PIEZOELECTRIC ENERGY HARVESTING MODEL FROM VIBRATION: EFFECT OF PATCH MATERIALS AND DIFFERENT SOURCE OF VIBRATIONS

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ABSTRACT

Piezoelectric devices are the device that used to convert mechanical vibration to electric energy. Numerous of study have propose related to piezoelectric energy harvesting over the past years for the implementation in this country. Malaysia has huge numerous potential for piezoelectric energy harvesting and it will be one of the reason towards green technology. However, the usage of piezoelectric as energy harvester has yet facing with the reliability and durability issues, and in addition, its working mechanism is not yet fully understood to become more essential to achieve an environment friendly harvester as well as sustainability energy generator. This research is conducted by gaining the data and the amount of energy that was harvested from vibration at certain place with different materials. On the other hand, this paper focus on the development of piezoelectric model vibration harvester using MatLab Simulink. The model development based on the transfer function for the piezoelectric sensor for Barium Titanate, Lead Zirconate Titanate and Zinc Oxide patch actuator. From the results, the highest direct current generated will be the railway vibration response. Based on the current generated data, the comparison has been made in comparison of the energy harvested using T8 Equivalent LED Tube.

Keywords: Vibration, Energy harvesting, Piezoelectric energy harvester, Piezoelectric generators

1. INTRODUCTION

Energy harvesting or also known as power harvesting is actually process whereby the obtaining energy or power from environment, then converting to electricity, and lastly storing for the other usage for electronic devices. There are few example of energy harvesting technology such as acoustic, axial-flow micro-turbine, thermal energy, mechanical vibration, wind energy, solar energy and etc. The advantage of using this type energy is to minimize or reduce the need of internal source of energy that used in daily life [1]. This is very importance for environmental friendly and can save the world for future generation. In addition, harvesting energy essentially free and having clean conversion process. This is one of the reason on energy harvesting need to be used extensively.

Piezoelectric materials constitute a well-established field of research activities with numerous practical application, such as sensor and actuators. This research is conducted to study about the total voltage, v that can be produce using a piezoelectric energy harvester with different type of materials used. There are many materials that been used in piezoelectric such Barium Titanate and Lead Zirconate Titanate. Each of this materials will produce a different voltage [2].

The energy consumption being critical issues because of the usage of electricity play an important role to make overall better in daily life. According to Malaysia Energy Statistic (2016), the average household electricity consumption in 2004 is 3,015 kWh meanwhile the average household electricity consumption in 2014 is 4,596 kWh. So the total difference in ten year is 1,581kWh [3]. In ten years the energy consumption increasing 1.5 times and it means that the bigger changes occur during that times. This energy consumption increases from year to year because of the development of technology. This increasing in energy consumption can be very polemic issue because of energy demand will be higher from year to year. The idea also indicated from the waste which is vibration from surrounding can be useful after knowing the way to utilize it. There is different type of piezoelectric patch materials such as Barium Titanate, Lead zirconate titanate, Zinc oxide, Polyvinylidene Fluoride and Potassium dihydrogen phosphate. This different type of materials will produce different voltage output [4]. The concept of Piezoelectric is to convert the kinetic energy which is vibration to electrical energy.

The present work aims to investigate different vibration sources of different piezoelectric materials. The analysis of voltage and current will be done in time space between those different materials. Several types of materials to be discussed include barium titanate, lead zirconate titanate, and zinc oxide.

2. METHODOLOGY

Computational simulation has been done using Matlab SIMULINK. Vibration data was acquired from experimental study tabulated in Table 1. Power density output was determined by the piezoelectric converter which produced at specific acceleration input. The power density output can be used to identify the suitable electronic appliances or devices. The source was classified in terms of power output as representative vibration sources used in this study.

Table 1: Vibration sources measurement

Vibration source	**Acceleration amplitude (m/s^2)**	**Frequency of peak (Hz)**
Railway	91	2372
Motor	38.36	1000
Blender	6.40	121

The mathematical model for each piezoelectric patch was based on the size of the patch, its mass, active area, the range of operating area etc. PI P-876 DuraAct transducers were used in the present work as it has fast response towards disturbances. Maslan et al. [5] had determined and validated the patch as;

$$G^{-1} = \frac{-0.04314 + 0.07153z^{-1} - 0.0284z^{-2}}{0.4795 - 1.487z^{-1} - 0.0071z^{-2}} \quad \text{Equation (1)}$$

where z is the discrete time transfer function. Note that alternate voltage is produced by piezoelectric materials under mechanical deformation. Compared to the adaptive circuit proposed by Ottman et al. [6], the non-adaptive rectifier circuit was used in the present work which harnessed more power [7]. This circuit can be utilized by mostly all electronic devices powered by direct voltage to rectify the alternate voltage from piezoelectric converter. Figure 2 illustrates the non-adaptive circuit which constitute a conventional diode bridge rectifier and a passive circuit. It was assumed that there was no voltage drop across the diodes. The capacitance, C was calculated based on the Equation (2), where *i* is the load current across the capacitor, Vp is the peak voltage of bridge rectifier output, and f is the AC supply frequency at 10 Hz.

$$C = \frac{5i}{V_p f} \quad \text{Equation (2)}$$

$$V = IR \quad \text{Equation (3)}$$

All specifications are tabulated in Table 2-4. The sensor's detail parameters were taken from previous work [5]. The operation of piezoelectric patch transducer was initiated when the patch is glued to a substrate. The force will be transferred over the patch surface. The piezoelectric patch is advantageous in terms of the fast response to changes on electric field by vibration.

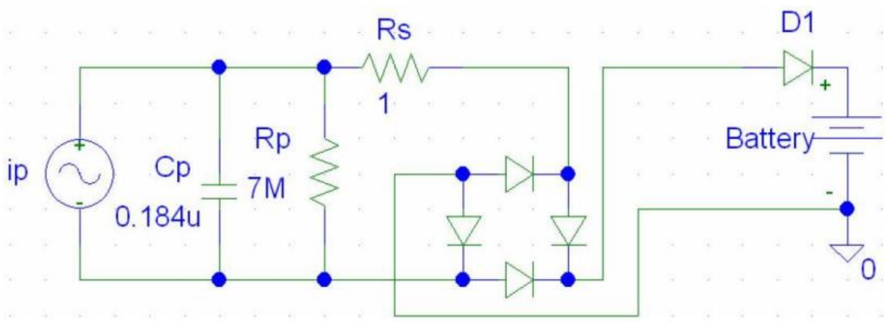

Figure 1: Non-adaptive harnessing circuit. Adapted from [7].

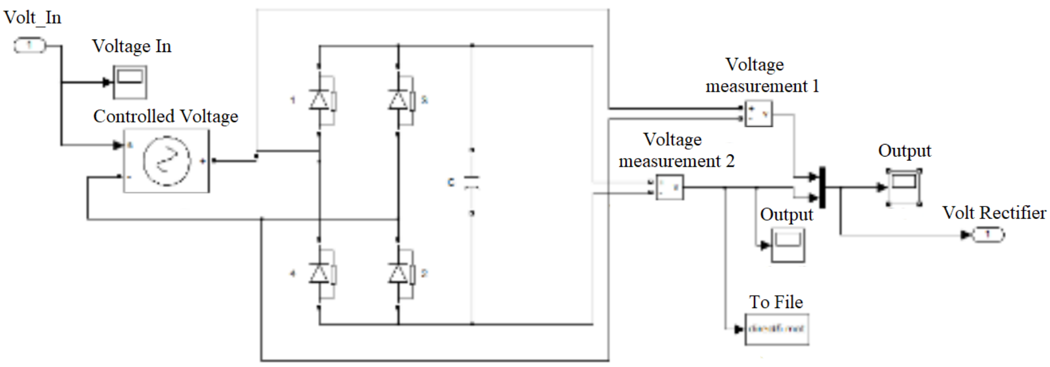

Figure 2: Non-adaptive circuit in MATLAB Simulink

Ohm's Law was used to determine the load resistance, R as per Equation (3) where V is the voltage, and I is the current. Figure 3 shows the non-adaptive harnessing circuit and piezoelectric converter process flow simulated in Matlab SIMULINK environment. Voltage input was taken from the piezoelectric converter from earlier simulation.

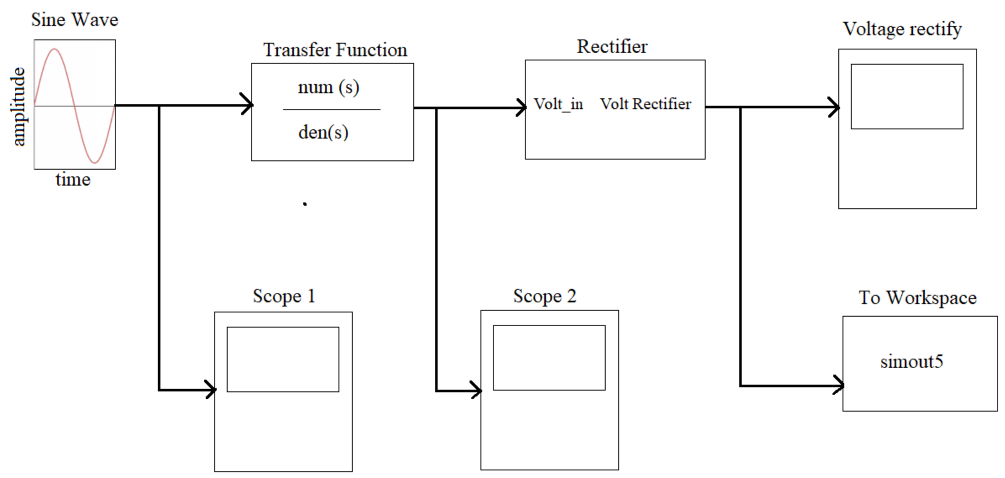

Figure 3: Matlab SIMULINK block for piezoelectric input source converter

Table 2: Parameters of Barium Titanate piezoelectric patch actuator

No	Parameters	Values
1.	Dimensions (L x W x T)	61.0 x 35.0 x 0.4 mm
2.	Mass	2.1 g
3.	Active area	15 cm^2
4.	Free lateral contraction, So	400 µm/m
5.	Lateral contraction / Voltage	1.6 (µm/m)/V
6.	Bending radius	12 mm
7.	Blocking force, FB	90 N
8.	Electrical capacitance	150 nF ±20%

Table 3: Parameters of Lead Zirconate Titanate piezoelectric patch actuator

No	Parameters	Values
1.	Dimensions (L x W x T)	60.0 x 30.0 x 0.5 mm
2.	Mass	2.5 g
3.	Active area	12 cm^2
4.	Free lateral contraction, So	350 µm/m

5.	Lateral contraction / Voltage	1.4 (µm/m)/V
6.	Bending radius	10 mm
7.	Blocking force, FB	80 N
8.	Electrical capacitance	130 nF ±20%

Table 4: Parameters of Zinc oxide piezoelectric patch actuator

No	**Parameters**	**Valu es**
1.	Dimensions (L x W x T)	30.0 x 15.0 x 0.5 mm
2.	Mass	2.8 g
3.	Active area	15 cm^2
4.	Free lateral contraction, So	380 µm/m
5.	Lateral contraction / Voltage	1.5 (µm/m)/V
6.	Bending radius	10 mm
7.	Blocking force, FB	80 N
8.	Electrical capacitance	130 nF ±20%

3. RESULTS AND DISCUSSION

Output of the system can be identified and analyzed from the developed model. Direct voltage generated from different vibration sources were recorded. Different acceleration input (m/s^2) for vibration sources was represented in Matlab SIMULINK as a sine wave input. The inputs were from railway, industrial motor, and blender casing system, respectively.

Based on the piezoelectric model developed, the result of the simulation was generated in order to show the research output of the study which is voltage. Figure 4 until Figure 12 show the output from the model of piezoelectric respectively.

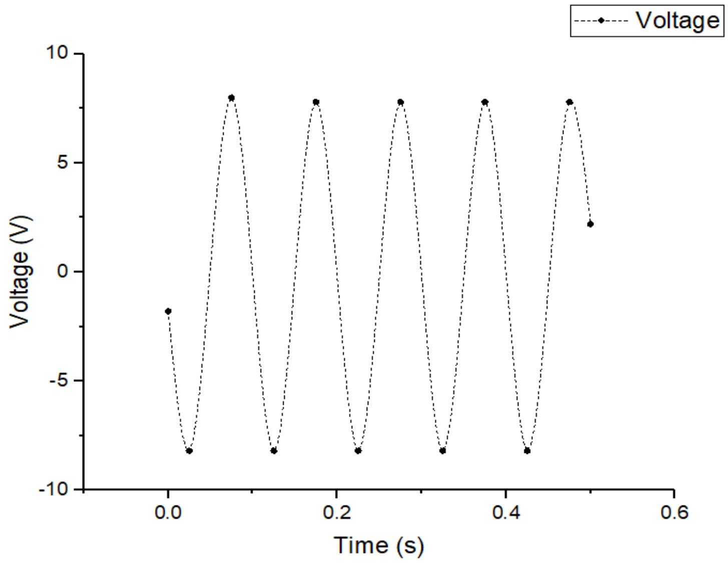

Figure 4: Voltage versus time of vibration in railway from Barium Titanate patch

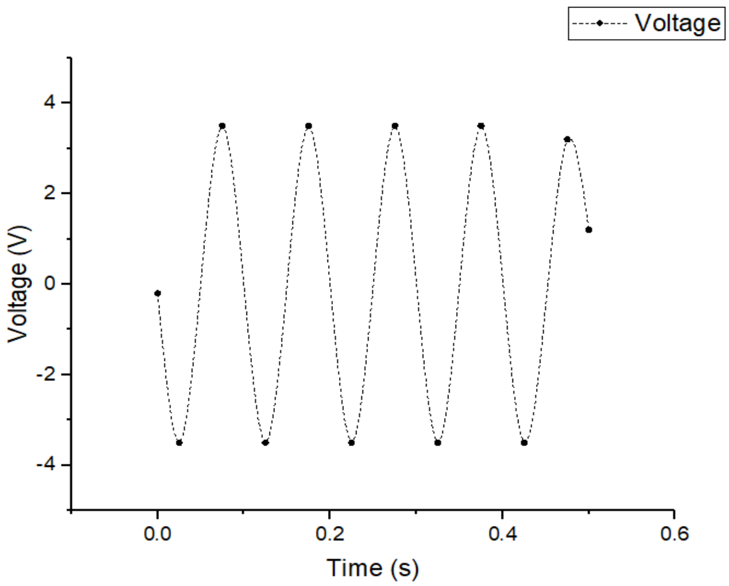

Figure 5: Voltage versus time of vibration in industrial motor from Barium Titanate patch

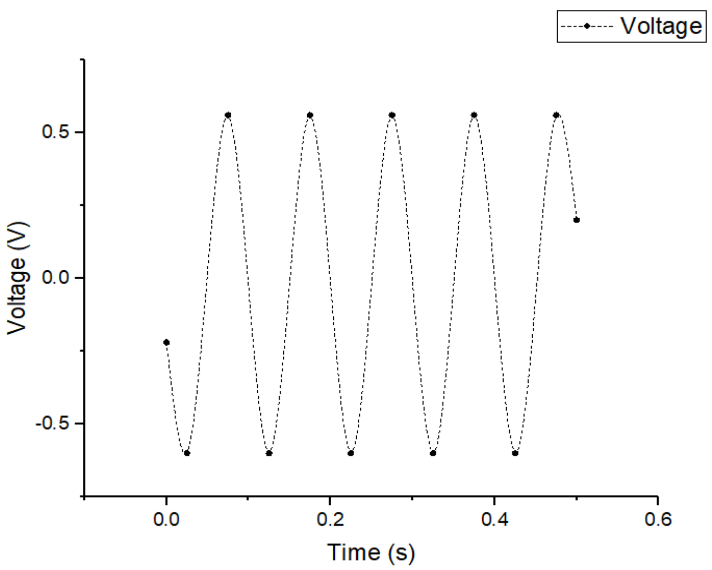

Figure 6: Voltage versus Time of vibration in blender from Barium Titanate patch

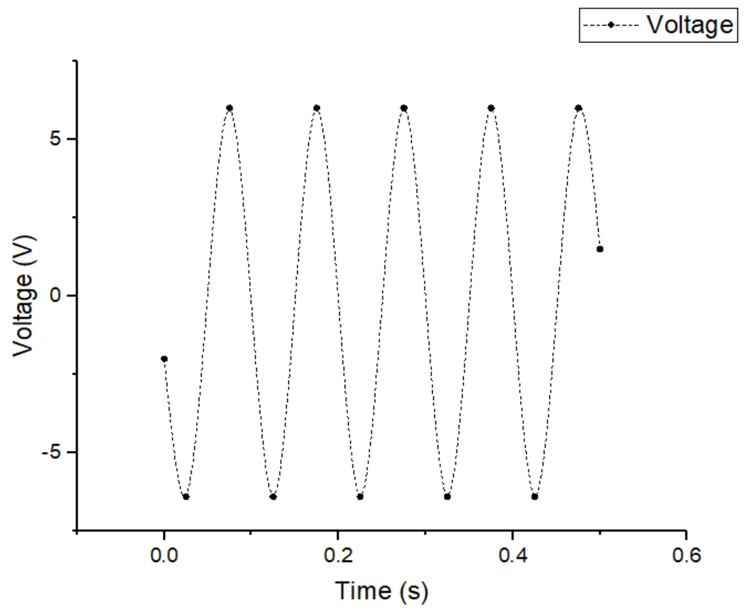

Figure 7: Voltage versus time of vibration in railway from Lead Zirconate Titanate patch

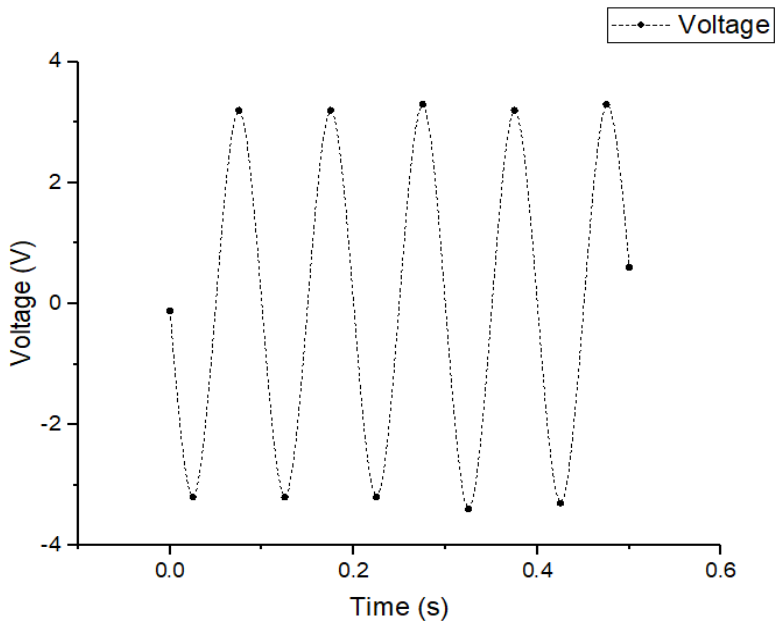

Figure 8: Voltage versus Time of vibration in industrial motor from Lead Zirconate Titanate patch

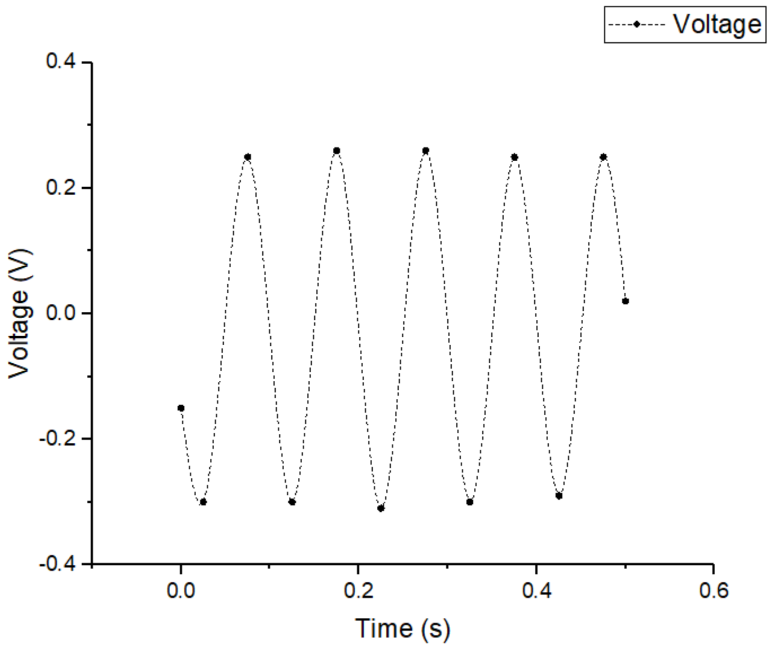

Figure 9: Voltage versus time of vibration in blender from Lead Zirconate Titanate patch

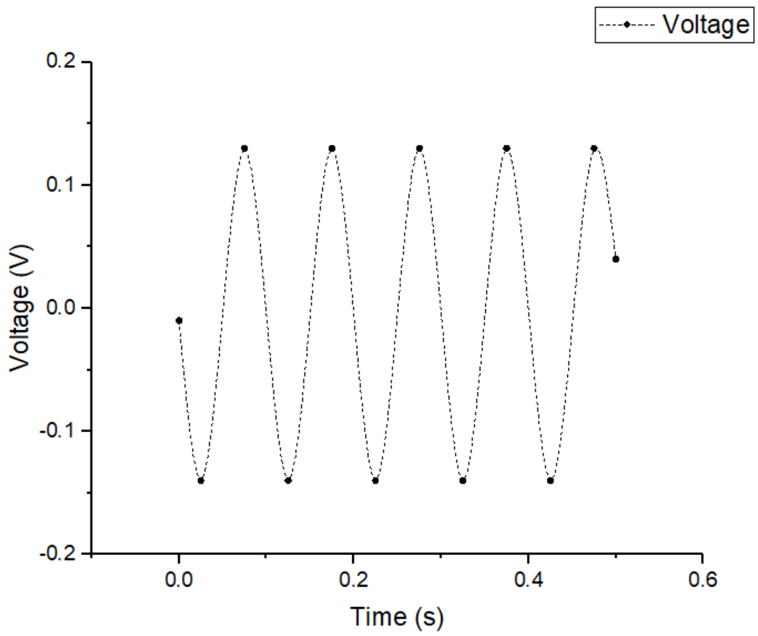

Figure 10: Voltage versus time of vibration in railway from Zinc Oxide patch

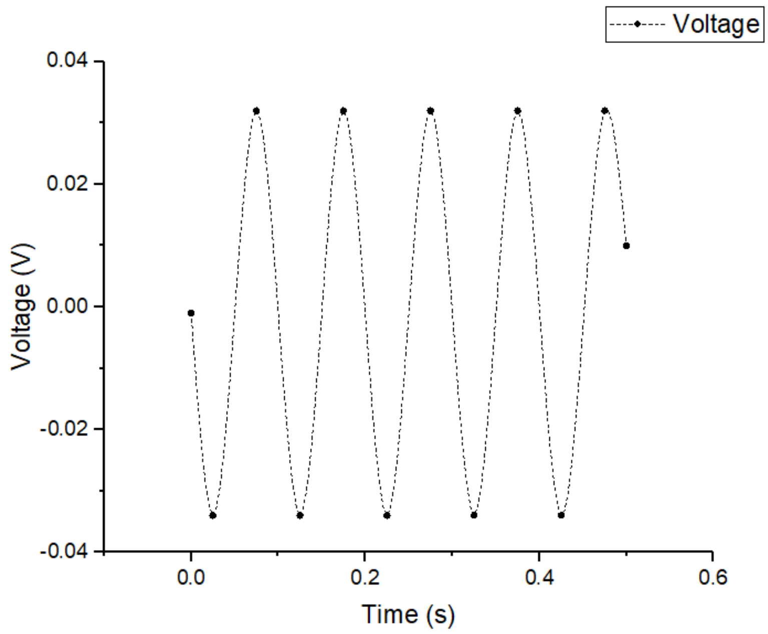

Figure 11: Voltage versus time of vibration in industrial motor from Zinc Oxide patch

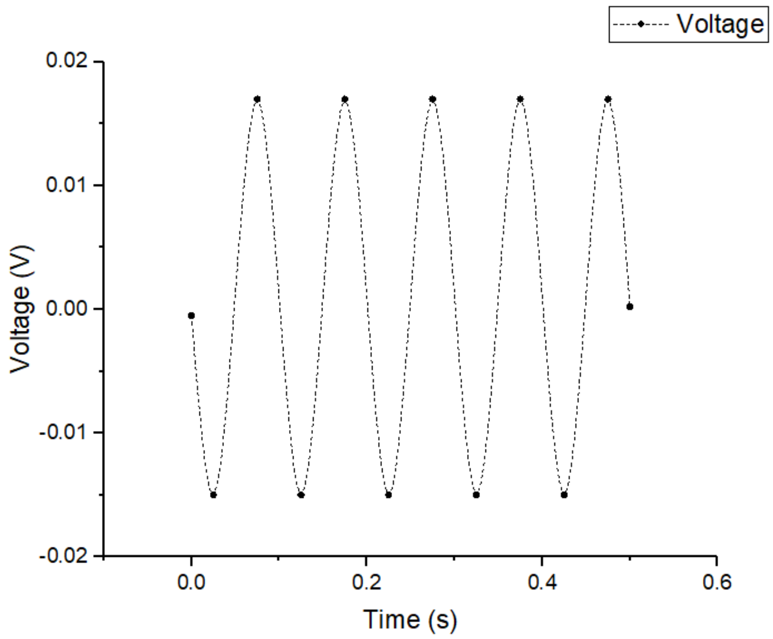

Figure 12: Voltage versus time of vibration in blender from Zinc Oxide patch

Based on the result from piezoelectric model as vibration harvester, there are a few things that should be discuss regarding this simulation. By looking at all the figure, all the line look sine a wave. This is cause by the vibration of railway, industrial motor and blender are assuming with homogenous vibration response. So, there are up and down of voltage in this process. For example, Figure 5 shows voltage versus time of vibration in industrial motor from Barium Titanate patch, there are positive voltage and negative voltage. But no all the voltage produced are the same due to difference piezoelectric response by each of vibration amplitude.

Besides that, there are different voltage (Figure 4, Figure 5 and Figure 6) produced between these three figures based on vibration modes. Voltage versus Time of vibration in railway from Barium titanate patch produced the highest voltage, Figure 9 shows the voltage versus time of vibration in industrial motor from Barium titanate patch produced the second highest and Figure 10 show voltage versus time of vibration in kitchen blender from Barium titanate patch produced the lowest voltage value. This because the railway has the highest value of acceleration vibration and kitchen blender have the lowest value of acceleration vibration According to Hanim et. al [8], the high value of acceleration vibration become the highest generation of electric.

In addition, all the three materials produced different voltage. Barium Titanate produced the highest voltage, Lead Zirconate Titanate produced the second highest voltage and Zinc Oxide produced the lowest voltage value. According to Bhang et. al. [9], when skin is wounded, endogenous electrical field (EF) is generated via trans-epithelial potential (TEP) differences at the damaged epithelial layer. Thus, this type of patch actuator is suitable to be used in medical process due to enhancement of piezoelectric capacity compare to other materials.

Additionally, the output of the study will calculate the cost saving and compared with the energy consumption of home appliance. For the home appliances that used as the variable is T8 Equivalent LED Tube. According to Ul-Haq et al. (2014), the current technology that less energy consumption of artificial lighting is LED light [10]. For makes the harvesting energy efficient, firstly the piezoelectric patch is added to 10-units. By assume the power generated from piezoelectric patch of 10-units is equivalent, it will decrease the time duration on harvesting from source of vibration. As the result, to light up the T8 Equivalent LED Tube for 1 hour by using 10-units of piezoelectric patch, it need to harvest energy from ducting system in 52 minutes only. Meanwhile, for harvesting from piping system, the time duration for harvesting energy at piping system is 13 hours and 4 minutes.

Secondly, added amplifier to the system. According to Rouse (2015), amplifier is an electronic device which can increase the voltage, current, or power of a signals [11]. Power amplifier also can be categorized as weak-signal amplifiers and power amplifiers. For weak-signal amplifiers commonly used in wireless receivers. It was designed for exceeding the small input signal from Nano-volts. Next, for power amplifiers used primarily in wireless transmitters hi-fi audio equipment and more. The importance considerations in power amplifier are power output and efficiency. In audio applications power amplifiers are about 30 to 50 percent efficient meanwhile, in wireless communication and broadcasting transmitters, efficiency range in range of 50 to 70 percent [11].

4. CONCLUSION

Based on the research that has been conducted, the followings conclusion of the findings can be drawn. First and foremost, there are three type of vibration source and three type of materials of the piezoelectric patch actuator that have been highlighted in order to identify which type of piezoelectric patch actuator will generate the largest amount of electricity. Various type of piezoelectric patch actuator has the different value of voltage.

Secondly, after the vibration from various sources of vibration were determined, the piezo model of Matlab Simulink was developed. The transfer function used for the model is based on the Discrete – Time (DT) Transfer Function system. The (DT) transfer function system is the suitable for this research based on the validation and verification by Maslan M. N. et, al. (2012). Thus, the first objective of the study was achieved.

Next will be the analysis of the result based on the model from Matlab Simulink. At this stage, the electricity generated from the difference type of piezoelectric patch actuator were shows and compared. The highest value of electricity generated is the Barium Titanate patch actuator and the lowest value electricity generated is Zinc oxide. The Barium Titanate patch actuator is the commonly used materials for piezoelectric patch actuator because it produces the highest voltage among any other materials. Thus, with the electricity generated from piezoelectric model as vibration harvester, the second objective was achieved.

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