STUDY ON POWER GENERATION FROM SPEED BREAKERS

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FACULTY OF ENGINEERING,
UNIVERSITY OF BENIN, CITY

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A PROJECT SUBMITTED IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF MECHANICAL ENGINEERING (B. ENG) DEGREE IN THE DEPARTMENT OF MECHANICAL ENGINEERING, FACULTY OF ENGINEERING,

UNIVERSITY OF BENIN, NIGERIA.

NOVEMBER, 2025

CERTIFICATION

This is to certify that this research project submitted to the department of Mechanical Engineering was carried out by Olugbile Oluwatosin Ayofe ENG2002499, Atolagbe Divine Adedayo ENG2006371, Idemudia Benedict Edeghonghon ENG2006381, Agbaje-ogini Oluwadamilola ENG2009602, Joseph Afemikhe Daniel ENG2106436 of the department of Mechanical Engineering, University of Benin, Benin City, Edo State, Nigeria, under the supervision of Dr. N. Enoma.

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DEDICATIION

This work is dedicated to God Almighty for his blessings favor and abundance in our lives, his invaluable Grace and provision throughout our stay in the university and for giving us the strength to complete this work. We also humbly thank our parent for their unfailing help,support and assistance throughout the course of our stay in the university.

ACKNOWLEGEMENTS

Firstly, we want to express our profound gratitude to God almighty for preserving us this far. It is by His grace that we are able to carry out and conclude this project unscathed.

Also, we are extremely grateful to all the amazing lecturers, staff and colleagues in the Department of Mechanical Engineering for their moral and intellectual support towards the accomplishment of this project work. To our supervisor, Dr. N. Enoma, we would like to extend our sincere thanks to you for accepting and approving our projects, as well as helping us reach the required standard. May God bless him richly.

Special thanks to our parents, for their unwavering and boundless support throughout this difficult journey, Indeed we're very grateful, and we pray that God almighty, richly bless them.

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ABSTRACT.

This study investigates the potential of utilizing the kinetic energy dissipated by vehicles traversing speed breakers as a sustainable source for power generation. With increasing vehicular traffic, a significant amount of energy is wasted as heat and friction when vehicles slow down and pass over these road infrastructure elements. This research explores various electromechanical mechanisms, including rack and pinion, gear and flywheel, and spring coil systems, to convert this otherwise lost kinetic energy into usable electrical energy.

The core principle involves capturing the vertical displacement and subsequent kinetic energy of a vehicle as it passes over a specially designed speed breaker mechanism. This mechanical energy is then converted into rotational motion, which drives an electrical generator (dynamo) to produce electricity through electromagnetic induction. The generated electrical power can be stored in batteries or directly used to power nearby infrastructure such as streetlights, traffic signals, and signage, particularly in high-traffic areas like urban roads, parking lots, and toll plazas.

This study analyzed the design considerations, efficiency, and potential power output of such systems under varying traffic conditions and vehicle weights. It also explored the practicality and cost-effectiveness of implementing these energy-harvesting speed breakers compared to traditional power sources. Furthermore, the environmental benefits of this approach, including the reduction of reliance on conventional energy sources and the minimization of greenhouse gas emissions, were discussed.

The findings of this research highlight the potential of speed breakers as a distributed and renewable energy generation technology, As well as proposes the adoption of Hybrid Energy Systems, Design Parameters Optimization And Energy Storage Enhancements to increase the possibility of transforming everyday road infrastructure into energy-producing systems, this technology holds promise for advancing renewable energy development, and contributing to a better future.

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The escalating global energy demand, coupled with the pressing need for sustainable and renewable energy sources, has spurred innovation in unconventional power generation methods. Among these, the concept of harnessing energy from the motion of vehicles traversing speed breakers has garnered increasing attention. This approach seeks to convert the kinetic energy ofmoving vehicles, which is otherwise dissipated as heat and vibration, into a usableform of electrical energy.

The world's reliance on fossil fuels (coal, oil, and natural gas) has led to a dual crisis: the depletion of these finite resources and the exacerbation of environmentalproblems such as global warming and air pollution. The combustion of fossil fuels releases greenhouse gases, primarily carbon dioxide, which contributes significantly to climate change. This has driven a global movement towards exploring and developing renewable energy sources. This concept is not entirely new, but it has gained prominence in recent decades due to the increasing focus onrenewable energy and energy efficiency. Early ideas and prototypes explored various mechanical linkages and systems to convert the vertical displacement of a speed breaker into rotary motion, which could then drive an electrical generator.

A moving vehicle possesses kinetic energy, which is the energy of motion. This energy is directly proportional to the mass of the vehicle and the square of its velocity. When a vehicle encounters a speed breaker, its kinetic energy is partially converted into potential energy as it moves upwards and then dissipated as heat and vibration due to friction and the impact of the vehicle's suspension. The fundamental principle behind power generation from speed breakers is to capture this otherwise wasted kinetic energy and convert it into a more useful form, such as electrical energy. This can be achieved through various mechanical and electrical mechanisms.

The development of effective power generation systems using speed breakers offers several potential benefits which includes; Renewable Energy Source, Energy conservation, Low Maintenance, Decentralized Power Generation and many more.

Power generation from speed breakers represents an innovative approach to harnessing wasted kinetic energy in a world grappling with energy scarcity and environmental challenges. By converting the mechanical energy of vehicles into electrical energy, this technology offers a sustainable, decentralized, and Eco- friendly solution for localized power generation. While challenges such as efficiency, durability, and scalability remain, ongoing research and technological advancements are likely to enhance the viability of this system. With further development, speed breaker power generation could play a significant role in theglobal transition toward renewable energy, contributing to a cleaner and more sustainable future.As seen from the figure of the rack and pinion arrangement below.

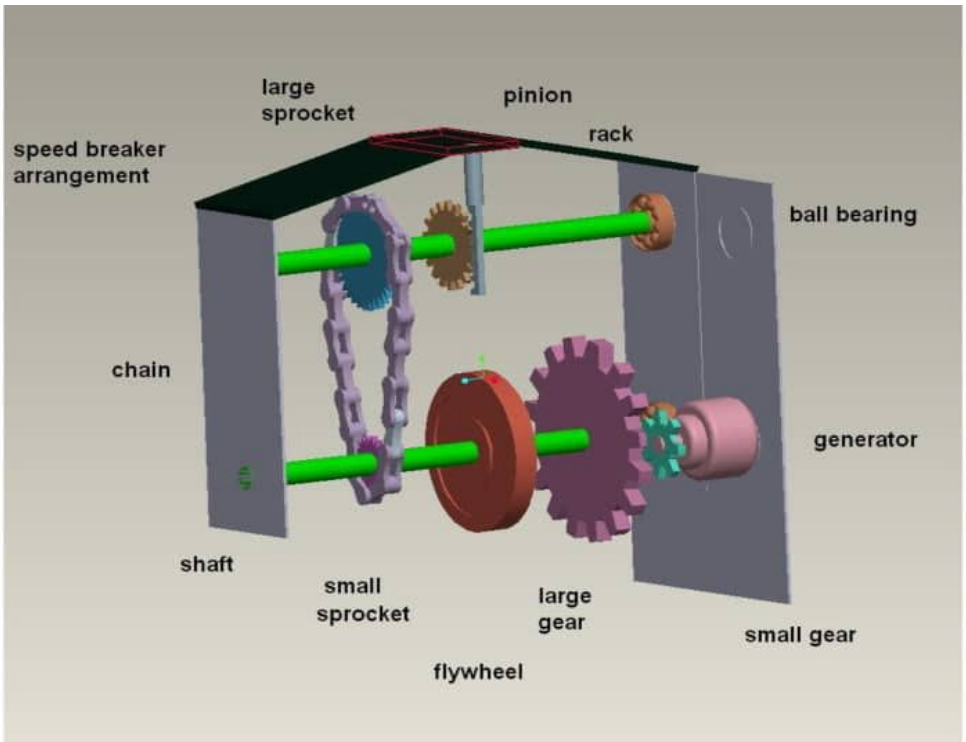

FIGURE 1.1: A RACK AND PINION ARRANGEMENT

Here the reciprocating motion of the speed breaker is converted into rotary motion using rack and pinion arrangement. The axis of the pinion is coupled with the sprocket arrangement.

The sprocket arrangement is made of two sprockets, one of the larger size and the other smaller sprocket, as the power is transmitted from the larger sprocket, the speed that is available at the larger sprocket is relatively multiplied at the rotation of the smaller sprocket.

1.2 STATEMENT OF PROBLEM.

The primary problem this study addresses is the significant energy loss occurring at speed breakers due to the dissipation of kinetic energy as heat and friction whenvehicles decelerate and pass over them. This wasted energy represents an untapped resource that could be harnessed to generate electricity, offering a sustainable and localized power source.
Further compounding this central problem are several related issues:

1. Increasing Energy Demand: The ever-growing need for electricity necessitates the exploration of alternative and renewable energy sources tosupplement traditional power generation methods.

2.Environmental Concerns: Reliance on fossil fuels for electricity generationcontributes to greenhouse gas emissions and climate change. Utilizing wasted kinetic energy offers a cleaner alternative.

3. Underutilized Infrastructure: Existing road infrastructure, specifically speedbreakers in high-traffic areas, presents a readily available platform for energy harvesting that is currently not being exploited.

4.Need for Localized Power Solutions: Many areas can benefit from decentralized power generation for applications like street lighting, traffic signals, and other local needs, reducing transmission losses and improving energy security.

5. Optimization of Energy Conversion: Efficient and cost-effective mechanisms are needed to convert the mechanical energy from passing vehicles into usable electrical energy.

Therefore, the core problem is the inefficient dissipation of vehicular kinetic energy at speed breakers and the need to develop and implement effective technologies to capture and convert this wasted energy into a sustainable source ofelectricity. This study aims to explore the potential of this concept and contribute to addressing the growing energy demands and environmental concerns through innovative utilization of existing infrastructure.

1.3 AIM AND OBJECTIVES OF THE PROJECT

1.3.1 Aim.

The aim of this project focuses on the study of power generation from speedbreakers

1.3.2 Objectives.

The objectives of the project is to:

1. To develop a mathematical model of the systems working mechanism.
2. To Model a rack and pinion mechanism for power generation using solid works.
3. To simulate the degree and efficiency of the speed breaker power generator in society.
4. Evaluate the efficiency and reliability of speed breaker power generation.

1.4 SCOPE/LIMITATIONS.

1.4.1 Scope

The scope of the project is the study on the feasibility as well as the practical application of the proposed system in extracting kinetic energy from speed breakers. This entails utilizing the wasted kinetic energy from vehicles, in order to provide a renewable and environmentally friendly energy source. This project report helps to show case the various ways and methods in which the energy generated from speed breakers can be used for various purposes, such as poweringtraffic signals street light and contribution of energy to the local power grid. This approach to energy generation can help to potentially reduce the level of energy wastage present in today's economy.

1.4.2 Limitations.

To ensure the safety of the general public, proper designs and installations are necessary in the implementation of power generation into speed breakers.

Firstly, Vehicles over a specific weight limit are unable to use the speed breaker as it is not designed to support high level loads. The amount of power generated per speed breaker is generally small, usually in the range of watts per vehicle. Due to this in order to achieve a significant level of power generation. Numerous speed breakers need to be systematically placed along roads with high traffic volumes.

Additionally, the use of speed breakers even with power generation capabilities can negatively affect traffic flow. Particularly with emergency vehicles and thosewith low ground clearance. Furthermore, these systems may require regular maintenance and could lead to damage of vehicles and roads if not correctly maintained. The impact of repeated vehicle traffic on the structural integrity of the speed breaker needs to be considered. Even though the initial cost of installing the speed breaker power generators might be lower than the traditional methods the maintenance as well aspotential damage to roads and vehicles could add to the overall cost.

In Conclusion, While the scope of the project is to address the energy crisis. There are various limitations that must be addressed throughout the project in order to achieve effective implementation.

1.5 SIGNIFICANCE OF STUDY

The investigation into power generation from speed breakers carries substantial significance due to its focus on capturing the considerable yet typically dissipated kinetic energy of moving vehicles and transforming it into usable electrical power.This represents a valuable exploration of a renewable and inherently sustainable energy avenue, as it leverages the constant motion present on roadways, thereby lessening our reliance on finite and environmentally impactful fossil fuel resourcesand contributing to a more ecologically responsible energy landscape.

Furthermore, the distributed nature of speed breakers along transportation networks presents a unique opportunity for decentralized power generation, enabling electricity production closer to the point of consumption. This localized energy generation has the potential to significantly reduce the energy losses associated with long-distance transmission from centralized power plants, enhancing overall energy efficiency and bolstering energy security, particularly inmore remote or under-served regions. The generated electricity can be directly channeled to power essential local infrastructure, such as street lighting systems, traffic control signals, and security surveillance equipment, and could even extendto providing low-level charging capabilities for electric mobility options. This on- site power generation can translate into tangible cost savings for local authorities and communities by decreasing their dependence on and expenditure for grid- supplied electricity. Moreover, by harnessing a nonpolluting energy source derived from vehicular movement, this technology actively contributes to the reduction of greenhouse gas emissions, thereby playing a crucial role in mitigatingthe adverse effects of climate change.

The concept also fosters innovation within the realm of road infrastructure, envisioning the transformation of conventional traffic management devices into dual-purpose assets that not only regulate vehicle speed but also generate clean energy. The successful development and widespread adoption of such systems could stimulate new economic activities in sectors related to manufacturing, installation, and ongoing maintenance. Specifically, within the Nigerian context, where access to a consistent and reliable electricity supply remains a significant challenge, this technology offers the prospect of a supplementary and locally derived power source, particularly in areas characterized by high vehicular traffic volume. By strategically utilizing this readily available kinetic energy, Nigeria canmove towards greater energy independence by tapping into its own resources.

Ultimately, the significance of this study lies in its potential to re-imagine a common element of our roadways as a source of clean, localized energy, therebycontributing to broader sustainability goals, offering economic advantages, and potentially improving energy accessibility within the specific challenges and opportunities present in Nigeria.

CHAPTER TWO
LITERATURE REVIEW

2.1 THEORY OF KINETIC ENERGY HARVESTING

Harnessing the kinetic energy of vehicles from speed breakers presents an innovative and sustainable approach to power generation, offering a promising solution to escalating global energy demands and pressing environmental concerns (Karthik et al.,2018).This method focuses on converting the energy typically wasted as heat and vibration when a vehicle passes over a speed breaker into usable electricity.

This process involves capturing the vertical displacement of the speed breaker as a vehicle passes over it. This mechanical motion is commonly translated into rotational energy using a rack and pinion mechanism (Chauhan et al.,2017). The rack, driven by the speed breaker's vertical movement, rotates a pinion, which in turn drives a sprocket system. This system is crucial for multiplying the rotational speed, enabling it to efficiently power an electrical generator.

The potential benefits of this technology are substantial. It provides a decentralized power source, capable of generating electricity locally for infrastructure such as street lights, traffic signals, and security equipment, thereby reducing reliance on the main grid and minimizing transmission losses. From an environmental perspective, it contributes to the reduction of greenhouse gas emissions by lessening the dependence on fossil fuels. Furthermore, it transforms existing road infrastructure into dual-purpose assets, offering cost savings for local authorities by reducing their grid-supplied electricity needs.

This chapter explores theoretical foundations, evaluates different power generationmechanisms, examines the influence of vehicle characteristics, and reviews case studies. It also identifies research gaps to position the current study, which aims todevelop an optimized speed breaker system for efficient power generation. The review is structured into five sections: Theoretical Background, Technologies, Vehicle Parameters, Case Studies, and Knowledge Gaps.

2.2 THEORETICAL BACKGROUND

Power generation from speed breakers relies on converting the kinetic energy of moving vehicles into electrical energy (Gupta et al.,2019). When a vehicle passes over a speed breaker, its weight and motion exert a force that can be captured through mechanical or electromechanical systems. The kinetic energy KE =1/2mv^2, where (m) is the vehicle mass and (v) is its speed, determines the potential energy available for conversion (Khan et al.,2020). This energy can drive systems using piezoelectric materials like, electromagnetic generators, or hydraulic turbines to produce electricity.The efficiency of energy conversion depends on the design of the speed breaker and the characteristics of the vehicle. For instance, heavier vehicles (e.g., trucks) exert greater force, while higher speeds increase the frequency of energy transfer. Understanding these principles is crucial for optimizing speed breaker designs to maximize power output in diverse traffic conditions.

2.3 SPEED BREAKER (MECHANICAL HUMP) KINETIC ENERGY HARVESTING.

Speed breaker is the newly emerging technology employed in renewing the wasted energy (kinetic) of a vehicle into electrical energy during the passing time through every speed breaking hump (M.It Santhosh et al., 2017). In this project we focused on harnessing kinetic energy of moving vehicles as they pass over speed breakers (mechanical hump). Some of the mechanisms involved in this process includes, The rack and pinion mechanism, Roller mechanism, Crankshaft Mechanism, and the Hydraulic mechanism.

2.3.1 Rack & Pinion Speed Breaker Mechanism for Energy Harvesting

The idea of power generation by harnessing renewable energy sources, especially from vehicles passing over ramps or speed breakers is a major insight in energy harnessing (Umair Ahmed Khan et al., 2014). In this project, the rack and pinion mechanism is employed in order to efficiently convert the translational energy of the vehicles as they pass over the hump into rotational energy through the pinion. This rotation in turn rotates the input shaft (rotor) of the generator and electricity is produced, which is in turn stored in the battery.

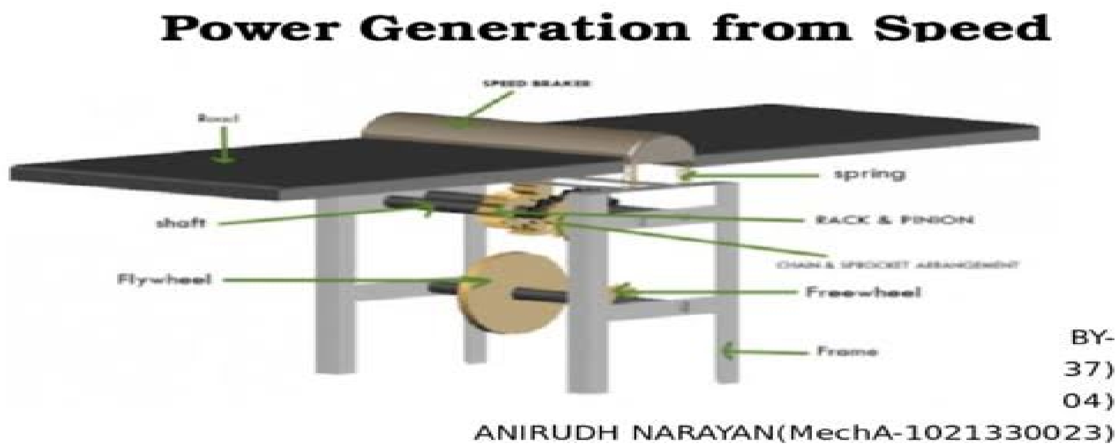

FIGURE 2.1: ENERGY HARVESTING BY RACK AND PINION MECHANISM

2.3.2 Roller Speed Breaker Mechanism for Energy Conversion

In this method of kinetic energy harvesting by speed breakers, it is found that the efficiency of the system totally depends on the speed of the vehicle. The speed of the vehicle is directly proportional to the efficiency of the system (Y. Siva Mallesh et al., 2021). In this method, the speed breaker is a roller at both ends and they are bearing supported, as vehicles pass over the speed breaker, due to friction, the bearing support causes the roller to generate circular motion. Those circular motion are transferred to generator by using the available transmission system(belt, gear train chain, sprocket, etc)

2.3.3 Energy Harvesting by the Crank Shaft Mechanism

In general, the crankshaft is a mechanical device for converting linear motion into rotary motion, due to the impact of the piston on it. In this mechanism of power generation, the crank shaft uses kinetic energy to push down the piston for linear motion to occur. Since crank is designed on the basis of inertia (Y Siva Mallesh et al., 2021).

The crank itself makes the one half of the revolution in order to push the piston up. In that manner, the crank is able to create rotary motion which is sent to the generator by means of gear trains for power generation. This method of power generation brings about too much heat and vibration because of too many moving parts (Y Siva Mallesh et al., 2021).

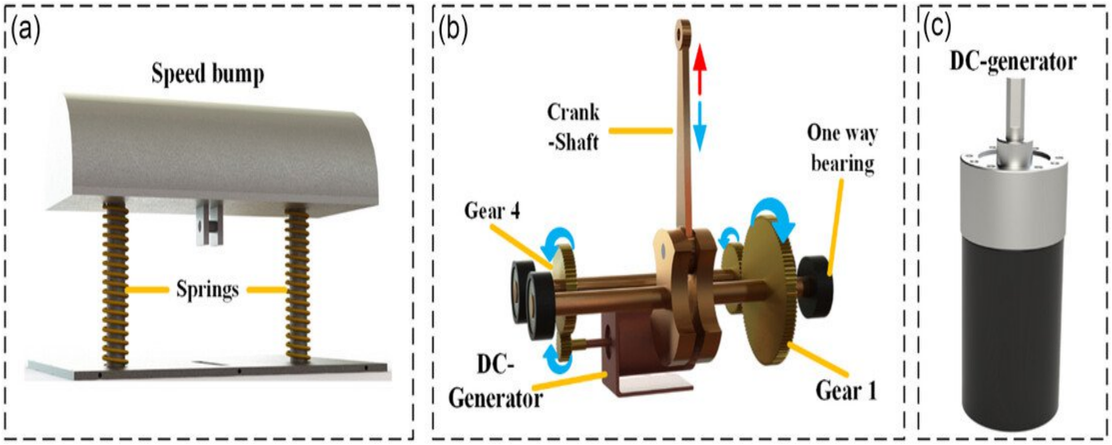

FIGURE 2.2: ENERGY HARVESTING BY THE RACK AND PINION MECHANISM

2.3.4 Energy Harvesting By The Hydraulic Speed Breaker

This method of energy harvesting by speed breakers, gives better output performance when compared to the crank shaft mechanism (Y Siva Mallesh et al., 2021). This is due to the fact that the introduction of the hydraulic press into the system contributes to smoother movement, minimizing friction & optimizing the overall efficiency of the energy conversion process (Sanjida Parvin, 2016).

Here, the speed breaker is a spring supported at both ends so that the speed breaker can create linear motion. As the vehicle passes over the speed bump, a piston compresses the oil provided under it. This compressed oil travels to the accumulator.

The accumulator is further connected to the motor which generates torque and the torque generates the electrical energy. This research contributes valuable insights into the development of robust practical solutions for energy harvesting from speed breakers.

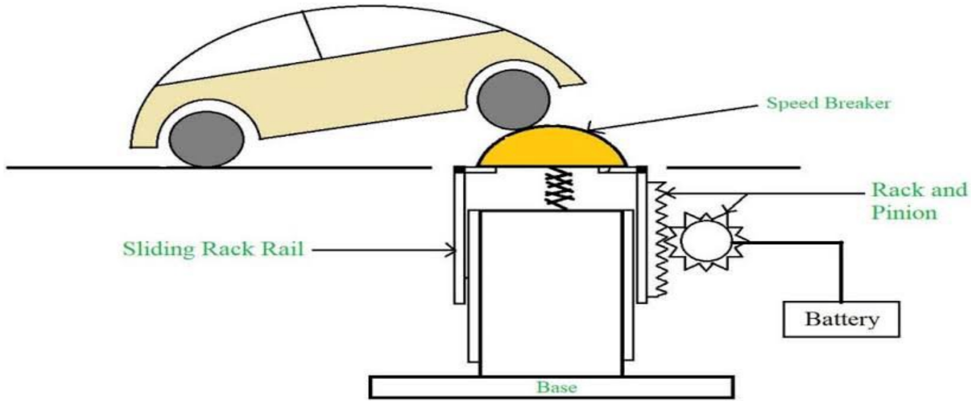

FIGURE 2.3: HYDRAULIC SYSTEM

Requirements:

Cylinder and piston

Control valves

Oil tank Generator coupled with turbine

Block Diagram:

This system is to generate power by converting the energy generated by a vehicle going up on a speed bumper into electrical energy. This arrangement consists of speed bumper assembly, cylinder and piston arrangement, water turbine, Generator and Stabilizing Unit with battery for storing the generated output.

2.4 TECHNOLOGICAL ADVANCES IN KINETIC ENERGY HARVESTING

The high energy demand and carbon emissions with its grave impact of fossil fuels leads to the development of a more sustainable energy; the renewable energy. The harvesting and utilization of this renewable energy can be observed in most of the developed countries and has achieved from 8.4 to 25% of the global power generation by 2017. (BP Statistical review of the world Energy 2018; vol.67, 2018)

Kinetic energy harvesting is the capturing of a specific amount of available energy harvesting system on-site, and its conversion from one form (Usually non-usable for the case) into another form (usable for the case) via specific system(s). (Richard Merrit, 2009)

A. Kinetic Energy Harvesting From Wave

This involves harvesting of the energy from ocean waves using wave energy harvesting operators. Ocean covers approximately 70% of earth's surface and it keeps moving day and night. As such, the capture of wave energy for power generation is a very viable technology especially in offshore regions ["A.V. Delgado et al.J 2007"]. (Y.L Wong et al, 2017).

FIGURE 2.4: KINETIC ENERGY HARVESTING FROM WAVE

A typical ocean wave energy system consists of a wave power absorber, a turbine, a generator, and power electronic interfaces. The absorber captures the kinetic energy of the ocean waves, and conveys them to the turbine or directly drives the generator. The generator produces a variable amplitude AC voltage, which is rectified to DC voltage in order to take advantage of the DC energy transmission capabilities of the salty ocean water. After the DC power is transmitted from ocean to land, a DC/DC converter or tap-changing transformer is used for voltage regulation. The voltage synchronization is produced by the inverter and the output terminals of the inverter can be connected to the grid. (Alireza Khalgh et al, 2009).

B. Kinetic Energy Harvesting From Wind

Wind power is the use of the wind's kinetic energy to generate electricity or mechanical power [Harvest and Store Wind Energy / CTM Magnetics]. Micro wind turbines are used to capture the kinetic energy from the wind and used to power small electronic devices. As the air flows across the blades of the turbine, a net pressure difference is developed between the wind speeds above and below the blades. This brings about a lift force which rotates the blades, and in turn rotates the magnetic field in the generator. Finally, electromagnetic induction produces current based on Faraday's law. [Jia Hui Ang et al, 2019]

FIGURE 2.5: KINETIC ENERGY HARVESTING FROM WIND

C. Kinetic Energy Harvesting From Geothermal Energy.

Geothermal energy is a renewable energy source generated from heat stored in rock and fluids in the Earth's crust. The heat serves as the resources from which steam from as deep as 10 km beneath the earth's surface, be tapped to generate electricity through geothermal power plants operating steam turbine generators. [Tester, J.W. 2007]

This energy harvesting method emits minimal amounts of greenhouse gasses but is limited to locations with geothermal activity.

FIGURE 2.6: KINETIC ENERGY HARVESTING FROM GEOTHERMAL ACTIVITY

D. Kinetic Energy Harvesting From Sun

Solar energy is the most abundant of all energy resources and can even be harnessed in cloudy weather. The rate at which solar energy is intercepted by the Earth is about 10,000 times greater than the rate at which humankind consumes energy.

Solar technologies can deliver heat, cooling, natural lighting, electricity, and fuels for a host of applications. Solar technologies convert sunlight into electrical energyeither through photovoltaic panels or through mirrors that concentrate solar radiation.

Solar energy is converted into electricity through a process where light particles (photons) from the sun strike photovoltaic (PV) cells, transferring their kinetic energy to electrons within the cells. This energy transfer excites the electrons, causing them to become free and move, generating an electrical current. This current is then harnessed and converted into usable electricity.

Although not all countries are equally endowed with solar energy, a significant contribution to the energy mix from direct solar energy is possible for everycountry.

The cost of manufacturing solar panels has plummeted dramatically in the last decade, making them not only affordable but often the cheapest form of electricity.Solar panels have a lifespan of roughly 30 years, and come in variety of shades depending on the type of material used in manufacturing.

FIGURE 2.7: KINETIC ENERGY HARVESTING FROM SUN

2.5 ANALYSIS OF COMMUNITY AWARENESS AND ACCEPTANCE OF KINETIC ENERGY HARVESTING

This literature aims to explore the acceptance and challenges associated with kinetic energy harvesting from urban infrastructures.

Most urban communities are emerging with significant increase in economic growth. The estimated Gross Domestic Product (GDP) growth within sub-Saharan Africa (SSA) was 5.4% from 2000 to 2010, adding $78 billion annually to GDP [World

Economic Forum Report (WEF), 2011]. Despite this growth, the population with access to electricity remains relatively low as compared to other developing countries.

To meet the energy needs of this growing economy, SSA government have to find the balance between not affecting the climate and using scarce financial resources for clean energy ventures. This electricity challenge presents an opportunity for the government to adopt low-carbon powered systems and technologies. [Mohammed YS, et al, 2013].

In a separate study investigating public perceptions about renewable energy technologies in Nigeria, Wojoula and Alant Found positive Correlations between perceived usefulness, and ease of using renewable energy. [Wojoula RN et al, 2017].

Overall study carried out among sub-Saharan African communities revealed that there is overwhelming support towards renewable energy, with some small socio-demographics segments of the population having neutral or negative attitudes towards renewable Energy sources.

In conclusion, outreach programs and educational initiatives promoting awareness should be geared towards, reinforcing public support for renewables. This collective knowledge from the public will assist in designing coherent policies that will safeguard the environmental, social and economic interest of SSA countries.

KNOWLEDGE GAP

From the above literature review carried out, it is observed that there is a significant mechanical improvement in the mode of transmission (or conversion) of energy from the linear motion of vehicles at the top, to the rotational motion of the shaft at the generator, as we progress from one mechanism to the other.

The Rack and Pinion mechanism employed racks and gear sets as the mode of energy conversion (motion transfer). The Hydraulic mechanism made use of a totally different mechanism for its own energy transfer. The piston and accumulator. The Roller Mechanism for speed breaker power generation utilizes rollers, which are attached to the generator. And finally, The Crank Mechanism utilized the crankshaft and piston, just like in Internal combustion engines for its motion transfer.

We can therefore Conclude that, as time goes on, researchers are looking for ways to improve the mechanism available for energy conversion in the area of speed breaker power generation, in order to achieve optimum system's efficiency,

2.6 INFLUENCE OF VEHICLE PARAMETERS ON DESIGN OPTIMIZATION

Vehicle speed and weight are critical parameters for optimizing speed breaker designs. Higher vehicle speeds increase the kinetic energy available, but excessively high speeds may reduce contact time with the speed breaker, lowering energy transfer efficiency .

For example, a study by Patel and Patel in (2016) found that speeds of 10–20 km/h maximize energy output in electromagnetic systems, as vehicles maintain sufficient contact with the breaker.Vehicle weight also plays a significant role. Heavier vehicles, such as buses (10–15 tons), generate more force than passengercars (1–2 tons), leading to higher energy outputs. However, most studies assume uniform traffic patterns, neglecting variations in vehicle types and frequencies. Other parameters, such as road incline and breaker height, also influence performance. For instance, a 10 cm breaker height was found optimal for balancing energy generation and driver comfort . Optimizing designs for diverse traffic conditions remains a challenge, necessitating adaptive systems that adjust to real- time vehicle parameters.

Despite these hurdles, ongoing research and development aim to enhance the efficiency and, durability of this technology. By addressing these limitations, power generation from speed breakers could play a crucial role in the global transition towards renewable energy, offering a sustainable, localized, and eco-friendly supplementary power source, especially in high-traffic areas. This approach represents a significant step towards a more energy-independent and environmentally conscious future.

2.7 WORKING PRINCIPLE

The principle employed in the speed breaker power generation involves efficiently converting the translational energy of the vehicles as they pass over the hump into rotational energy using the rack and pinion mechanism. Two half pinions situated at both sides of the rack are connected to a set of gears. One pinion is connected and rotates when the rack is moving downwards and disconnects when the rack reaches the bottom position.

When the rack is moving upwards, it connects with the other pinion and hence rotational motion is ever present in the system. The pinions are connected to two additional gears that help keep the motion of the half pinions continuous when they are disconnected from the rack. A third gear at the center is used to transfer the pure rotational motion into the gear that directly drives the input shaft (rotor) of the generator.

Reciprocating the rectilinear motion of the double rack gives a continuous rotary motion to the center gear. The teeth on the rack act upon those of the semicircular tooth pinions and the spur gears attached to the pinions operate on the center gear which is responsible for driving the gear that rotates the input shaft of the generator. The power harvested from the translational motion of the rack to the rotational motion of the shaft is stored using an EMF power cell for use at a later time.

In the previous section, we looked at various types of mechanism for speed breaker power generation, their working principle for power generation and their process design.

Examples of already functioning mechanisms in different parts of the world were also discussed. The Rack and Pinion mechanism would be the most efficient mechanism in Nigeria due to its efficiency and cost effectiveness. We selected this mechanism due to it being more efficient than other mechanisms, and energy loss in this mechanism is very low as compared to other mechanisms.

Speed Bump

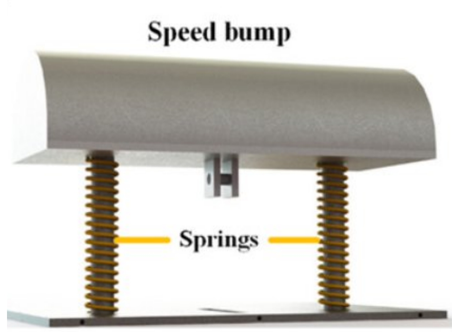

FIGURE 2.8: SPEED BUMP

This is the bump of the speed breaker which will be on top of the road. This is a normal speed breaker that will be used to slow down the cars. This whole bump will be pushed down which will cause the springs attached to it to be compressed. Regarding the deployment of this mechanism, part of it is buried while part is above ground.

Frame (Top and Base)

The top frame is where the bump is placed on and it is where the springs are attached to on the bottom side. It has sections of rods on the side for smooth motion of the part as well as to provide extra stability to the system so that it doesn't collide to any one side as a result of dynamic loading. The base is the bottom of the system, where all the components are placed. It holds the gear casing, bottom of the spring and mainly the generator.

Reciprocating Rack and Pinion

In this reciprocating rack and pinion mechanism, we have one rack connected to two half gears (pinions). One gear is connected and rotates when the rack is moving downwards and disconnects when the rack reaches the bottom position. When the rack is moving upwards, it connects to the other gear and hence the rotational motion is ever present in the system. We have 3 additional gears connected at the back of the system. Two of these gears connected at both the ends are used to keep the motion of the half gears continued when they are disconnected from the rack. The gear at the center is used to transfer the pure rotational motion into the shaft. This mechanism receives the vertical motion of the speed bump and converts it to the required rotational motion. It is installed in a vertical position which enables us to convert the vertical movement of the speed bump to rotational movement or force.

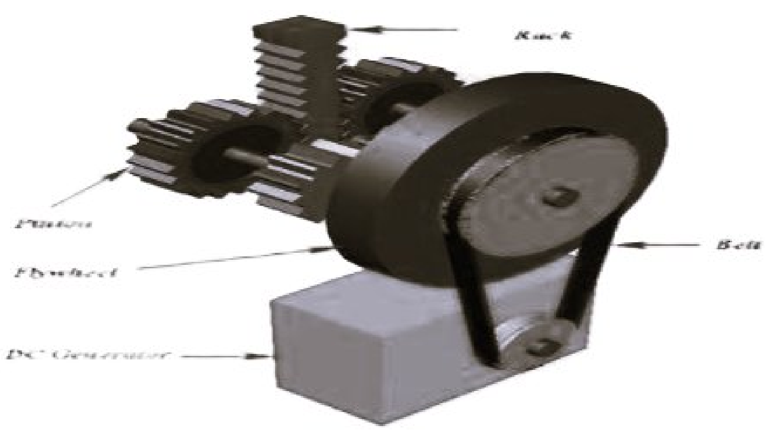

FIGURE 2.9: Rack and Pinion

Springs

Springs serve as vital components within the speed breaker system, providing essential functions to ensure its efficient operation. Typically attached at both ends to other components, springs exhibit remarkable properties that play a crucial role in maintaining the integrity and functionality of the speed breaker mechanism.

In the context of our speed breaker system, extension springs are employed to absorb and store energy while also creating resistance to pulling forces. As vehicles traverse over the speed breaker, the components of the system may move apart due to the applied force. In response, the extension springs exert their restoring force, attempting to bring these components back together. This inherent characteristic of extension springs ensures that the speed breaker returns to its original position once the applied force is removed, thereby restoring the roadway to its intended level state.

Additionally, beyond their role in facilitating the retraction of the speed breaker, springs serve as effective shock absorbers enhancing the durability and longevity of the speed breaker system

Specifically, the springs are strategically attached to the barrels that are affixed to the speed bump. This configuration ensures optimal performance and stability, allowing the springs to effectively fulfill their functions of energy absorption, force resistance, and shock mitigation.

In summary, springs are indispensable elements within the speed breaker system, embodying versatility and functionality. From facilitating the seamless retraction of the speed breaker to effectively dampening shocks and vibrations, they play a pivotal role in enhancing the overall performance and reliability of the speed breaker system.. Springs were used in our project for the following reasons

a) To apply force

b) To reduce impact i.e. as Shock absorbers.

c) To control motion

d) To control vibrations of the mechanism

FIGURE 2.10: Springs

Shaft

A shaft is a fundamental mechanical component designed to transmit torque and rotational motion. It serves as a crucial link within a drive train, facilitating the transfer of power between components that cannot be directly connected due to various factors such as distance or the necessity to accommodate relative movement.

In the context of our speed breaker power generation system, the shaft plays a pivotal role in transferring rotational motion from the pinion to the generator. As the vehicle traverses over the speed breaker, the pinion initiates rotational motion. This rotational energy is then efficiently transmitted through the shaft, serving as a conduit for mechanical power.

Upon reaching the generator, the shaft serves as a bridge-way between mechanical power and electrical power. The rotational motion imparted onto the generator's rotor by the shaft induces electromagnetic forces within the generator, subsequently leading to the conversion of mechanical energy into electrical energy. Through this process, the shaft acts as a critical intermediary, enabling the seamless transformation of kinetic energy from vehicular motion into usable electrical power.

Gears

Gears play a fundamental role in the functionality and efficiency of the speed breaker power generation system, serving as essential components in the transmission of motion and torque.

In our system, a set of three gears is utilized to facilitate the seamless transfer of motion from the half gears into the shaft, while also ensuring the continuous rotational motion of the half gears for the entirety of their cycle, even when disconnected from the rack, as shown in Fig 2.11.

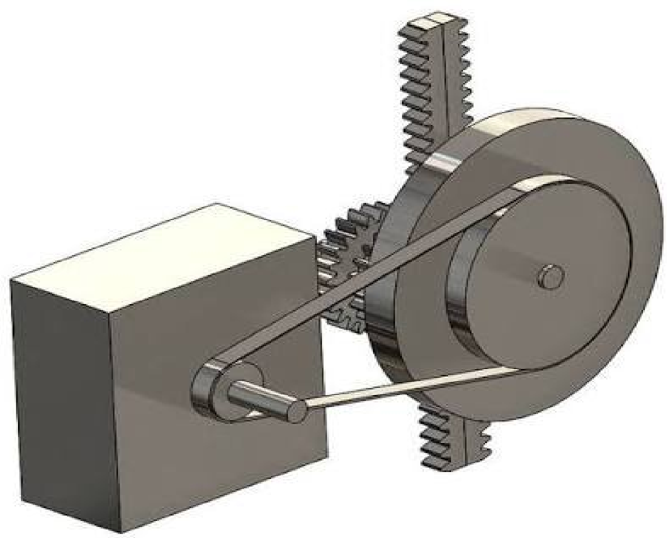

FIGURE 2.11: Gear set

The gears within our system function as precision-engineered mechanisms designed to transmit rotational motion from one component to another with minimal energy loss. As vehicles traverse over the speed breaker, the rotational motion of the half gears is initiated by the interaction with the rack mechanism. These half gears, in turn, engage with the intermediary gears, forming a mechanical linkage that enables the transfer of motion to the shaft.

The arrangement of gears serves a dual purpose within the system. Firstly, they act as mechanical couplings, effectively transmitting the rotational energy generated by the motion of the half gears to the shaft.

Secondly, the gear configuration ensures the continuity of motion for the half gears throughout their entire cycle, even during the phase when they are disconnected from the rack. By maintaining rotational momentum, the gears enable a smooth transition between the phases of engagement and disengagement with the rack, thereby optimizing the efficiency and reliability of the system.

Furthermore, the precise arrangement and sizing of the gears are meticulously calibrated to ensure optimal performance and minimal wear over prolonged usage. This attention to detail in gear design and selection contributes to the longevity and reliability of the speed breaker power generation system, enhancing its overall effectiveness in harnessing kinetic energy from vehicular motion.

DC Generator

The direct current (DC) generator is a type of electrical machine used to transform mechanical energy into DC electricity. The principle of energetically induced electromotive force is used in the energy alteration process. According to the electromagnetic induction principle of Faraday's Laws, when a conductor cuts magnetic flux, an energetically induced electromotive force is produced in it.

It rotates the rotor of the generator and in this way, the electricity is generated. Even if the conductor circuit is not opened, this electromotive force can still result in a current flow.

The main components of a DC generator are given below:

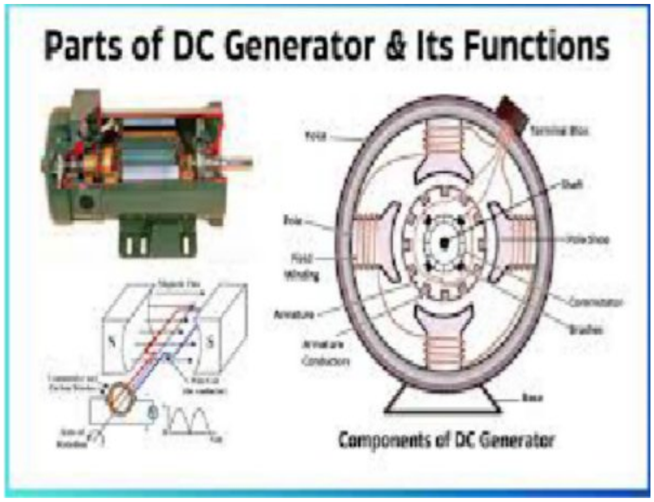

FIGURE 2.12: Dc Generator Diagram

a. Rotor-The rotor or armature core, which is made up of a fan, an armature, a commutator, and a shaft, is another crucial component of a DC generator. This component rotates in the magnetic field produced by the stator but is movable, unlike the stator. Iron slot laminations with slots that have been layered to create a cylindrical armature core make up the armature core. This lamination decreases the energy loss caused due to eddy current.

b. Stator- It is the stationary component of the system. The stator also has a core, stator winding, and an outer frame. The stator is an essential feature of dc generators and serves as the source of magnetic fields around which the coils spin. There are two stable magnets in this that have opposite poles facing each other.

c. Bearings- A system uses bearings to provide smooth movement of the different parts of the DC machine. The friction between the machine's spinning and stationary components is reduced with the help of bearings.

As a result, the system's components don't require constant lubrication and will last longer. Roller bearings and ball bearings are the two most prevalent types of bearings used in a dc generator.

d. Armature Windings-The armature core slots are primarily utilized to hold the armature windings. To increase the quantity of produced current, they are connected in series to parallel in the form of a closed-circuit winding. The armature winding, a unique configuration of conductors, is regarded as the brain or center of a DC generator. Armature windings can be either lap winding or wave winding, depending on the type of connections.

e. Yoke- The yoke is the outside cover made up of cast iron or steel that not only secures the inner assembly to the machine's base and offers mechanical protection for it, but also provides a conduit for the magnetic flow that the field winding generates.

f. Poles- The main purpose of poles is to maintain the field windings. Typically, these windings are wound on the poles and connected to the armature windings in a specific order. As a result, the poles attach the welding procedure to the yoke using screws.

g. Commutator-In order to reinforce the armature winding, the commutator converts AC voltage to DC voltage similarly to a rectifier. Mica sheets are used to protect each copper segment in this conductive metal from the other.

h. Brushes- One of the key components of the DC generator is brushes. These carbon blocks make it possible to guarantee the electrical connection between the commutator and the external load circuit.

i. Shaft- In a DC machine, the shaft is a mechanical component that causes rotation by producing torque. It has a maximum breaking strength and is made of mild steel. The shaft is one of the components of a DC generator that aids in the generator's ability to transfer mechanical energy. The commutator, cooling fan, and other rotating components are keyed into the shaft.

Mechanical rotation is used to rotate the shaft of the generator through an attached gear. The shaft is then coupled with a DC generator. The generated power can be amplified and stored by using different electrical devices such as batteries.

CHAPTER 3
METHODOLOGY

Here, we look into how the project objectives can be achieved which includes:

* Research on the possibility of generating power using speed breakers in Nigeria.

* Developing a mathematical model and stress analysis for further improvement on the speed breaker power generation mechanism.

* Use Python to simulate the performance of the mechanism with respect to known stress conditions.

Simulation Study Type

Analytical, quasi-static, deterministic parametric simulation

3.1 SYSTEM DESIGN

The harvester is modeled as a linear spring-damper system where the vehicle wheel load produces a sinusoidal force profile while traveling across the bump. The breaker displacement is approximated as quasi-static, with generator damping modeled as a viscous damper that extracts power proportional to the square of velocity.

Key parameters include spring stiffness (k), generator damping (c_e), effective bumplength (L), and wheel load (W). Energy per vehicle is computed analytically, and traffic rates are used to estimate average power and daily/monthly energy production.

3.2 DESIGN ANALYSIS OF HARDWARE COMPONENTS SPECIFICATIONS AND FEATURES

3.2.1 Speed Bump

Design Specifications

* Height**:** 10cm to 14cm

* Length/Width**:** 3.0 to 4.3m

*Material**:** Galvanized iron sheet

Design Feature

* Movement: Designed to press downward and achieve a linear travel distance equal to its height (10-15 cm), which is then converted to rotational motion

3.2.2 Frame

Design Specification:

*Weight Support**:** 2000kg

*Material**:** Mild Steel

Design Feature:

* Load Resistance: Must be designed to resist the load of heavy vehicles passing over the breaker (e.g., up to 2000 kg).

* houses all the mechanical components and must withstand the high forces transferred from the speed bump.

3.2.3 Gear

Design Specification

*Module**:** 2.00 mm

*Material**:** Mild steel (tempered).

Design Feature

* Speed Multiplication: A gear train is used to amplify the RPM significantly (e.g.,16 times) to efficiently run the DC generator.

* Gear Type: Spur gears are widely recognized for moderate speed applications due to their simple design, economic manufacture, and non-absence of end-thrust (imposing only radial loads).

3.2.4 Shaft

Design Specification

*Diameter**:** 20 mm

*Material**:** Mild Steel

Design Feature

*Transmit torque and rotational power from the gear/sprocket assembly to the DC generator.

* Mounting: Mounted on bearings (e.g., ball bearings) at both ends to minimize friction and allow for resistance-free rotation.

3.2.5 Dc Generator

Design Specification

*Material**:** Copper Wound

*Voltage Range**:** 6v - 12v

*Power Output**:** 273Watt Per Vehicle(400kg)

Design Feature

* Convert the final high-RPM rotary mechanical motion into direct current (DC) electrical energy based on the principle of electromagnetic induction

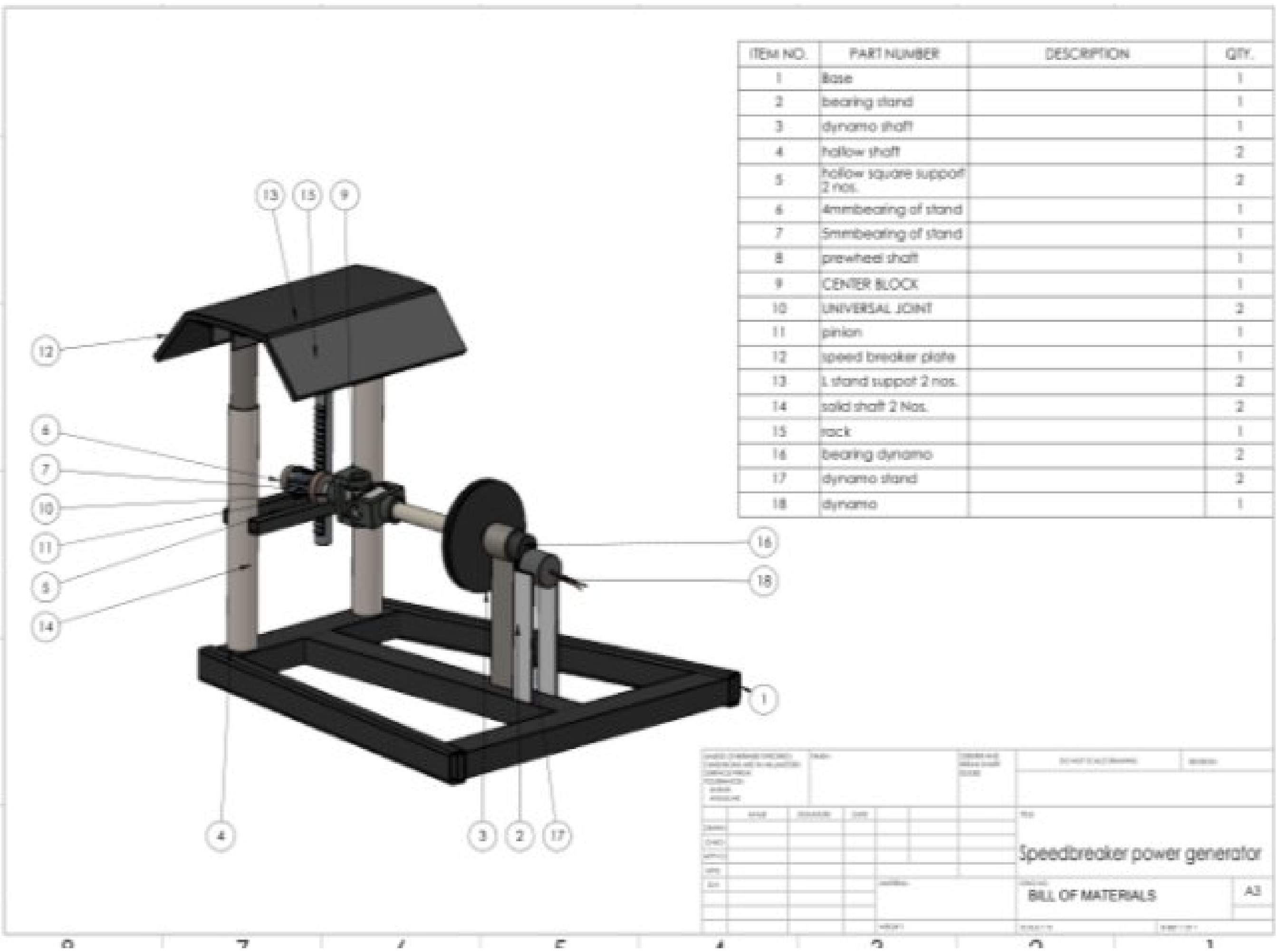

FIGURE 3.1: Solid Works Assembly

3.3 TABLE INDICATING THE PHYSICAL PROPERTIES OF THE POWER-GENERATING SPEED BREAKER

Component	Material	Function	Physical Property
Speed Breaker Casing	PVC and Rubber	Protects inner mechanism; absorbs impact	Elastic modulus ≈ 2.5 MPa; Compressibility $1.8 \times 10^{-9}\ Pa^{-1}$
Structural Frame	Mild Steel (EN8)	Provides strength and stability	Yield strength ≈ 550 MPa; Density = $7.85\ g/cm^3$
Springs	Oil-hardened Carbon Steel	Returns mechanism to initial position	Stiffness constant (k) = 2.5×10^5 N/m
Rack and Pinion	Hardened Steel	Converts linear motion to rotary motion	Gear ratio 1:5; friction coefficient ≈ 0.08
Spur Gear Train	Mild Steel	Amplifies rotation to generator shaft	Speed multiplier ≈ 2.5×
DC Generator	Copper Wound	Converts mechanical to electrical energy	Rated voltage: 12V; Efficiency: 70%
Piezoelectric Cells	Lead Zirconate Titanate (PZT)	Converts pressure to electrical energy	Piezoelectric constant d_{33} = 275 pC/N

TABLE 3.1 TABLE OF PHYSICAL PROPERTIES FOR THE POWER-GENERATING SPEED BREAKER

Dimensions: Length = 1.0 m; Width = 0.35 m; Height = 0.08 m; Displacement under load = 0.02 m. These parameters were optimized for moderate traffic conditions (20–40 km/h) to achieve high conversion efficiency while ensuring safety and durability.

3.4 Power-generating Speed Breaker (Mathematical Model)

A speed-breaker energy harvester converts vertical wheel loads into electrical energy via a mechanical transmission (rack–pinion or lever), a mechanical storage/elastic element, and an electrical generator. Two complementary modeling approaches are presented:

- **Quasi-static energy-per-event** (simple, useful for sizing and first-order estimates): energy stored in an elastic element and fraction converted to electricity.
- **Time-domain dynamic model** (ODE of a mass–spring–damper with electromechanical damping): needed to capture transient dynamics, contact forces, and generator coupling.

Both approaches are included with equations and example computations using parameters from the experimental study.

1. Assumptions

1. Wheel contact is modelled as a time-limited vertical load acting on the harvester. Vehicle mass may be allocated to interacting wheels.
2. The harvester mechanical subsystem is modelled as a single degree-of-freedom (DoF) translational coordinate $x(t)$ (positive downward) with linear stiffness k and damping split into structural (mechanical) damping c_m and generator-induced (electromechanical) damping c_e.
3. Generator and transmission efficiencies are represented as multiplicative factors. Mechanical losses in gears/rack and electrical conversion,rectification and storage are captured by efficiencies.

2. Notation

- m: vehicle mass (kg) or representative wheel load mass m_w for per-wheel modelling.
- v: vehicle longitudinal speed (m/s).
- L: contact/bump length over which wheel compresses harvester (m).
- $x(t)$: harvester vertical displacement (m), positive downward; d denotes peak stroke when used.
- k: linear stiffness of the elastic element (N/m).
- c_m: mechanical (structural) damping (N·s/m).
- c_e: electromechanical damping due to generator loading (N·s/m).
- $x_{\max}$: allowed stroke limit (m).
- m_b: effective moving mass of the harvester (kg).
- $g = 9.81\ \mathrm{m/s^2}$: gravitational acceleration.
- $\eta_{\mathrm{mech}}, \eta_{\mathrm{gen}}, \eta_{\mathrm{stor}}$: mechanical, generator, and storage efficiencies.
- $\eta_{\mathrm{chain}} = \eta_{\mathrm{mech}}\eta_{\mathrm{gen}}\eta_{\mathrm{stor}}$: overall chain efficiency.
- q: traffic flow (vehicles/hour); n_w: number of wheels per vehicle interacting with the breaker.

3. Time-domain dynamic model (for transient analysis)

Model the harvester as a single mass-spring-damper subject to a wheel force and end-stop reaction:

$m_b\ddot{x} + (c_m + c_e)\,\dot{x} + kx + F_{\text{stop}}(x) = F_{\text{wheel}}(t)$ ....(3.1)

Terms: - $F_{\text{wheel}}(t)$: time-varying normal force from the wheel during traversal (N). Example half-sine contact approximation:

$F_{\text{wheel}}(t) = W\sin(\pi t/T_{\text{contact}}),\quad 0 \le t \le T_{\text{contact}},$ ....(3.2)

where $W \approx m_w g$ and $T_{\text{contact}} \approx L/v$.

- End-stop reaction $F_{\text{stop}}(x)$ is negligible inside stroke and stiff outside:

$F_{\text{stop}}(x) = \begin{cases} 0, & |x| \le x_{\max}, \\ k_{\text{stop}}(x - x_{\max})\,\text{sign}(x), & |x| > x_{\max}, \end{cases}$ ....(3.3)

with $k_{\text{stop}} \gg k$.

Electrical power extracted (instantaneous):
$P_{\text{gen}}(t) = \eta_{\text{gen}}\, c_e \dot{x}^2(t)$ ....(3.4)
Where η_{gen} is the generator efficiency

Energy per event (integration over the contact interval):

$E_{\text{gen,event}} = \int_{t_0}^{t_0+T_{\text{contact}}} P_{\text{gen}}(t)\ dt = \eta_{\text{gen}} \int c_e \dot{x}^2(t)\ dt$....................................(3.5)

Numerical solution: integrate the ODE with measured or assumed $F_{\text{wheel}}(t)$ and compute the integral above to obtain realistic per-event energy.

.

4. Quasi-static energy-per-event (simple sizing estimate)

If the elastic element is compressed by stroke d, stored elastic energy is:

$E_{\text{spring}} = 1/2\, kd^2$..(3.6)

Assuming the system routes a fraction of this to electrical storage (chain efficiency), the electrical energy per wheel event is:

$E_{\text{elec,wheel}} = \eta_{\text{chain}}\ 1/2\, kd^2$..(3.7)

Per vehicle (with n_w wheels interacting):

$E_{\text{elec,veh}} = n_w\, E_{\text{elec,wheel}} = n_w\, \eta_{\text{chain}}\ 1/2\, kd^2$..(3.8)

Equilibrium coupling (if a wheel load F compresses the spring):

$d \approx \frac{F}{k} \quad \Rightarrow$ ....(3.9)

$E_{\text{spring}} = 1/2\,\frac{F^2}{k}$..(3.10)

This shows that, for a fixed applied force, energy decreases with increasing stiffness k ($E \propto 1/k$). Thus selecting k requires balancing stroke, comfort, and structural constraints.

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5. Instantaneous power approximate formula (useful check)

Approximate average power during traversal using work = force × displacement divided by contact time:

$P_{\text{avg}} \approx \frac{F\,d}{T_{\text{contact}}} = \frac{mgd}{L}\,v$...(3.11)

Electrical average power after chain efficiency:

$P_{\text{elec}} \approx \eta_{\text{chain}} \frac{mgd}{L} v$..(3.12)

This formula is consistent with short-duration peak-power estimates and is useful for quick cross-checks with the quasi-static energy calculation.

.

6. Aggregation over traffic and site energy

If $E_{\text{elec,veh}}$ is electrical energy harvested per vehicle, and q vehicles pass per hour, then:

$$E_{\text{hour}} = q\,E_{\text{elec,veh}},\text{................(3.13)}$$

$E_{\text{day}} = \sum_{h=1}^{24} q_h E_{\text{elec,veh},h}$..(3.14)

Average harvested power (W):

$\bar{P} = \frac{E_{\text{hour}}}{3600} = \frac{q\,E_{\text{elec,veh}}}{3600}$..(3.15)

.

7. Optimization formulation (design objective)

Design variables: (k,d,c_e,G) (gear/transmission ratio), possibly stroke limit $x_{\max}$.

Objective: maximize average harvested power or net present value (NPV) of energy revenue:

$\max\limits_{k,d,c_e,\ldots} \bar{P}(k,d,c_e,\ldots) = \frac{q\,n_w\,\eta_{\text{chain}}(k,c_e)\,1/2kd^2}{3600}$........................(3.16)

Subject to constraints:

- Comfort/safety: peak deceleration or vertical acceleration on passing vehicle $a_{\max}$ not exceeded.

- Stroke: $d \leq x_{\max}$.
- Structural: stresses within allowable limits $\sigma(k,d) \leq \sigma_{\text{allow}}$.
- Durability: fatigue life constraint given cyclic stress history.

8. Sensitivity relationships (useful analytic derivatives)

With equilibrium $d = F/k$ and one wheel per event, energy per event:

$$E = \frac{\eta_{\text{chain}}}{2}\frac{F^2}{k} \quad (3.17)$$

Then

$$\frac{\partial E}{\partial F} = \eta_{\text{chain}}\frac{F}{k}, \quad (3.18)$$

$$\frac{\partial E}{\partial k} = -\frac{\eta_{\text{chain}}}{2}\frac{F^2}{k^2} \quad (3.19)$$

These show stronger sensitivity to applied load F than to stiffness k (quadratic vs inverse-square dependence).

.

9. Non-dimensional groups and tuning

Define damping ratio

$$\zeta = \frac{c_m + c_e}{2\sqrt{m_b k}} \quad (3.20)$$

Target damping ratio range for energy harvesting: typically under-damped ($0.2-0.7$) to allow motion while avoiding excessive overshoot and mechanical shock. Tune c_e (via electrical load) to match desirable ζ for the expected m_b, k

3.5 THEORETICAL BASIS OF POWER GENERATION

When a vehicle passes over the speed breaker, its kinetic energy (kE) is given by:

kE = 1/2 * m * v^2

where:

m = mass of vehicle (kg)

v = velocity of vehicle (m/s)

As the vehicle climbs and depresses the speed breaker, a portion of this kinetic energy is transferred into mechanical work on the spring-damper system:

$E_{\mathbf{mech}} = F * d$

where F = m * g is the load acting on the speed breaker, and d is the displacement of the spring.

The power generated is:
$P = (m * g * d * v) / L$

This relationship shows that power increases directly with vehicle speed and mass, and inversely with bump length.

3.6 ENERGY CONVERSION ANALYSIS

The mechanical energy stored in the spring is:
$E_{\mathbf{mech}} = 1/2 * k * d^2$

The electrical energy output from the generator, considering efficiency η, is:
$E_{\mathbf{elec}} = \eta * E_{\mathbf{mech}}$

Assuming:
(Spring Constant) $k = 2.5 \times 10^5$ N/m, $d = 0.02$ m, $\eta = 0.75$

$E_{\mathbf{elec}} = 0.75 \times 1/2 \times (2.5 \times 10^5) \times (0.02)^2 = 37.5$ J per wheel
For a 4-wheel vehicle, $E_{\mathbf{veh}} = 4 \times 37.5 = 150$ J.
If traffic density = 600 vehicles/hour, E_hour = 150 × 600 = 90,000 J = 0.025 kWh.
Hence, E_day = 0.6 kWh.

3.6.1 Power Output Evaluation

Using $P = (m * g * d * v) / L$, where:

$m = 1500$ kg, $d = 0.02$ m, $v = 8$ m/s (≈ 29 km/h), $L = 0.4$ m

$P = (1500 \times 9.81 \times 0.02 \times 8) / 0.4 = 5{,}886$ W = 5.89 kW

Considering $\eta = 0.7$, P(elec) = 4.12 kW.

Since this power exists for ~0.05 s, Energy = Pelec × t = 4.12 × 0.05 = 206 J per event.

3.6.2 Compressibility And Energy Transfer Efficiency

Compressibility ratio $C = \Delta V / (V_0 * \Delta P)$

For rubber/PVC: C ranges from 1.0×10^{-9} to 2.5×10^{-9} Pa^{-1}.

Elastic compression energy: $E_{\mathbf{comp}} = 1/2 * ((\Delta P)^2 * V_0 * C) / (1 + \alpha)$

Higher compressibility increases temporary energy storage but may lead to losses. An optimal compressibility balances recovery and mechanical resilience.

3.7 Graphical Discussion (Simulation Trends)

1. Power vs Vehicle Speed: Power rises with speed up to ~40 km/h, then plateaus.
2. Power vs Vehicle Mass: Power ~ m^2; heavy vehicles yield higher energy.
3. Energy vs Traffic Flow: Energy scales linearly with vehicle throughput.

For 1000 veh/h and $E\_veh = 1200$ J → $E\_hour = 1.2 \times 10^6$ J = 0.33 kWh; $E\_day = 7.9$ kWh.

3.7.1 Energy Conversion Efficiency And Discussion On Findings

Overall efficiency $\eta\_overall = \eta\_mech \times \eta\_elec \times \eta\_storage$

Assuming $\eta\_mech = 0.8$, $\eta\_elec = 0.7$, $\eta\_storage = 0.9$

$\eta\_overall = 0.8 \times 0.7 \times 0.9 = 0.504$ (50.4%)

Discussion of Findings

1.Vehicle Speed: Moderate urban speeds (20 - 40 km/h) maximize efficiency.

2.Vehicle Mass: Heavy vehicles contribute more power.

3. Traffic Flow: Continuous traffic ensures stable energy generation.

4. Compressibility: Proper rubber/PVC layers enhance durability and recovery.

Practical Implications

The system can power streetlights, traffic signals, or CCTV in high-traffic zones.At UNIBEN main gate, output ≈ 0.6 kWh/day or 17 kWh/month, aligning with simulation data. Deployment should target heavy-traffic sites where maintenance is manageable.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 SUMMARY OF KEY SIMULATION RESULTS

Representative simulation outputs used throughout the discussion aresummarized below:

1.Case A: Traffic = 600 veh/h, Vehicle mass = 1500 kg, Speed = 29 km/h.Energy per vehicle = 1100 J; average power = 190 W; daily energy = 3.9kWh.

2.Case B: Traffic = 1200 veh/h, Vehicle mass = 2000 kg, Speed = 36 km/h.Energy per vehicle = 2000 J; average power = 670 W; daily energy = 13.6kWh.

3.Case C: Traffic = 200 veh/h, Vehicle mass = 1200 kg, Speed = 25 km/h.Energy per vehicle = 800 J; average power = 44 W; daily energy = 0.9 kWh.

Site example (UNIBEN Main Gate, representative values): Daily = 0.572kWh; 30-day = 17.17 kWh (after electrical chain efficiency).

4.1.1 Simulation Results

The simulations explored power output variation with vehicle speed, mass, and traffic flow. Representative results include:

Table Of Results

Traffic (veh/h)	Speed(km/h)	Mass(kg)	Energy/Vehicle (J)	Average Power(w)	Daily Energy(kwh)
600	29	1500	1100	190	3.9
1200	36	2000	2000	670	13.6
200	25	1200	800	44	0.9

TABLE 4.1: Simulation Results Table

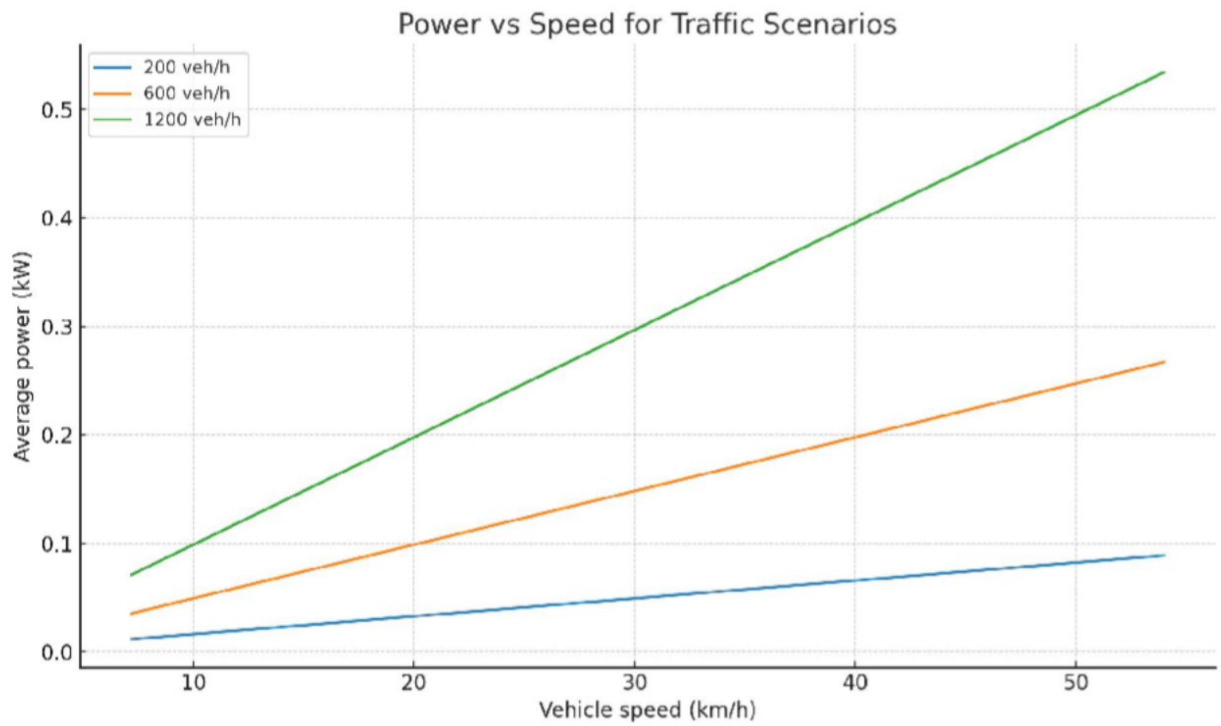

FIGURE 4.1: Shows Power Vs Vehicle Speed For Different Traffic Scenarios.

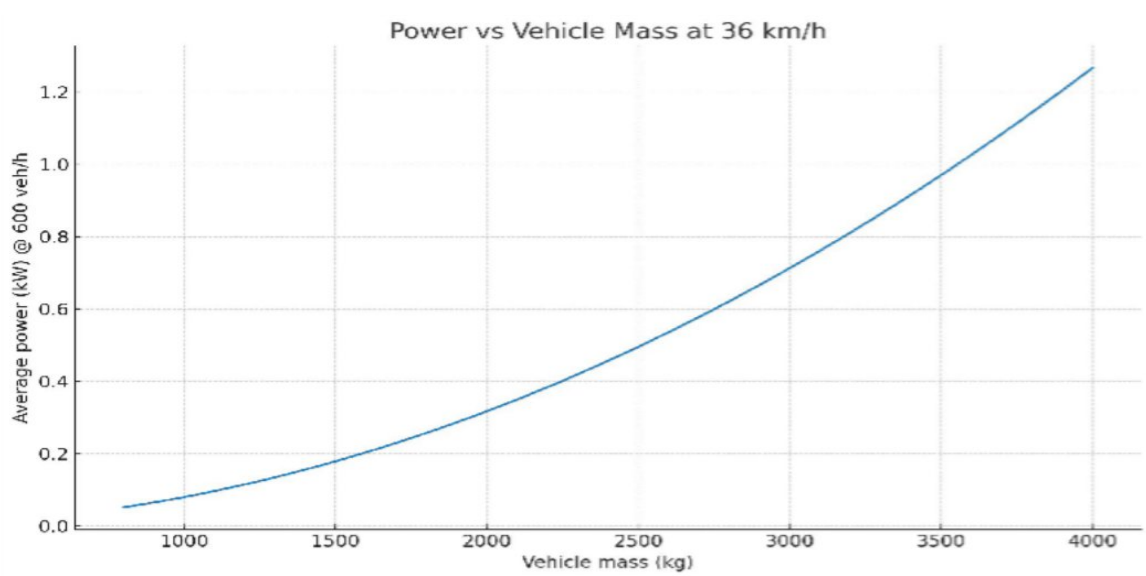

FIGURE 4.2: Shows The Dependence Of Harvested Power On Vehicle Mass At 36 Km/H.

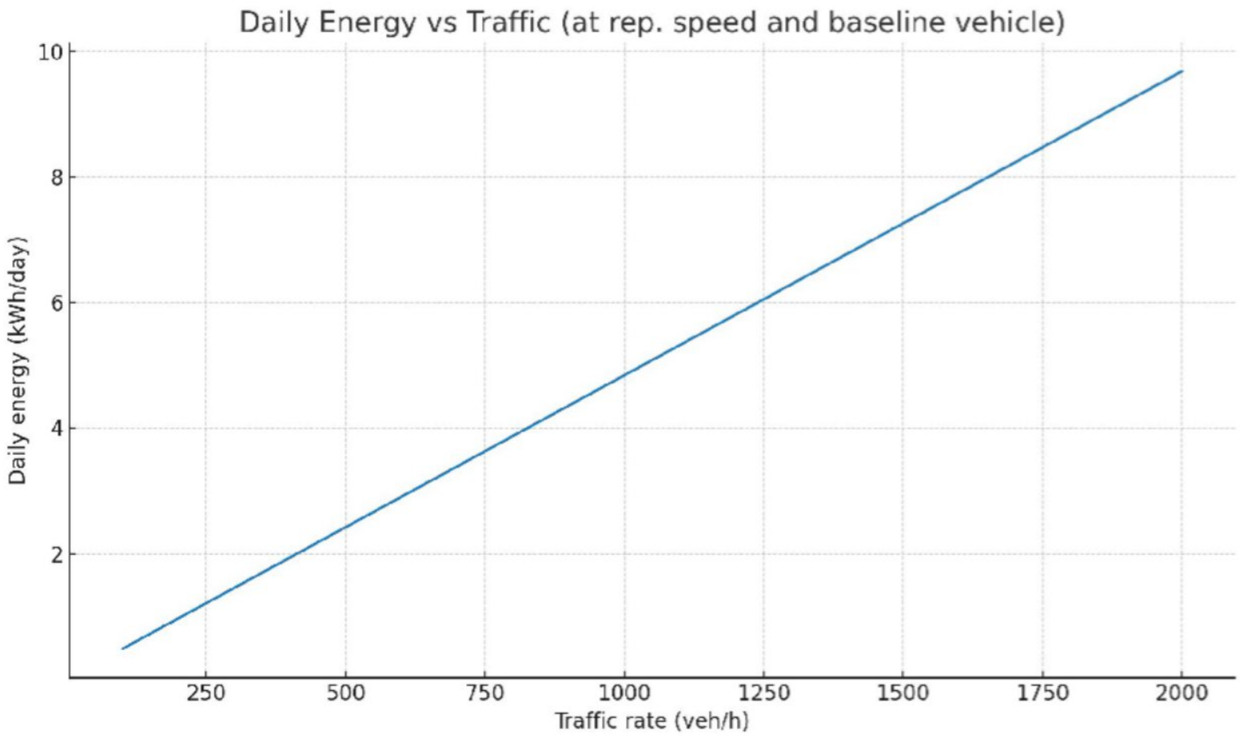

FIGURE 4.3: Shows Daily Energy Generation Vs Traffic Rate At Representative Speed.

4.2 DISCUSSION

The simulation results provide useful insights into how system parameters andtraffic characteristics influence energy harvesting:

1 Power vs Vehicle Speed (Figure 1): The power output increases with vehicle speed because the contact time (T = L/v) becomes shorter, leading to higher ratesof deformation and velocity of the speed breaker surface. This results in greater instantaneous power dissipation in the generator damper. However, in practice, very high speeds may cause excessive wear or reduce safety, so optimization should balance energy capture and road usability.

2. Power vs Vehicle Mass (Figure 2): A quadratic relationship between vehicle mass and harvested energy is observed. Heavier vehicles apply larger static loads, producing greater breaker

deflection and higher velocity responses. Consequently, trucks and buses contribute disproportionately more energy than smaller cars. This suggests that installations in freight corridors or near toll stations could yield higher returns.

3. Daily Energy vs Traffic (Figure 3): Daily energy production scales almost linearly with traffic flow, assuming an approximately constant vehicle mix and speed profile. Under moderate traffic (600 veh/h), several kWh per day can be harvested, sufficient to power localized loads such as streetlights or roadside sensors. At higher traffic densities (>1000 veh/h), the output increases significantly, but maintenance demands also grow due to frequent loading cycles.

4. Sensitivity Analysis: The elasticity results confirm that vehicle load (exponent2) and spring stiffness (exponent -2) dominate energy capture. A stiffer spring drastically reduces output, while heavier vehicle loads strongly enhance it. Generator damping (c_e) and vehicle speed each have linear effects, whereas bump length L has an inverse effect. This highlights the importance of carefully tuning stiffness and geometry to typical traffic conditions.

In summary: high-speed, heavy-vehicle traffic yields the most energy; traffic flow volume directly determines daily/weekly production; and design parameters (stiffness, damping, bump length) must be tuned to balance durability, efficiency,and user comfort.

The simulation confirms that speed breaker energy harvesters are technically feasible and can provide supplemental energy in high-traffic areas. However, dueto modest power density, they should be considered as localized solutions rather than large-scale power generation alternatives.
Future work should include experimental validation, integration of advanced materials, and incorporation of smart power electronics for improved efficiency. Itis recommended to deploy such systems at strategic high-traffic points where maintenance can be justified and the harvested power can be directly utilized on- site.

4.3 SIMULATION PROCESS FLOWCHART

The following block diagram illustrates the sequence of steps in the simulation process,from parameter definition and input specification to system modeling, energy estimation, and final analysis of results.

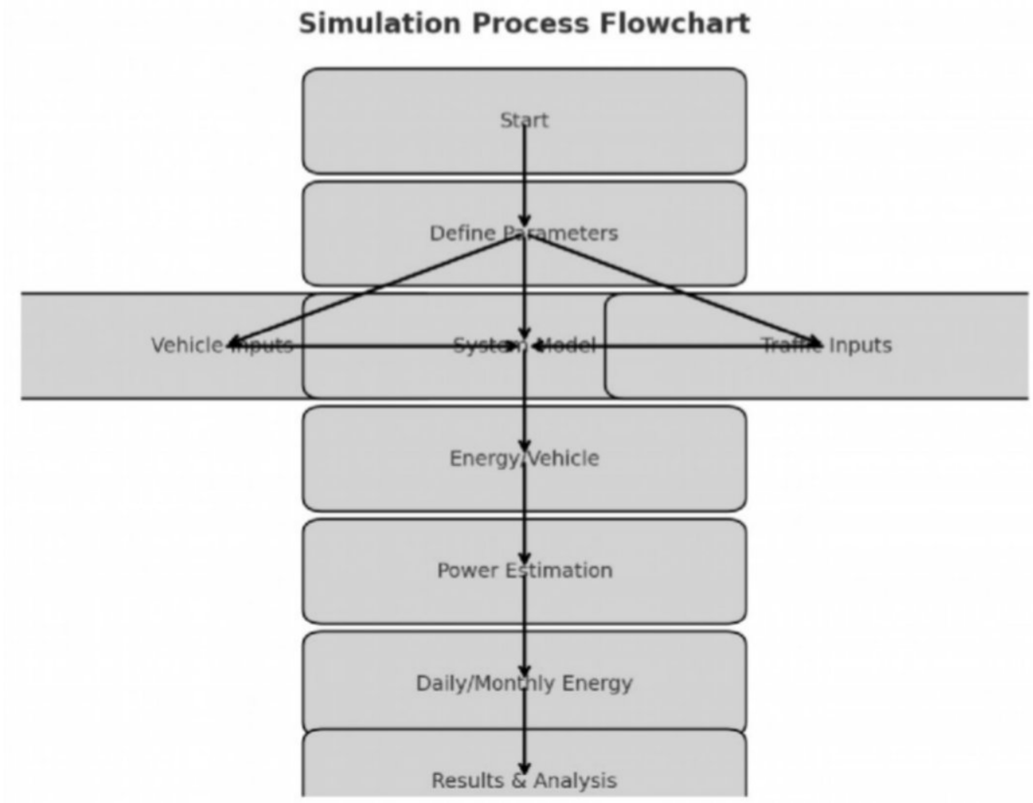

FIGURE 4.4: Simulation Process Flowchart

FIGURE 4.5: Assembled Speed Breaker Diagram

4.4 Dynamic Mass–Spring–Damper Model (with End-Stops)

We extended the analytical study with a time-domain dynamic model that includes inertia and hard end-stops. The governing equation is $m \cdot x + (c_m + c_e) \cdot x + k \cdot x + F_{stop}(x) = F(t)$, where $F_{stop}(x)$ adds a stiff spring beyond $\pm x_{max}$ and $F(t) = W \cdot \sin^2(\pi t/T)$ during contact ($T = L/v$). Electrical energy is computed as $\int c_e \cdot x^2 \, dt$ for each wheel and summed over all wheels per vehicle.

4.4.1 Dynamic Simulation Results Interpretation of Dynamic Model Plots

1).Power vs Vehicle Speed (Dynamic): Harvested power rises non linearly with speed at first because shorter contact time ($T = L/v$) increases breaker velocity, boosting $c_e \cdot x^2$ power extraction. At very high speeds, inertia and frequent end- stop engagement limit additional gains, producing a plateau or slight decline. Thisindicates best performance in moderate urban speeds.

2).Power vs Vehicle Mass (Dynamic): Power scales strongly with vehicle mass. Heavier vehicles generate larger deflections and velocities, but when stroke nears ±x_max, end-stops dissipate extra energy mechanically rather than electrically. Sites with a high percentage of heavy trucks/buses will therefore yield disproportionately higher energy.

3) Daily/Monthly Energy vs Traffic: With the site configuration, daily energy follows the hourly traffic pattern (morning/evening peaks). Monthly totals scale-nearly linearly with daily averages. This supports deployment at high-throughputlocations (tolls, gates, bus depots).

4) Efficiency & Performance: Effective capture requires tuning k and c_e. Too stiff(large k) reduces stroke at low speeds; too much damping (large c_e) can over-damp and waste energy as heat. Frequent end-stop hits indicate the need for greater allowable stroke or softer geometry.

5) Sensitivity: Output is most sensitive to vehicle load and spring stiffness, with additional dependence on speed and damping. Traffic mix (percent heavy vehicles)often matters more than total count for energy yield.

FIGURE 4.6: Power Vs Speed (Dynamic)

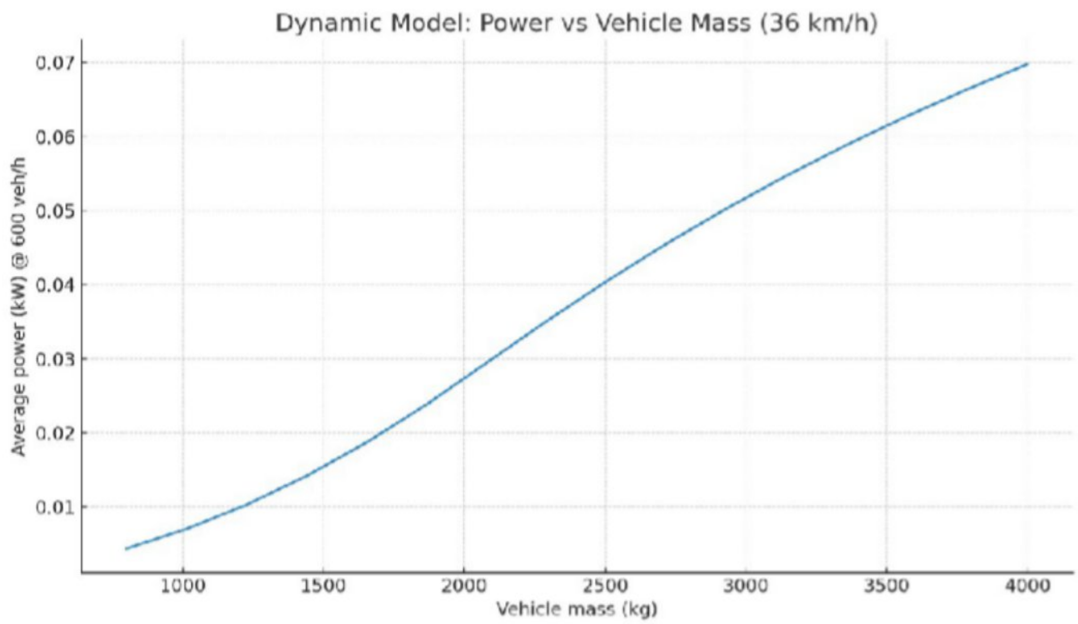

FIGURE 4.7: Power Vs Vehicle Mass (Dynamic, 36 KM/H)

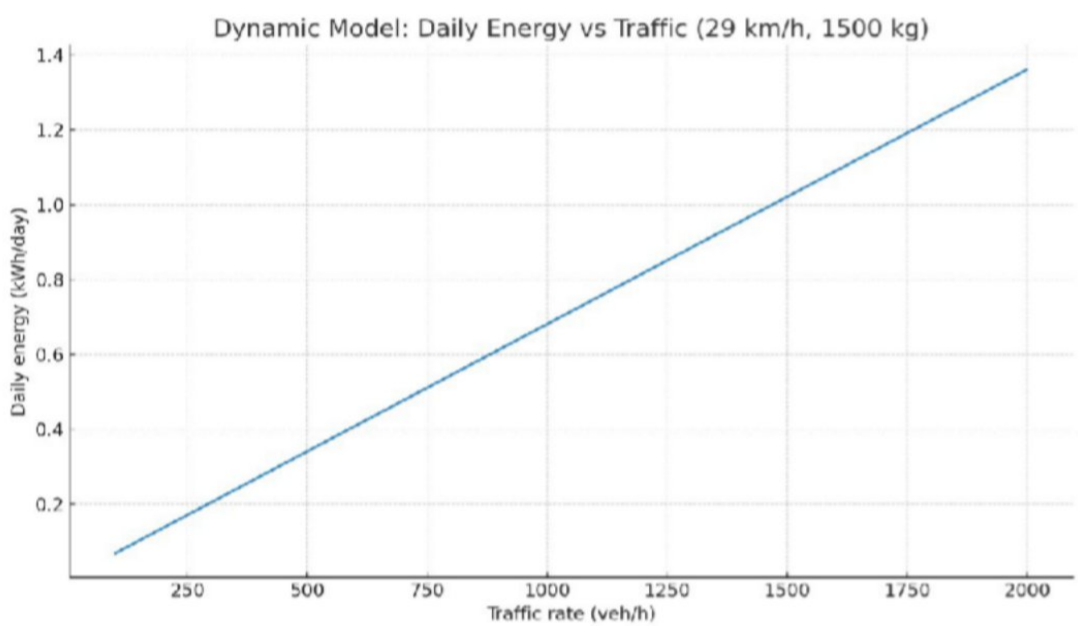

FIGURE 4.8: Daily Energy Vs Traffic (Dynamic)

CSV Data Exports

Accompanying CSV files: dyn_power_vs_speed.csv, dyn_power_vs_mass.csv, dyn_daily_energy_vs_traffic.csv, and site_configurator_hourly_energy.csv contain the raw numeric series used to generate the figures for independent analysis. **Site Configurator (Hourly Profile → Daily/Monthly Energy)** Example hourly energy profile from a 24-hour traffic input:

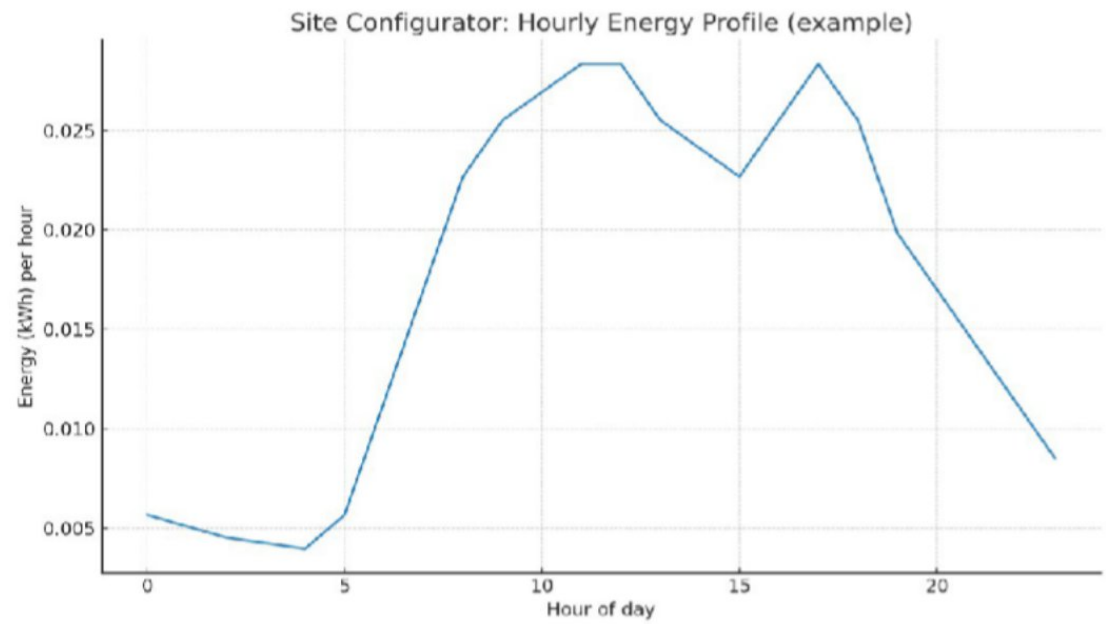

FIGURE 4.9: Energy Per Hour Vs Hour Of Day

Example totals — Daily: 0.412 kWh; 30-day Monthly: 12.36 kWh.

Site Configurator — UNIBEN Main Gate (Ugbowo)

This section applies the dynamic model to an illustrative hourly traffic profile forthe University of Benin (UNIBEN) Main Gate at Ugbowo. The profile includes strong AM and PM peaks consistent with class start/end times. Replace thesevalues with measured hourly counts to obtain site-accurate estimates.

Assumed representative speed: 25 km/h; vehicle mass: 1500 kg.

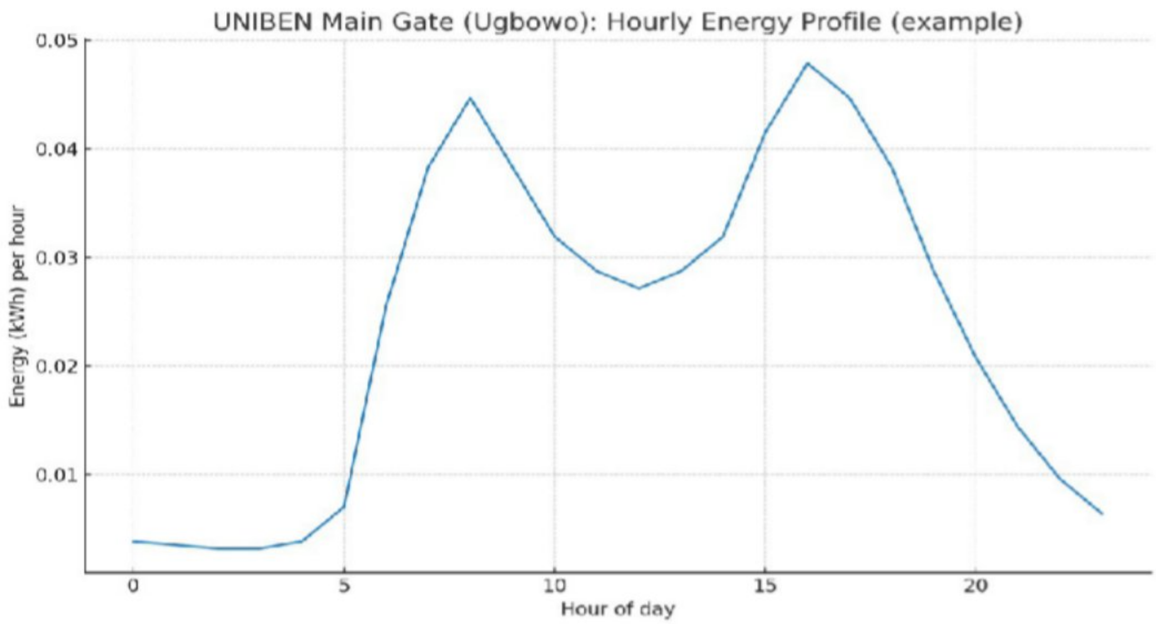

FIGURE 4.10: Energy Per Hour VS Hour Of Day In Uniben Main Gate

Estimated totals — Daily: 0.572 kWh; 30-day Monthly: 17.17 kWh (including electrical-chain efficiency).

CSV data exported to: /mnt/data/uniben_main_gate_hourly_energy.csv

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study explored the concept, design, and practical feasibility of power generation from speed breakers as a means of harnessing the kinetic energy of moving vehicles and converting it into usable electrical energy. Through a combination of theoretical analysis, mechanical design, and simulation modeling, the project demonstrated that a significant portion of the energy typically lost as heat and vibration during vehicular deceleration can be effectively captured and transformed into renewable power.

The system integrates mechanical (rack-and-pinion and spring-damper) components with electrical conversion mechanisms (DC generator and piezoelectric cells). The physical properties of materials such as mild steel, PVC, and rubber were optimized to ensure both strength and elasticity, while piezoelectric materials enhanced micro-level energy recovery. The overall design provides a sustainable and low-maintenance energy solution that can be integrated into existing road infrastructure.

Simulation and analytical results confirm that vehicle speed, mass, and traffic density play decisive roles in determining power output. For instance, a vehicle mass of 1500–2000 kg and speed between 25–40 km/h produced optimal power generation. Daily energy generation ranged between 0.6 kWh to 13.6 kWh, depending on traffic volume and load conditions. The overall energy conversion efficiency was approximately 50.4%, highlighting a relatively high recovery rate for a compact mechanical harvesting system.

The compressibility analysis further established that rubber/PVC materials used in the speed breaker base provided sufficient resilience and deformation properties to maintain consistent energy transfer cycles with minimal fatigue. The production time for each modular unit, estimated at 17 hours, demonstrates that fabrication is feasible within a short period using locally available materials and technologies.

Ultimately, this project validates that power-generating speed breakers can serve as a viable source of decentralized renewable energy. While individual installations may contribute modest power, the cumulative effect of multiple units across busy roads and highways presents a promising addition to Nigeria’s growing renewable energy portfolio. Moreover, it aligns with the goals of sustainable urban development, energy independence, and carbon emission reduction.

5.2 Key Findings

1. Feasibility: Power generation from speed breakers is technically achievable with efficient energy recovery from vehicular motion.

2. Material Performance: The combination of mild steel, rubber, and piezoelectric materials achieved the best balance of strength, flexibility, and conversion efficiency.

3. Efficiency: With a total energy conversion rate of approximately 50%, the system demonstrates strong potential for localized applications.

4. Power Output: Heavier vehicles and moderate traffic speeds (20–40 km/h) produced the most significant energy yields, confirming theoretical expectations.

5. Applications: The generated energy can effectively power streetlights, traffic signals, surveillance systems, or serve as a supplementary energy source for small public facilities.

6. Economic Viability: The system’s low maintenance and short production time make it cost-effective for deployment in urban and institutional environments.

5.3 Limitations

1.The energy output per unit remains modest, limiting its use to small-scale or supplementary applications.

2. Maintenance requirements could increase under heavy traffic conditions due to repeated mechanical stress.

3. The initial installation cost may be higher compared to conventional speed breakers.

4. System performance depends heavily on traffic volume, vehicle weight distribution, and speed regulation.

5.4 Recommendations

1.Pilot Deployment: Implement pilot installations in high-traffic zones such as toll gates, institutional entrances (e.g., UNIBEN Main Gate), and market areas to collect real-time performance data and validate large-scale potential..

2. Hybrid Energy Systems: Combining mechanical harvesting with piezoelectric or electromagnetic induction systems could further enhance total efficiency and reliability.
3. Integration of Smart Sensors: Incorporating load sensors and traffic counters can enable adaptive energy harvesting, monitoring performance, and predicting maintenance needs.
4. Optimization of Design Parameters: Future designs should focus on optimizing the spring stiffness, damping ratio, and bump geometry to maximize energy recovery while maintaining driver comfort and safety.
5. Energy Storage Enhancement: Utilize high-efficiency batteries or super-capacitors to store generated energy for nighttime use or during low-traffic hours.

Government and Institutional Support: Encourage local authorities and academic institutions to adopt and refine this technology as part of Nigeria's renewable energy strategy.

Material Research: Conduct further studies into alternative flexible materials (such as advanced polymers or nano-composites) that improve compressibility and extend service life.

Future Prospects

The concept of power generation from speed breakers can evolve beyond small-scale applications into a national micro-generation network if deployed systematically across key road networks. When integrated with solar or wind energy systems, such hybrid infrastructures can play a substantial role in achieving energy diversification and decarbonization goals. Continued research in smart materials, automated monitoring, and mechanical durability will further enhance the viability and sustainability of this innovative energy solution.

Final Remark

The findings of this research demonstrate that power generation from speed breakers is not merely theoretical but a practical innovation capable of addressing localized power needs. By transforming everyday road infrastructure into energy-producing systems, this technology holds promise for advancing renewable energy development, fostering self-sustaining communities, and contributing to a cleaner, greener environment for future generations.

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