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PERFORMANCE MEASURE OF SERIES-PARALLEL PIEZOELECTRIC TRANSDUCER CIRCUITY FOR IMPROVEMENT OF OUTPUT VOLTAGE

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***Abstract*—** This project presents a comparative study between power generation using piezoelectric transducers available in the literature and the proposed model design. The parallel and series-connected piezoelectric transducers arrangement in this project, when subjected to mechanical stress (footsteps), generates an electric charge. The power generated from piezoelectric transducers will be given as input to bridge rectifier and chopper for conversion to dc quantity and its amplification respectively. This energy will be stored in a Li-ion battery. The paper mainly highlights aspects of improvement of power generation by optimizing circuit design and adapting output enhancement and amplification. Comparative analysis of power generated from predecessor circuit designs and output voltage obtained from current circuit design is validated and presented.

Keywords— Piezoelectric Transducer (PZT), DC chopper, invertor, AC regulator; Bridge rectifier

I. INTRODUCTION

Available energy resources will not sustain in the times to come; alternate technology is, therefore, essential to safeguard the means to generate sufficient energy in the future. Electricity demand is increasing exponentially with the increasing population [1]. Although electricity can be generated from renewable sources like water and wind, which do not have many impacts but there is no assurance that these sources will remain favorable and continue to fulfill the need for electricity for people. Energy has been wasted unconsciously in various ways and there is immense potential to create free and clean energy from an available resource. Daily household and physical activities involve translation of energy and tapping it, would be of immense value. Energy can be generated from physical activities such as walking, and this energy can be converted into usable form with the use of a piezoelectric sensor [2]. Piezoelectric transducers convert mechanical energy to electrical energy and with the same principle, the Piezoelectric sensor exploits this effect by measuring the voltage across a piezoelectric element generated by the applied pressure. They are sufficiently robust and are used in a wide range of industrial applications [3]. Piezoelectric sensors are not normally suitable for measuring static pressure. They are sensitive to dynamic changes in pressure across a wide range of frequencies and pressures. Piezoelectric sensor elements require no external voltage or current source; they generate an output signal directly from the applied strain [4]. This project titled, “Piezoelectric energy harvest and storage from footsteps” is based on the principle of piezoelectricity achieved through a combination of the components such as sensor, amplifier, bridge rectifier and energy storage elements, in a specific design. This project mainly aims at harvesting energy from the footsteps and storing this energy for the recurring mini and micro use. This project design is divided into four sections mainly input unit, display section, harvest and storage section and the energy consumption (load) end. The piezoelectric sensor will detect or sense the stress/pressure offered while walking on the sensor and produces electric charge which will be in the form of an AC signal. The low AC signal is being converted to a DC signal using a rectifier [5] and then it is fed to the chopper to boost the DC signal and this energy will be stored in the battery or capacitor. The value of energy harvested from the sensor will be displayed by 16X2 LCD through the Arduino.

II. LITERATURE REVIEW

To generate electrical energy from footsteps there are several generating elements like a solar panel, windmill, hydropower, gear and fly wheel. All these methods are economically unfavorable and often unfriendly to the environment whereas power generation using a piezo sensor is an economically sound and technically achievable idea.

2.1 *Research paper on Footstep Power Generation using Arduino Uno* [6]

A journal and research by Tengku Azita Tengku Azizland Muhammad Syamir Subri1 have developed a new source of renewable energy having low-cost aspects with the help of Arduino Uno as the microcontroller. The piezoelectric sensor of the circuit will send the pressure signal into the Arduino Uno and transformation of these signals into electrical energy is done with appropriate peripherals. An LCD is used to display the level of voltage generated by the circuit and the highest voltage generated in this project was 8.29 V. Then, the voltage stored in the battery could be used to charge the mobile phones. The output showed 0V when force was not applied to the piezo-electric sensor. When low pressure was applied, the amount of voltage generated was 0.04V. For low pressure, the level of voltage generated increased to 1.53V whereas, for medium pressure, the voltage generated was 2.89V. And for high pressure, the voltage generated was 5.81V and for very high pressure, the voltage generated is 6.90V. For successive increases of pressure, the highest generated voltage was up to 8.29V. The conclusion of an increase in voltage with applied pressure was helpful.

2.2 *Electrical Power generation by footstep using Piezo- electric Transducer.* [7]

A research paper on Electrical Power generation by footstep using a Piezo-electric transducer by Madhu and Dr. Pardeep provided an alternative way to generate electricity that was efficient, clean and pollution-free. The electricity-generating tiles (EGT) were used in this work which are cheap and easy to install. Piezoelectric Transducers (PZT) were connected in a series-parallel manner and to increase the efficiency Prieto battery, were used (rechargeable battery made of nanotechnology), and voltage could be effectively increased using a boost converter. They made use of 72 piezoelectric sensors, which were arranged in 8*9 matrixes. The output voltage from the model has a voltage of 10-15v and a current of 50-400 microampere. A study on series and a parallel connection was done. The output from series-parallel in AC condition was 20 microamperes and in DC condition was 181 microamperes.

2.3 *Footstep Power Generation Using Piezoelectric Material* [8]

Mathane Nitashree V, Salunkha Arati L and Gaikwad G, concluded that to generate better voltage and current, piezoelectric material like PZT needs to be connected in series-parallel since series connection gives low current and parallel connection generates lower voltage. However, to overcome such a problem bridge rectifier along in a series-parallel connection to generate the required power was a proven solution. It was found that the output of the piezoelectric material was not constant, so variable to linear voltage converter circuit bridge rectifier was useful.

They also made use of an AC ripple neutralizer circuit to reduce the ripples from the piezoelectric output along with a rectifier and ripple filter. However, their output voltage from this piezoelectric was then stored in a battery through an AC ripple neutralizer which does exactly the opposite job of the rectifier and filter which converts the stored direct current (DC) energy in batteries back into alternating current (AC). Moreover, an inverter was connected to a battery to drive the AC load. An LCD for displaying generated voltage with AT89S52 microcontroller was used. Load (mobile charging) circuit was designed to amplify the incoming signal. For storing the charge in the super capacitor which has a capacity of 50V it was found that the level was not enough so again voltage amplification was performed. The output signal was rectified and filtered to pure DC. The charge was stored in the super capacitor and the level was displayed on an LCD. A voltage regulator was used to regulate the required voltage level to meet the charging of the mobile phone battery.

2.4 *Footstep Power production using Piezoelectric Sensors* [9]

The paper written by Marshiana. D, Elizabeth Sherine. M, Sunitha. N and Vinoth Kumar. C was based on power generation using piezoelectric sensor and solar panel. Arduino has two analog inputs; one was connected to the piezo output and another was connected to solar panel output. Bridge circuit was used to convert the variable voltage into linear after dc voltage generates was stored in a capacitor. Weight exerted versus power generated graph was plotted. This method of generating power can be utilized as a part of rural zones where accessibility of power is exceptionally low. It can be utilized to drive both AC and DC loads.

2.5 *Energy Harvesting from Piezoelectric Materials Fully Integrated in Footwear* [10]

The paper on Energy Harvesting from Piezoelectric Materials Fully Integrated in Footwear by J.G. Rocha, gives information about harvesting energy from the footwear. The piezoelectric transducer is placed inside the shoes and whenever a wearer walks, the pressure is applied on the sensor which generates power. The type of sensor used was Electro active βPolyvinyliden Fluoride.

2.6 *Footstep Power Generation Using Piezoelectric Sensors* [11]

The journal by Jitha Varghese and Paul Karikottil has designed a system to generate electricity from the footsteps using piezoelectric sensors, whereby in these systems the pressure applied to the piezoelectric material is converted to electrical energy. The pressure applied is either from the weight of the moving vehicles or from the human movement (walking). Since the output of the piezoelectric material is not steady, a bridge rectifier is used to convert the variable to the linear voltage and an AC ripple filter is used to filter further output fluctuation. The DC output voltage is then stored in a rechargeable battery and also investigation on the combination of piezoelectric sensors were carried since the output power from one piezo was extremely low. The test was based on two connections; series and parallel connections. In the parallel connection, it was found that the output voltage was not increasing substantially and when sensors were connected in series there was a significant increase in output voltage but not in linear proportion.

III. Methodology

This project is based on a research approach to solve optimization using the decision matrix method to finalize its course of action.

- Literature review helped to find research gaps and possibilities, for problem and solution definition.
- Problem statement definition and solution optimization used a decision matrix to select two plans of action.
- Block diagram framing and manual calculation of component values, gave shape to the circuit modification.
- Circuit simulation was carried out in relevant software.
- Test and sample data were collected and compared.

- Analysis and inference were presented through numerical and graphical comparison.

The following illustration figure 1, lists the methodology scheme.

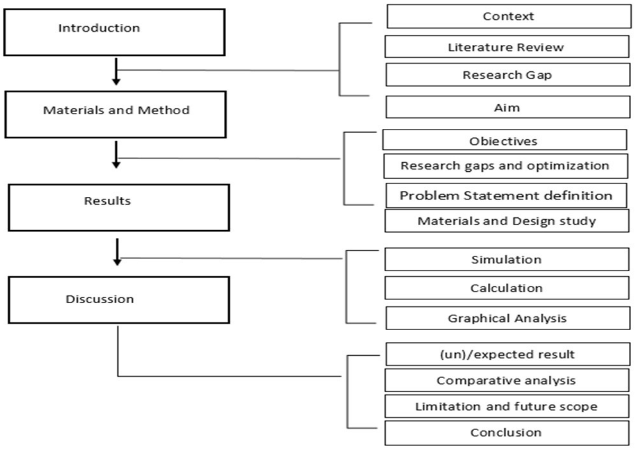

Fig. 7. Methodology

IV. SYSTEM ARCHITECTURE

Energy is generated from the piezoelectric sensor when stepped onto or when a sensor is kept under constant pressure. The sensors are arranged in series-parallel to obtain the required amount of current and voltages. The sensor is based on the principle of piezoelectricity [1]. Since the generated energy from the sensor is very low, an amplifier circuit is designed to amplify the signal. The amplifier circuit consists of a bridge rectifier which firstly converts alternating current produce from piezo to direct current and is given to chopper circuit which helps in amplifying DC. For storing the charge super capacitor which has a capacity of 63Vor lead-acid battery is being used. The circuit details will be explained later in section VI. The amount of charge stored in the super capacitor or battery is displayed in the LCD display where it was interfaced with Arduino UNO. For charging the mobile phone battery, a constant voltage source of 5V is required, so the DC load is given to the phone using a DC regulator.
The principal architecture of the system is represented in figure 2.

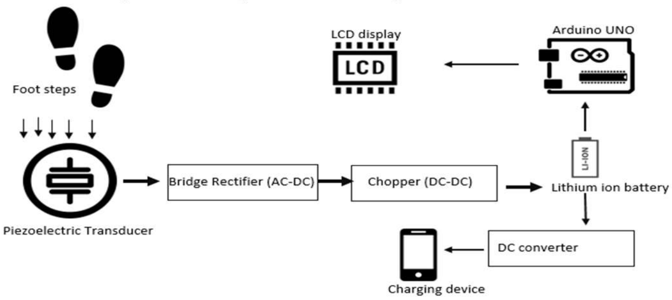

Fig. 8. System Architecture

V. FLOWCHART

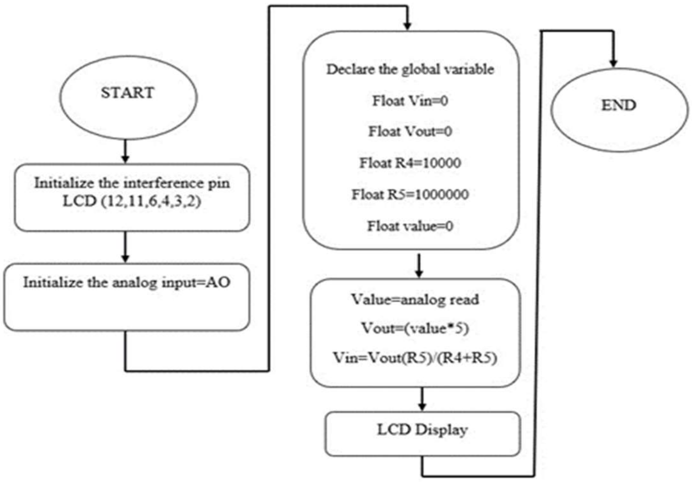

Fig. 9. Flowchart

VI. COMPONENT USED

Some of the components used in the project are elaborated in the sections below.

1) **Piezoelectric sensor** is a sensing device that works on the principle of piezoelectricity where it will detect the pressure applied to it and produce electric charge consequently. Piezoelectric materials can convert mechanical energy into electrical energy. PZT voltage generation will range from 1-100V depending upon its size and pressure applied on it. PZT is made up of lead and zirconium combined with the chemical compound titanate under extremely high temperatures. Its shape can be changed and it is used in ultrasonic transducer and piezoelectric resonators. [12]

2) **Super Capacitor** assumes very high capacitance compared to a regular capacitor and it is also called an ultra capacitor or double-layer capacitor. A super capacitor stores charges using a static charge as opposed to an electrochemical reaction. The charging of the super capacitor happens when the voltage is applied to the two plates of the capacitor. The super capacitor can be charged and discharged a vertically unlimited number of times. Unlike the electrochemical battery, which has a defined life cycle, there is little wear and tear by cycling a super capacitor. The self-discharge of a super capacitor is substantially higher than that of an electrostatic capacitor and somewhat higher than an electrochemical battery. [13]

3) **Liquid crystal** display is a display module with liquid crystal and it is used to display the level of voltage across battery or capacitor.

4) **Arduino Uno** is the central processing unit to control the complete system. Arduino is an inbuilt device and acts as the brain of the system and is responsible for transmitting all the signals from the code fed into it and also collects feedback from the various sensors and input to process the values. [13]

5) **IC Voltage regulator** is an electronic component that generates a fixed output voltage from the stored voltage which remains constant regardless of changes to its input voltage or load conditions. The main purpose of the regulator is to convert unregulated DC current into regulated DC current and voltage.

It has a small size but is highly efficient which can operate at highest speed with less power consumption, it generates less heat and it is very cheap.

6) **Step up Chopper/ Boost DC-DC** Converter is a static device that converts fixed dc input voltage to a variable dc output voltage directly and it is also known as dc-to-dc converter. A DC to DC converter takes the voltage from a DC source and converts the voltage of supply into another DC voltage level.

7) **Bridge Rectifier** is an Alternating Current (AC) to Direct Current (DC) converter that rectifies mains AC input to DC output. Bridge Rectifiers are widely used in power supplies that provide necessary DC voltage for electronic components or devices.

8) **Lithium -ion battery** is made up of lightweight lithium and carbon electrodes and loses charge very slowly when a battery is not used. It requires intensive protection due to the fragile technology used. They have no memory and do not require scheduling to prolong battery life. The self-discharge of Lithium-Ion batteries is less than half that of Nickel Cadmium. It is used to store the DC voltage from the chopper to be given to the load

VII. SIMULATION

Before the simulation, manual calculation of component design values was carried out. The calculated values were used in appropriate design software to test. The Arduino IDE software was used to program the Arduino UNO to interface with an external circuit. Proteus software was used to simulate the virtual circuit and test the program code.

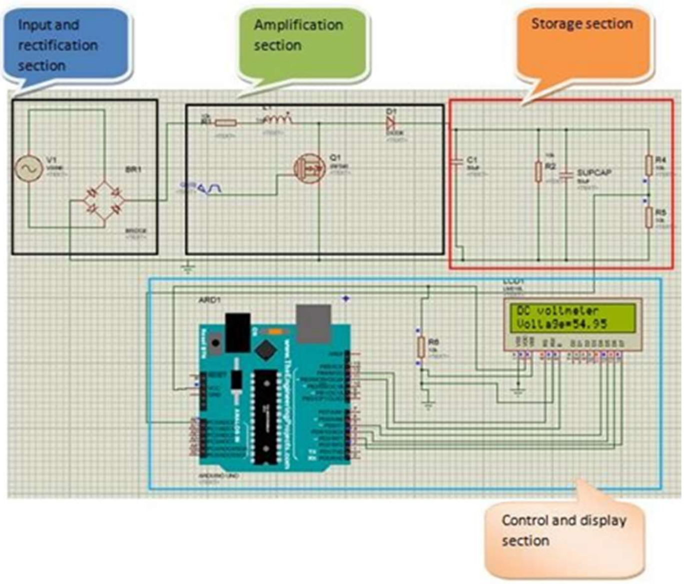

Fig. 10.Circuit Diagram of the system

VIII.ANALYSIS

Comparison of output data from various reference paper and the simulated output data from this research was done and advantages of former is listed below:

8.1 Madhu and Dr. Pardeep have used 72 numbers of series-parallel connected PZT to have better output voltage and to increase the efficiency they have used Priezo battery (rechargeable battery made of nanotechnology) and voltage effectively increased using a boost converter. The output voltage from the model has a voltage of 10-15V and a current of 50-400 microampere [13]

8.2 The journal by Jitha Varghese and Paul Karikottil have used piezoelectric material connected in series and parallel manner and applied weight from either moving vehicles of human movement. Bridge rectifier was used to convert variable AC input from piezo material to linear DC output and stored in a battery. 24V voltage of output was generated directly from piezoelectric material without any amplification circuit [14].

8.3 Kiran and Anumol, made use of the most efficient piezoelectric material; Piezo electric transducers (PZT) and Polyvinylidene difluoride (PVDF) for the generation of electricity from the footsteps. And it was found that the voltage from PZT was around 2V and PVDF was around 0.4V, which proved PZT is better. Weight V/s power graph of piezo tile was plotted and found that maximum voltage is generated when maximum weight is applied, therefore maximum voltage of 40V was generated across the tile when 75kg weight was applied on 30 numbers of series and parallel connected PZT [15].

8.4 Mathane Nitashree and Salunkha concluded that to generate better voltage and current, piezoelectric material like PZT should be connected in series-parallel manner. With the help of 20 numbers of PZT they have generated 40V of output where they have not used amplification circuit [16].

8.5 A journal by Tengku Azita has developed a new source of renewable energy with a low-cost budget with the help of Arduino Uno as the microcontroller to display the amount of voltage generated. The variable force was applied on the 8 numbers of PZT connected in series and parallel manner were for extremely high pressure 8.29Vwas generated as output [17].

8.6 According to Dimpal Hatware Kajal Ladhe, and Rakhi Sontakke research [18], the force applied to the piezoelectric crystal is converted into electrical energy. The fluctuations in the generated voltage and the battery charging are controlled by the Arduino. They found out that series and parallel combination connections gave better output. An output of 5v was produced when pedestrians weighing 50kg when applied pressure on 20 numbers of the piezoelectric sensor.

8.7 Mr. G. Dhanalakshmi has shown that series parallel combination was more suitable for generating high voltage and have produced 40v voltage with high current density. The output was converted into a linear voltage using a bridge circuit converter and stored in a rechargeable battery. The output voltage was displayed in LCD and for this purpose, ARDIUNO UNO was used but no amplification circuit was being used [20].

8.8 Mr. K. Gracy describes the energy of the person or vehicle released during motion can be used to produce electricity thereby saving the energy wasted and also generating green power using PZT piezo material. The piezoelectric crystals were used as the voltage source which generates an alternating voltage of 5V AC out of 8 numbers of piezo material and was followed by a rectifier to convert the alternating to direct voltage. 5V output from PZT was boosted to 11V by passing it to boost converter and was used for higher voltage appliances [21].

8.9 In a journal by Niraj Panthi, piezoelectric crystals we rearranged in 4*4 patterns, the first 4 crystals were connected in series and these sets of 4 crystals were connected in parallel. To prevent the physical damage occurring due to the application of extra pressure, a rubber sheet was used in the crystal panel. They were able to generate 3V voltage while a 50kg pedestrian walked over the arrayed PZT [22].

8.10. Ms.Varshahave also found ceramic lead zirconate titanate, also known as PZT, is still the most commonly used material for piezoelectric harvesting although barium titanate was the first piezoelectric ceramic discovered. The system was developed using a micro controller-based boost DC-DC converter and was able to amplify 3.3V output voltage to 15V with 16 numbers of PZT arranged in series parallel connection [23].

A table of comparison of input AC voltage to output DC voltage from the respective circuit design as described in section VIII (8.1-8.10) has been summarized in table 1. The data presented in the table would be challenged by the proposed circuit design of the project. The simulated parameters from available series, parallel and designed series-parallel arrangement is represented in table 2.

*a) **Comparison of desired parameters from available literature.***

TABLE 1. Input Vs Output voltage from section VIII (8.1-8.10)

Research paper serial number	Input voltage (V)	Output voltage(V)
1	15	15
2	24	24
3	2	40
4	40	40
5	8.9	8.9
6	5	5
7	40	40
8	5	11
9	3	3
10	3.3	15

TABLE 2. Input Vs Output voltage from proposed circuitry

Sl.no	Input voltage (AC)	Amplified output voltage (DC)
1	5	54.95

A graphical representation of the above information is plotted for easy interpretation and decision-making.

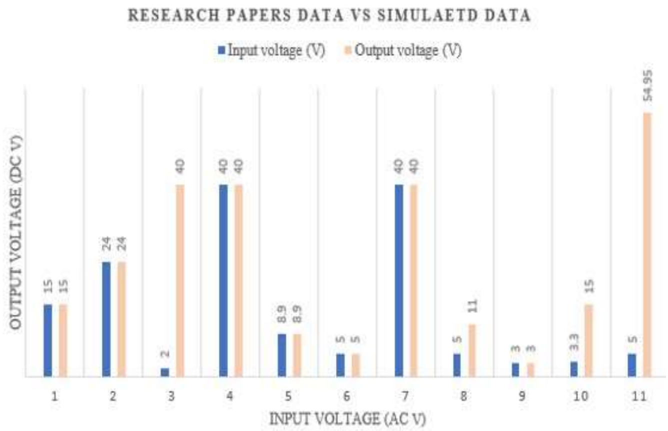

Fig. 11. Graph for comparison between research and reference paper in terms of voltages

The above graph shows a comparison of collected data from ten (10) reference papers by various authors and simulated data from research showing input AC voltage from PZT piezo and output DC voltage. The x-axis represents input voltage in voltage (V) and y-axis represents amplified output voltage (V). The maximum voltage generated from reference papers was 40V with series-parallel connection of piezo. Whereas this research paper uses 5V as the input voltage with the same connection of PZT piezo that is a series and parallel combination and generates up to 54.95V as the amplified output voltage. The increased output generated from this research is evident that the combined arrangement of series-parallel with amplification circuit is better than the output generated from the same arrangement from the referred documents.

b) ***Comparison of desired parameters from various circuit orientation.***

A comparison of Series, parallel and combination of series-parallel arrangement of PZT was simulated and tested to conclude an efficient circuit. The following tabulation was concluded from the simulation:

TABLE 3. Comparison of Series, Parallel and Series-Parallel connection of PZT

Sl no	Orientation of PZT	Number of PZT	Output voltage from Transducer
1	Series	7	5
2	Parallel	10	3.7
3	Series-Parallel	6	5

The comparative table shows the evidence of output voltage being greater and circuit being economically efficient with series parallel arrangement.

Clearly, Parallel is ruled out from being economically sound, because of the requirement of more transducers, to barely meet the output of the other two arrangements.

For the same value of output voltage, i.e 5V, the number of series-parallel arrangements requires fewer transducers. The transducer output is fed into Bridge rectifier with a filter and further to a boost chopper circuitry to achieve an output voltage of 54.59V as represented in table 2. This is a pilot and miniaturized scenario, and on a large scale, significantly reduces cost and working space.

A figurative description of the series, parallel and series-parallel circuitry using PZT can be realized from the figures below.

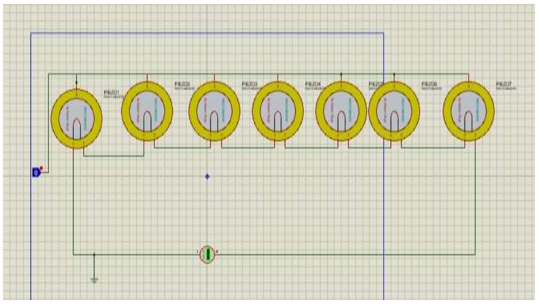

Fig. 12. Series connection of PZT

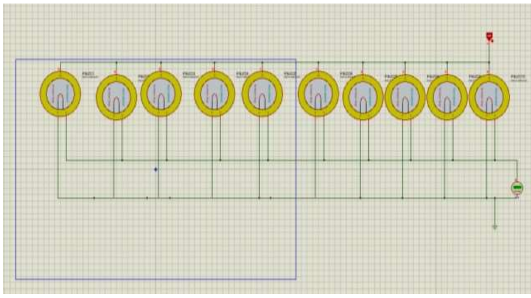

Fig. 13. Parallel connection of PZT

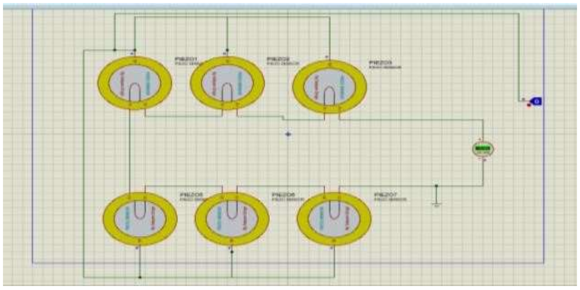

Fig. 14. Series-Parallel Connection of PZT

CALCULATION on several phones batteries (3000mAh), chargeable from a one-time full charge of Li-ion battery.
To charge one phone battery, it will take 4.5V,
= 12 phones.

CHARGING TIME OF PHONE BATTERY (LI-ION)

Charge time (T) = $\frac{miliampere\ hou\quad (mAh)}{ampere(A)}$

Ah = Ampere hour of the battery
T: time in hours.

For example, the general Samsung phone has a battery capacity of 3000 milliampere-hour and the charger use which can supply 2A of current. The charging time is

$$t = \frac{mAh}{A}$$

$$t = \frac{3000}{2}$$

$$t = 1.5 \text{ hours}$$

IX. CONCLUSION

Increasing the output valuation and utility from a PZT, with variable circuit component alignment and power boost has been found as an optimized alternative of power generation from footsteps using Piezoelectric material. The solution and problem statement optimization has been based on usage of Decision Matrix, and research gaps were indicated to be filled with additional boosting of output power from PZT and rearranging the circuit arrangement with the collaboration of series and parallel alignment of PZT

In this proposed project, the piezoelectric transducer particularly PZT is connected in series-parallel manner and this piezo generates AC voltage when pressure is applied to it. As voltage generated from piezo was comparatively low, amplifier circuits were designed for amplification using Bridge Rectifier and DC-DC step-up Chopper. The generated output is used for charging a mobile phone where the maximum voltage required for charging a device is 5V.

The paper also highlighted the output values of d.c power generated from successor projects and the currently modified paper. The result tabulation conveniently concludes, the increased power value of output from this paper compared to its sample studies mentioned. This system will be much effective in crowded places and under static conditions where the pressure and density of footsteps will be significant. The paper presents data and electronic simulated values, under the assumption of static environment conditions and factors.

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