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Performances of Multi-Configuration Piezoelectric Connection with AC-DC Converter in Low Frequency Energy Harvesting System

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Abstract- Harvesting energy by capturing vibration from low frequency energy have been explored extensively. In essence, a single piezoelectric transducer or an array of piezoelectric connections are used to convert kinetic energy into electrical energy in order to produce low frequency energy. In this paper, multi-configuration array piezoelectric connections are used to investigate the performances of different converter circuit types in low energy harvesting applications. This research utilized three pieces of circular piezoelectric sensor to test the combinations of array connection. There are four options for the piezoelectric sensor configuration: parallel (P), series (S), parallel-series (PS), and series-parallel (SP) while the full wave bridge rectifier (FWBR), parallel voltage multiplier (PVM), and parallel Synchronized Switch Harvesting on Inductor (P-SSHI) converter circuit are chosen AC-DC converter circuits. The system is assessed using a variety of load configurations, including 10 kΩ and 1 MΩ with a 3 Hz input frequency. In order to produce the highest possible output of collected power, the observation focuses on identifying the ideal combination of array piezoelectric connections with AC-DC converter. The result shows that 3-Parallel (3P) piezoelectric connection obtained a higher power output among the other types of array piezoelectric which was 5.97μW. The FWBR circuit generated the highest output power with 2.42μW for a combination of piezoelectric sensors array of 3P connection with the AC-DC converter.

Keywords: series, parallel, AC-DC converter, low frequency energy harvesting, circular piezoelectric sensor

1. Introduction

Vibration energy is one of the significant research nowadays that used the vibration mechanism to convert into the electrical energy using energy harvesting technique. This technique collect the ambient energy and transform it into electrical energy in order to energize low power electronic devices [1-3]. There are many types of vibration energy that can be generate from surrounding like human walking, car instrument panel, car engine compartment, rain and others [4-7]. In recent years, some researchers have looked into piezoelectric energy harvesting based on vibrations. A study published in 2015 described a piezoelectric energy harvester that used two piezoelectric beams and two cylinders. This investigation explores the transformation of fluid kinetic energy into electricity. The maximum output power of 20.5 μW was generated using an optimal resistance of 170 kΩ, a cylinder diameter of about 30 mm, and vibration frequencies of 1.28 Hz and 0.31 m/s, respectively [8]. A 2016 study described a novel technique for a self-powered wireless application called the soft-push-type piezoelectric energy harvester. Two parallel bimorph piezoelectric beams with a maximum resistance of 250 kΩ were used to test the output. The output of power was 4 mW [9]. A rotatable piezoelectric energy harvester for wind energy harvesting was created in 2017.The impact of induced vibration from the wind energy was used to generate electricity. The PVDF beam was proposed as the method for modifying the vibration frequency to increase the harvester performance. At a wind speed of 14 m/s, a maximum root mean square (RMS) voltage of 160.2 V and an output power of 2566.4 μW were generated. [10].

In 2013, pyroelectric effects and piezoelectric effects were combined together in another investigation of power harvesting to demonstrate a hybrid harvesting technology. For parallel and series SSHI (synchronised switch harvesting on an inductor), a detailed presentation of the methodology and theoretical analysis is made. The PZT elements produced 6.049 mW through a 2.1771 MΩ resistor in parallel at 20 Hz and Qi = 3, while the parallel SSHI PMN-0.25PT elements produced 2.667 mW through a 16.456 MΩ resistor [11]. Ain Atiqa Mustapha reviewed the performance of the different types of voltage multiplier in 2013. PSI-5A4E from Piezo Systems, Inc. was used as a model of the piezoelectric cantilever sized 0.51 mm x 31.8 mm x 63.5 mm with a resonance frequency of around 68 Hz. The output power for half of the wave parallel voltage multiplier was P_o = 4mW [12].

This paper focusing on harvesting low frequency vibration energy using different piezoelectric connection with dedicated AC-DC converter. As significant problems encountered in this research are related to the nature of the vibration force that is not consistent [13-15] and affected by several factors including frequency, pressure applied to the piezoelectric surface plate and displacement [16,17]. Additionally, it is essential to check the circuit design for vibration extraction to make sure it is appropriate and reliable with the piezoelectric and the variable vibration source Therefore, the objective of this study is to design an array of piezoelectric and AC-DC circuits that is configured appropriately to extract low frequency vibration and provide the most optimal output for low power device powering.. The insufficient gape on previous research with regards of the piezoelectric configuration with an appropriate AC-DC combination motivate this research.

2. The operation of piezoelectric energy harvesting system.

The system started with harvesting vibration with the piezoelectric transducer. The vibration energy will be converted to electrical energy by the piezoelectric transducer. The voltage that was obtained was in the form of an AC voltage. Therefore, in order to transform the generated energy from AC forms to DC voltage forms, an AC-DC converter circuit is required. The block diagram for a piezoelectric transducer-based low-frequency energy harvesting system is shown in Figure 1.The main focus was the piezoelectric sensor array arrangement and the design of AC-DC converter. Several array topologies, including parallel (P), series (S), combination parallel-series (PS), and combination series-parallel (SP), were investigated at this harvesting stage. Meanwhile for the AC-DC converter implementation, a few types of converter namely as Full Wave Bridge Rectifier (FWBR) [18-20], Parallel-SSHI (P-SSHI) [21,22] and Parallel Voltage Multiplier (PVM) [18,19] were taken in to consideration. These converters will be combine with the piezoelectric sensor array configuration in order to investigate the most optimum output obtained from each of the converter. Once the voltage has passed through the DC/DC converter circuit and the energy has been extracted, the battery is where the energy is stored before being transferred to the load.

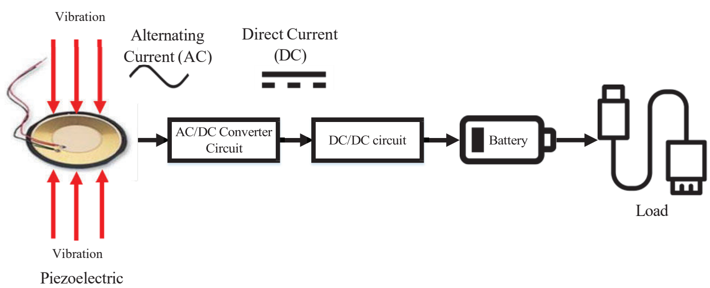

Figure 1. Block diagram of a piezoelectric sensor-based system for harvesting low-frequency energy

3. The Experimental Setup

The objective of this experiment is to design an appropriate configuration array of piezoelectric together with its AC-DC circuit that extracts low frequency vibration at different configuration by using different variation piezoelectric connection and three types of AC-DC circuit. The experimental setup for generating an electric voltage from a pressure device is shown in Figure 2. The array of piezoelectric configuration was implemented embed in a tile and has been employed under the pressure device. In this setup, an arrangement of a circular piezoelectric was placed on the solid transparent plastic of polymethyl methacrylate, namely as acrylic. This material was used due to its features that easily shaped and durable.

Figure 3 shows the schematic diagram of a single piezoelectric plate from the model ABT-448-90-RC, the type of piezoelectric model used for this study. A piezoelectric ceramic disc was bonded to a thin metal plate to create this piezoelectric device. The brass plate had one of the two wires welded to it, while the piezoelectric ceramic disc had the other wire. The thickness direction was polarised in the piezoelectric ceramic discs. The brass plate was 35mm in diameter, while the piezoelectric ceramic disc measured 25mm. In addition, the brass plate and ceramic disc both had a 0.53mm thickness.

Figure 2. The hardware of piezoelectric pressure device.

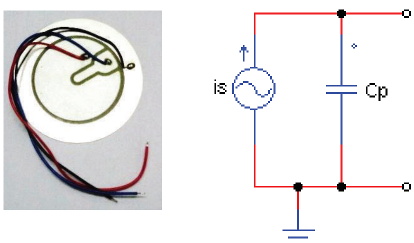

Figure 3. The physical piezoelectric plate and its schematic diagram.

In order to test the array connection of the piezoelectric sensor circuit, a controlling switch was used. A total of 13 switches on the array connection circuit were needed to test the different array connections with three piezoelectric sensors. The switches can be set (ON/OFF) to create the array connection whether in series, parallel and combination in the same circuit as shown in Figure 4. In the final step, three different types of AC-DC circuits were fabricated and connected to the piezoelectric circuit's output in order to analyse the overall output power of the harvesting system. The AC-DC circuit's power output was compared by interfacing it with the different types of an array of piezoelectric connection through the different values of resistor acting as a load. Figure 5 shows the types of the circuit used in this research, which was the FWBR, P-SSHI and PVM.

The output power can be calculated with respect to relationship between voltage and current. The relationship can be expressed as

$$P = VI \quad (1)$$

Where P is the power in watts (W), V is the voltage generated by the piezoelectric and AC-DC circuit (V), and I is the current in amps (A) as determined by the load resistance.

Figure 4. Array connection circuit plate

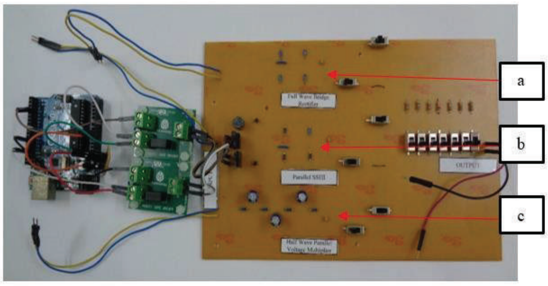

Figure 5. Types of circuits (a= FWBR, b= P-SSHI and c=PVM)

Figures 6 and 7 show the diagram of experimental test setup and the hardware experimental test setup. The mechanical pressure device was linked with the Arduino controller to count and control the pressure. The number of the count is set using the Arduino software on a laptop. A piezoelectric tile is placed on the mechanical pressure device shown in Figure 2. The piezoelectric was connected to an external array connection circuit as in Figure 4 ad 5. The AC-DC circuit received the piezoelectric device's AC source output. A picoscope 2207B device connected via USB to the laptop interface was used to monitor the output voltage from the AC-DC circuit. Then, the data and waveform were recorded using the Picoscope software.

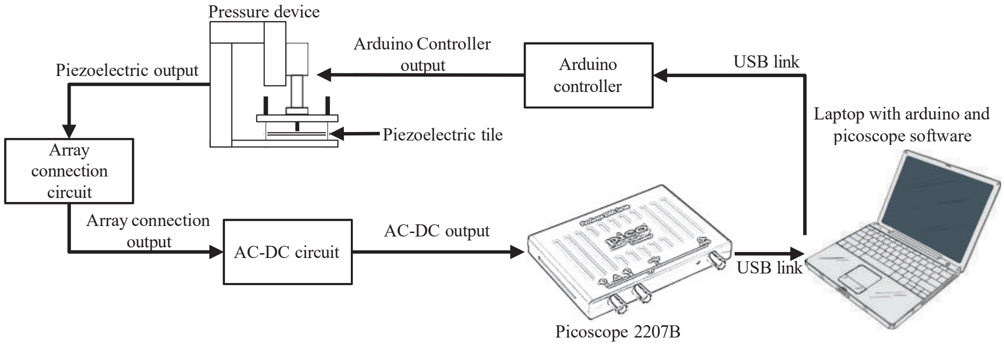

Figure 6. The diagram of experimental test setup

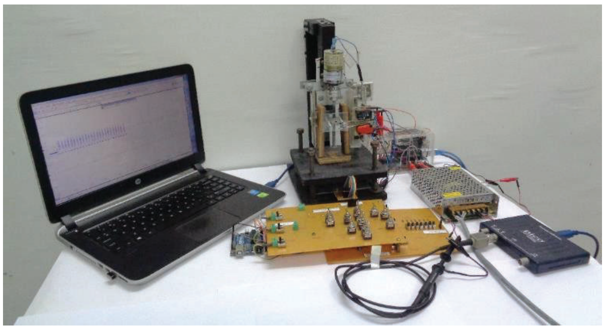

Figure 7. The hardware experimental testing setup

4. Results and Discussions

4.1 The results of hardware experiments using various connections for array piezoelectric sensor.

The variations of output voltage across 1 MΩ of load resistance for piezoelectric sensor at different types of array connection are shown in Figure 8. It shows that 3P piezoelectric connection obtained a higher power output among the other types of array piezoelectric which was 5.97μW compared. In view of the results obtained below, the 3P array connection was 49.41% higher from 2S1P while 85.09% higher than 1 piezoelectric sensor. As previously discussed in the simulation section, the types of array piezoelectric connection corresponded to the related theoretical equations.

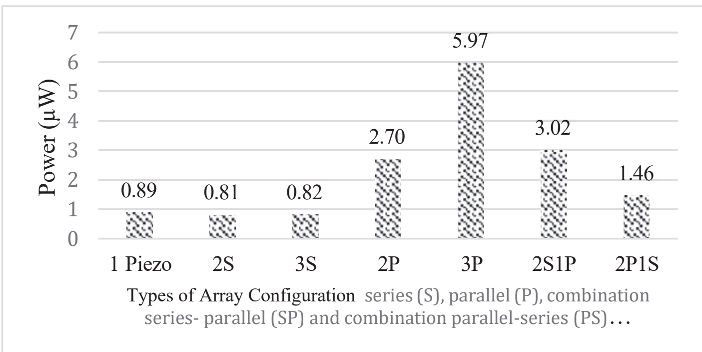

Figure 8. The types of array connection of piezoelectric sensor hardware fabrication

4.2 The experimental result of the AC-DC converter circuit combined with a variety of piezoelectric connections.

As part of the experiment, a circuit comprising an array of piezoelectric connections and an AC-DC converter was used, along with load resistances of 1 MΩ and 10 kΩ. The PVM, P-SSHI, and FWBR circuit types were used, and they were connected to 1 piezoelectric, 3P, 3S, 2S1P, and 2P1S. Figure 9 shows the output power generation for the experiment at a frequency of 1 Hz between AC-DC circuits and various array piezoelectric sensor connections across 1 MΩ.The graph of the output power versus types of array connection showed that the 3 piezoelectric sensor in parallel connection with FWBR converter circuit had the highest output power value among the other types of array connection at 2.42μW. It appeared that with 3 parallel array connection, the FWBR circuit produced output 24.79% higher than P-SSHI and 86.96% higher than PVM circuit across the 1 MΩ load resistor.

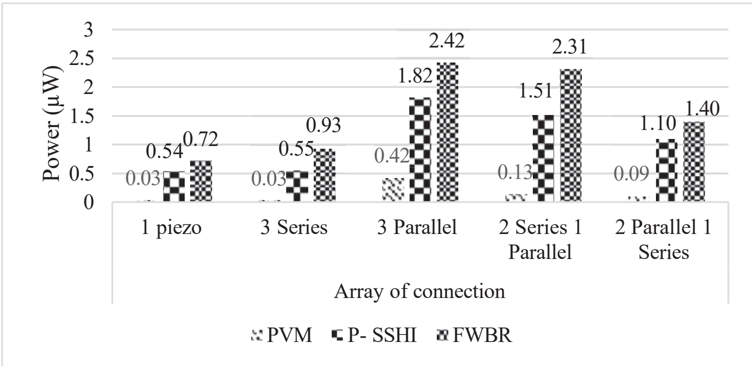

Figure 9. The comparison of different types of piezoelectric configuration with AC-DC converter circuit across 10kΩ hardware fabrication at frequency of 1 Hz

Figure 10 presents the output power versus types of piezoelectric array connection to obtain the highest output by using different types of circuits among all of the interfaces between several types of array piezoelectric connections and the AC-DC circuit across 10kΩ. According to the results, the highest power output value of 32.4 pW was obtained using an array connection of three piezoelectric sensors connected in parallel with FWBR. It is shown that the percentage of power increment compared with P-SSHI circuit using 3 parallel piezoelectric connection was 16.14% while combination with PVM will increase 83.8%.

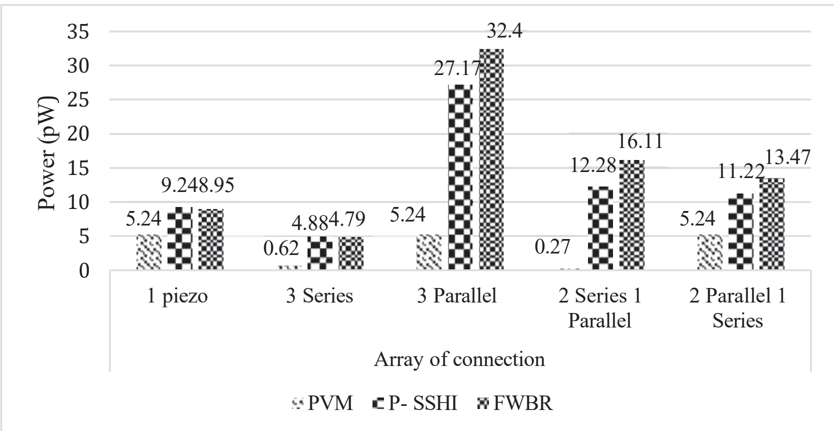

Figure 10. Comparison of output power generation using various array piezoelectric connections with AC-DC converters across 10 kΩ hardware manufacturing at 1 Hz frequency

5. Conclusion

The hardware development was done for the variation of piezoelectric sensors array connection as in combination of both arrays of piezoelectric sensors with the AC-DC converter. The result for a combination of an array of piezoelectric and AC-DC converter circuits show that the 3P piezoelectric sensors array connection using the FWBR converter circuit provide the highest output power values among the other types of array connection which is 2.42 µW. It appears that the configuration of 3P piezoelectric sensors array connection with the FWBR circuit produced 24.79% high output power compared to the P-SSHI converter circuit and 86.96% for the (PVM) converter circuit across the 1 MΩ load resistor. However, these values is much lower than been obtained without the AC-DC converter which is 5.97 µW for 3P array connection. Nevertheless, the energy harvesting system still requires the AC-DC converter because the piezoelectric source is an AC source. As a conclusion, with the optimum output around 2.42 µW it is a promising result to at least power up low power device using free low vibration energy from environment. Furthermore, in depth research and testing on real application are needed for more finding.

6. Acknowledgement

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