# Design and Analysis of Rotational Machinery System for Harnessing Vehicle Vibrations on Roadways for Energy Harvesting Applications

Migara Karunarathne
*Department of Electrical Engineering*
*SLTC Research University*
Padukka, Sri Lanka
migarak@sltc.ac.lk

Ruwan Jayakantha
*Department of Electrical Engineering*
*SLTC Research University*
Padukka, Sri Lanka
ruwanj@sltc.ac.lk

Chamith Chandrarathna
*Information and Communication System-on-chip(SoC) Research Center*
*Kyung Hee University*
South Korea
chamithc@sltc.ac.lk

R.A. Sahan Dilanka
*Department of Electrical Engineering*
*SLTC Research University*
Padukka, Sri Lanka
sahand@sltc.ac.lk

Mishel Anjalika
*Department of Electrical Engineering*
*SLTC Research University*
Padukka, Sri Lanka
meshela@sltc.ac.lk

***Abstract*—Energy is a fundamental determinant of our quality of life, and our modern lifestyle depends heavily on it, yet the resources used for generating it are depleting rapidly, leading to an energy crisis. The vitality of this arises as fossil fuels are being overconsumed, which makes it challenging to provide sufficient power in the next era as an effect of a growing population. To address this issue, numerous research work is being conducted on renewable energy sources. However, certain unconventional methods, such as renewable energy formed from objects in motion, various vibrating machines or any other source of mechanical energy have yet to be fully explored. Hence, this source of energy is dispersed and thus wasted.**
**In response to this challenge, we have developed an innovative energy harvesting system, designed to capture energy from moving vehicles as they move on roadways, particularly when passing over speed bumps. Our approach mitigates some of the significant limitations found in earlier systems and presents novel solutions to these issues. Remarkably, the system can achieve 720 J energy with only 66 passing vehicles, providing an efficient means of energy storage. The system will be able to store power which could be used for street lighting in both urban and rural areas, road signs, and various other essential road-related devices. This abstract outlines the development of this energy harvesting system, its applications, and its significant potential to transform the energy landscape**.

***Keywords—Energy harvesting, mechanical, converter, gear wheel***

## I. INTRODUCTION

### A. Background and Significance

One of the most important resources that determine the quality of life is energy. The search for a new energy source has been a key problem for today's civilization, given the limited fossil energy available for the next century [1]. Oil, gas, and coal may continue to exist for the next several decades [2] . To meet the expected energy demand as the population rises and to sustain economic growth, alternative forms of energy such as renewable energy needs to be expanded [3]

The term Energy Harvesting or Renewable Energy, is a method of producing electrical energy by utilizing the energy surrounding the environment from the sun and wind, for example. [4] Energy harvesting techniques are emerging as environmentally friendly energy sources, which form a promising alternative to existing energy resources [5]

However, apart from the various known methods, renewable energy formed from various vibration machines, objects in motion, or any other source of mechanical energy is not being captured. Therefore, this source of energy is dispersed and thus wasted. [4]. In this sense, numerous researchers are working on technologies for renewable energy harvesting and exploring increasing the energy harvesting efficiency of the energy harvester system. [6]

A large amount of kinetic energy is wasted in the form of friction and heat when vehicles pass over the speed bumps and it can be converted into electrical energy in different ways [7]. On the road, pressure has a wider range of force recovery options. As a result, this technology uses the force generated by road bumps as a new, alternative renewable energy source. [8]

An electromagnetic renewable energy harvesting system is a mechanism of harvesting energy from moving vehicles on the road designed to be installed under the road surface This system uses both mechanical and electrical components to generate electricity.

The project aims to design a sustainable, cost-effective solution for the utilization of waste energy from vehicles passing over a speed bump, which is much relevant and important as the number of vehicles is rapidly increasing day by day. The process is modeled and simulated using a vehicle track force, gear wheels, and the motor to convert rotational energy into electricity, a converter to increase the voltage and a supercapacitor bank with 12V, (720J)

The output is a variable current due to differences in the type of motion, therefore, a full-wave rectifier is used to convert the current, which is alternating in nature to unidirectional D.C current that can be stored and used in multiple ways. The generated power will be stored in a 12V supercapacitor bank, which is practically useful for supplying safety signals, streetlights, automated ticket machines at road bumpers, and other systems on the road, which requires power that the proposed energy-harvesting system has the potential as a renewable alternative energy source.

### B. *Literature Review*

In recent years several research works have been carried out on road-based energy harvesting using different mechanisms. Several review articles, publications, and product prototypes have been published on this topic covering a wide variety of mechanisms and techniques [5]. Within the electronic energy harvesting field, piezoelectric, pyroelectric, and triboelectric energy harvesting have attracted the most research attention.

Piezoelectric materials are widely used to generate energy to power low-energy-consuming equipment. A system was made to generate voltage ranging from 400 to 700 v under a traffic volume of 4000 vehicles per day. using multiple cylindrical piezoelectric elements. The corresponding power output was obtained, yielding a power range between 0.08-2.1 Watts per system. [8]

Another paper has developed an energy harvesting system based on piezoelectric elements embedded into the pavement structure. It involved numerical modeling of the stress distribution in the power generation module and economic analysis of the value of the electric power generated, under a given traffic composition scenario. [9] Subha [4] illustrated the streetlight glowing system on vehicle detecting movement and the functionality of piezoelectricity in roads to utilize energy executed from the moving vehicles. Electromagnetic energy harvesting systems capture energy from subtle structural movements, like vibrations in roads and buildings, by converting kinetic energy into electricity through the interaction of magnets and coils. Numerous studies have explored this method of converting motion into electrical power through electromagnetic induction [10].

Padma Rao developed a system of the rack and ratchet (pinion) mechanism which is used to develop the power from speed breakers with the potential to generate approximately 0.98 kilowatts of power when a 1,000 kg vehicle ascends a 10 cm high speed-breaker [11]. *Jassoja* presented a system by using a sliding plate mechanism aimed at harnessing wasted energy from road tire friction caused by increasing vehicle traffic. This system effectively converts this frictional energy into usable electrical power. [12].

[10] X. Zhang developed a renewable energy harvesting system using a mechanical/track vibration rectifier (MVR) for railroads.

## II. Methodology

### A. *Working Mechanism*

In order to regenerate maximum energy, a highly efficient energy conversion mechanism is designed as shown in (Fig.1). The project's core mechanism resides within the road bumper. As a vehicle passes over the speed bump, it imparts a downward force upon the top plate of the system, initiating the energy conversion process.

This force triggers the downward motion of a pinion rack, which is connected to an axial shaft. Two gear wheel systems are parallelly connected in this shaft: one with a higher number of teeth (44) and another gear wheel with a higher ratio, connected to a chain and a driven gear wheel on the opposite side.

In order to maintain a continuous and consistent motion within the mechanism, a flywheel is incorporated. Additionally, a ratchet-type bearing is used to get the pinion's unidirectional motion,

The flywheel serves as an energy reservoir, storing rotational energy to ensure smooth and uninterrupted operation even when vehicles pass intermittently.
The driven wheel, now synchronized with the rotational energy generated from vehicle movement, is directly linked to the motor and outputs an AC voltage. This AC voltage is subsequently converted to DC by an AC-to-DC converter. A boost converter increases the voltage and the increased voltage is sent into supercapacitors and store the energy. In addition, capacitor stored generated voltage status can be measured by an Android phone.

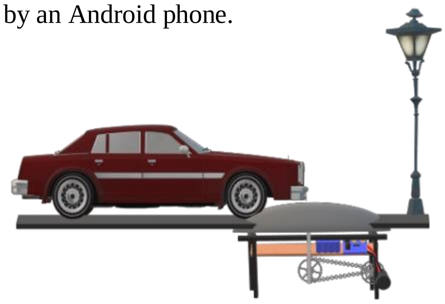


Fig. 1. Project application overview

### B. *System Design*

#### 1) *Structure*

The upper iron plate is intended for use as both a road surface for vehicles and as a method for regulating their speed while they are on the road. Gear wheels are mechanical devices used to transmit power and motion from one part of a machine to another. The rack and pinion mechanism consists of a linear gear(rack) and a rotating gear (Pinion), which is commonly used to convert rotary motion into linear motion or vice versa, such as in steering systems for vehicles. Rubber rollers help to keep the linearity when the rack and pinion go down. The flywheel acts as an energy reservoir, providing stability, smoothing out variations, and helping to ensure that the system operates consistently and efficiently. Chains in combination with gearwheels are a versatile and reliable means of transmitting power, adjusting speed and direction, and ensuring robust and efficient mechanical operation in a wide range of applications.

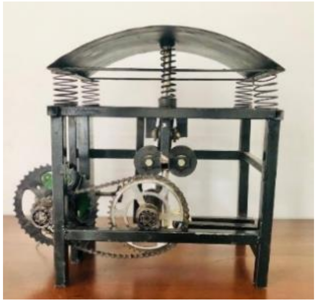
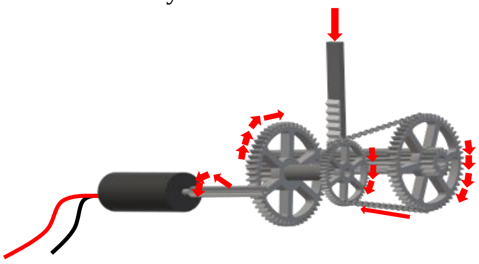


Fig. 2. Structural development

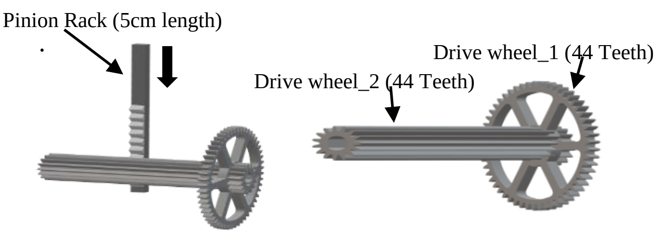
As soon as the car's front wheel passes by the top iron plate, it will recover to its initial position in a short period of time, after its linearly down motion. This is achieved by the springs compatible to weight which doesn't affect the rotation system. Flywheel helps to maintain the same direction to rotate.

*2) Gear wheel system*

When a vehicle exerts force on the upper plate, it causes the pinion rack to move linearly downwards by a distance of 5 cm. The drive wheels, known as Drive Wheel 1 and Drive Wheel 2, are part of a compound gear wheel system, with both gear wheels rotating in the same direction. Remarkably, as the pinion rack descends by 5cm, the drive wheels complete approximately 0.75 full revolutions. Five types of gear wheels are used in the system in various sizes.

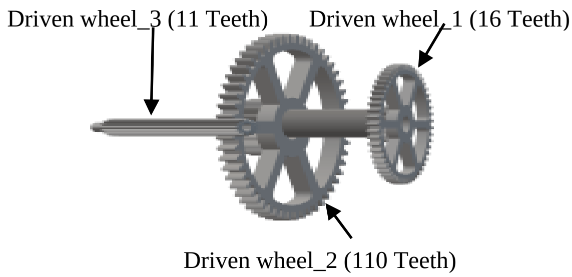


$$Gear\ Ratio = \frac{No.of\ teeth\ of\ Driven\ wheel}{No.of\ teeth\ of\ Drive\ wheel}$$




$$Gear\ Ratio = \frac{(No.of\ teeth\ of\ Driven\ wheel\_1)\ 16}{(No.of\ teeth\ of\ Drive\ wheel\_1)\ 44} = \frac{4}{11}$$

When the Drive wheel completes 4 rotations, the Driven wheel 1 turns 11 times. If the Drive wheel makes just 1 rotation, the Driven wheel 1 rotates about 11/4 times.
When the Drive wheel completes 0.75 rotations, both Driven wheel 1 and Driven wheel 2 turn approximately 2.063 times.
11/4*0.75 = 2.063 rounds




$$Gear\ Ratio = \frac{(No.of\ teeth\ of\ Driven\ wheel\_3)\ 11}{(No.of\ teeth\ of\ Driven\ wheel\_2)\ 110} = \frac{1}{10}$$

When Driven Wheel 2 rotates 1 round it equals 10 rounds in Driven Wheel 2.

When Driven wheels 1 and 2 complete 2 rotations, Driven wheel 3, linked to the motor shaft, turns 20 times. Consequently, a single force on the iron plate causes the motor to rotate 20 times.
The pinion rack's upward motion does not affect motor rotation because the driven wheel is a freewheel that rotates freely in the opposite direction. Despite force release, the system maintains consistent rotation, and upon the release of the vehicle wheel, the spring tension rapidly readjusts to its initial position in preparation for the next wheel/vehicle transition.

*3) Circuit Breakdown*

When the road bumper mechanism on top of the plate is pressed, the 24V wiper motor turns 20 times. While it turns, it makes 22.8V of electricity in the AC form. To make this power more useful, the electricity is transformed into a 12V DC voltage. This conversion makes the electricity more practical for the device.

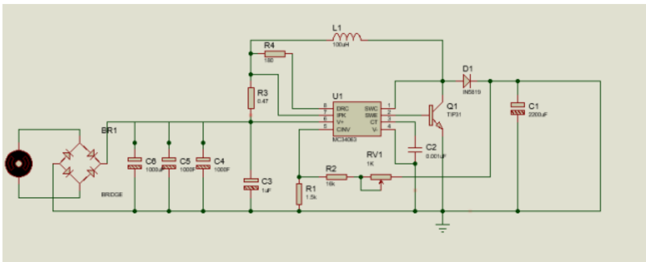


Fig. 3. Schematic diagram of the circuit

AC to DC converter - The circuit is used for converting AC to DC voltage since the 24V wiper motor outputs AC voltage, and a DC voltage is required. Wiper motor was selected due to its high output current and voltage, ensuring optimal performance for achieving a substantial output. This conversion is achieved through an AC-to-DC converter, which includes a bridge rectifier and three 1000µF electrolytic capacitors connected in parallel. As the AC voltage goes through the converter, it rectifies the signal, resulting in a stable 12V output.

Boost converter circuit-The DC voltage from the previous converter, which is at 6.6V, is then boosted to 12V using a boost circuit. The MC34063 special power IC is utilized in this circuit, and it's noteworthy that the MC34063 IC can handle step-up, step-down, and voltage inverting functions. This circuit operates by energizing and de-energizing an inductor in tandem with the IC's switching component, which is regulated by an external capacitor. The circuit yields an output voltage of 14V within an input voltage range of 3V to 13V. Furthermore, the circuit's efficiency is approximately 65.95%. If an adjustment to the output voltage is necessary, it can be achieved using the following equation by substituting the values of resistors R4 and R3.

$$Vout = 1.25\left(1 + \frac{R4}{R3}\right)$$

The selection of a 12V (720J) supercapacitor bank for this energy storage device is primarily driven by its considerably lower internal resistance compared to other battery options. Furthermore, supercapacitors are known for their capability to provide exceptionally high output currents when needed, making them a preferred choice for the application.

#### 4) *Voltage monitoring*

In order to monitor the voltage, the system was further developed with a voltage monitoring system. The charging status is displayed into an android mobile phone using a voltage sensor.

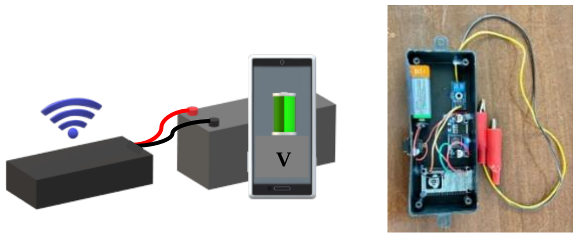



Fig. 4. Voltage monitoring circuit

## III. EXPERIMENTED RESULTS

The experimented results of the system reveal that, following experimental procedures, 11 forces generated 1V, while 132 forces provided a substantial 12 volts, equivalent to 720 joules of energy. A single vehicle contributing two forces demonstrated the system's efficiency. In practical terms, the collective effort of 66 vehicles is required to supply the necessary 132 forces, allowing for the complete charging of the 12-volt, 720-joule battery.

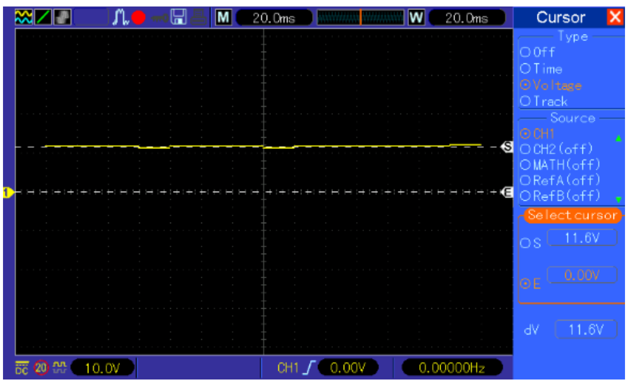



Fig. 5. System performance output


Fig. 6. System performance output with 11.6V

Fig. 7. Energy harvesting system

## IV. CONCLUSION

In conclusion, the development of this innovative energy-harvesting system represents a significant step toward addressing the escalating energy crisis and environmental concerns. The results demonstrate the system's ability to capture and store energy effectively, with just 66 passing vehicles (approximately 1900 kg weight car), required to fully charge the 12V super capacitor bank so that it can generate 720 J energy. This holds the potential to revolutionize the way we approach energy generation and consumption, ushering in a cleaner, greener, and more resilient energy future.

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