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Development of an Alternative Energy Harnessing System using the Piezoelectric Effect

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Abstract: ***In order to meet the growing demand for global consumption, a new form of renewable, green and clean energy is needed to meet societal needs. The reduction of fossil fuels can only be made possible by newer green energy projects. This article aims to provide an alternative energy source through the use of piezoelectric material. The piezoelectric effect is the most important principle behind the piezoelectric material. It collects the waste energy generated on the highway by moving vehicles to obtain renewable, sustainable energy. It also provides a feasibility study of electrical generation from piezoelectric generators embedded on a highway in the asphalt surface. The energy generated can be used to power street lamps and can be fed into the grid in the future.***

Keywords: Smart roads, piezoelectric material, road power generation, asphalt layer, energy harvesting, piezoelectricity, electric roads, ceramics, piezoelectric effect, sustainable energy.

I. INTRODUCTION

Today, electricity is the lifeline of today's civilization, so its demand is enormous and continues to grow. Energy consumption per capita is of 1200 KWHR in India. A survey on energy consumption in India published disastrous reports that electricity is not yet available in 85,000 villages in India. From time to time several attempts have been made by human to find alternative sources for the generation of electricity. Alternative energy sources are becoming more and more important as fossil fuels are depleted and the environment is damaged. Energy requirements and traffic conditions facilitate the construction of roads and generate energy from vehicles that cross the road. This article explains the concept of harnessing the vehicle's wasted kinetic energy. The kinetic energy is the result of speed and mass of the vehicle which is in the form of vibration. This energy is then delivered to street lights, traffic lights, and homes. In this way, energy requirements can be minimized and greenhouse gas emissions can be reduced. Piezoelectric devices are used for harnessing energy from roads and walkways. In our study, IOT was used to set up a light pole intensity control system. This system controlled the intensity of the lamppost as a function of time. In addition, an approximate calculation and actual implementation are shown in our article to erase the basis of the proposed theoretical idea.

II. LITERATURE SURVEY

Several designs are being proposed and utilized for energy harvesting mechanisms in different places in the world. Reference [1] proposed a technique for collecting energy using a piezoelectric device. The device is working due to vehicle stress. They represented instrument dimensions as 30 cm × 30 cm × 9 cm. Universal Testing Machine is used to measure the performance of the energy harvester.

They have used a model called Third-Scale Model Load Simulator that harvests in lab-scale as it applies load which is similar to actual traffic loads. In their experiment, they concluded that load is inversely proportional to the frequency.

Reference [2] emphasizes the method of harvesting energy using windmills, solar panels, kinetic energy, etc. The author has used a piezoelectric sensor to produce electricity on the road. When pressure is generated on the piezoelectric sensor, it converts mechanical energy into electrical energy.

This piezoelectric power sensor, placed under roads or lanes, generates electricity when vibrations are created. With the help of a piezoelectric sensor array, they proposed a system known as an “energy vehicle”.

Reference [3] studies Piezoelectricity as an alternative renewable energy source. The paper explains the different vibration sources of piezoelectric crystals and their working. With the latest development in MEMS and wireless technology, this technology has achieved increasing attention, allowing it to install sensors in remote areas and function at very low power. Through the paper, the author has offered two new approaches to generating piezoelectric energy. The document presented the concept of a piezoelectric windmill that solves the problem of the continuous discharge of microcells in equipment used in remote locations or difficult terrain. The notion of merging two electricity sources piezoelectric strength and electromagnetic strength has been shown in the paper.

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III. METHODOLOGY

A. What is piezoelectric material?

Piezoelectric crystals are materials that have the ability to generate electric charge from applied mechanical stress as shown in fig.1. The term piezo is Greek for "push". When the pressure of vehicles or strain applied to piezoelectric materials results in voltage generation. This resulting voltage can be as high as several thousand volts. They also have a unique property of generating pressure when voltage is applied.

Some examples of piezo materials are barium titanate, lithium niobate, quartz, Rochelle salt, topaz and lead zirconate titanate.

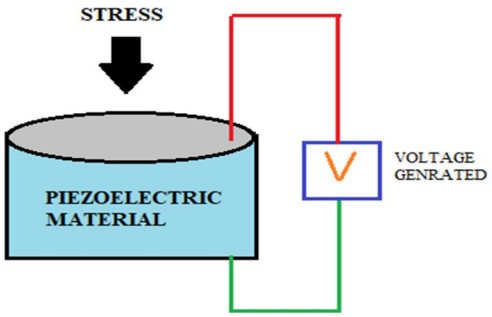

Fig.1. Working principle

B. Construction of Piezoelectric Road

1) A base layer initially consists of fine sand and gravel.
2) A layer of asphalt is laid to give the generators a stable and steady base.
3) As per the design, the piezoelectric generators are left for 30 min in a quick-drying concrete
4) To attain higher voltage, the piezoelectric generators are arranged in a non-parallel manner to get combined output.
5) Placing a bitumen sheet that covers the generators ensures a better bond of concrete to asphalt.
6) Finally, a thick layer of asphalt is applied to complete the construction.

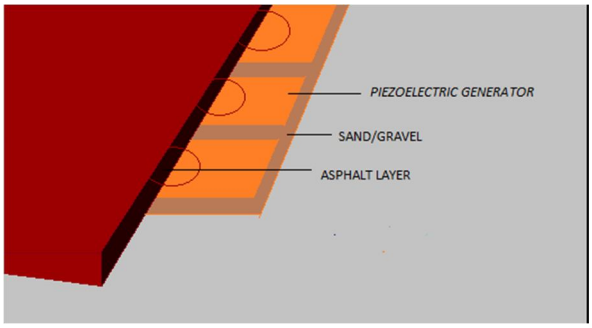

Fig.2. Construction of piezoelectric road

C. Factors Affecting Piezoelectric road

The following factors are responsible for altering the competence of a piezoelectric road.

1) *Vehicle speed*: Power is directly proportional to speed. A higher speed has a strong effect on the vibrations of the piezoelectric material, which leads to higher output power. Thus energy generated on a highway will be greater than energy generated on a normal road.
2) *Vehicle weight*: Deformation of piezoelectric material is directly proportional to the weight of the vehicle resulting in high power output. Thus a heavy weight vehicle (for eg. Truck) will generate more energy than a light weight vehicle (for eg. Motorcycle)
3) *Traffic flow capacity*: It is considered that the piezoelectric system must be used on busy roads instead of roads where the traffic rate is very less. This will make sure that the frequency of vehicles exerting the pressure will be more.
4) *Dimension of road*: The size of the road determines the number of piezoelectric generators integrated beneath the surface of the paved road. Since the piezoelectric generator is directly proportional to the output power, the greater the piezoelectric generator, the greater the output power.

D. Working

The flowchart above shows the overall operation of the proposed system. Piezoelectric generators are incorporated to a depth of about 5 cm in the zone of maximum pressure. These piezoelectric converters get their power from the mass of the vehicle and the kinetic energy caused by moving vehicles. As the surface of the asphalt road is flexible, the vibrations caused by contact between the tire and the surface of the asphalt road are given as an input source for energy. The "piezoelectric generator" block absorbs the pressure from mechanical energy and generates electrical power(AC). Rectifier block is used to convert power into DC power output. Piezoelectric transducers are made up of rectifier blocks and piezoelectric generators. A DC to DC power conversion is done by using a DC boost converter. It increases the voltage supplied by the piezoelectric generator as an input. Direct current is now supplied by the booster as an input to the inverter, which converts it to alternating current before it is sent to subsequent transmission.

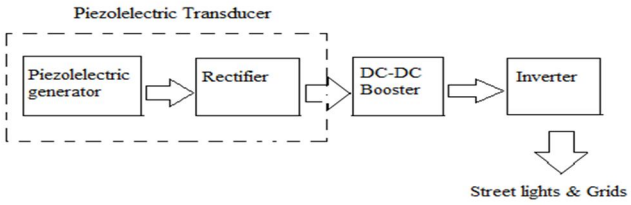

Fig 3. Process flow diagram

IV. ANALYSIS AND RESULT

Vehicles passing on the road are subjected to the effects of vibration. These vibrations are converted to electrical energy using a piezoelectric plate embedded in the road below. The vibrations are dependent on factors like speed, the weight of the vehicle and the dimension of the road.

Rolling resistance of the wheels is calculated by

$F_r = N_f \times C_r = m \times g \times C_r$

N_f – normal force. C_r -coefficient of rolling friction(varies between 0.03-0.15).

Power required to compensate the rolling resistance is P_r.

$P_r = F_r \times v$

v is the speed of the vehicle.

t is the time taken by a vehicle to pass over piezoelectric road.

$t = l_p / v$

l_p- length of piezoelectric generator road.

The mechanical energy generated from each vehicle's impact is calculated as integral of power over time.

$U_{in} = \int P_r \, dt$

Co-efficient λ is 0.078 according to [7] for the efficient energy conversion.

$\lambda = U_e / U_{in}$

U_e is the power generated per vehicle.

Based on the above calculation, the figure shows the real-time simulation between the energy generated and the generated voltage which varies with the external load in case of one-way traffic. The output power and voltage depend on the piezoelectric plate for each unit which is placed beneath the road. It is observed that 250 two-wheeler vehicles at a speed of 60km/hr pass the road within 5 seconds. The overall output of power generated and the mean voltage generated is about 32mW and 22V as shown in the figure. Assuming a similar number of vehicles, the proposed 24-hour performance is 72.5 watts per unit per plate.

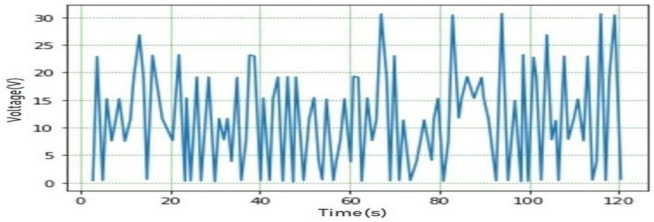

Fig 4. Voltage-Time graph of a one-way road

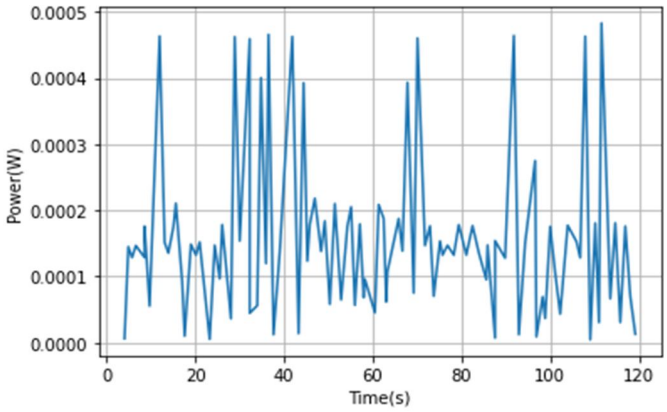

Fig 5. Power-Time graph of the one-way road

V. STORAGE SYSTEM

Since public lights only work at night, it is necessary to store the energy generated during the day. The selection of the system for energy storage depends on the energy produced and its usage. Supercapacitors and Rechargeable batteries are typically used for storing electrical energy generated on a highway by a piezoelectric generator. However, with the advancement of supercapacitors, studies have shown that supercapacitors are better suited to piezoelectric science than rechargeable batteries.

VI. CONCLUSION

The paper illustrates the generation of green and sustainable energy. Energy harvesting from the embedded piezoelectric generator is an attractive technology that can harness the excess energy wasted on the highway caused by moving vehicles. With the increasing number of vehicles day by day, the presented system can be beneficiary and instrumental to produce a considerable amount of electricity. In the case of a highway, having a traffic rate of 2000vehicles/hour it is possible to harvest up to 800kW/km of electric power. The accumulated energy can be used to power traffic light or street lamps and in the future could be routed into a grid. In addition to that, charging stations for electric cars can be constructed. The results of this paper are useful rules for future models and their physical execution.

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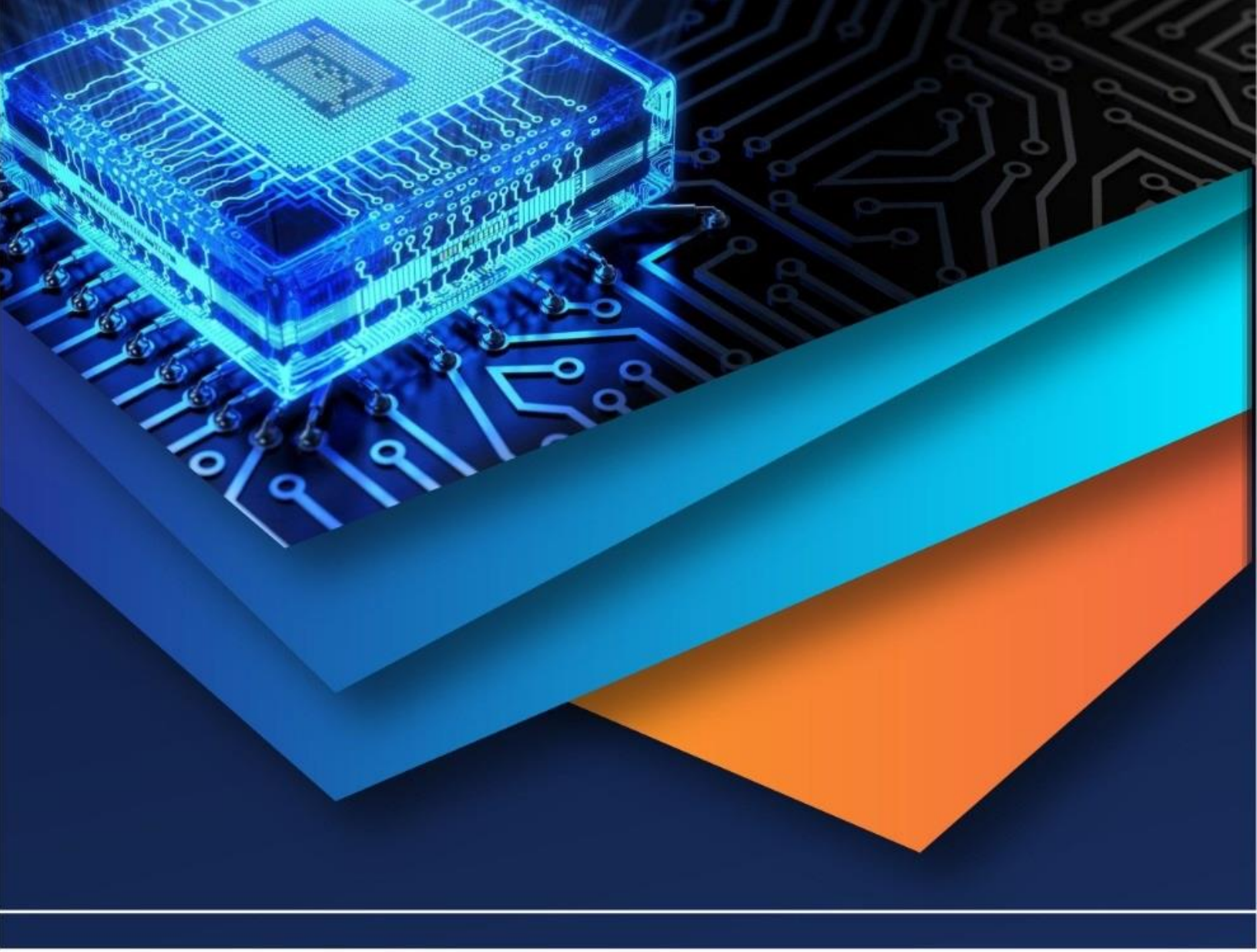

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