT}, most of the charge obtained from the harvester to flow into the output but the output voltage is low. At high values of V_{RECT}, little charge flows into the output [10].

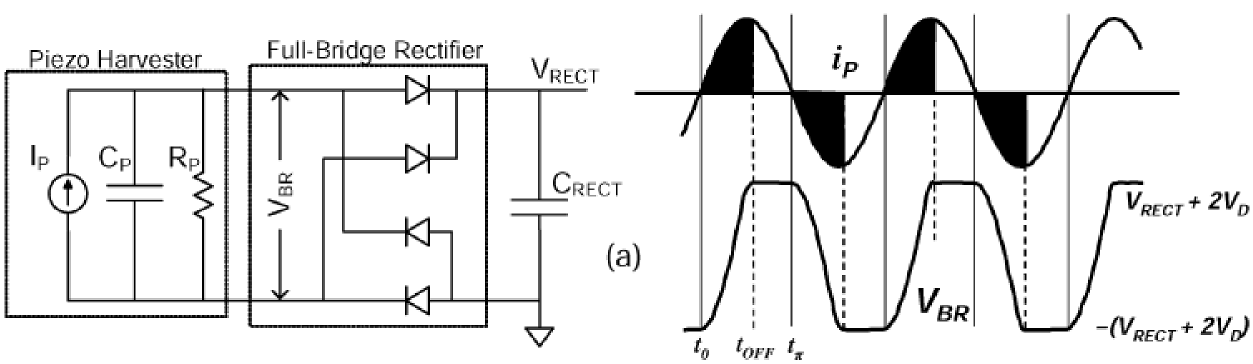


Figure 2.3 Full bridge rectifier used to convert AC signal to DC signal from piezoelectric energy harvester and associated generated voltage and current waveform [10]

The opposite trend causes full bridge rectifier output power to vary with V_{RECT}. Output power obtained by the full bridge rectifier in the presence of diode non-idealities can be given by equation 2.1 [10]

$$P_{RECT,\,FB} = 4C_P V_{RECT} f_P \,(V_P - V_{RECT} - 2V_D) \tag{2.1}$$

where the term V_P is the open-circuit voltage amplitude at the output of the piezoelectric harvester which can be represented as $V_P = I_P / \omega_P C_P$. The maximum power [11] that can be obtained using the full-bridge rectifier is given by equation 2.2

$$P_{RECT,\,FB}\,(max) = C_P\,(V_P - 2V_D)^2 f_P \tag{2.2}$$

and this is achieved at $V_{RECT} = V_P / 2 - V_D$.

2.3.2. Filter

A filter that usually used in the piezoelectric harvesting circuit is capacitor. This capacitor act as smoothing element and also called filter capacitor. Its function is to smooth the ripple in half wave / full wave output from bridge rectifier into smooth DC signal. Large value of capacitor is connected to the load function as a storages device. When the varying DC voltage from the rectifier is falling, this capacitor will supply current to the output.

The Figure 2.4 shows the full bridge circuit with smoothing capacitor and waveform that produce from smoothing process.

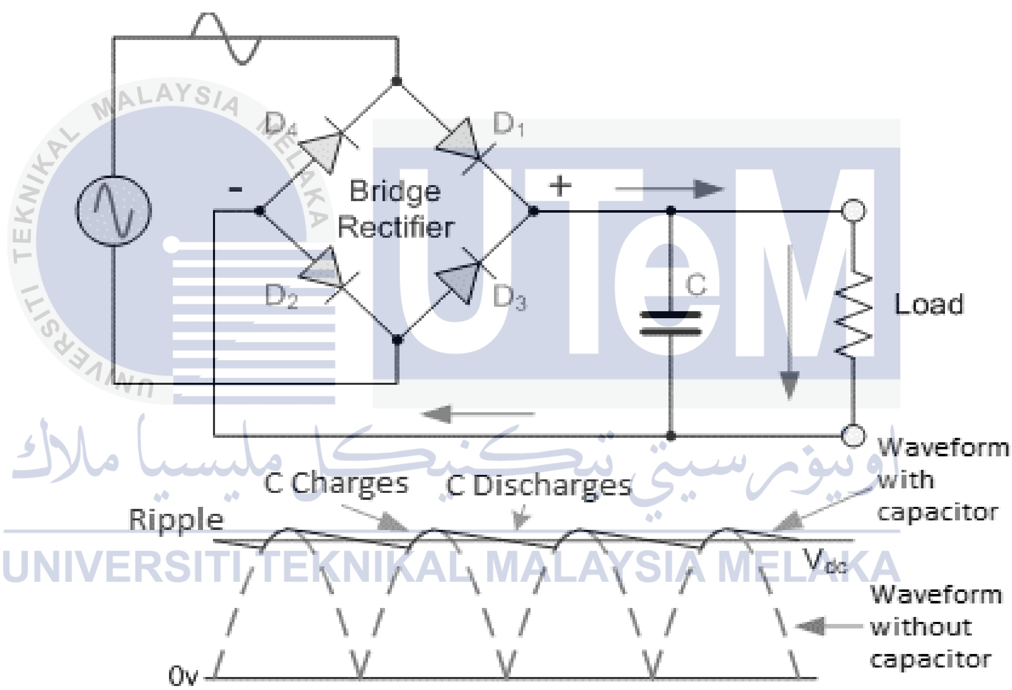


Figure 2.4 Full bridge circuits with smoothing capacitor and output wave

2.3.3. Storage device

Energy harvesters use a storage supercapacitor as shown in Figure 2.5 to store energy that generated. The battery is not been use in this project because limited in their ability to deliver power, the battery can store a lot of energy but it takes a long time to recharge. Furthermore, the output current of the piezoelectric element is very low and it can take long time to fully charge the battery. Supercapacitors are unique in that they are able to combine the characteristics of energy storage battery with the discharge characteristics of a capacitor power. Supercapacitors are very high surface area activated carbon capacitors that use a molecule-thin layer of electrolyte, rather than a manufactured sheet of material, as the dielectric to separate charge. As the stored energy is proportional to the surface area of the charges and inversely proportional to the thickness of the dielectric, these capacitors have a very high energy density. They are able to provide very high charges that can be discharged in a controlled method [12].

There are many advantages of supercapacitor such as:

- Prolong battery run time
- Supply backup power
- Enables design to meet current specifications
- Cuts pulse current noise
- Allows low/high temperature operation
- Reduces space of components use
- Reduces battery size
- Improves load balancing when used in parallel with a battery

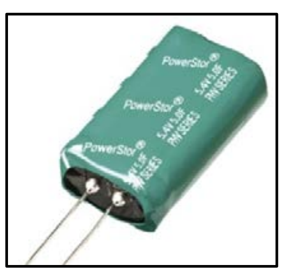


Figure 2.5 Supercapacitors 0.47F 5.4V

2.3.4. Load

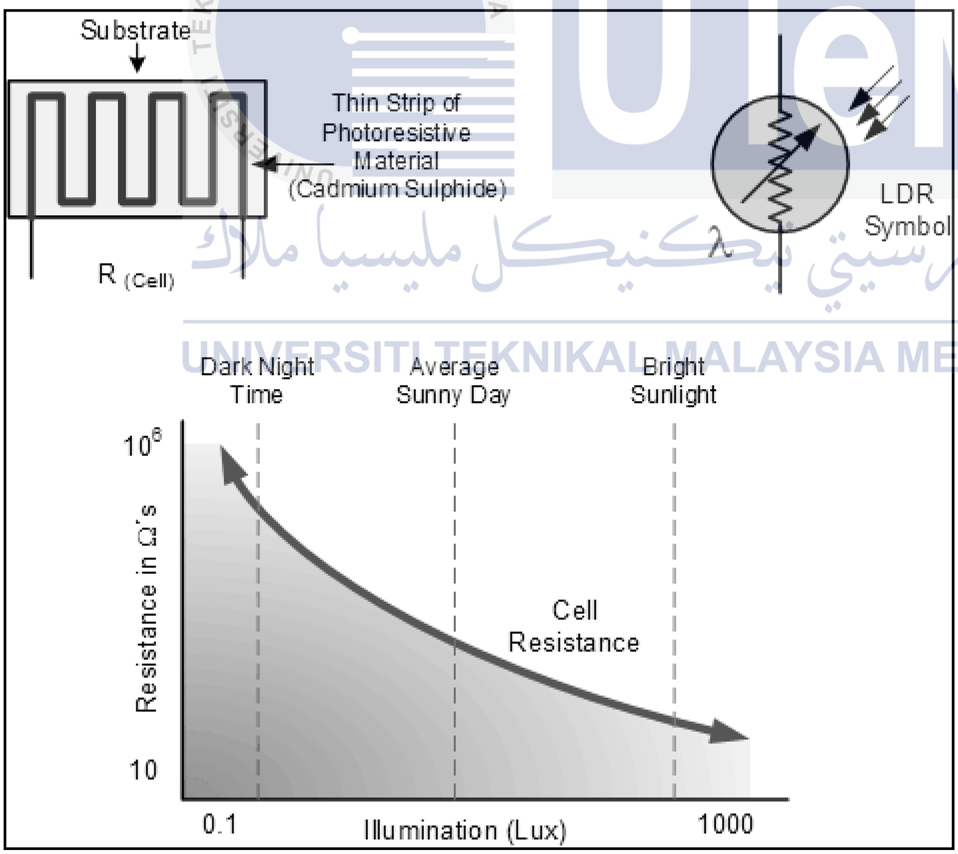
There are many applications that can be used as a load from the energy that harvested from piezoelectric harvesting system. The output from the piezoelectric harvesting system is varied from high power to low power output. Low power energy harvesting from vibration to electricity generation covering several appliances – WSN, building automation wireless, battery-less, low-power switches, automotive, medical uses such as body area networks; precision agriculture and consumer electronics [13].

For high power load, energy that generated from piezoelectric harvesting system covering several application such as power the signs board light and street light.

2.3.5. Control circuit for automatic night lamp

Light dependent resistor (LDR) is used in dark sensor circuit. The resistance of LDR usually is very high, as high as 100000 ohms as shown in Figure 2.6, but they are illuminated with light resistance drops significantly.

Material used as the semiconductor substrate include, lead sulphide (PbS), lead selenide (PbSe), indium antimonide (InSb) which sense light in the infra-red range with the most normally used of all photo resistive light sensors being Cadmium Sulphide (Cds). Cadmium sulphide is used in the construction of photoconductive cells because its spectral reaction curve closely equals that of the human eye and can even be controlled using a torch as a light source. Usually, it has a peak sensitivity wavelength (λp) of about560nm to 600nm in the visible spectral range [14]. Figure 2.7 show the typical LDR that was used in this project.



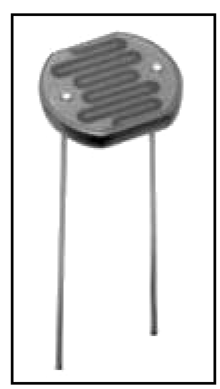


Figure 2.6 Resistance graph of LDR and it symbol

Figure 2.7 Typical LDR

2.4 Previous work about piezoelectric

2.4.1 Energy harvesting from piezoelectric materials fully integrated in footwear [15].

The development of energy harvesting in footwear using electromechanical transducers such as piezoelectric is being discuss in this paper [15]. It uses principle: to convert mechanical energy into electrical energy by reaction from movement between piezo material and sole. In this paper, piezoelectric material that has been use is polymeric material based on polyvinylidene fluoride (PVDF). Piezoelectric materials have been place in places that has high variable pressure applied while walking. That material was place on the top of sole. Figure 2.8 show the preliminary result performed by simple jumps.

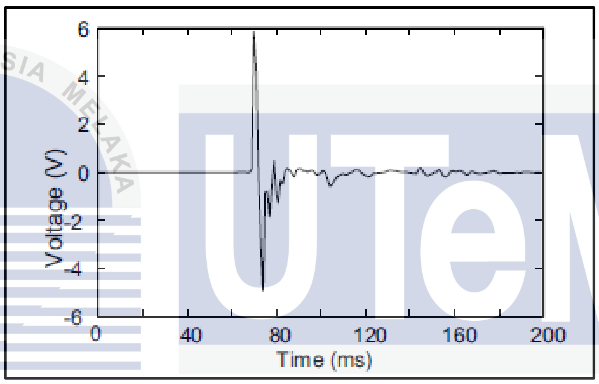


Figure 2.8 Output voltage perform by single jump [15]

The rectifier circuit using four Schottky diode was use in order to get the maximum output by obtains a single polarity voltage from piezoelectric generator. Result in Figure 2.9 shown that output voltage from piezoelectric generator.

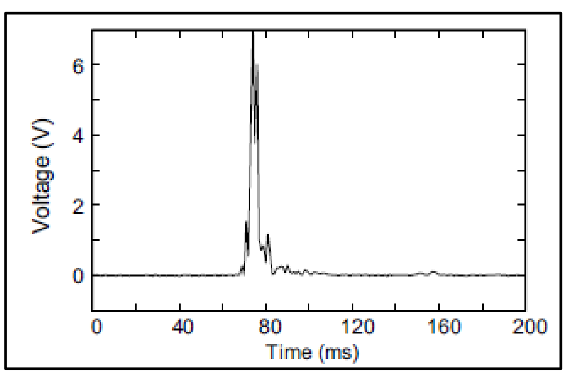


Figure 2.9 Output voltages after rectified [15]

2.4.2 Novel piezoelectric energy harvesting devices for unmanned aerial vehicles [16].

Technology nowadays has become more interesting and able to give more benefit to people. The aircraft is one of the technologies that have achieved a great interest in the research community. Lately, the research of small aircraft such as unmanned aerial vehicles (UAVs) and micro air vehicles (MAVs) has become more famous among the researchers [16]. The main important aspect to build this type of aircraft is their ability to fly in long duration. Normally, these types of aircrafts are using battery as their power source. The use of piezoelectric material as an energy harvesting on these aircraft can prolong it battery capacity by self recharge on the air.

On this paper [16], the experiment of self charging piezoelectric was done using a SigLab data acquisition system to record the output voltage. The results from the paper [16] are shown in the Figure 2.10.

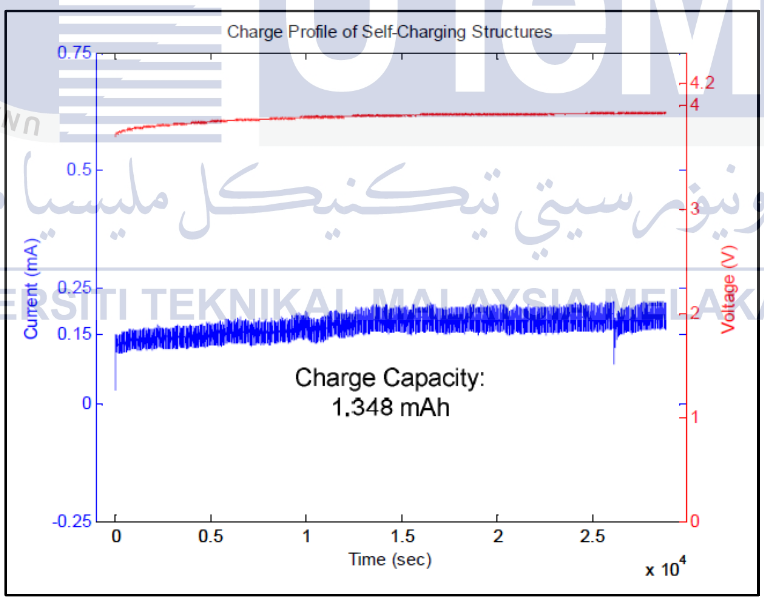


Figure 2.10 Output voltage using SigLab data acquisition [16]

Form Figure 2.10, it can be seen that piezoelectric materials are able to generate an average of about 0.165 mA of current into the battery. The battery voltages also slowly increase from about 3.7 V to 3.92 V.

CHAPTER 3

METHODOLOGY

3.1. Project Development Process Steps

The Figure 3.1 shows the process of the developing this project. The initial process literature review and research is begins after the title project was decided. Research have been made through articles, journals, books and internet source to make a review about the piezoelectric include its effect, characteristics and its application. The main purpose of this research is to obtain more detail information and theories that involve in development of this harvesting system.

In the hardware development, it will be divided into two parts, mechanical development and circuit development. In the circuit part, the rectifier circuit and storage circuit will be designed. The circuit will be design using MATLAB software and the output value will be determined from the simulation. After the circuit combined with all components such as piezo disk, supercapacitor and load, the next step is to test the circuit to ensure that it meets the necessary requirements of the output specification.

For the mechanical development part, it consists of process on design the model of bus stand and piezoelectric harvester base. Hardware compilation will be done when both circuit and mechanical parts are ready. After that, the experiment and analysis will be conducted to determine the output of the piezoelectric energy harvester.

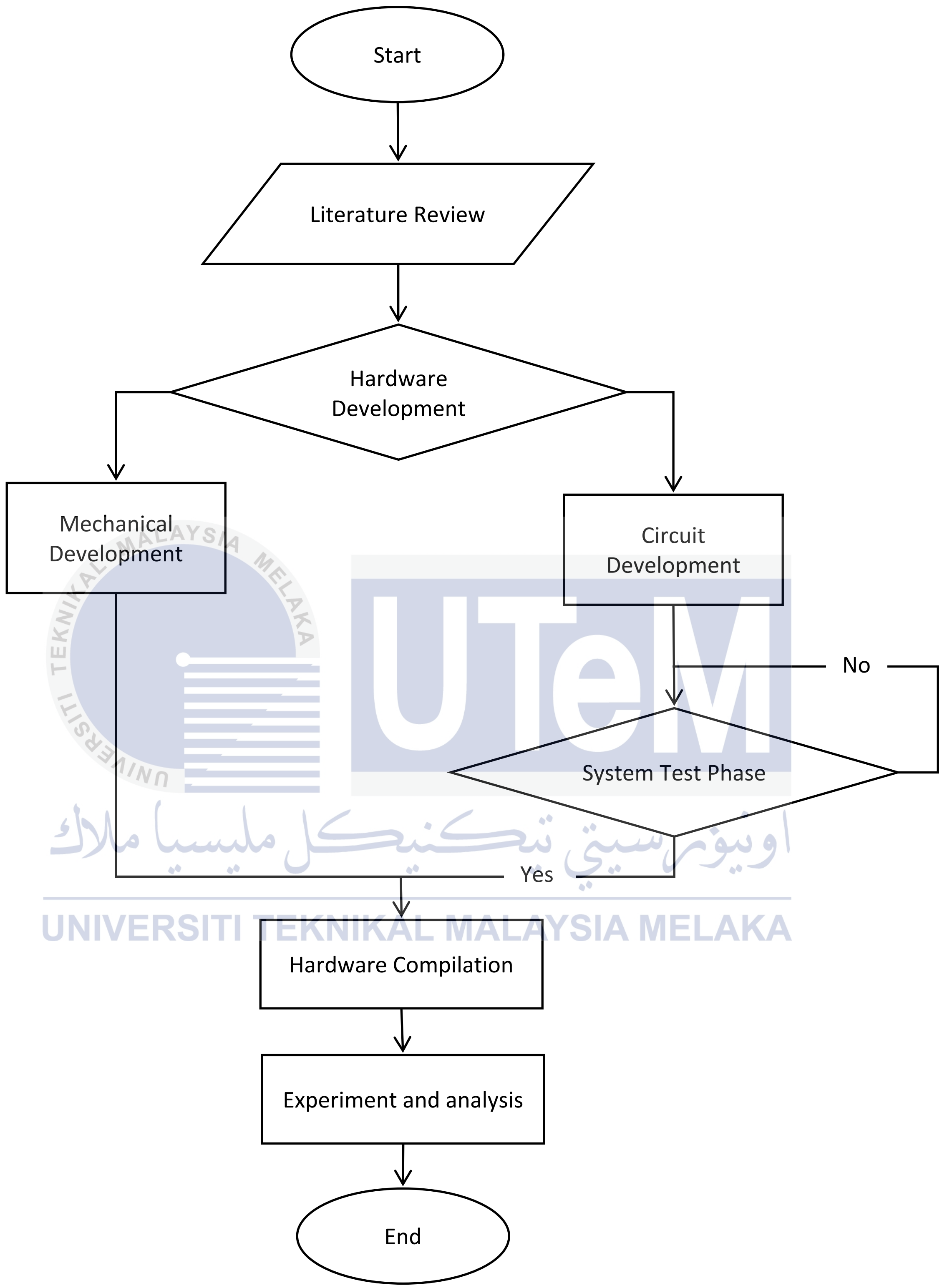


Figure 3.1 Flowchart of Project Flow

3.2. Project Block Diagram

The block diagram in Figure 3.2 shows an overview of the piezoelectric energy harvester system. The main component of this piezoelectric energy harvesting system is piezoelectric disc, rectifier circuit, supercapacitor as a storage device and light emitting diode (LED) as a load. Piezoelectric disc converts vibration energy into electrical energy. Electrical energy that generated from piezoelectric is in AC signal need to convert into DC signal using full bridge rectifier circuit. The DC voltage then will be stored in supercapacitor and then supplies the load LED. This LED using control circuit will turn on at night.

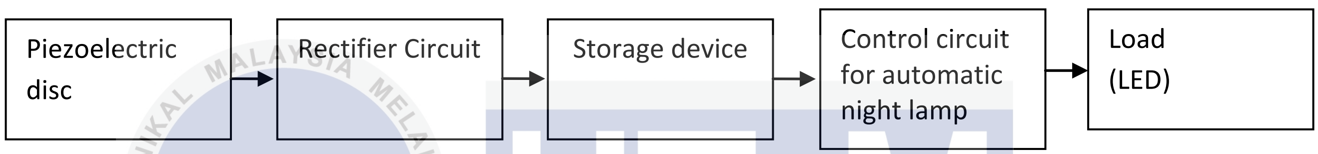


Figure 3.2 Piezoelectric Energy harvesting system block diagram

3.3. Simulation

MATLAB software is used to design the circuit of piezoelectric energy harvester. It includes the design of full bridge rectifier that function to converts AC signal that generated from piezo disc into DC signal. Figure 3.3 show the configuration for the circuit piezoelectric harvester system. In this simulation, AC source is use to replace the piezoelectric effect which also can generated AC signal because of piezoelectric component is not included in this software. This simulation circuit just only to show the construction of the full bridge rectifier circuit that will be used in this system.

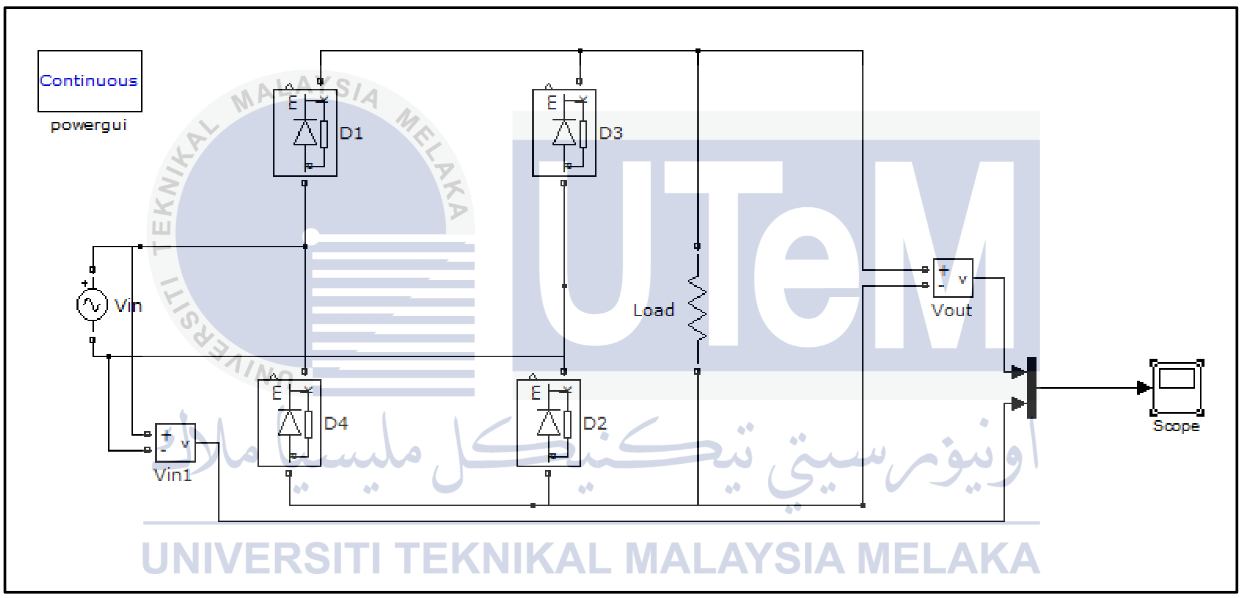


Figure 3.3 Simulation circuit using MATLAB

3.4. Hardware Implementation

The piezoelectric energy harvester system consists of piezoelectric disc, full bridge rectifier and supercapacitor as storage. Electrical energy generated from piezo discs are stored in supercapacitor before use to load.

3.4.1. Piezo disc

In general, by connecting piezo disc in parallel, the total voltage produced is maintains but current is increase. Meanwhile by connecting in series, total voltage will increase but current is maintains. For the piezoelectric energy harvester configuration, piezo disc will be connected in parallel in order to maximum their output current that produced. Figure 3.4 show the piezo disc connected in parallel.

Figure 3.4 Piezo disc connected in parallel

3.4.2. Supercapacitor

Supercapacitor used in this project as energy storage to replace batteries. The battery is not used as storage for the output of the piezoelectric harvesting system because it produces very low output current. Low output current will increase duration to charge the battery. Cooper Bussmann PowerStor supercapacitor type in Figure 3.5 has been used in this project. Its working voltage is 5.4V and nominal capacitance range is 0.47F. Table 3.1 shows the specification of this supercapacitor.

Figure 3.5 Cooper Bussmann supercapacitor

Table 3.1 Specification for supercapacitor

Specification	
Working voltage (maximum)	5.4V
Surge voltage	6.0V
Nominal Capacitance range	0.47F to 5F
Capacitance tolerance	-10% to +30% (20°C)
Operating temperature range	-40°C to 65°C
Extended operating temperature range	-40°C to 85°C (within linear voltage derating to 4.0 V @ 85°C)

3.4.3 Bus stand model design

A bus stand is a place that provides shelter for people that use public transport such as bus and taxi. The design intent is for the bus stop to provide lighting to the users of bus stop. For this project, a bus stand model as shown in Figure 3.6 is used. The piezo disc is located on the floor of the bus stand. The location of piezo disc is place on center of the bus stand floor because want to maximize the capturing amount of foot step from people.

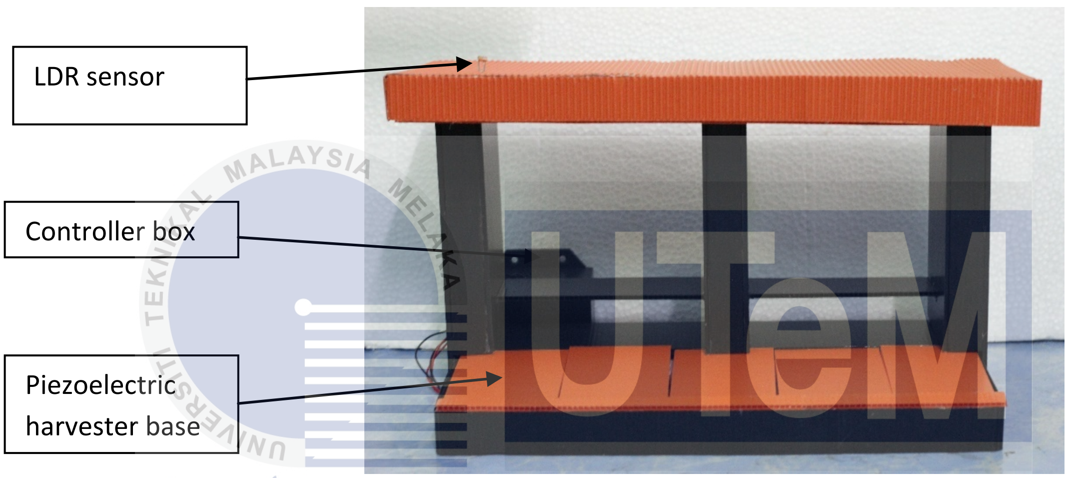


Figure 3.6 Bus stand model for energy harvesting

3.4.4 Energy harvester base design

The important part of this energy harvester was it base. This base development started by using solid work software before fabricate the real product. The Figure 3.7 shows the rendered design using solid work software. It has 81 small compartments that will hold the piezo disc. This base was design to make it portable and easy to setup.

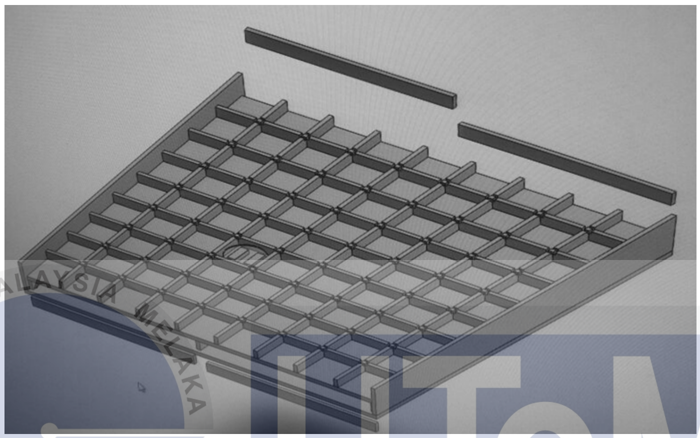


Figure 3.7 Rendered design of piezoelectric harvester base

The figure 3.8 shows the real product of this energy harvester base. Artificial turf was placed on the top of the base to represent of its green energy.

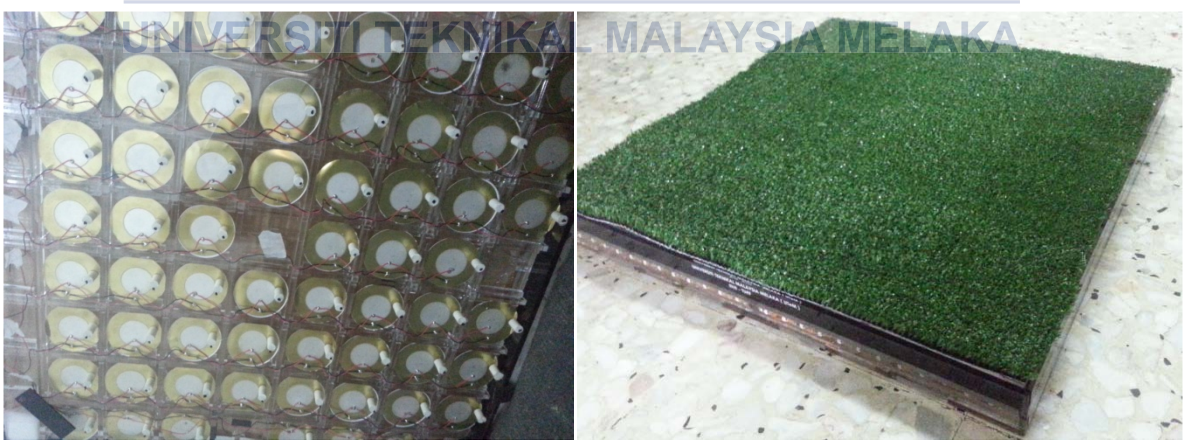


Figure 3.8 Real product of piezoelectric energy harvester base

CHAPTER 4

RESULT, ANALYSIS AND DISCUSSION

4.1. Experimental Result

After completing the design of the bus stand model and energy harvester base, the experiment was conducted to determine the output voltage that can be generated by this model of piezoelectric energy harvesting system. The parameters that were used during this experiment are weight of the dumbbell as shown in Figure 4.1 to represent the weight of the people step on the base of energy harvester and the effect of the output voltage when weight applied at certain position at the base. The setup of experiment is shown in Figure 4.2.

Figure 4.1 Size of dumbbell that used in experiment

Figure 4.2 Set up for experiment

4.2. Result, Analysis and Discussion for Experiment 1

The experiment 1 was conducted to measure the output voltage and current that can generate by the energy harvester base. The dumbbell was placed on the center, left and right of the base at height 4cm to represent as foots step from people. Table 4.1, Table 4.2 and Table 4.3 show that complete results that have been taken from the experiment 1.

Table 4.1 Output voltage of energy harvester base from experiment 1 when load applied at center

Weight of the dumbbell (kg)	Output voltage (V)	Output current (A)
0.5	6.5	0.054
1.25	18.2	0.078
1.75	25.1	0.114
2.5	28.4	0.134
3.0	30.4	0.205
3.75	36.2	0.372

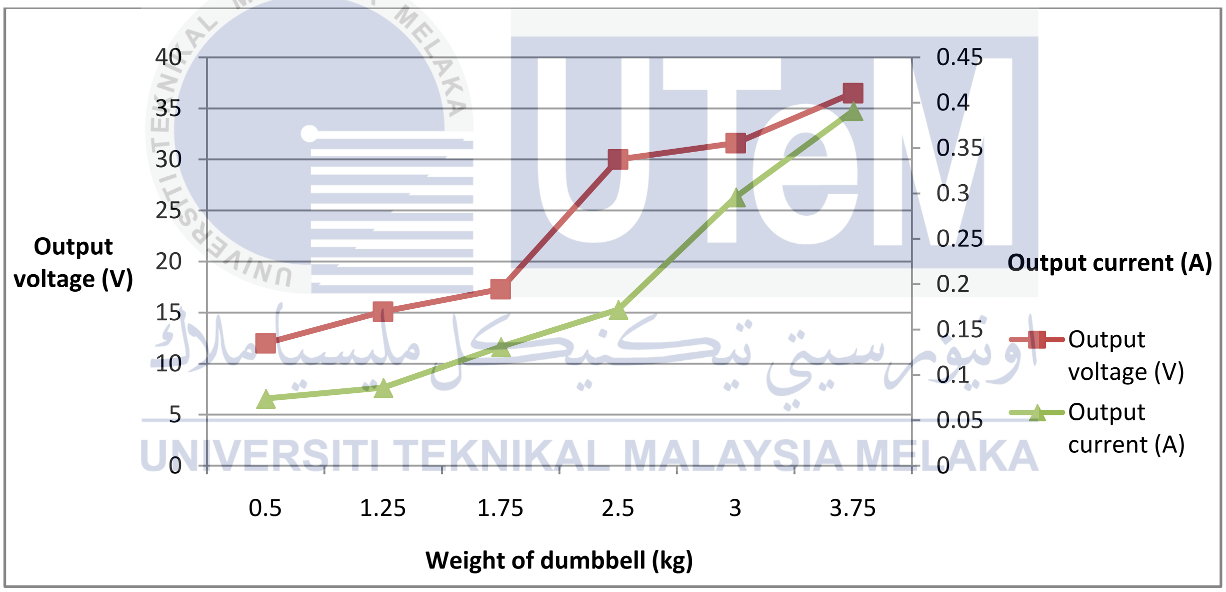


Figure 4.3 Output voltage and current of harvester base from experiment 1 when pressure applied at center

The line graph in Figure 4.3 shows the output voltage and current versus weight of dumbbell of the piezoelectric energy harvester base. The load was applied at the center of the base. Overall, it can be seen that the output voltage and current are increasing proportionally to the change of the weight of the dumbbell.

Table 4.2 Output voltage of energy harvester base from experiment 1 when load applied at left side of the base

Weight of the dumbbell (kg)	Output voltage (V)	Output current (A)
0.5	4.4	0.042
1.25	17.8	0.067
1.75	19.7	0.092
2.5	21.4	0.124
3.0	29.3	0.193
3.75	33.6	0.272

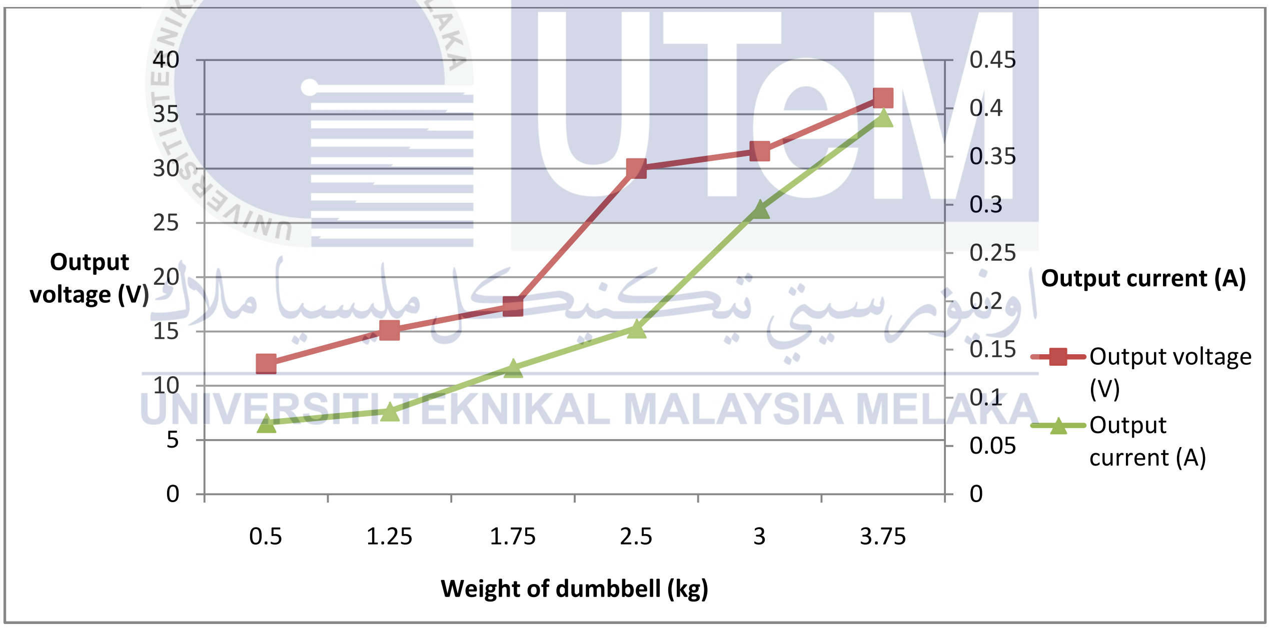


Figure 4.4 Output voltage and current of harvester base from experiment 1 when pressure applied at left side of the base

The line graph at Figure 4.4 illustrates the output voltage and current from piezoelectric energy harvester base when the load applied at the left side of the base. The value of voltage and current were increased proportionally to the weight of the dumbbell. As can be seen, the maximum value of the output current and voltage are slightly lower compared to the results when force was applied at the center of the energy harvester base.

Table 4.3 Output voltage of energy harvester base from experiment 1 when load applied at right side of the base.

Weight of the dumbbell (kg)	Output voltage (V)	Output current (A)
0.5	5.0	0.045
1.25	17.2	0.072
1.75	20.9	0.114
2.5	22.2	0.136
3.0	28.4	0.251
3.75	34.2	0.297

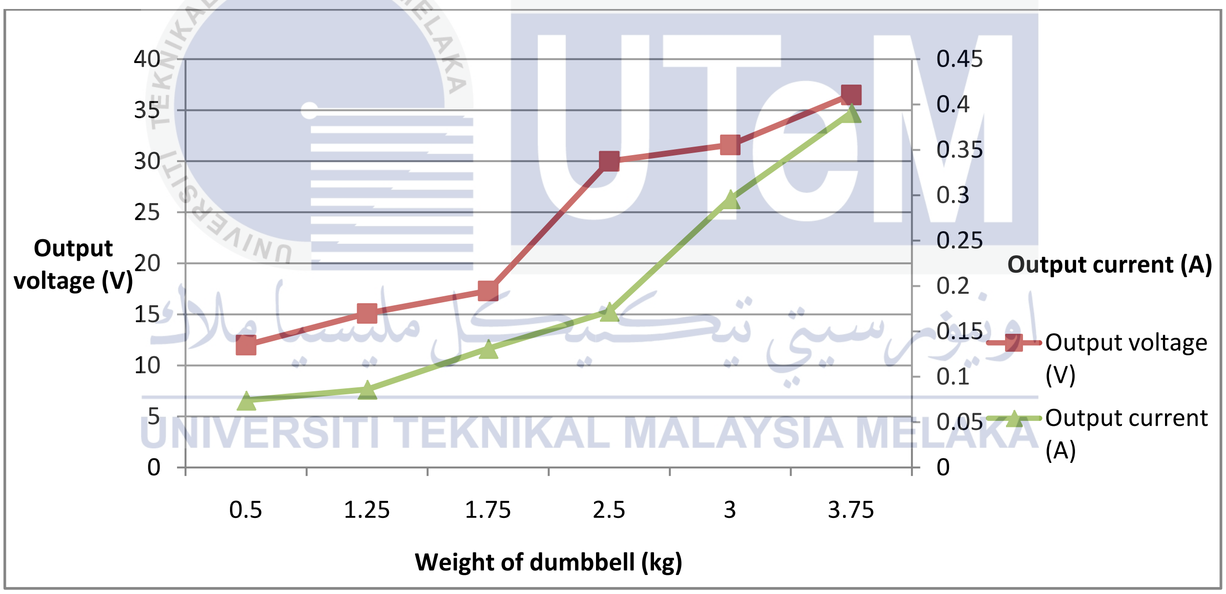


Figure 4.5 Output voltage and current of harvester base from experiment 1 when pressure applied at right side of the base

The graph in Figure 4.5 shows the value of voltage and current that piezoelectric energy harvester can produce when the force was applied at the right side of the base. The value of voltage and current were increased proportionally to the force applied to the base. As can be seen, the output voltage and current for this graph are slightly higher compared with the results when force was applied at the left of the energy harvester base.

First experiment was conducted to determine the output voltage and current from piezoelectric energy harvester when. For this experiment, the dumbbell was released at height of 4 cm and force was applied at centre, left side and right side. As can be seen from figure 4.3, the maximum output voltage and current are 36.2V and 0.372A when force was released at the centre of the base. At weight of 0.5kg to 1.25kg, the output voltage increased dramatically from 6.5V to 18.2V. This was because of the piezo disc start to bend more and covered a lot of piezo disc when received a higher pressure. The characteristic of piezoelectric material was it will produce more voltage when more force applied to it. So, it can be seen that, when weight of dumbbell was at 3.75kg, output of energy harvester base produced highest reading compared when the weight of dumbbell at 0.5kg.

From this experiment, several parameters were changed such as force was applied to the left side and right side of the energy harvester base. As can be seen from the both results of left side and right side of the base, the maximum output voltage and current were almost the same. It maximum output voltage and current was 33.6V, 0.272A for left side of the base and 34.2V and 0.297A for right side of the base. The output from the centre of the base was slightly higher when compared with output produce from the left and right side of the base. This was because when force was applied at centre of the base, it will actuate and bend more piezo disc compared with force applied at left or right side.

4.3. Result, Analysis and Discussion for Experiment 2

The experiment was conducted to measure the output voltage and current that piezoelectric energy harvester base can generate. For this experiment, it repeats the previous experiment but at height 8cm to represent as foots step from people. The results that have been recorded were shown in Table 4.4, Table 4.5 and Table 4.6.

Table 4.4 Output voltage from energy harvester base from experiment 2 when load applied at centre of the base

Weight of the dumbbell (kg)	Output voltage (V)	Output current (A)
0.5	14.2	0.087
1.25	17.9	0.092
1.75	19.3	0.132
2.5	30.5	0.193
3.0	36.5	0.242
3.75	38.7	0.421

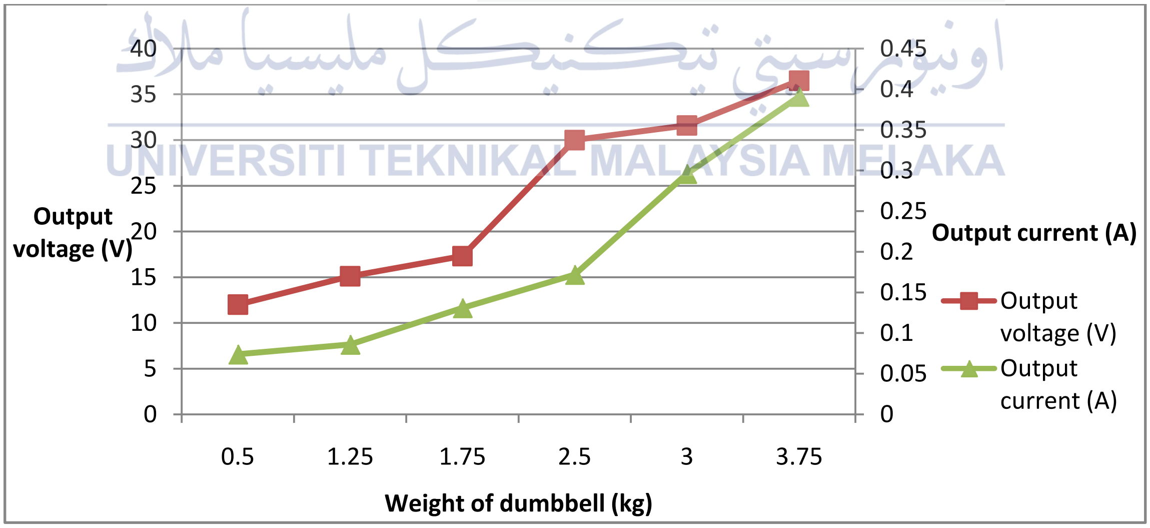


Figure 4.6 Output voltage and current of harvester base from experiment 2 when pressure applied at center of the base

The line graph in Figure 4.6 shows the output voltage and current that energy harvester base produced. As the weight of dumbbells increased, output voltage and current also increased.

Table 4.5 Output voltage from energy harvester base from experiment 2 when load applied at left of the base

Weight of the dumbbell (kg)	Output voltage (V)	Output current (A)
0.5	11.5	0.062
1.25	14.7	0.079
1.75	16.9	0.112
2.5	29.7	0.143
3.0	32.3	0.211
3.75	35.9	0.389

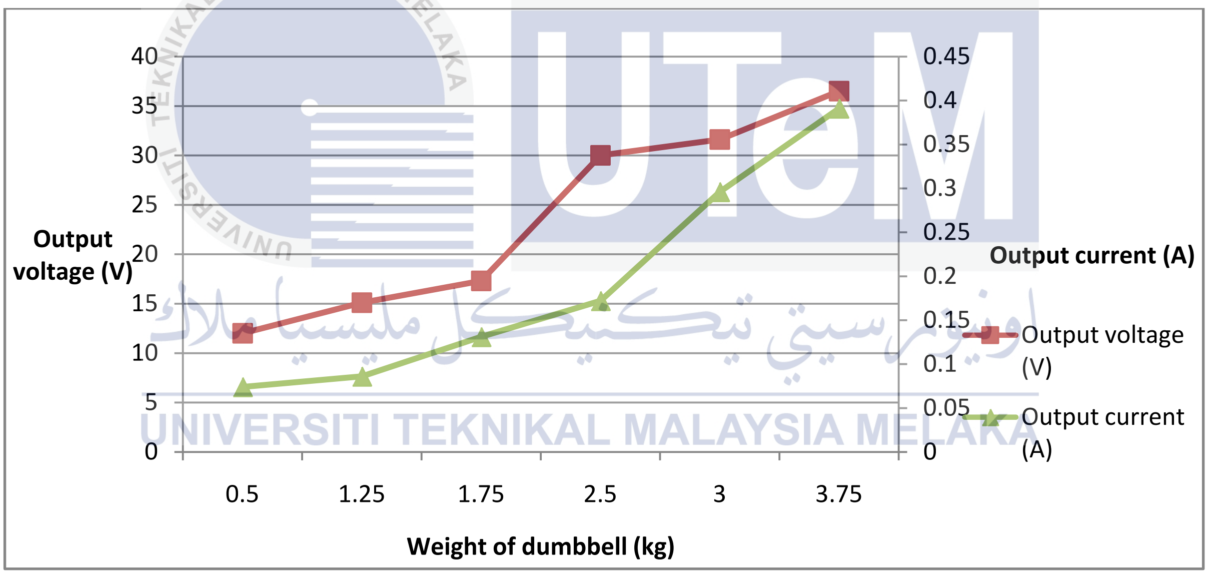


Figure 4.7 Output voltage and current of harvester base from experiment 2 when pressure applied at left side of the base

Figure 4.7 shows the line graph of voltage and current versus weight of dumbbells. As can be seen, the value of the output voltage and current was increased significantly when weight of dumbbells increased from 1.25kg to 1.75kg. After that, the value has increased steadily with proportional to the weight of dumbbells.

Table 4.6 Output voltage from energy harvester base from experiment 2 when load applied at right of the base

Weight of the dumbbell (kg)	Output voltage (V)	Output current (A)
0.5	12.0	0.074
1.25	15.1	0.086
1.75	17.3	0.131
2.5	30.0	0.172
3.0	31.6	0.296
3.75	36.5	0.391

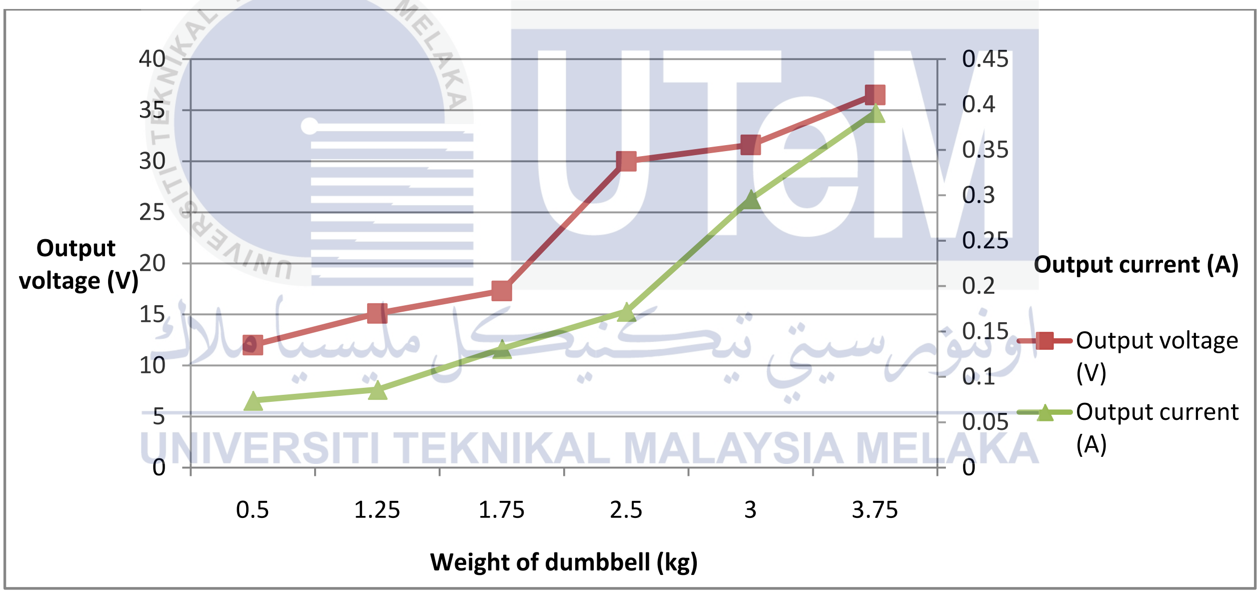


Figure 4.8 Output voltage and current of harvester base from experiment 2 when pressure applied at right side of the base

The line graph show in Figure 4.8 is the graph of output voltage and current versus weight of dumbbell. As can be seen, the output voltage was increased steadily from 12V to 17.3V. But the value increased dramatically when the weight of dumbbell was changed from 1.75kg to 2.5kg. The output current also increased but not so dramatically compared to the output voltage.

In the experiment two, the data was collected from the piezoelectric energy harvester base which the dumbbells was released at height of 8cm. For experiment two, the procedure is same as previous experiment, but the dumbbell was released at different height. As can be seen from the Table 4.4, the output voltages are 14.2V compared with the previous experiment, the output voltages are 6.5V when weight of the dumbbell at 0.5kg applied at centre of the energy harvester base. It can be seen that the difference between these two levels will affect the output voltage and current for this energy harvester. From this, it can be concluded that the weight of the person stepping on an energy harvester will affect the output voltage and current of this energy harvester.

The result of output voltage and current from Table 4.5 and 4.6 are almost the same since the arrangement of piezo disc on left side and right side of the base are same. In comparison, the output voltage and current from Table 4.4 is slightly higher compared to the output voltage and current from the Table 4.5 and 4.6. This happens because when there was a pressure in the middle of the base, many piezo discs affected and bended compared with the pressure applied to the left or right side of the base.

4.4. Summary from the experiments

Table 4.7 Summary of result from two experiments

	V max (V)			I max (A)		
Position	center	left	right	center	left	right
Experiment 1 at 4cm	36.2	33.6	34.02	0.372	0.272	0.297
Experiment 2 at 8cm	38.7	35.9	36.5	0.421	0.389	0.391

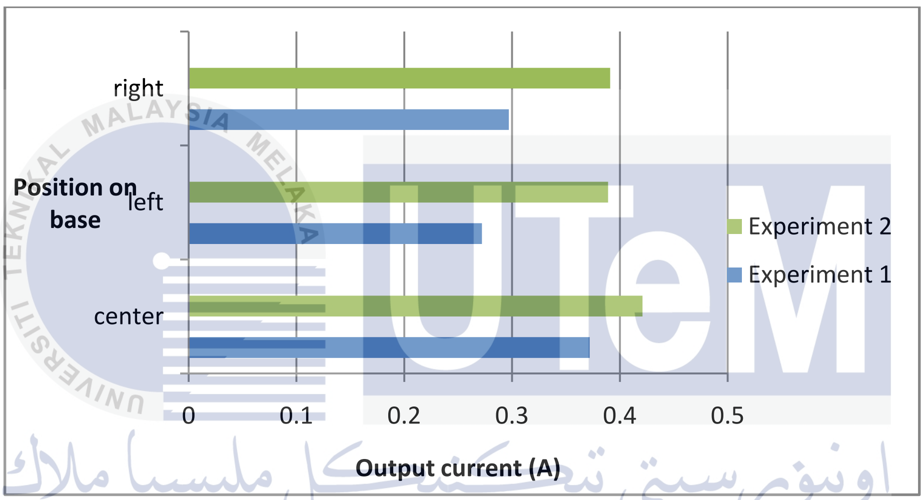


Figure 4.9 Comparison of maximum output current from two experiments

From Table 4.7, as can be seen the maximum output current is 0.421A. Highest output current that piezoelectric energy harvester base can generate is when dumbbell was released on the center of the base. From this result, it shown that this piezoelectric harvester base can generate enough amounts of currents to charge the battery.

CHAPTER 5

CONCLUSION

5.1. Conclusion

The past few decades, the idea of harvesting energy from clean energy has become increasingly popular. The improvements on technology in ability of capturing the ambient energy surrounding encourage people to study more about piezoelectric effect. Piezoelectric materials have the ability to capture the energy of pressure of the footsteps that normally wasted energy and converting it to electrical energy can be used. Output energy produced by this material is too small to directly supply the electronic system. But with high quality piezoelectric material such as bimorph element and polymer film, the output energy generated can be higher compared using traditional piezo ceramic disc material.

In conclusion, the objective has achieved and the concept of energy harvesting using piezoelectric material is presented. A model of piezoelectric energy harvester base has been developed and the reliability of this system has verified by conduct the experiments to determine the ouput volatge and current.

5.2. Recommendation

The output energy generated from piezoelectric energy harvester can be improved by using piezoelectric material such as bimorph material and polymer film. Besides that, the output power also can be improved by using piezoelectric energy harvesting power supply module. The module such as LTC3588-1 from Linear Technology integrates with a low-loss full wave bridge rectifier with a high efficiency buck converter to form a complete energy harvesting solution optimized for high output impedance energy sources such as piezoelectric transducers.

Another improvement to get the higher output power is actuator design for piezo disc. The actuator function is to actuate the piezo disc from foot step. The proper design of the actuator for piezo disc can improve the maximum power that can be generated by this piezo disc element.

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