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Power in Every Step: A Piezoelectric Staircase Solution

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ABSTRACT

Coal, along with other fossil fuels, is still the major source of power generation. However, with a rapid consumption speed, these fossil fuels will be exhausted in the future. Also, the use of fossil fuels for power generation causes air pollution and the greenhouse effect. So, to deal with these problems, we need a greener solution. This project mainly aims to build a power generator using the piezoelectric sensor. The sensor converts the pressure into an electrical charge. When pressure is applied to piezoelectric sensors, an electric charge is generated. This generated output in the form of alternating current (AC) is then converted into Direct current (DC) to store for further use. This generation technique can be used in more vibration-producing areas, mainly staircases in public places (like railway stations), for lower power applications.

Keywords: *Sustainable Power Generation, Piezoelectric Staircase, Footstep Energy Conversion, Smart Cities, Energy Storage and Utilization*

1. INTRODUCTION

In today's world, the demand for the sustainable energy sources is keep on increasing. The available renewable energy sources are solar, wind and hydropower. An another technique of power generation has come. This the piezoelectric power generation. Due to increasing population and the increasing demand for energy, the fossil fuels are at the merge of exhaustion. Proposing this piezoelectric staircase project can be the best solution for this problem. This project paves a way for the utilization of energy of foot power of the humans in highly populated countries like India. In these countries railway stations and other public places are crowded all time. When the staircase of such public places are engineered with piezoelectric technology, the electrical energy can be generated from the pressure produced due to pressure of the footsteps of humans. This energy can be stored and can be used for applications like lighting and energy source for sensors. This research paper is about the generation of electricity form the human footsteps. So main principle is converting the kinetic energy into electrical energy. Piezoelectric power generation is more suitable for using in cities, and because it is almost unaffected by climate and weather, it can be applied throughout a whole nation. Piezoelectric power generator can be integrated with buildings, not affecting landscape and not occupying extra area and space. During this conversion of mechanical energy to electrical energy, there is no emission of harmful gases or any heat. So this type of piezoelectric power generation is a green power generation without any harmful effect to the environment.

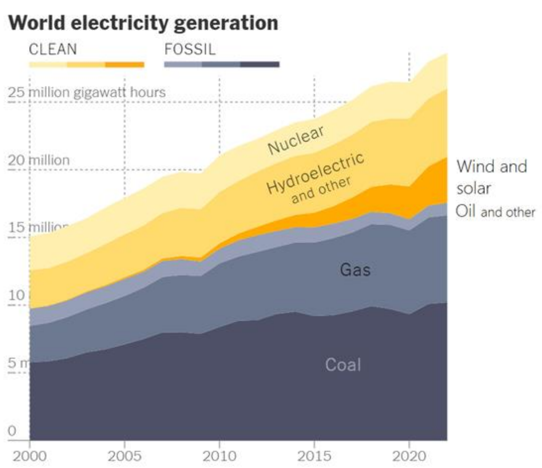

Fig.1.World electricity generation from various sources

2. PIEZOELECTRIC EFFECT

A phenomenon known as the piezoelectric effect occurs when mechanical stress is applied on specified piezoelectric materials, it produces an electric charge. There are two process of this phenomenon: the direct piezoelectric effect, which results in production of electric charge when mechanical stress is applied and the inverse piezoelectric effect, which results to mechanical deformation when an electric field is supplied. This power generation which is specified in this paper is based on the direct piezoelectric effect. In a piezoelectric staircase, the mechanical force exerted by pedestrians when stepping on the stairs transmits pressure to piezoelectric transducers which are embedded in the steps. Charges get accumulated on the electrodes due to the displacement of electric dipoles within the piezoelectric material, caused by this stress. So the electric charge now produced is in the form of alternating current (AC). To convert alternating current (AC) into direct current (DC), the resulting voltage is collected, rectified, and stored for later use.

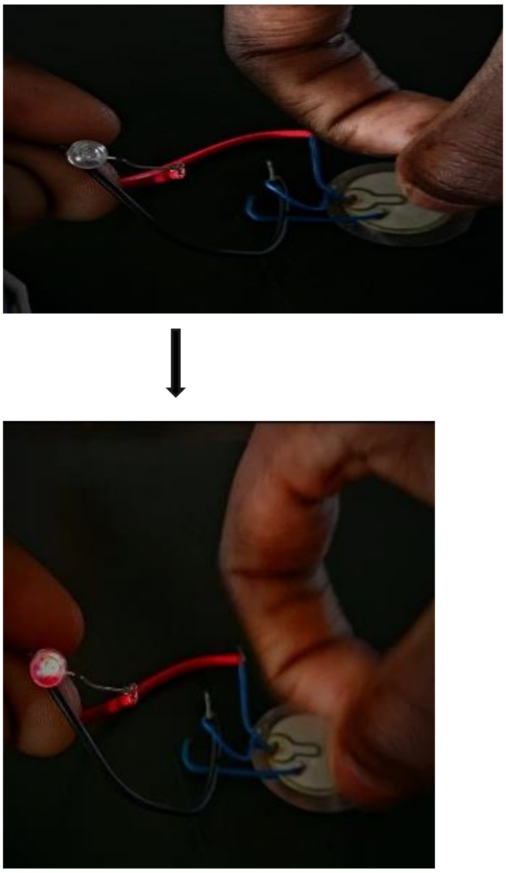

Fig.2.Figure depicting the current generation from the piezoelectric sensor

The type of piezoelectric material used such as polyvinylidene fluoride (PVDF) or lead zirconate titanate (PZT), the amount of force applied, the frequency of footfalls, and the structural design of the staircase all influence how efficiently energy is converted. This harvested energy can be used for power applications like LED lighting, sensor activation, or mobile charging by carefully arranging several piezoelectric devices across the staircase.

3. ELEMENTS OF PIEZOELECTRIC POWER GENERATION UNIT

The elements of the piezoelectric power generation unit mainly contains piezoelectric sensors, rectifiers, lithium ion battery and inverter.

3.1. Piezoelectric sensor

A piezoelectric sensor is a device that uses the piezoelectric effect to measure pressure, acceleration,
strain or force by converting them to an electrical signal. Piezoelectric sensors have proven to be versatile tools for the measurement of various processes. They are used for quality assurance, process control and for research and development in many different industries. It was only in the 1950's that the piezoelectric effect started to be used for industrial sensing applications. Since then, this measuring principle has been increasingly used and can be regarded as a mature technology with an outstanding inherent reliability. It has been successfully used in various applications, such as in medical, aerospace and nuclear instrumentation.

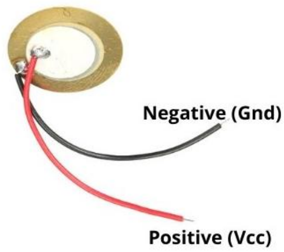

Fig.3.Piezoelectic sensor

3.2. Rectifier

A diode bridge rectifier transforms the AC signal into direct current (DC) so that the energy can be used. The majority of electronic equipment need a steady DC power source, hence this is required. However, there may still be voltage ripples or oscillations in the rectified DC signal, which could compromise the

stability and effectiveness. A capacitor or a voltage regulator circuit is used to reduce these oscillations.
The capacitor helps to steady the voltage by temporarily storing excess energy. Regardless of changes in the input energy, the voltage regulator makes sure that the output voltage stays constant, guaranteeing that the energy is reliable and useful.

Fig.4.Bridge rectifier diode

3.3. Lithium ion battery

A Lithium-ion battery is defined as a rechargeable battery that utilizes lithium ions moving between electrodes during charging and discharging processes. These batteries are commonly used in consumer electronics due to their high energy density and long cycle life. They also have a low self-discharge rate, which means it can store their charge for a long time even when not in use. Lithium-ion (Li-ion) batteries are used in many products such as electronics, toys, wireless headphones, handheld power tools, small and large appliances, electric vehicles and electrical energy storage systems.

Fig.5.Lithium ion battery

3.4. Inverter

An inverter is an electrical device that converts direct current (dc) to alternating current (ac); the converted ac can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply ac power from dc sources such as solar panels or batteries. A pure sine wave inverter produces a nearly perfect sine wave output (<3% total- harmonic distortion) that is essentially the same as utility-supplied grid power. Thus it is compatible with all ac electronic devices. The inverter performs the opposite function of a Rectifier.

4. METHODOLOGY

When the pedestrians walk on the staircase integrated with the piezoelectric tiles, the piezoelectric material experiences vibrations. When the target infrastructure experiences stress, the embedded sensors generates electrical charges by converting the mechanical stress or pressure into the electrical energy. This process is

called as the piezoelectric effect, which is converted mechanical energy into electrical energy. The electrical charges generated by the piezoelectric sensors are stored in the lithium ion battery for future consumption. The charge accumulation process is facilitated by the voltage regulator circuits. The accumulated electrical energy is then utilized to power various applications like mobile charging, streetlights etc. The piezoelectric power generation system is equipped with control and monitoring to prevent system failures. By this methodology, the mechanical energy of the footsteps of the pedestrians is converted into electrical charge.

The below figure Fig.5. depicts the proposed prototype of the piezoelectric power generator.

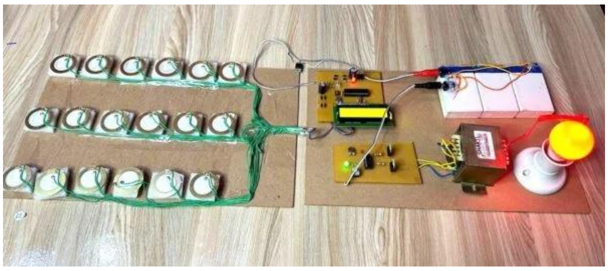

Fig.6.Prototype

5. BLOCK DIAGRAM

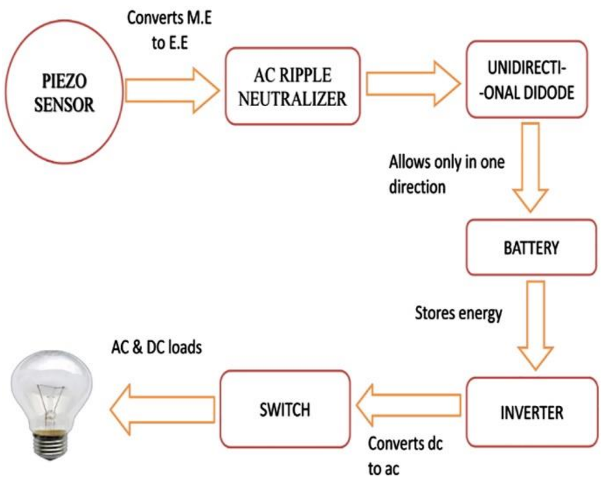

Fig.7.Block diagram of the piezoelectric power generator

6. EQUATIONS

In a piezoelectric cymbal transducer-based energy harvester, the direct piezoelectric effect is considered, and polarization occurs on the vertical surface of the PZT

material. The mathematical relation between piezoelectric polarization of the cymbal transducer and stress due to mechanical vibration is expressed as,

$P3=\sum d3iTi$

where P3 is the piezoelectric polarisation in the 3rd principal direction, d3iis the piezoelectric strain constant, and Ti is the stress tensor.
The initial electric field generated in PZT can express as,

$E3=\sum g3iTi$

The PZT patch polarization generates the voltage that can be calculated from the following equation,

V3=∫E3dtp

The power output of the piezoelectric based energy harvester is expressed
as,
U3=1/2P3E3Atp

7. RESULTS AND DISCUSSION

Piezoelectric power generating experiments have produced interesting findings, especially when considering material characteristics, system architecture, frequency response, and ambient factors. For example, in order to evaluate the generated voltage, several piezoelectric materials were tested under mechanical stress, such as bending and compression. The highest voltage output was shown by lead zirconate titanate(PZT), which produced a peak of 12 V from a single PZT under the bending stress.

Zinc oxide (ZnO) and barium titanate ($BaTiO_3$) yielded lower outputs, 1.5 V and 3 V, respectively. PZT's greater piezoelectric coefficients are responsible for this notable difference, yet its brittleness and expense continue to be major disadvantages. A study of a piezoelectric harvester exposed to vibrations at 50 Hz (the material's resonance frequency) produced a peak power output of 0.8 mW for vibration-based systems. When exposed to non-resonant frequencies, the device's power output dropped dramatically (to about 0.1 mW), highlighting how crucial it is to adjust the device to match the source frequency. With a maximum power production of 0.3 mW during

active footsteps, this system produced enough energy to run the sensor continuously for up to eight hours. Piezoelectric energy harvesting's limits in terms of scaling up for higher power demands are highlighted by the fact that the total energy generated was only adequate for low-power devices.

Table-1: Voltage description

S.No	PRESSURE(Pa)	VOLTS(V)
1.	10	0.012
2.	20	0.094
3.	50	2.300

The following graph depicts the power produced due to a wide range of weights:

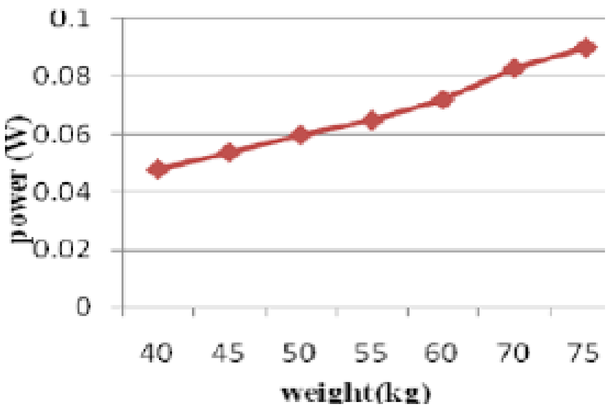

Fig.8. Graph of weight vs power produced

8. CHALLENGES AND FUTURE PROSPECTS

While the Piezoelectric Power Generation Project shows immense promise, it also faces certain challenges. One of the primary obstacles is achieving optimal efficiency in converting mechanical energy into electrical energy. Researchers are actively exploring novel piezoelectric materials and engineering techniques to enhance the power generation capabilities and improve overall system efficiency. Additionally, the project requires significant investments in infrastructure and widespread implementation to realize its full potential. Collaborative efforts among governments, research institutions, and private industries will be vital in realizing large-scale deployments of piezoelectric power generation systems. The Piezoelectric Power Generation Project represents a remarkable step towards the future of sustainable energy. By harnessing the power of piezoelectricity, we can transform our surroundings into active energy generators, reducing our carbon footprint and promoting a cleaner environment. With continued research and development, this innovative project has the potential to revolutionize the way we generate and consume energy, bringing us closer to a sustainable and greener future.

9. CONCLUSION

This paper introduces a new method of using a piezoelectric staircase to generate sustainable energy. The potential to capture mechanical energy from human motion and transform it into electrical energy is effectively demonstrated by the suggested device. Results from experiments confirm the concept's viability while pointing out its benefits and drawbacks. Even though the current implementation is a proof-of-concept, more study and development are required to increase economic feasibility, scalability, and efficiency. Energy sustainability and smart city efforts can benefit from the incorporation of such technologies into municipal infrastructure. The advantages of piezoelectric power generation are compelling. By converting kinetic energy into electricity, we can power public spaces, streetlights, and even charge electric vehicles, making our cities more sustainable and energy-efficient. Moreover, this technology offers an opportunity for decentralized power generation, reducing transmission losses and enhancing energy resilience. However, the Piezoelectric Power Generation Project also faces challenges. Enhancing the efficiency of energy conversion, optimizing the design and placement of piezoelectric materials, and scaling up the implementation are areas that require further research, development, and collaboration among researchers, engineers, and policymakers.

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