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Analysis of Piezoelectric Energy Harvester System

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ABSTRACT :
Power generation remains an alarming issue in this modern era. Nowadays, despite the presence of a huge number of non-renewable and renewable power sources, we could not satiate our power requirements. The nation is prone to check the daily load shedding schedule like a daily weather report. The extinction of the natural resources for electricity generation and the increasing human population are the major causes of energy crisis. Therefore, this research presents the development of the system that can be benefitted by an increasing human population. The system consists of lead zirconate titanate (PZT) piezo sensors and other components. It works in a way that the kinetic energy applied on piezoelectric sensors (PZT) is converted into electrical power which is then stored in rechargeable battery cells. Later that energy is utilized for domestic application. This piezoelectric energy harvester system can be installed on footpaths where the force produces by human steps could be used for power generation.

KEYWORDS *Piezo sensor, Energy Harvester, Energy Source, Piezo plate*

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I. INTRODUCTION

At present, electricity has become lifeline of human population. Our lives are totally dependent on electricity. Today, 80% of the energy requirements are supplied by fossil fuel, oil, coal, and natural gas [1-4]. These are the non-renewable sources which will run out someday. Also, these sources are not environment friendly as they cause air pollution and are harmful to human health. To bring an alternative solution for generation of electricity, we have worked on the piezo smart roads in which vibrational energy is being converted into electrical energy. This electrical energy lightens the streetlights and nearby homes without supplying power from the grid stations.

In this research, the piezoelectric material is use as medium to develop power. With harvesting energy being one of the firmest techniques in formulating a solution for global energy crisis, here we present our prototype for energy harvesting from road infrastructure. The prototype is designed to show the working of the system in a demonstration environment. Also, to show how to extract a significant amount of energy getting wasted over the roads and sidewalks due to the frictions involved in walking and cars running on roads. The demonstration environment includes the road and its surroundings like pedestrians' sidewalks cars, traffic signals, streetlights, sign boards, few buildings, and houses. The piezo sensors embedded over 2*3 ft area covering the entire environment. It implies that a layer of piezo sensor is also buried under the sidewalk. Not only just vehicles but also the people on feet can contribute much to generating electricity, thus making it a prolific energy harvesting model. The electricity produced by this model is later stored in a battery. The battery can be installed on roadsides, somewhere it could not cause any hindrance to the traffic flow. Later, the output can be manipulated for providing electricity to nearby houses. It is very feasible for the provision of electricity in the remote areas where there is particularly no grid station to supply electricity. The output would suffice for power requirements of traffic light signals to function properly. Also, the streetlights could be turned ON by the generated electricity. The most enticing feature of this design is that unlike solar, we do not need to worry about storing enough energy to charge the battery in daylight so they can work over night. Piezo Smart Road design works well regardless or day or nighttime.

The paper is organized into five sections. Following the introduction, Section II presents the literature review, Section III describes piezo system model, Section IV describes the implementation process, Section V illustrates testing and results of model and finally, conclusion is drawn in Section VI.

II. LITREATURE REVIEW

Few authors define piezoelectricity as charge stored in the material having non centrosymmetric crystal shape by applying mechanical force [5]. While some others explained as a form of interchanging between electrical and mechanical behavior of crystal and ceramics belonging to specific categories [6]. The word 'piezo' is driven from Greek word 'piezein' that is synonym of pressure or press [7]. The word points to the material having piezoelectric characteristics, that generates electric charges on applying mechanical pressure [8]. The piezoelectric effect is further divided into two main types. Direct and Conserve piezoelectric effect. The direct piezoelectric effect was first discovered by Curie in 1880, where the electric charges are produced directly by pressing the piezo material surface. While the conserve or inverse piezoelectric effect was later discovered by Lippman [9] by applying some rules of thermodynamics. It states that piezoelectric material deforms by applying electric field on it.

We already know that the power requirement for the day-to-day work increase as technology use of human being increasing, in such condition the regenerative power sources requirement is an important topic to research the vibration energy harvesting for the regenerative power source. Since the discovery of the piezoelectric phenomenon, much work has been done on it. Many commercial applications were developed, and many modifications were made. Different approaches were adapted to harvest electrical energy by different mechanism. In [10] the author developed piezo tile consisted of 64 piezoelectric transducers with series and parallel configuration to harvest useful energy by footsteps of human. Piezo plate was installed under the speed breaker on road in [11] for collecting electric voltages from movement of vehicles maximum voltages were record 12 voltages. A new pavement system called waynergy was developed with the collaboration of university of Coimbra and waydip company based in Portugal. Waynergy system was made up of several different shapes of piezoelectric material blocks, diode-based rectifier, and boost circuitry. They installed waynergy at the main entrance of university so that maximum footstep can be placed on the system, the maximum voltages observed for this system were 24 volts [12]. Another application of piezoelectric sensor was carried out [13]in which silicone gel was used as to apply pressure on two hundred (200) PZT sensors in order charge lithium battery. Streetlights were provided supply from another harvester system using piezoelectric technique which was composed of piezo plates with strong spring under them as the pressing mechanism on road, Schottky diode-based rectifier circuit, charging circuit, battery, inverter, step up transformer and streetlight as load [14]. In this work [15] piezoelectric energy harvester (PEH) consisted of 1. Piezoelectric units 2. The packaging material 3. The internal circuit boards 4. Sealing fastening components was developed and installed under the road to lighten up the LED display board. Another analysis and modelling of piezoelectric energy harvesting has been carried out in [16] the authors followed basic harvesting energy method with test bench for piezoelectric sensors with AC motor and they performed simulation of rectifier circuit and voltage doubler circuit in proteus software. The author designed the test bench from 15 cm radius of cake plate and attached four wheels with it and at lower layer of plate he connected 8 piezoelectric sensors so that wheels can fully press the sensors and observed 2.471 voltages [17]. In [18] the authors developed footstep generator using 12 piezoelectric sensors on the two acrylic sheets for pressing mechanism in series configuration and observed 13.4 voltages. Another piezoelectric energy harvester was developed from series and parallel combination of 35 piezoelectric sensors on wooden planks and they used LTC 3588 energy harvester in which diode-based rectifier is built in [19]. The mobile phone was charged from piezo shoe consist of 12 piezoelectric sensors on the sole of shoe in the series configuration so from human weight and its motion the electric charges were collected using rectifier as the output from piezo is fluctuated ac further the author used regulator IC L7805 to get regulated 5V and 1A which is sufficient for mobile charging [20]. The author presented the prototype in which one PZT sensor was kept inside of shoe sole and was tested using different weights of human. They added harvester circuit which converts ac into dc and stored dc voltages in capacitor the maximum output, they observed were approximately 5 volts from walking using piezoelectric shoe [21].

III. PIEZO SYSTEM MODEL

The infrastructure of devised piezo-electric platform depends following basic components.

Wooden planks: Two well-furnished wooden planks each having dimensions of 1 square ft constitute the frame of device. One wooden plank embeds the piezo electric sensors that are the core of this project. The sensors are interspersed at the chosen pressure points equidistant from each other so that equal and distributed force is applied on each of them. The other wooden plank holds the metallic pressure dots for pressing the sensors on its inner diameter, so the piezoelectric property could play its part.

Metallic rods: The metallic rods are placed at the 4 edges of the wooden plank. The metallic rods serve as the pillars. They hold the two wooden planks together so they can form a frame. The positions of metallic rods are chosen as the edges to distribute the force over its area.
Springs: We have used 4 springs, with each one of them encompassing a metallic rod. The springs are used to establish a suspension mechanism. The suspension produces the pressure needed for the piezoelectric sensors (PZT) to break the covalent bonds or in other words to deform the symmetry between the ions so that an asymmetric arrangement of positive and negative ions could impart an electric dipole behavior. The dipoles develop the potential difference tantamount to the pressure applied. In other words, greater stress causes the dipoles to move apart so the degree of polarization depends on the stress applied.
Pressure Dots: The pressure dots were fixed at one of the wooden planks in such a way that the piezoelectric sensors (which were arranged in series and parallel configuration on another wooden plank) could be pressed on their center part for maximum output voltage.
Sensors: The piezo electric disc sensors are chosen for this project. A piezo electric sensor job is to respond to the deformation by generating signals as shown in figure 3.1.7 below. The outer diameter of 41 mm holds the piezo electric material and is made from brass. The inner diameter is made up of PZT material. Also, 10mm leads are extended out of it for external connections.
Rectifier Circuit: The flickering alternating voltages obtained are of no domestic use since that would mean a bulb would light up to its maximum intensity at one moment and to a different intensity at the other moment. This would rather give a blinking effect. To make it constant the alternating output voltages obtained from piezoelectric plater were converted into DC with the help of rectifier.
AC Ripple Neutralizer: Though output from the rectifier circuit is unidirectional in nature but it does contain some ripples or pulses in it. It other words the output is pulsating DC. So, to filter out ac components AC ripple neutralizer circuit was used. This AC ripple neutralizer circuit work as voltage stabilizer circuit consisting of capacitor. The output from this stage is saturated DC voltage.
Boost Converter: The DC output received from previous stage is of low amplitude. To increase the voltage amplitude a dc-to-dc boost converter is this stage.
Battery: To constantly supply the voltages, we needed to store voltages in a rechargeable battery. A 9 volts rechargeable battery was used. Which can be charged from the voltages generated from the piezoelectric plate. The output from the battery can be given to dc motors and mobile for charging purpose etc.
Voltage Regulator: The voltage stored in a 9-volt battery could damage the low power appliances which usually work on 3-5 volts. Hence, the voltage regulator was used to get desired voltage.

Figure 1 shows the block diagram of piezo energy harvesting system integrating with all these components together in sequential order.

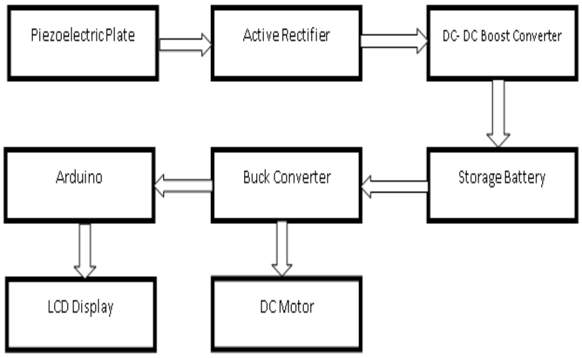

Fig 1. Block diagram Piezo system

IV. IMPLEMENTATION

Two connections were implemented, the parallel and series connections. The parallel connection did not signify any augment in the voltage output so, the series connection was tried. Additional piezo sensors in cascade resulted in a rise in voltage output but the output was not linear. Later, the hybrid connection of both parallel and series connection was implemented. It resulted the output voltage augment to 40V with an increase in current as well. This series-parallel interconnection is called as the grid network. The pressure applied on the sensor and the voltage generated are examine and figured out to possess a linear relation.

Right after designing piezo mechanism for extracting voltages, a precautionary circuit is designed to mark the devices safe from any kind of damage. Two voltage regulators of different specifications were used according to the desired application. LM7809 is used to convert the 30-40 V obtained from the harvesting circuit to 12 V. This voltage is later reduced to 4-5V to be fed to the loads without damaging them by sufficiently high voltages.

The output from the voltage regulator is given to the loads to charge devices like mobile, ipod, tab, mp3 devices and charger light etc. Figure 2 shows the complete mechanism of piezo harvester model.

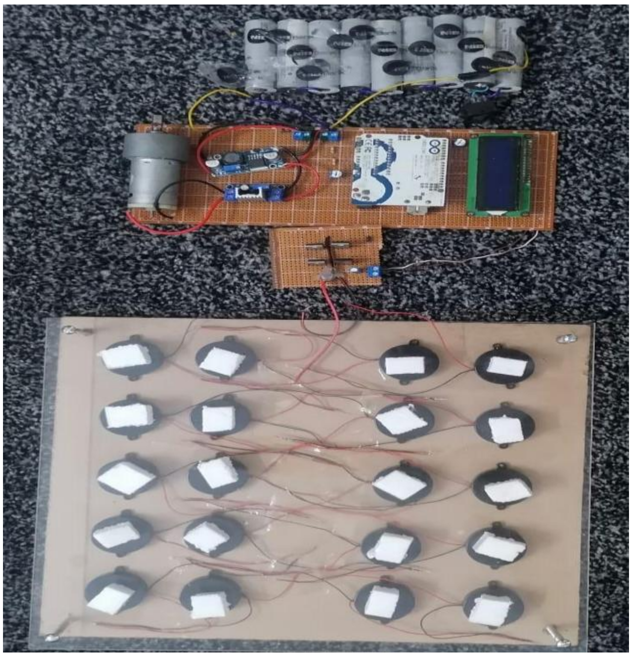

Fig 2. Complete Setup of Piezoelectric Energy Harvester System

V. RESULTS

The project underwent series of testing phases during the implementation. The mechanism was tested after adding each stage to the prior circuit.

Testing at 1st Phase: The initial trial was testing the type of connections for which the maximum output can be attained. We first tested for the parallel connection and arranged the piezo sensors in a single column. The generated voltage and currents values were noted.

Testing at 2nd Phase: In the second phase all the piezoelectric transducers were connected in series configuration. The output current and voltages were measured by applying force on the sensors. It was observed that. in series connection a good voltage level is attained, but the current rating was very low. While in parallel connection good current level was obtained but at the same voltage generated were very low. The figure 3 shows the output current and voltage of both series and parallel connection.

Testing at 3rd Phase: The third test was performed on hybrid setup by combining both series and parallel configuration and we observed maximum voltage and current at output. The relationship is depicted in the chart below.

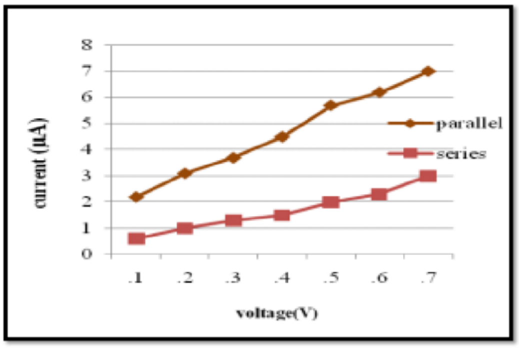

Fig. 3 Series and Parallel Output Ratings

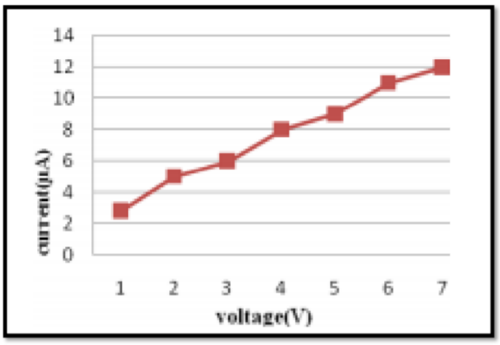

Fig. 4 Series-Parallel Output Ratings

VI. CONCLUSION

With a deceasing number of natural resources day by day, our posterity would need a selfsustained power generation system. The steady flow of vehicles on roads makes the system more superior. Meanwhile the green nature of this system makes it echo friendly, its nonchalance towards the atmospheric conditions because of being unaffected by it makes it more efficient. Piezo Smart Road generated electricity can be supplied to traffic signals, charging stations near smart roads and streetlights. The system has long term benefits and adds much to a county's economy by limiting the cost of energy production.

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