Progress in Engineering Application and Technology Vol. 3 No. 1 (2022) 454–469

PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Footstep Power Generation Using Piezoelectric Transducers

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DOI: https://doi.org/10.30880/peat.2022.03.01.046
Received 17 January 2022; Accepted 11 April 2022; Available online 25 June 2022

Abstract: The demand for using electricity is increasing day by day and generating electricity from green resources is becoming heavy. Therefore, harvesting wasted energy is one of the methods to solve the power generation issue. The wasted energy produced in surrounding such as vibration especially in the popular area. The piezoelectric effect is about, when a certain material applied force on it, it will generate a voltage on the surface. This effect achieved free energy, no pollution issue and simple. Therefore, the purpose of this project "footstep power generation by using piezoelectric transducers" is to produce a voltage by using piezoelectric effect to power low voltage electric application or charge battery. The Material for piezoelectric is ceramic, ceramic has a strong structure and produces more voltage compared with polymer. The piezoelectric effect happens when people walk or step on the tiles that installed the piezoelectric disc. Piezoelectric disc deform and generate electric, for stable the electric generated, AC-to-DC is required. Full-wave bridge rectifier converts voltage from positive and negative cycle to DC, since the output is DC voltage, it able to supply low DC electric application or charge battery. The number and connection of piezoelectric transducers respond to output voltage, the greater number of piezoelectric transducers the greater the output voltage produced. And proven 150 steps on the piezoelectric tiles charged 0.30 v to 12 V 7.2 Ah battery by using this technique. The voltage stored in the battery is DC voltage. An inverter is used to invert DC voltage from battery to AC voltage. The DC-to-AC inverter of this project uses IC SG3526A, SG3526A produce 50 hz signal to feed MOSFET and amplify voltage from 12 V to 240 V by using center tapped transformer. the performance of inverter is successfully applied to below 60 W electric application, with adding MOSFET and replace the transformer with 12 V 10 A is possible to supply to 120 W maximum.

Keywords: Piezoelectric Transducers, Electricity, Footstep Power Generation

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1. Introduction

Electricity is one of the common energies used energy resources. In Malaysia, the energy demand is increasing. However, electricity can be generated from green resources such as wind, ocean, and solar, these facilities require a massive facility to install. In addition, due to the increasing population of people, the usage of electricity increased. Therefore, fossil fuel is taken to generate electricity, especially in Malaysia. Electricity generation by using fossil fuels increased from 1995 to 2017 in Malaysia [1]. Fossil fuel is a natural resource to generate electricity efficiently, easily found and limited source on earth. Fossil fuels contribute to greenhouse gases, it causes air pollution to the environment and affects the health of humans [2]. The method for decreasing and resolving energy difficulties is ambient energy gathering. It includes numerous ways for harvesting and recycling waste energy from the environment [3]. Vibration, heat, wind, and other forms of energy are all around us. They are a form of waste energy that may be recycled and converted into electrical energy. As a result of mechanical stress, certain materials create electric charges on their surfaces [4] and achieved convert mechanical energy into electric energy [5]. That is the direct piezoelectric effect from the piezoelectric effect. The direct piezoelectric effect is, the material is polarized and produces voltage under an applied tensile or compressive stress [6]. The connection of piezoelectric transducers and piezoelectric materials will affect the output voltage. Piezoelectric transducer with PZT material has good piezoelectric properties and produces voltage more than polyvinylidene fluoride [7,8], piezoelectric transducers with series connection increasing voltage output [9]. This effect achieved free energy and no pollution issue [10]. Therefore, the purpose of this project “footstep power generation by using piezoelectric transducers” is to produce a voltage by using the piezoelectric effect to power low voltage electric applications or charge batteries.

2. Methodology

Figure 1 shows the overview of the methodology flowchart starting from the beginning to the end, this is major steps needed to be followed in order to run the project smoothly. First, beginning with search and data collection from literature reviews that related to piezoelectric energy harvesting, to find out the reason and technique taken by the researcher. Next choosing the right material for this project, the material of piezoelectric transducer responds to output voltage produced. After that, design and simulate the circuit by using proteus ensure circuit is works. Then design structure piezoelectric tiles via AutoCAD. Next, to validate the prototype via real hardware experiment and collecting the data outcome from this prototype.

Figure 1: Methodology flowchart

2.1 Block diagram

Piezoelectric transducers produced electrical when it was been pressed, which is piezoelectric effect, it converts mechanical energy to electrical energy. The generated electrical of the piezoelectric transducer is in Ac. Thus, an Ac signal can be obtained. Getting Dc voltage requires Ac to Dc converter such as a full-wave rectifier, to rectify and filter voltage before storing to the battery (storage devices). The Dc signal obtained from the rectifier (Ac to Dc converter) is supplied to Dc-to-Dc boost converter. The Dc-to-Dc boost converter is used to step up voltage before applying it to storage devices. DC-to-DC converter connect with storage device will cause reverse voltage to happen, for this purpose, the diode is used to block the reverse voltage flow from the battery to Dc-to-Dc converter. The generated voltage is charged to storage devices, for using generated voltage in Ac electrical applications requires Dc to Ac inverter which inverts Dc voltage to Ac voltage. Flowchart of this project is show in the Figure 2.

PIEZOELECTRIC TILES

AC-TO-DC CONVERTER

DC-TO-DC CONVERTER

VOLTAGE REGULARTOR

STORAGE DEVICES

DC-TO-AC INVERTER

Figure 2: Block diagram of proposed system

2.2 Software

The software is chosen for design feature of the project and simulate circuit for this project such as Proteus design suite and AutoCAD. Proteus design suite is used to simulate the prototype and AutoCAD is used to design the structure of the piezoelectric tiles.

2.2.1 Proteus design suite

Proteus 8 is a simulation and design software tool for electrical and electronic circuit design created by Labcenter Electronics. The initial version of the proteus design suite was dubbed PC-B, and it was built for DOS in 1988 by the company's chairman, John Jameson. After several of updated, proteus 8 become a proven simulator for circuit design. Figure 2 show logo of Proteus Design Suite

Figure 2: Proteus Design Suite

2.2.2 AutoCAD

AutoCAD is a commercial computer-aided design (CAD) and drafting software application. Developed and marketed by Autodesk, AutoCAD was first released in December 1982. After several updated, it able to draw object in 3D, this is the reason AutoCAD is chosen. Figure 3 show logo of AutoCAD.

Figure 3: AutoCAD

2.3 Piezoelectric Tiles Design

The project designed by using AutoCAD, the isometric, front, and top view are show in the Figure 4, Figure 5, and Figure 6. The dimension of this piezoelectric tiles is 36cm*36cm*10cm.

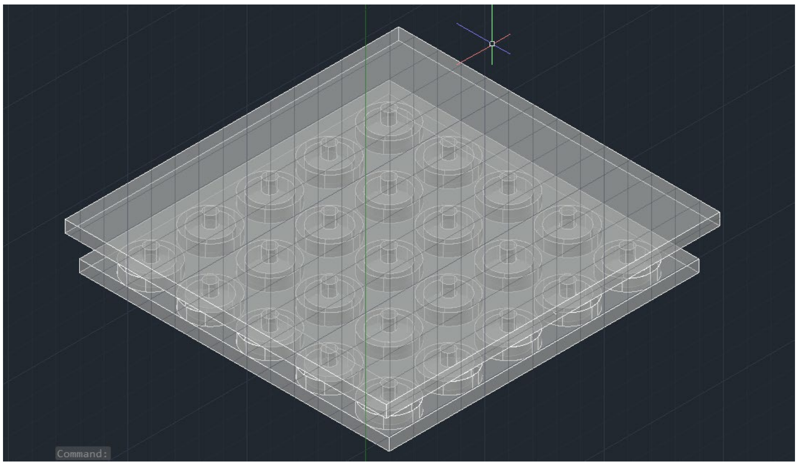

Figure 4: Isometric View of Project

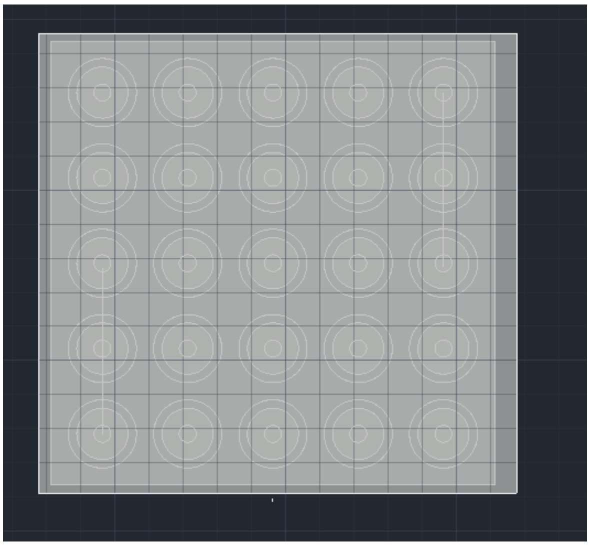

Figure 5: Top View of Project

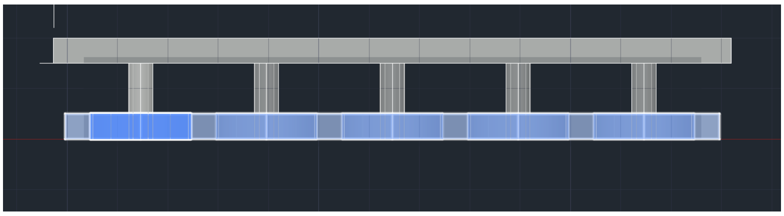

Figure 6: Side View of Project

3. Results and discussion

The piezoelectric transducer produces voltage depending on the force applied to it, which means voltage produced by piezoelectric transducer is unstable. To find out voltage produce on each step or press on piezoelectric transducers by measuring multimeter and the result is show in Table 1. Base on result shown in Table 1, average voltage produced by single piezoelectric transducer is around 10 V.

Table 1: voltage produce on each step or press on single piezoelectric transducers by measuring multimeter

Number of impacts	Generate voltage (V)	
	Positive	Negative
1	8.9	-8.59
2	12.00	-10.35
3	9.81	-8.51
4	10.15	-10.22
5	12.59	-9.32
6	11.00	-12.21
Average	10.74	-9.87

3.1 AC-to-DC converter

The schematic circuit of Full wave bridge rectifier and voltage doubler are shown in Figure 7 and figure 8 respectively. The experiment was carried out from one impact until ten times impact. Table 2 shown output voltage through full-wave bridge rectifier and voltage multiplier respectively.

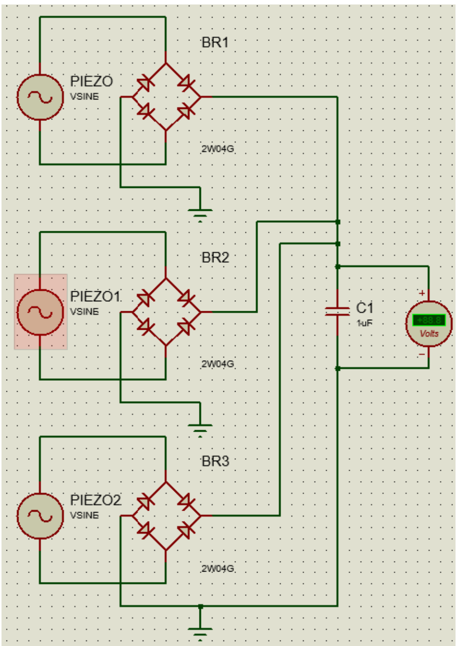

Figure 7: Schematic Circuit of Full-wave bridge rectifier

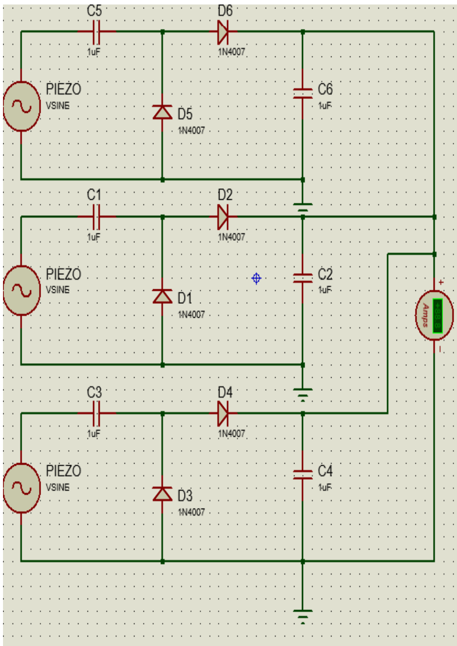

Figure 8: Schematic Circuit of voltage doubler

Table 2: Output voltage through full-wave bridge rectifier and voltage multiplier respectively

	Voltage(V)	
Number of impacts	Full-wave bridge rectifier	Voltage multiplier
1	5.32	5.20
2	7.52	7.50
3	10.20	10
4	13.23	13.20
5	16.55	15.20
6	18.30	17.11
7	21.80	20.30
8	25.60	23.80
9	28.20	25
10	30.3	28.2

Base on the result shown in table 2, piezoelectric transducers received more impacts, increasing the more voltage in the capacitor. Both converters produce high DC voltage output from a low AC voltage input. However, after the 5th number of impacts, the Full-wave bridge rectifier produced a higher output voltage than the voltage doubler.

3.2 Connection of piezoelectric transducers

Using the experiment, determine which connection of piezoelectric transducers gives the highest voltage. The voltage and current produced by piezoelectric transducers are measured by using a multimeter and recorded. And simulate piezoelectric transducer by using proteus. The result is show in Table 3 and Schematic circuit using full wave rectifier show in Figure 9.

Table 3: Result of connection of piezoelectric transducers

		voltage (V)		current (A)	
no of units	combination	simulation	measured value	simulation	measured value
		Single Step			

30	25 in series and 5 in parallel	233	245	0.25mA	0.317ma
30	20 in series and 10 in parallel	178	182	0.500mA	0.640ma
30	15 in series and 15 in parallel	141	152	0.75mA	0.800ma
30	10 in series and 20 in parallel	94	105	1mA	1.0mA
30	5 in series and 25 in parallel	49	75	1.25mA	1.300mA
30	30 in series	280	283	0.050mA	0.051mA
30	30 in parallel	25	10	1.51mA	1.712mA

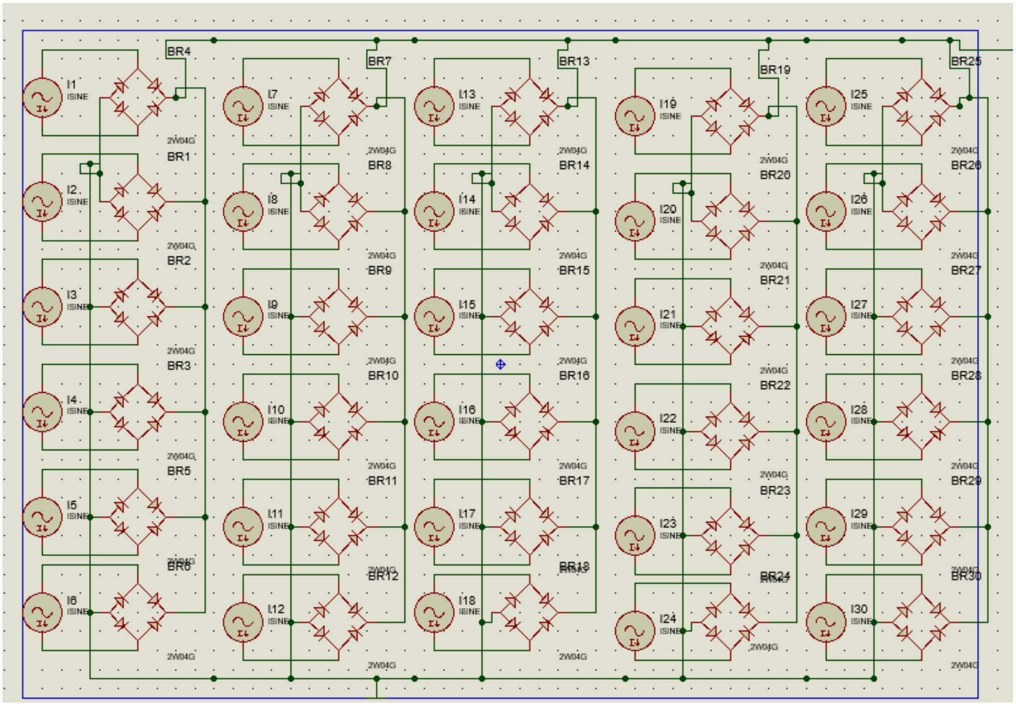

Figure 9: Schematic circuit using full wave rectifier

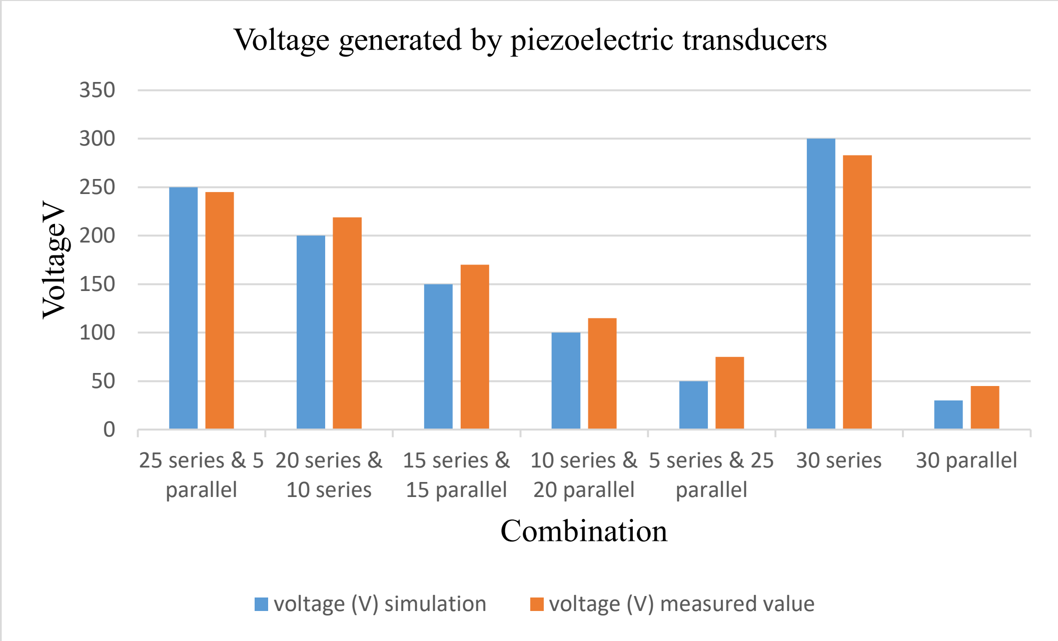

Figure 10: Compare the value of measured value and simulation value of voltage generated by piezoelectric transducers

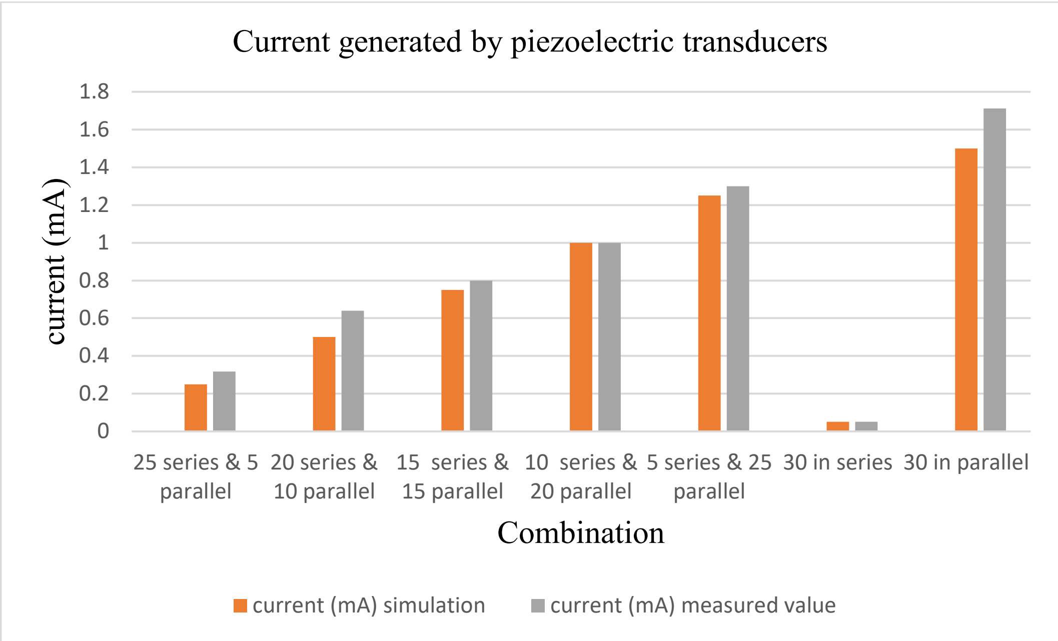

Figure 11: Compare the value of measured value and simulation value of current generated by piezoelectric transducers

Bases on data Table 3, Figure 10 and Figure 11. The results 30 units piezoelectric transducers, connecting 30 units in series connection created 300 V but only 0.051 mA; as current is the primary source of joules, the parallel connection is required to enhance current in piezoelectric transducers. Therefore, 30 units of piezoelectric transducer connected in parallel connection is chosen for this project.

3.3 Dc-To-DC converter

DC-to-DC converter performed to boost voltage from 3.0 V to 73.5 V. Figure 7 shown the DC-to-DC boost converter performance. The voltage input given is 3.7 V from battery and the measured voltage is 72.5 V (maximum). The MOSFET used are IRF540 which is N-channel MOSFET with the maximum voltage that can be applied between the drain and source while gate and source are short circuit is 100.0 V. 555 timer is used to oscillate a PWM signal to apply at the MOSFET and boost the voltage. The output voltage is not fixed to the desired voltage and can changes if the input voltage is changed because the output load has no feedback. The performance of Dc-to-Dc converter by using NE555 is shown in figure 12. Performance of XL6009 is similar to NE555 timer, but it only boosts voltage from 5V to 40.0 V and performance of XL6009 module is show in Figure 13. And NE555 timer of DC-to-DC is chosen for this project.

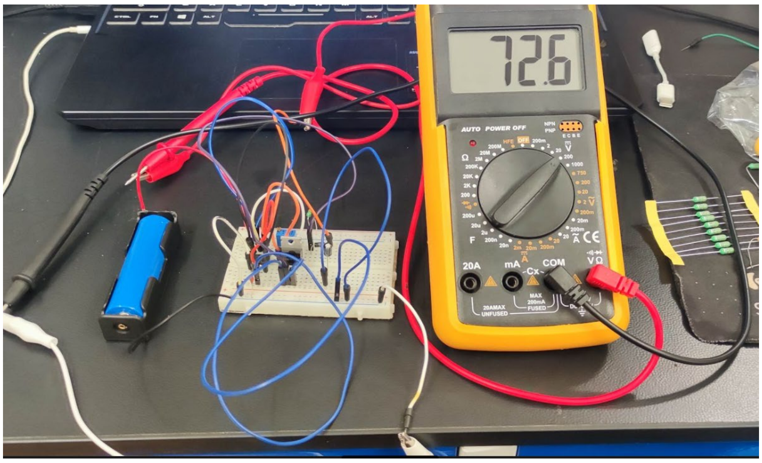

Figure 12: performance of Dc-to-Dc converter by using NE555

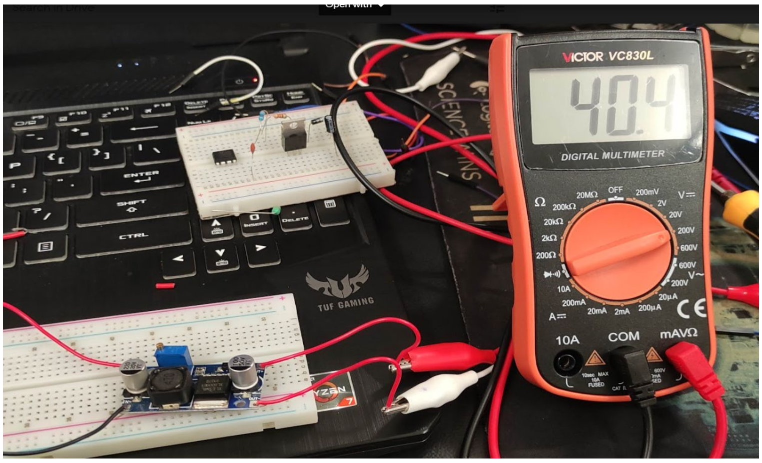

Figure 13: performance of XL6009 module

3.4 The voltage regulator

The voltage regulator was designed for a 12.0 V rechargeable battery so that it could receive an appropriate voltage throughout the charging process. The capacitor is essential to ensure the regulator's stability. The performance of voltage regulator is shown in Figure 14.

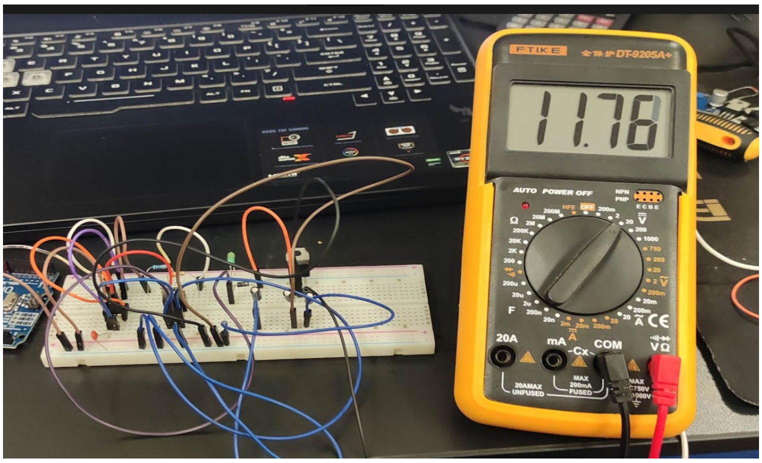

Figure 14: Performance of voltage regulator

3.5 DC-to-AC inverter

The purpose of a DC-to-AC inverter is to convert the voltage stored in the battery to AC voltage, which is a sine wave. The result of inverter is shown in figure 15 by measuring multimeter. Furthermore, most electrical items or equipment built in Malaysia operate at 220 volts and 50/60 Hz, the inverter used to provide electricity to them should operate at 50 to 60 Hz. The performance of this inverter was tested by connecting it to various electrical applications and result is show in Table 4.

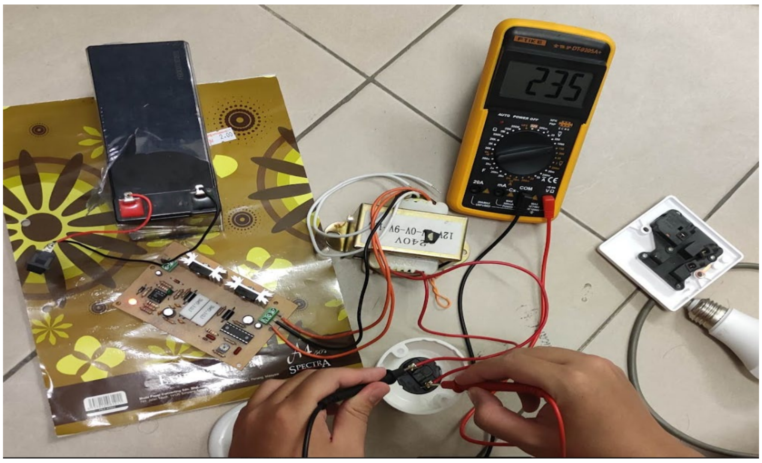

Figure 15: Measure the output inverter

Table 4: Test performance of inverter with connecting to different electrical application

Subject	State
Led light (18 W,50/60 hz)	Working
Phone charger (20 W, 50/60 hz)	Working
Lamp (25 W, 50/60 hz)	Working
Table fan (60 W, 50/60 hz)	Working
Soldering iron (60 W, 50/60 hz)	Working
Pedestal Fan (80 W, 50/60 hz)	Not working

According to Table 4, this inverter does not function with an 80 W pedestal fan. Based on the P=IV formula calculation, the transformer employed in this inverter is 12 V 5A, with a maximum performance of 60 W. Adjust the transformer to 12 V and 10 A if more than 60 W of electrical power is required.

3.6 The performance of footstep power generation

Test performance of footstep power generation to charge 12 V 7.2 Ah battery recorded voltage after 150 steps on piezoelectric tiles and pass 5 tests to obtain more accurate data. The result is shown in Table 5.

Table 5: performance of footstep power generation

No	Voltage charged to battery
1	0.30
2	0.32
3	0.29
4	0.30
5	0.31
Average voltage 0.30 V	

3.7 Prototype

Figure 16, Figure 17, and Figure 18 shows the different view of piezoelectric tiles. Thirty units of piezoelectric transducers are placed in between the upper and lower of this tile. The material chosen for this tile is wood plywood, which is good in strong and enduring structure and designed in square shape. The dimension of tile is 36cm*36cm*10cm. This tile is screwed at its 4 edges and combined with a spring to bounce back the upper wood plate to the normal condition after a person step on it. In figure 14 and 15 show the schematic circuit of this project and Figure 16 show the complete prototype of this project.

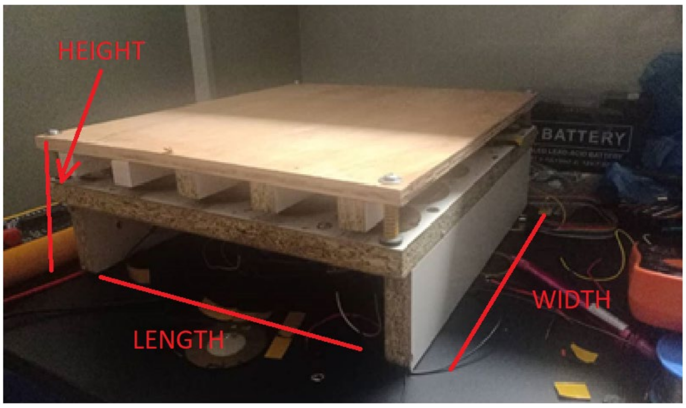

Figure 16: Isometric views of piezoelectric tiles

Figure 17: Top views of piezoelectric tiles

Figure 18: Front views of piezoelectric tiles

3.8 Discussion

This project has proved that the connection of piezoelectric transducers responds to the output voltage produced. Based on data Table 3, 30 units piezoelectric transducers in series connection will increase the output voltage but the current remains but in parallel connection will increase output current and voltage remain. Getting Dc voltage requires AC to DC converter to rectify and filter voltage before storing to the battery. 2 types of AC-to-DC converters tested in this project, which are Full-wave bridge rectifier and voltage doubler and result is shown in table 2. Piezoelectric transducers connected with the Full-wave bridge rectifier is produced more output voltage compared with the voltage doubler so the Full-wave bridge rectifier is chosen for this project. The Dc signal obtained from the rectifier (AC-to-DC converter) is supplied to the DC-to-DC converter. DC converter tested in this project which is NE555 and XL6009, performance of NE555 is better than XL6009 which is capable boost 5.0 V to 72.6 V and XL6009 only 5.0 V to 40. V. LM7812 voltage regulator was designed for a 12.0 V rechargeable battery so that it could receive an appropriate voltage throughout the charging process and 1N5406 diode connected in output pin of a voltage regulator, 1N5406 diode treat as a blocking diode to prevent reverse voltage and damage the circuit. The performance of this project is 150 steps on the piezoelectric tiles charged 0.3 V to 12.0 V 7.2Ah battery by using this technique. The voltage stored in the battery is DC voltage, unable to apply to AC electric application. Getting AC voltage requires a DC-to-AC inverter. The DC-to-AC inverter of this project uses IC SG3526A, SG3526A to produce a 50 hz signal to feed MOSFET and amplify voltage from 12.0 V to 240V by using a center-tapped transformer. The inverter is successfully applied to below 60 W electric application, with adding MOSFET and replace the transformer with 12.0 V 10 A is possible to supply to 120 W maximum. In Figure 19, Figure 20 and Figure 21 show the full prototype schematic circuit. And complete prototype of this project is show in Figure 22.

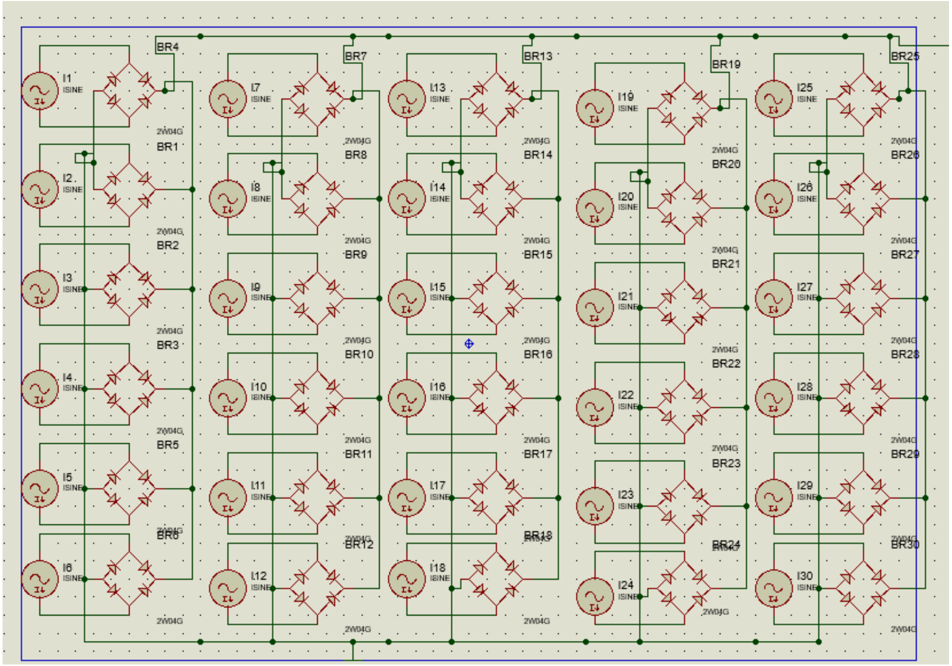

Figure 19: Full prototype schematic circuit part 1

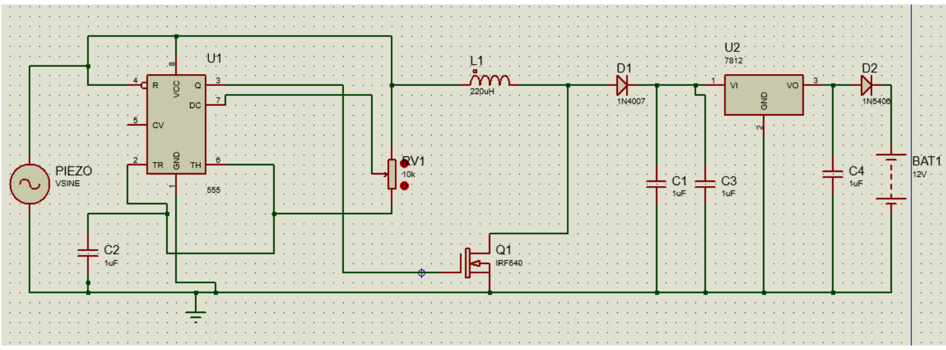

Figure 20: Full prototype schematic circuit part 2

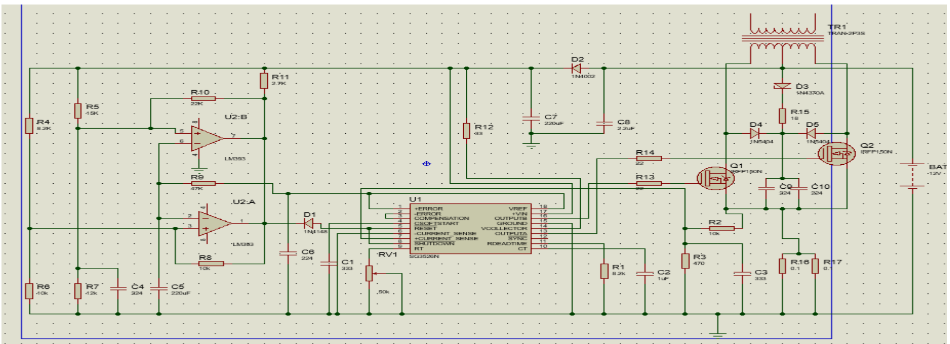

Figure 21: Full prototype schematic circuit part 3

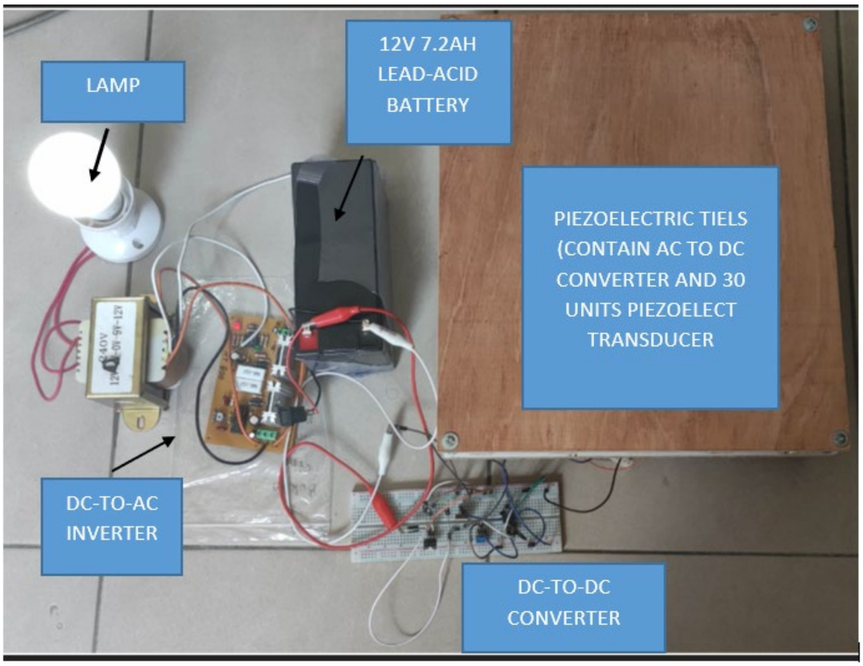

Figure 22: complete prototype of this project

4. Conclusion

The purpose of this project is to develop an energy renewable source through piezoelectric transducers, harvest waste energy from vibration or pressure by human walking, and convert mechanical energy into electrical energy. And this project proves that the wasted energy can be harvested to generate electricity.

Research limitation of this project, voltage produced by using this technique is not constant. Although piezoelectric transducers are high output impedance, producing relatively high output voltage at low electrical current and rather large mechanical impedance but the main source to increase efficiency of charging battery is current.

Future recommendation work for this project, increase units of piezoelectric transducers and in parallel connection. Material of piezoelectric, the resonant resistor will affect piezoelectric transducers produces voltage. The less resonant resistor of piezoelectric transducers, the more electric generated.

In conclusion, the piezoelectric effect is not a dependable source for charging the battery or harvesting energy, but for applications in low voltage electronic devices is available. And The number and connection of piezoelectric transducers respond to output voltage, the greater number of piezoelectric transducers the greater the output voltage produced. Therefore, the number of piezoelectric transducers and piezoelectric materials will affect the output voltage.

Acknowledgement

The authors would like to thank Faculty of Engineering Technology, Faculty of Engineering Technology for its support.

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