Generating, Rectifying and Stepping Up the Voltage Output of Piezoelectric Plate

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Abstract

Energy is required in all sectors that either supports or improves human life. However, some of the methods of power generation e.g. the fossils fuels are non-renewable and have byproducts that harms the environment. For example, they cause pollution that leads to greenhouse effect which will result in global warming hence causing climate change. There is a need for generation of electricity by methods where renewable/green energy sources can be used for generating electric power. Piezoelectric power is one such method where mechanical energy is converted into electrical energy. A lot of mechanical energy is wasted when people move on the streets, pavements, gymnastic rooms and also by the movement of vehicles on the road. present work aimed at harvesting mechanical energy (for example from human footsteps, vehicle movements on roads and public gathering situations for clean and pollution free power generation. the general objective was to generate, rectify and step up the voltage output of the piezo electric plate. This study designed a portable kit comprising of the piezoelectric transducers either in parallel or series combination, together with a voltage step up and rectifier. The study experimented energy generation with the kit results using weights ranging from 10g-1000g. The results shows that the output voltage was directly proportional to the weights. The kit stepped up and the output of 1.5 v to 3 v. From the analysis the series combination of the PZT gives the highest output and thus for any designer who needs to generate power using PZT should consider the series configuration connected to the voltage doubler circuit.

Keywords: piezoelectric transducer, generating, rectifying, stepping up, output voltage

1. Introduction

Power is a key factor for the development of a country, as result each and every country has a way of generating the power. Kenya as a country employs several methods of generation power. One of the methods the country employs is the hydro electrical power generation [1]. Water from man-made dams is used to rotate the turbines which generates the electricity The hydro electrical generation becomes a challenge when the water level in the dams goes down as it has happened successively severally in Kenya [2-4], and with alternate times the dam levels may go up easing the pressure of power production [5]. Therefore despite the advantages of hydro power generation, the method is not all seasons reliable. It depends and therefore limited by the storage capacities of dams.

Another method is the geothermal power production [6]. This method employs the use of piped hot steam from the underground reservoirs direct into turbines. The rotation of the turbines results in the power production. This method is limited by the fact that there is a possibility of depleting steam resources from the underground wells. The exploitable sites are also limited.

Kenya also makes use of the fossil power plant for the power generation. This method employs the burning of fossil fuel such as coal or natural gas to generate the electricity. This method intensively pollutes the air and also the fossil sources are exhaustible. Other method is the wind power generation in Ngong Hills [7] and Turkana [8]. The challenges with these methods are that the sources of the energy to rotate the turbines have irregular occurrences. For the case of the wind power, there is a possibility of having calm days which means that a less or even no power is going to be generated.

Piezoelectricity generation could curb these challenges since its power generation is non-exhaustible. The piezoelectric effect is a molecular phenomenon that can be observed at the macroscopic level as a change in electric potential that is created when a piezoelectric substance is deformed. This was first observed by Carl Linnaeus and Franz Aepinus in the mid-1800s, but it was not was not put into practice until it was demonstrated by two French physicists, Jacques and Pierre Curie in 1880 [9,10]. Certain materials such as quartz, salt, and even sugar would generate a voltage when placed under stress [11]. These materials all had characteristic crystal structures formed from a lattice of molecules with asymmetric dipole moments that would respond to mechanical pressure. Thus, they were named piezoelectric crystals after the Greek word *piezo* meaning press [12].

The piezoelectric effect is due to the asymmetry in the crystalline structure [13]. This allows the ions to move along one axis than the others. When a mechanical stress is applied, each side of the crystal acquires opposite charges leading to a voltage drop across the crystal. This effect is linear and the voltage disappears when the mechanical or heat stress is removed [14].The piezoelectric effect may be direct piezoelectric effect in which the electric charge develops as a result of the mechanical stress or reverse or indirect piezoelectric effect (converse piezoelectric effect) in which a mechanical force such as vibration develops due to the application of an electric field [15]. A typical example of direct piezoelectric effect is the generation of measurable amount of piezoelectricity when the Lead Zirconate Titanate crystals are deformed by mechanical or heat stress. The Lead Zirconate Titanate crystals also shows indirect piezoelectric effect by showing vibration when an electric potential is applied. This is the principle of sound generation in Piezo buzzer, Piezoelectric mic etc. [16].

Piezoelectric materials are composed of molecule groups that are polarized. As with other crystalline materials, these molecules are high structured in a lattice, but as a mechanical stress is applied, the molecules must re-orient, thus changing the symmetry of the molecules [17]. This results in a change in polarization and is accompanied by dipole density and large potential difference. If in a circuit, the potential difference only lasts until both sides are balanced by moving charges. This repeats again but in the opposite direction when the crystal returns to its original shape.

Use of piezoelectric effect would greatly utilize the mechanical energy which goes into the waste during the daily human activities. These activities include; walking, motor vehicles in the highways and gymnastic activities [18]. This energy is non-exhaustible since these are human daily activities which are utilized for the production. There is need of studies that would harvest this mechanical energy, transform it to electricity through piezoelectric effect, rectify the power output from the PZT and step up the voltage to ease transmission.

Research studies have utilized the use of the PZT for the generation of voltage. Some have used a single PZT mounted on a shoe then the output connected to a charger adapter for charging phones [19]. Other studies has experimented on the energy harvesting from footsteps [20, 21]. Experimentation for the use of piezoelectric effect for energy generation had been attempted in Japan [22]. They implement piezoelectric effect on the stairs of the bus [12]. Thus, every time passenger steps on the tiles; they trigger a small vibration that can be stored as energy. Dance Floors Europe is another one of the countries which started experimenting use of piezoelectric crystal for energy generation in night clubs [12, 22, 23].

The voltage output from the PZT is AC. The voltage has to be rectified for storage purposes [22]. The voltage output from the PZT is usually very low, this drives in the need for stepping up the voltage output in order to get a meaningful output. Publications have been made in this area of study. Most of the publication have designed a voltage doubler circuit which doubles the voltage from the PZT [25], and a study by Staworko & Uhl [26] did an *in situ* experimentation of piezoelectric elements and comparison of available methods and tools. In this study, we sought to experiment generation of electricity for parallel and series connection of transducers, step up the voltage and rectify the output.

2. Materials and Methods

2.1. Study Materials

This study utilized the following material all procured from an electronic shop: PZT (shown in Figure 1), rectifying diodes, breadboard, connecting wires, DMM, inductor (5MH), MOSFET transistors, resistors (100 KΩ 220 KΩ, 560Ω), Zener diode, plywood, capacitor(22µF).

Figure 1: Piezo electric plate. Obtained from electronicscomponents.com

2.2. Methods

This study connected 6 PZT both in parallel and series. These connections of the PZT were mounted on a plywood. Their outputs were connected to the bridge rectifier mounted on a bread board for rectification. All the components of the step-up circuit were connected and mounted on the bread board. The circuit diagram for the bridge rectifier and step up are shown in Figure 2a and 2b respectively. .

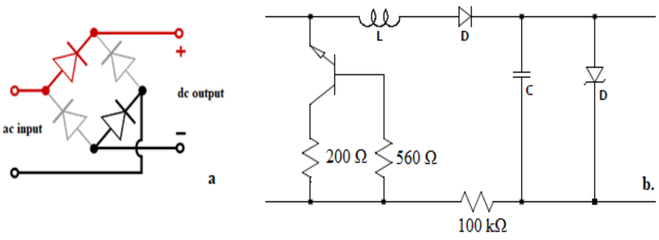

Figure 2: (a) The bridge rectifier, (b) the voltage step-up circuit.

The study applied known weights in increment of 10g starting from 10g to 100g on the PZT while recording the voltage and current output from the digital multimeter. The data analysis for this study included; Calculation of power output from the PZT by using the formula,

$$P = VI$$

Where; V is the output voltage, and I is the output current.

3. Results and Discussion

3.1 Results

The study connected PZT in series and parallel, and added varying dead-weights from 10g-1000g in arrangements shown in Figure 3a and 3b respectively.

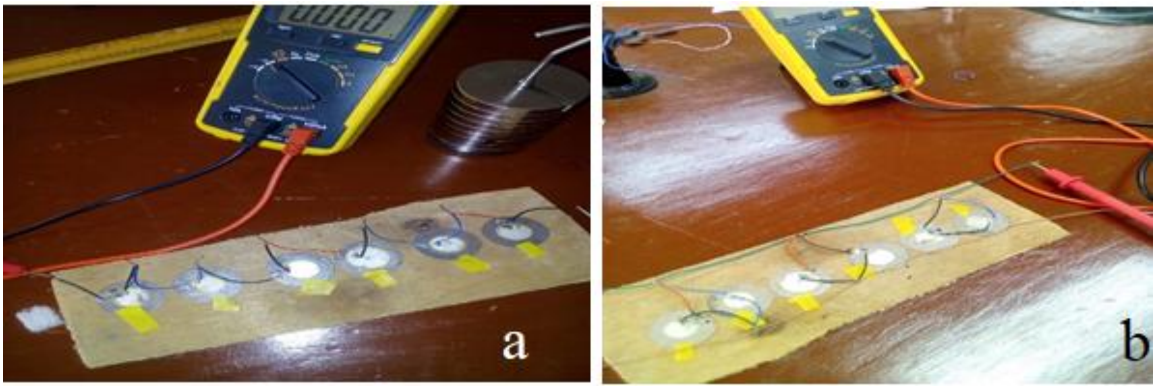

Figure 3: PZT connection in (a) Series and (b) parallel

The unrectified voltages for the different weights are shown in table 1. Graphs of the voltage output against the weights applied for both the parallel and series connection was plotted, and are shown in Figure 4. From this plot it was possible to compare the voltage outputs for the two connections. The connection giving the maximum voltage was observed from the graphs. The output trendline curve has a gradient of 0.0852v/g for series connection and 0.0833v/g for parallel connection.

Table 1: PZT output before step up.

Series		Parallel	
Weight (g)	Peak Voltage (v)	Weight (g)	Peak Voltage
0	0	0	0
10	0.465	10	0.096
20	0.52	20	0.1675
30	0.526	30	0.205
40	0.55	40	0.475
50	0.60	50	0.52
60	0.705	60	0.585
70	0.794	70	0.666
80	0.84	80	0.775
90	0.95	90	0.925
100	1.075	100	1.005
200	1.104	200	1.04
300	1.175	300	1.06
400	1.345	400	1.115
500	1.42	500	1.205
600	1.525	600	1.29
700	1.60	700	1.315
800	1.675	800	1.46
900	1.725	900	1.51
1000	1.85	1000	1.644

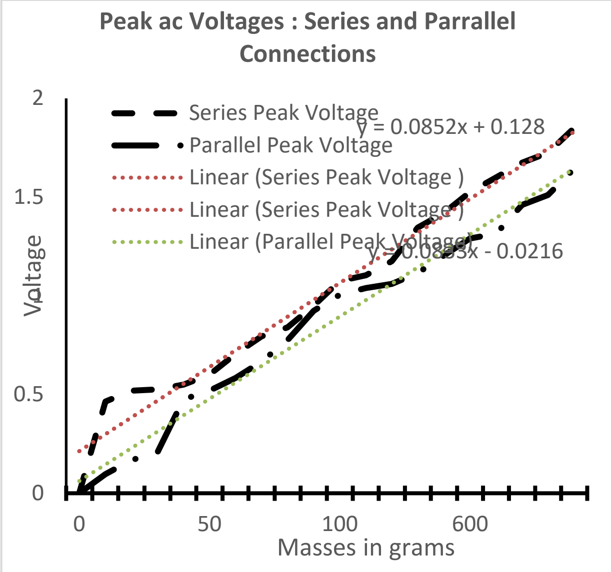

Figure 4: Peak ac voltages for series and parallel connection

The study connected the unrectified output of the PZT to the digital CRO which gave the ac output waveform as shown in Figure 5.

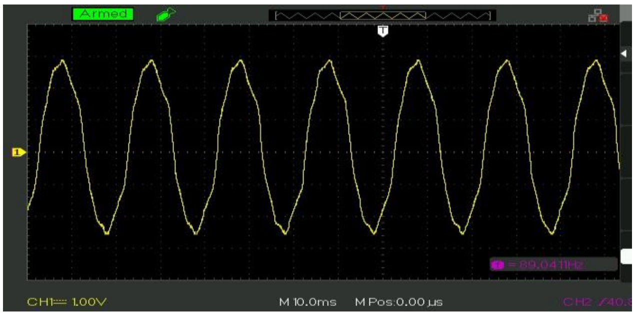

Figure 5: Unrectified output waveform

From the output waveform it was clear that surely the voltage output is AC as it is depicted by the sinusoidal waveform. The frequency set was 89.041 Hz and the peak voltage was 1 v. The voltage output of the PZT (parallel and series configuration) was connected to a bridge rectifier for rectification and a step-up circuit as shown in the Figure 6a and 6b respectively.

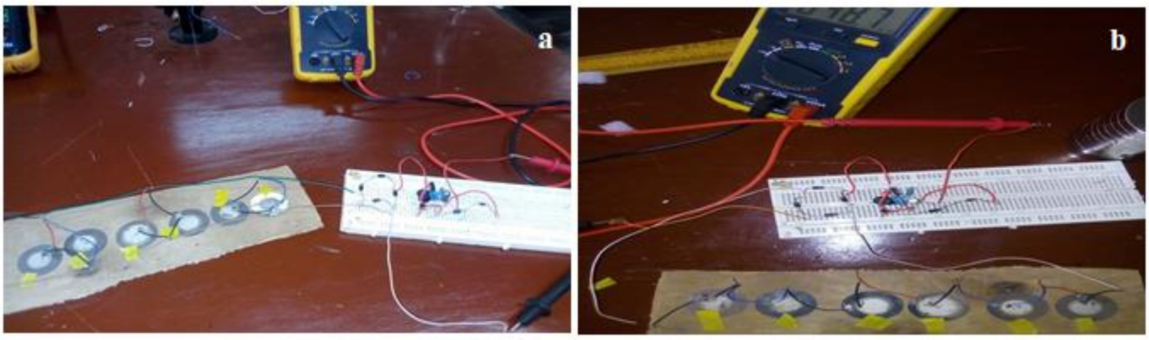

Figure 6: Parallel PZT output connected in (a) parallel and (b) series to rectifier and step-up circuit

The output from the bridge rectifier was connected to digital CRO which recorded the waveform shown in figure 7.

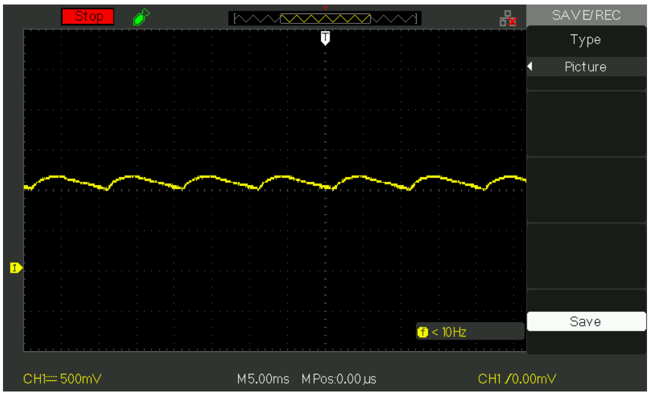

Figure 7: Rectified waveform as recorded on a digital CRO

From the waveform it was clear that the bridge rectifier was really effective since it was able to give the desired rectified waveform. The peak voltage for the wave was 500 mv and the frequency was 10 Hz.

The study applied varying masses on the series and parallel connection of PZT ranging from 10 grams to 1000 grams. The voltage and current outputs were collected and recorded in the table 2. The power output from the data was also calculated using the formula ($P = VI$) and tabulated. The result shows a direct proportionality between the masses applied and the voltage output.

For clear comparison of the voltage outputs from the two connections the two graphs were plotted on the same axis as shown in the figure 8. The output trend line curve has a gradient of 0.0028v/g for series connection and 0.0026v/g for parallel connection. Which clearly shows that an increase in the weight loaded on the PZT results in progressive increase in the voltage output.

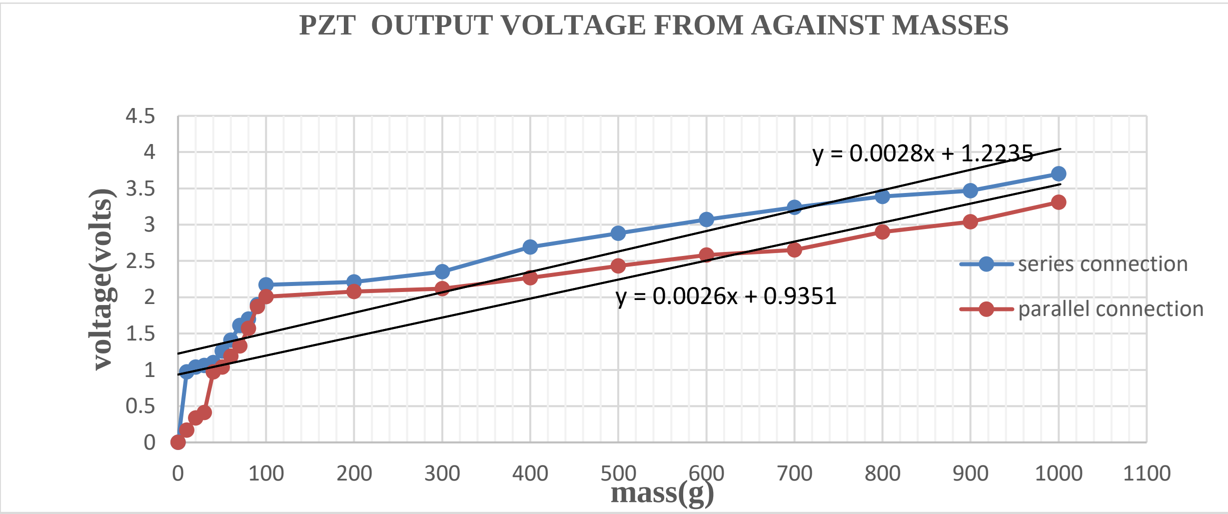

Figure 8: Voltage output graphs for both parallel and series connection with trendline fitted.

3.2 Discussion

From the results obtained, it was clear that the voltage output from any of the PZT connection was direct proportional to the applied masses. By comparing the graphs for the two connections, the study was able to find that the series connection gave a higher voltage output for different masses applied. Due to time factor the study was unable to fix the PZTs in the pavements and the streets to get the actual real-life output from the generator.

Table 2: Results for stepped-up series and parallel connections of PZT

Masses(g)	Voltage output (volts)		Current output (x 10^{-6}A)		Power (x 10^{-7}W)	
	Series	Parallel	Series	Parallel	Series	Parallel
0	0.0	0	0.0	0	0.0	0
10	0.97	0.168	0.1	0.1	0.97	0.168
20	1.04	0.337	0.1	0.1	1.04	0.337
30	1.06	0.41	0.1	0.1	1.06	0.41
40	1.1	0.97	0.2	0.1	2.2	0.97
50	1.26	1.04	0.2	0.2	2.58	2.08
60	1.41	1.19	0.3	0.2	4.23	2.38
70	1.61	1.33	0.3	0.3	4.83	3.99
80	1.7	1.57	0.4	0.3	6.8	4.71
90	1.9	1.87	0.4	0.4	7.6	7.48
100	2.17	2.01	0.5	0.4	10.85	8.04
200	2.21	2.08	0.8	0.5	17.69	10.4
300	2.35	2.12	1.2	0.5	28.2	10.6
400	2.69	2.27	1.4	0.6	37.66	13.62
500	2.88	2.43	1.6	0.6	46.08	14.58
600	3.07	2.58	1.7	0.6	52.19	15.48
700	3.24	2.65	1.7	0.7	55.08	18.55
800	3.39	2.9	1.9	0.7	64.41	20.3
900	3.47	3.04	2.1	0.8	72.87	24.32
1000	3.7	3.31	2.4	0.9	88.8	29.79

4. Conclusion

This research aimed to: design a DC voltage generator from the PZT, design a voltage step up circuit and to compare the voltage output from different PZT connections. This study was able to design the voltage generator from the PZT(s) and also a step-up circuit was designed. Out of the results collected from the two PZT connections, graphs of voltage against masses applied were drawn. Based on the analysis it was concluded that the series connection gave the highest voltage output of 3.7 volts as compared to 3.31volts of the parallel connection when the 1000grams mass was applied. The study has shown that the series connection has a higher voltage output. Therefore, it is recommended that for any designer who intends to design a voltage generator from the PZT should consider the series connection of the PZT(s). The study also recommends that for any researcher who intends to do more research on this should consider installing the PZTs on the pavements and the streets in order to get the output from the real situation.

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