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Research paper

Modelling And Analysis Road Energy Harvester Using Piezoelectric Tranducer

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Abstract

This paper describes the design of energy harvester from the road using piezoelectric transducer for creating a clean energy source without disturbing any existing ecosystem. The clean energy source is not only able to sustain the well-being of the environment, but is also recognized as a renewable energy source comparable to the energy sources generated by solar energy, wind, biomass and others. This study is intended to answer the fundamental question for design energy harvesters using Proteus Software. In this paper, the piezoelectric sensors are used as a key element in generating electricity. Piezoelectric sensors that conduct for converting kinetic energy to electricity have placed vibrations from the movement of vehicles and humans as the main focus of the project. Simulation by Proteus Software is used to determine the best circuit connection for converting an alternative current (AC) to direct current (DC). Comparison of voltage doubler and rectifier circuit is applied to obtain better voltage output. Furthermore, designing a model that required the road energy harvesting characteristics is implemented to validate the analysis of two different sources which are vehicle and walking people vibration. As a result, an output voltage produce by 4 Series 2 Parallel circuit connection for voltage doubler is selected with contribute 6.634 V at maximum setting frequency.

Keywords: *Energy harvester; Vibration; Piezoelectric; Voltage doubler; Rectifier*

1. Introduction

Generating electricity through natural resources such as wind, solar, biomass, geothermal and tidal wave are often the main focus of many researchers. This is because energy generation through this renewable energy source not only guarantees a safe ecosystem, but it can also be used for a long time. However, there are other nonconventional means of electricity generation which depends neither on conventional source nor renewable source. Energy production for this method is not only capable of reducing the future electricity crisis, but it is the quest to develop new technologies at a cost-effective way to generate electricity. By recover the on the waste energy, a significant amount of the energy can be generating. For example, designing electricity toward the vehicle. In fact, only a small part of energy from the on-board source of vehicles is used for driving, while most of the energy dissipating during vibrations and motions [1]. This because most of the kinetic energy will be wasted as heat when the passes over a speed breaker [2]. From this case, the wasted energy can be used for electricity generation. So, when fully vibration of the vehicle can be absorbing and reused, it can helpful to improve the energy produce. This paper has been focusing on kinetic energy of vehicle is selected as an energy harvester to generate power. The technique for harvesting the vibration of the vehicle via piezoelectric sensor. Basically, when the force and pressure has been exerted on the elastic piezoelectric material, it can make the piezoelectric crystal to deformed and develop the charge between them [2]. In recent year, an analysis toward the energy harvester from road has been done by applying the rotating gear [1]. An electricity is utilize by kinetic energy of moving vehicle over speed breaker. However, the piezoelectric sensor in this study has replaced as important part for collect energy from vibration of the vehicle during the impact. In this paper will discuss the circular piezoelectric with two different level of resonance frequency, investigate the performance of both circular piezoelectric in term of voltage and choose the suitable piezoelectric regarding to different weight of the load applied. The variety of frequency also will be considered in this project.

2. Methodology

For designing the energy harvester from road by piezoelectric sensor, there are some major equipment that must be consider. So, **Fig. 1** shows the power conversion circuit that can be need to consider in order to generate an electricity from the road.



Fig. 1: Power Conversion Circuit Design [17, 19]

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2.1. Rectifier Circuit

Rectifier circuit can be justified as main function for convert alternating current (AC) to direct current (DC). **Fig. 2** shows a rectifier circuit drawn by Proteus Professional 8 Software. An AC source is representing the piezoelectric sensor. There are four kind of circuit connection which is series, parallel, 2 series 4 parallel and 4 series 2 parallel connection is simulated. In this case, each of piezoelectric sensor contribute own bridge diode circuit. A bridge circuit is required to convert the AC periodically reverse direction to one direction which is DC.

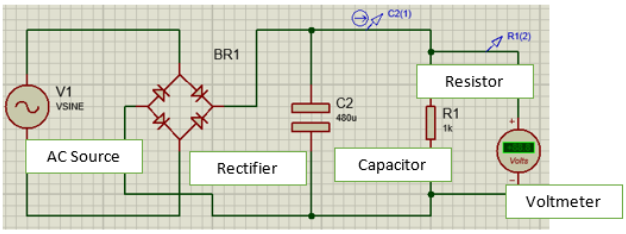


Fig. 2: Rectifier circuit in Proteus Professional 8 Software.

2.2 Voltage Doubler Circuit

A voltage doubler circuit is voltage multiplier which has a voltage multiplication factor of two that consists of two diodes. In theory, it would produce output voltage that is twice the input voltage. An example of voltage doubler is shown in **Fig. 3**. The function of voltage doubler is same with rectifier circuit which is converting an AC supply to DC source. However, the DC output that generated by voltage doubler is higher than rectifier circuit. To construct this voltage doubler circuit, there are need two capacitor and diode which are connect in series connection for each other. According to **Fig. 3** capacitor one (C1) is trigger when positive cycle of AC is operated, while another capacitor (C2) is trigger when negative cycle of AC is operated. As a result, the twice output from input voltage can be generated.

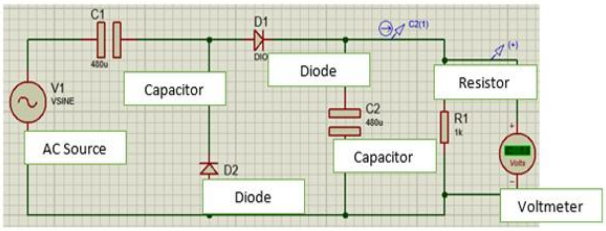


Fig. 3: Voltage Doubler circuit in Proteus Professional 8 Software.

2.3 Modelling the Base of Test Bench

The size of bench test is determined by the distance between the motor driver and plastic wheel. The 15cm radius of cake plate is select as the upper base for the prototype to hold the 4 wheels. Hence, 14cm distance between motor and wheel is chosen because of the limitation space of the plate sizing. Making the base for the test bench in rounded is to allow the simulation of vehicle shaking by the wheel to be implemented. From that, the base sizing for 15cm radius with a 4cm thickness is selected for holding 8 piezoelectric sensors. The position of the base in the middle of the driver's motor is also selected for allow the distance between the wheel and all piezoelectric sensor to be reduced. **Fig. 4** shows an image for base of the test bench that has been designed.



Fig 4: Model for base of test bench

In order to make sure the wheel is fully press and touch on the surface of piezoelectric sensor, a few layers of the cardboard is place on the base of test bench. Each of the cardboard contribute 1mm height. So, 3 layers of the cardboard with 30 cm diameter has been attached on the base of test bench. In this case, the bumping area is designed to produce the vibration process to press the piezoelectric sensor surface. From that, 1mm displacement of the harvester is selected because of the durability of the harvester [10]. A hitting stick which lay on layer will touch the piezoelectric device when a wheel passes the harvester. **Fig. 5** shows an illustration between damper area and piezoelectric sensor and actual design of damper is representing on **Fig. 6**.

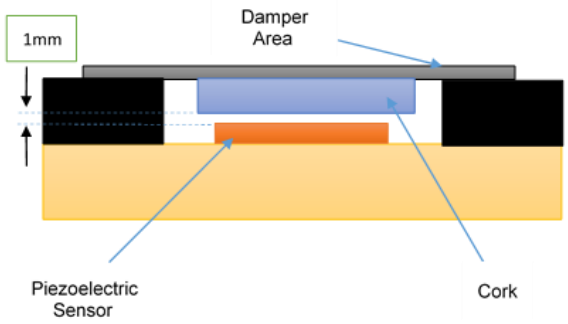


Fig. 5: Illustration of damper area and piezoelectric sensor



Fig. 6: Actual image of damper area of project

In this project, the spin extractor motor is control by AC regulator speed motor device. According to the circuit connection, the variable resistor is the main component for conduct the speed motor of the wheel. The regulator speed motor is installed by connecting the 4 pins cable which has been provided in the circuit.

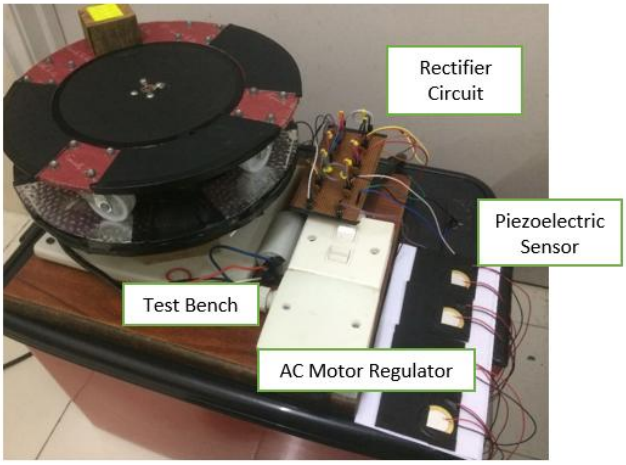


Fig. 7: Complete prototype of test bench

2.4 Desired Frequency

To conduct further analysis, selecting the desired frequency is the first part need to consider. For this project, adjusting and labelling the desired frequency is done using AC Drive Machine. **Fig.8** shows an image of AC Drive Machine.



Fig. 8: Image of AC Drive Machine.

In this project, considering the dominant frequency range of vibration in 10 to 15 Hz is set for represent the vibration of the vehicle at the road. An idea for selecting this frequency is get by the Yewon Song study [10] which consider 10 to 14 Hz to represent the speed of 60 km/h to 80 km/h. Other than that, a 3 to 7 Hz of frequency range is set for represent the vibration of human walk at the road. This frequency is coming from the Tianjian Ji researcher [20] which conclude that 1.74 Hz to 2.26 Hz has consider as the speed human walk for 1.16 m/s to 1.6 m/s. At this point, to set the desired frequency that consider by the researcher is not possible to applied using spin extractor motor. Because of that, the frequency of 1 to 5 Hz is selected to make an analysis of energy harvester on human walk on the road.

2.5 Output Voltage Analysis

An analysis toward piezoelectric output voltage is measured at an open circuit and including load of 300 ohm and 10 kilo-ohm condition. **Fig. 9** shows an experiment setup for the road energy harvester with oscilloscope.

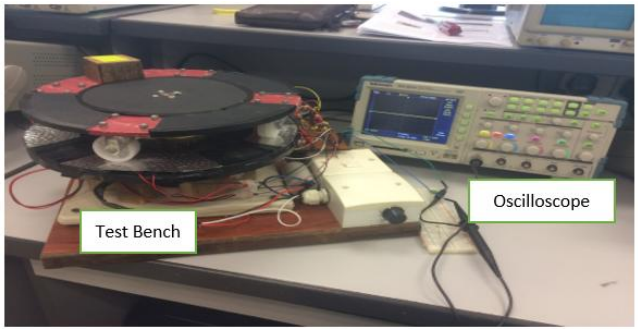


Fig 9: Experiment setup for the road energy harvester with oscilloscope.

3. Result and Discussion

3.1 Simulation Result

The data was recorded over 7 level of setting frequency from 2 Hz to 14 Hz. Overall output current produce by both rectifier circuit is increasing when higher value of setting frequency is applied. **Table 1** shows the output current and voltage produce by voltage multiplier circuit is slightly increase according to the higher value of setting frequency. The small range of output current and voltage of full bridge rectifier circuit make the low efficient among of these circuit.

Table 1: Comparison between Full Bridge Rectifier and Voltage Multiplier for single piezoelectric

Circ / Freq	Full Bridge Rectifier Circuit		Voltage Multiplier	
	Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
2	0.655	0.649	0.711	0.727
4	0.693	0.687	1.316	1.284
6	0.711	0.701	1.811	1.707
8	0.721	0.718	2.013	2.079
10	0.733	0.721	2.125	2.086
12	0.754	0.723	2.311	2.126
14	0.767	0.740	2.471	2.306

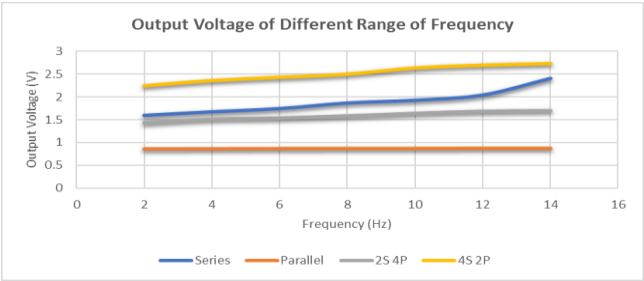


Fig. 10: Output voltage generate for the different level of full bridge rectifier circuit

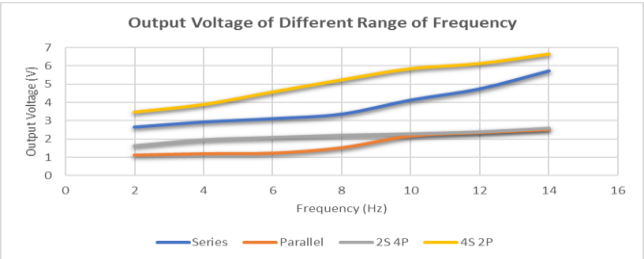


Fig. 11: Output voltage generate for the different level of voltage multiplier rectifier circuit

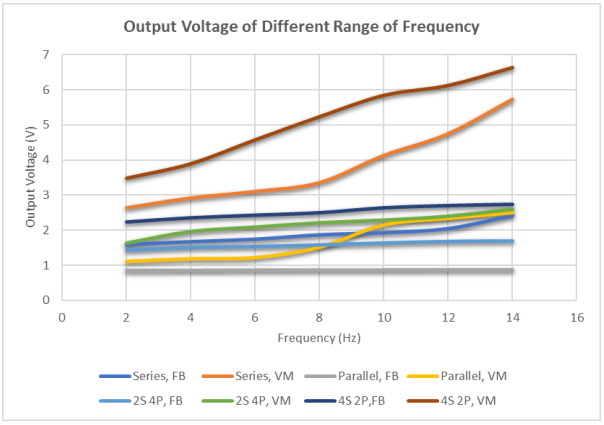


Fig. 12: Comparison for all result

Fig. 12 shows an output voltage generate for the different level of both topology rectifier circuit. The graph illustrates the comparison between 4 different arrays of circuit connection. The data was recorded over 7 level of setting frequency from 2 Hz to 14 Hz. Overall, an output voltage produce by all circuit connection is increase regarding higher value of setting frequency.

In generally, an output voltage generated by 4 series 2 parallel and series connection for voltage multiplier circuit are shows the highest range. An output voltage generated for the both circuit connection is linearly increase regarding to the higher level of setting frequency. Based on the result, there are 21.56% shows the different range between 4 series 2 parallel connection of voltage multiplier and full bridge rectifier circuit. The different range for 4 series 2 parallel of voltage multiplier is slightly increase until 41.63% compare to full bridge rectifier circuit at the end of setting frequency.

On the other hand, the result for parallel and 2 series 4 parallel circuit connection for both rectifier topologies are shows the lowers result of output voltage generated. Regarding to the result, an output voltage produces by parallel and 2 series 4 parallel circuit connection are not too significant because of small range of output changes. At the starting setting frequency, the different range between parallel connection for full bridge and voltage multiplier results is achieve at 12.66%. The different for both topologies are slightly increase at the 8Hz setting frequency. The difference range from 26.81% is slightly increase until 48.12% at the end of setting frequency.

The footstep analysis is conduct by set the operating frequency from 1 until 5 Hz. An idea for selecting this frequency is coming from Tianjian Ji [21] analysis. The result is taken according to the different level of frequency that has been set in the hardware. Testing were done in 1 minute before result were taken. **Table 2** shows the result for the output voltage produced by circular piezoelectric sensor in variety of frequency. Then, the data collected were plotted and shown in **Fig. 13**.

Table 2 Output voltage for footstep analysis

Frequency (Hz)	Voltage (V)		
	No load	330 Ω	10 k Ω
2	3.92	0.0264	0.128
3	4.24	0.0252	0.160
4	4.40	0.0304	0.180
5	4.64	0.0394	0.188
6	4.72	0.0440	0.244

Fig. 13 shows the comparison based on two different load application in term of output voltage. The data was recorded over 5 level of setting frequency from 2 Hz to 6 Hz. The graph has shown that a voltage across 10 kΩ load is better than 330Ω load. At the starting point, an output voltage across 10 kΩ is slightly increase until 3 Hz setting frequency. At these point, the voltage across is constant on 0.18V from 4 Hz to 5 Hz setting frequency before continue increase to 0.244V at 6 Hz. On the other hand, the small range of voltage across 330Ω made the result is not significant compare to 10kΩ load.

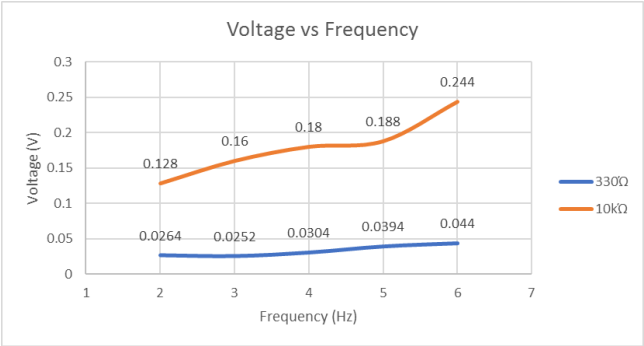


Fig 13: Output voltage for footstep analysis

The hardware analysis is continues by conducting an analysis for vehicle vibration application. In this analysis, the setting frequency has been increase from 10 Hz to 14 Hz. The idea for selecting this frequency value is coming from Yuwon Song [10] analysis. This frequency value is representing the speed vehicle from 60 km/h to 30 km /h. **Table 3** represent an output voltage generated by circular piezoelectric sensor via variety of vehicle frequency level.

Table 3 Output voltage for vehicle vibration analysis

Frequency (Hz)	Voltage (V)		
	No load	330 Ω	10 k Ω
10	5.36	0.0368	0.200
11	5.60	0.0376	0.224
12	5.76	0.0440	0.240
13	6.00	0.0456	0.276
14	6.32	0.0464	0.284

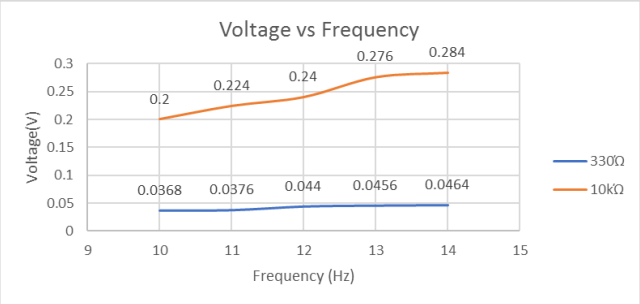


Fig. 14: Output voltage for vehicle vibration analysis

Fig. 14 shows the comparison based on two different load application in term of output voltage. The data was recorded over 5 level of setting frequency from 10 Hz to 14 Hz. Overall output voltage applied on 10 kΩ load is better than 330Ω load. At the starting point, an output voltage across 10 kΩ has been performed with slightly increase until the end of setting frequency. From this experiment, the output voltage on 10kΩ is continuously increase from 0.20V until 0.28V. However, the small range of voltage across 330Ω made the result is not significant compare to 10kΩ load. For 330Ω load system, an output voltage has been produced is increase from 0.036V to 0.046V.

4. Conclusion

Generally, this paper for analysis the road energy harvester is an idea to develop a renewable energy system. An opportunity toward the movement of vehicle and walking people which are commonly used in road is fully taken for generating an electricity from both kinetic energies. Regarding to the result, conducting an action on both vibration source can be implemented in road energy harvester. However, the different level of setting frequency in the experiment can produce the different result of output voltage. In this case, the desired frequency of vehicle vibration can generate better output result compare to desired frequency of walking people vibration. This result is occurring because of the faster and continues pressuring on the surface of piezoelectric can develop the higher output voltage. Other than that, the suitable circuit connection and rectifier circuit also can consider as another factor to obtain an optimize result of output voltage. Regarding to this concept which designing an electricity from reused energy can made an idea to develop a green power generation. The source is easier to develop among of people and environment friendly make the strong evident for promoting the concept of harvesting vibration energy to the world.

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