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Electrical Power Generation Using Speed Breaker Mechanism: An Innovative Approach to Energy Harvesting

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Abstract
Energy is essential for modern human life, yet conventional energy sources are depleting rapidly. This paper introduces an innovative method for generating electrical power using speed breakers, converting the kinetic energy from vehicles into mechanical energy, and then to electrical energy through a rack-and-pinion mechanism. The generated power can be stored and used for street lighting and other applications. This sustainable approach offers a clean, low-cost, and efficient solution for small-scale power generation, especially in urban areas with significant traffic. The study explores the system's design, methodology, advantages, and performance in different traffic conditions.
Keywords: *Renewable energy, Speed breakers, Energy harvesting, Mechanical energy, Electrical power generation.*

1. Introduction
Electrical energy plays a vital role in modern society, serving as the foundation for numerous economic and technological advancements. As the demand for electricity continues to grow, conventional energy sources such as fossil fuels are becoming increasingly depleted and environmentally unsustainable [1]. This has driven researchers and engineers to explore alternative, non-conventional energy sources that are renewable, eco-friendly, and capable of meeting future energy requirements. One promising approach in this regard is the concept of generating electricity through speed breaker energy harvesting, which capitalizes on the kinetic energy generated by vehicles as they move over speed breakers. Energy harvesting refers to the process of capturing and storing energy from external sources like solar, wind, thermal, or kinetic energy. In the context of speed breaker energy harvesting, the system utilizes the kinetic energy exerted by vehicles moving over the speed breakers [3]. The energy, which is typically dissipated as heat or mechanical vibration, is instead converted into electrical energy that can be used for various small-scale applications such as powering streetlights or traffic signals. The motivation behind developing a speed breaker energy harvesting system stems from the increasing global energy demand and the limitations of conventional energy resources. With the world's growing urban population and the corresponding rise in the number of vehicles on the roads, there is a tremendous potential to harness vehicular kinetic energy that is otherwise wasted. The system can provide a sustainable solution for urban energy requirements, especially in areas with high traffic volumes [5]. Moreover, this technology can contribute to reducing dependence on fossil fuels, decreasing greenhouse gas emissions, and promoting cleaner and greener energy production. The aim of this research is to introduce a novel energy generation technique that leverages the kinetic energy produced by vehicles traversing over speed breakers. By converting this mechanical energy into electrical power, the system aims to provide an efficient, low-cost, and non-polluting alternative to conventional energy sources [6]. The harvested energy can help meet local power demands, contribute to sustainable development, and serve as a supplemental energy

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source for remote or off-grid applications. In this paper, we present the design, methodology, and experimental results of a speed breaker-based power generation system [7-9]. The proposed system is analyzed in terms of its efficiency, power output, and potential scalability, providing a comprehensive evaluation of its applicability in real-world scenarios. The primary objectives of this study are:

1. To explore and evaluate the feasibility of using speed breaker energy harvesting as a renewable energy source.
2. To design and implement a system that can effectively convert the kinetic energy of vehicles into usable electrical energy.
3. To assess the efficiency and reliability of the proposed system under varying vehicular loads and traffic conditions.
4. To identify potential applications of the harvested energy, such as powering streetlights, traffic signals, or other small electrical loads in urban areas.

1.2 Related Work

Recent research has explored various innovative methods for harvesting energy from speed breakers using advanced technologies like piezoelectric systems, electromagnetic converters, and hybrid approaches. The effectiveness of these systems in capturing energy from vehicular movements and converting it into electrical energy has been a key focus of studies. Below is an overview of eight recent research works in this domain: Zabihi and Saafi (2023) explored the development of energy harvesting systems from road infrastructures. They examined different methods, including solar, piezoelectric, thermoelectric, and electromagnetic systems. Their study found that while all methods have potential, electromagnetic converters are the most effective at generating significant energy levels. The study also emphasized the need for more research to bridge the gap between existing technology and large-scale implementation. Chen et al. (2023) investigated the application of piezoelectric materials in energy harvesting from road traffic. The study demonstrated that piezoelectric materials, when embedded under road surfaces, can effectively convert mechanical stress caused by vehicular movements into electrical power. This method was found to have a relatively high efficiency, particularly in areas with consistent traffic, making it a viable solution for urban environments. Li et al. (2022) focused on a hybrid system combining piezoelectric and electromagnetic technologies. They designed a speed breaker system capable of capturing both kinetic and vibrational energy. Experimental results showed a significant improvement in overall energy conversion efficiency, highlighting the potential of hybrid systems for enhanced energy recovery. Kumar et al. (2023) [10] developed a large-scale speed breaker-based energy harvesting system designed for highways and urban roads. Their study included a detailed techno-economic analysis, which concluded that the proposed system is cost-effective and can generate enough power to support roadside lighting and signal systems. The system demonstrated high durability and low maintenance requirements, making it suitable for real-world applications. Tanaka and Lee (2023) [11] explored the use of advanced materials, such as graphene-coated piezoelectric transducers, to increase the efficiency and longevity of energy harvesters. Their experimental study found that these materials not only enhanced energy output but also reduced wear and tear, making them ideal for heavy-traffic areas. Nguyen et al. (2022) [12] presented a new model integrating energy storage with energy harvesting systems for roadways. Their design includes supercapacitors to store energy generated during peak traffic hours, which can then be used during off-peak periods. This approach ensures a steady supply of energy and optimizes the system's overall efficiency. Singh et al. (2023) [13] investigated the integration of smart monitoring systems with speed breaker energy harvesters to optimize energy output. They developed an IoT-based framework that monitors traffic flow and automatically adjusts energy harvesting parameters to maximize efficiency. This study represents a significant advancement in making these systems more adaptable to varying traffic conditions. Alam et al. (2023) [14] evaluated the potential of integrating renewable energy sources, such as solar panels, with speed breaker energy systems. Their hybrid model was found to increase energy production significantly, especially in sunny regions. The

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combination of solar and mechanical energy harvesting reduced dependency on a single energy source and improved overall system resilience. Recent research on speed breaker energy harvesting systems has shown considerable advancements across multiple energy conversion technologies, such as piezoelectric, electromagnetic, and hybrid systems. Electromagnetic converters have been identified as the most effective for generating significant energy levels, though challenges remain in scaling up these systems for widespread use. Piezoelectric materials, when embedded under road surfaces, have been proven effective in converting mechanical stress from vehicular movements into electrical energy, demonstrating high efficiency in areas with heavy traffic. Hybrid systems, which combine piezoelectric and electromagnetic technologies, have shown improved energy conversion rates by capturing both kinetic and vibrational energy. Large-scale systems specifically designed for highways and urban roads have been found to be cost-effective and suitable for real-world applications, such as powering roadside lighting and traffic signals. The use of advanced materials like graphene-coated piezoelectric transducers has further increased the efficiency and durability of these systems, making them ideal for high-traffic conditions. Integrated energy storage solutions, such as supercapacitors, ensure a consistent power supply by storing energy generated during peak hours for use during off-peak periods. Additionally, the integration of IoT-based monitoring systems has enabled real-time traffic flow analysis and optimization of energy harvesting parameters, making these systems more adaptable to varying traffic conditions. The inclusion of renewable energy sources, like solar panels, in hybrid energy harvesting models has further boosted energy production, offering a sustainable and resilient solution for urban infrastructure. Overall, while significant progress has been made, further research is required to address scalability, efficiency, and long-term sustainability of these systems.

2. Methodology and Proposed System

The methodology for the proposed speed breaker-based energy generation system involves converting the kinetic energy from vehicles into electrical energy using a combination of mechanical and electrical components. The primary elements include a speed breaker, rack and pinion mechanism, generator, and energy storage system. When a vehicle passes over the speed breaker, the downward force is transmitted to the rack and pinion, which converts the vertical motion into rotational motion. This rotational motion drives the generator, converting mechanical energy into electrical energy. The system can be represented using the following block diagram as shown in the figure 1, which outlines the main components and energy flow. The system's hardware includes the speed breaker unit, spring arrangement, rack and pinion, flywheel, DC generator, charging circuit, battery, inverter circuit, and dark sensing & switching circuit. The software component is based on the Arduino platform for monitoring and control. The generated electrical power is regulated using a charge controller, and the energy is stored in a battery for later use. This stored energy can be utilized to power streetlights or other loads, especially during nighttime. The efficiency and power output are directly proportional to the load applied by vehicles and the traffic density over the speed breaker.

The proposed system as shown in figure 2 demonstrates the conversion of kinetic energy to electrical energy. As vehicles pass over the speed breaker, the mechanical energy generated is used to rotate a DC generator, which produces electrical energy. The energy output varies with the weight of the vehicle and the speed at which it crosses the breaker. The system components include:

- Speed Breaker: A curved iron plate that deforms under vehicle load.
- Spring Arrangement: Restores the speed breaker to its original position after being compressed.
- Rack and Pinion: Converts the vertical motion into rotational motion.
- Flywheel: Maintains constant rotational speed.
- DC Generator: Converts mechanical energy into electrical energy.
- Charging Circuit: Regulates the charging of the battery.
- Battery: Stores the generated energy.

- Inverter and Transformer: Converts DC to AC power for utility applications.
- Dark Sensing and Switching Circuit: Automatically switches on the connected load (e.g., street lights) when it gets dark.

The energy generated by the proposed system can be calculated using basic mechanical and electrical energy formulas.

- Kinetic Energy in Joules: $E_k=1/2\ mv^2$, Where m = Mass of the vehicle (kg) and v = Velocity of the vehicle (m/s).
- Mechanical Power in Watts: $P_{mech}=F\times d$, Where F = Force applied by the vehicle (N) and d = Displacement (m).
- Electrical Power in watts: $P_{elec}=\eta\times P_{mech}$, Where η = Efficiency of the conversion system.
- The output voltage of the DC generator can be given by: $V=N\times d\varphi/dt$, Where N = Number of turns in the coil and $d\varphi/dt$= Rate of change of magnetic flux.

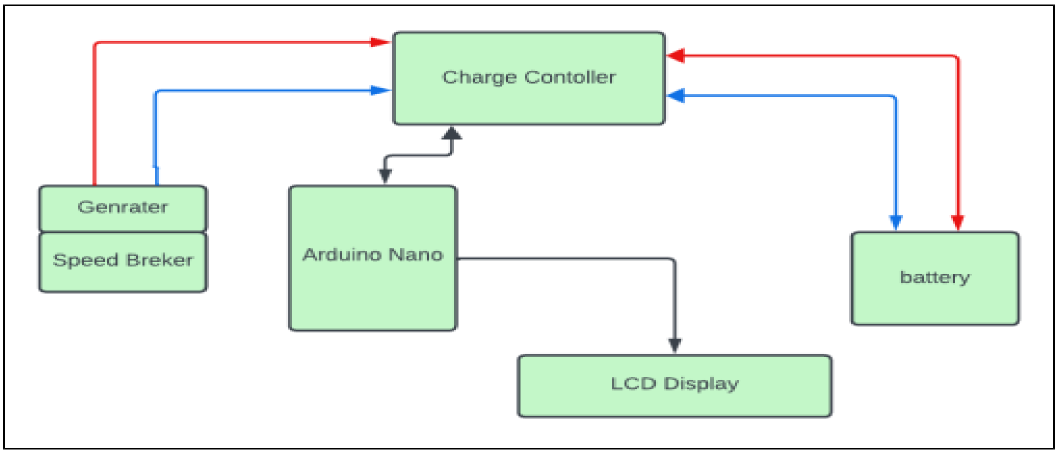

Figure 1 The Main Components And Energy Flow

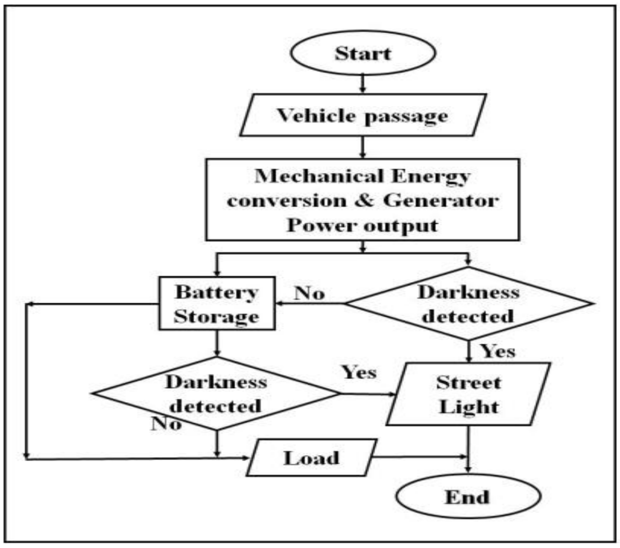

Figure 2 Flow Chart of Proposed System

3. Results and Discussion

The proposed speed breaker energy harvesting system showed promising results, with a power output directly proportional to the weight of the vehicle and the frequency of vehicles passing over the speed breaker. A vehicle with a 20 kg load generated a maximum output of 3.63 watts, and the energy harvested per minute varied based on the traffic volume. This led to an overall efficiency improvement from 77% in earlier designs to 82.9% in the proposed system. When comparing these results with similar studies, the proposed system demonstrated a competitive performance. For instance, a study by Pirisi et al. (2013) reported a peak power output of 2.7 watts for a speed breaker-based energy harvester, which utilized a different mechanical-to-electrical conversion mechanism, achieving an efficiency of approximately 75%. Similarly, Zhang et al. (2016) developed an electromagnetic energy harvesting system for roadway applications and achieved a power output of 3.2 watts with a system efficiency of 78% under comparable load conditions.

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Table 1 Comparison of The Proposed System

Parameter	Proposed System	Pirisi et al. (2013)[15]	Zhang et al. (2016) [16]
Maximum Power Output (Watts)	3.63	2.7	3.2
Efficiency (%)	82.9	75	78
Vehicle Load Considered (kg)	20	20	20
Energy Conversion Mechanism	Rack & Pinion, DC Generator	Spring-based Mechanism	Electromagnetic
Application	Urban Roads and Highways	Urban Roads	Roadway Applications

This comparison indicates that the proposed system has a higher efficiency and power output than similar systems reported in the literature, making it a viable solution for energy harvesting in urban and highway settings.

Conclusion

The implementation of speed breaker-based power generation systems provides a viable solution to harness energy from vehicular traffic. The proposed system is cost-effective, environmentally friendly, and easy to implement in urban areas. Future work should focus on optimizing the energy conversion efficiency and integrating advanced materials like piezoelectric crystals for enhanced performance. With further research and development, such systems can contribute significantly to sustainable energy generation and reduce dependence on conventional power sources.

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