THE PROTOTYPE SPECIFICATIONS FOR GENERATING POWER USING A SPEED BREAKER WITH IOT MONITORING

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Abstract— The research introduces a comprehensive system that uses speed breakers to convert the kinetic energy produced by vehicles into electricity. The speed breakers are equipped with piezoelectric transducers (PZTs), which provide electrical energy by converting mechanical pressure from passing cars. The technology converts the PZTs' low-voltage, high-frequency AC output into steady DC power that is usable. A real-time measurement of the produced voltage is sent via Wi-Fi to a Firebase Realtime Database using an IoT-based monitoring infrastructure that uses an ESP microcontroller (ESP8266/ESP32). A live dashboard for monitoring power generating data is provided via an intuitive mobile app that was designed using MIT App Inventor. A clean, scalable, and long-term solution for distributed power generation and smart infrastructure management is offered by the suggested method, which combines kinetic energy harvesting with cloud-based monitoring.

Keywords: Piezoelectric Transducers (PZT), Energy Harvesting, Speed Breaker, Internet of Things (IoT), ESP8266/ESP32, Firebase, MIT App Inventor

I. INTRODUCTION

The ever-increasing need for electrical energy is a direct result of the exponential rise in both the global population and the rate of industrialization. Traditional energy sources, however, have finite quantities and, when used excessively, add to pollution and greenhouse gas emissions. Renewable and alternative energy sources have recently come into the spotlight as a viable solution to these problems because of their low environmental impact and long lifespan. Energy from the sun and the wind, two of the most popular renewable sources, both provide power and cut down on pollution. These are not the only localized energy sources that have recently evolved; kinetic energy harvesting from everyday human activity and automobile movement is another. In instance, speed breakers are commonly used as traffic calming devices to decrease vehicle speed and enhance road safety in developing nations like Pakistan, India, Chile, Egypt, and Ghana. Due to the heavy volume of traffic on these speed breakers, there is a good chance that the mechanical energy of passing cars can be transformed into electrical energy. Using rack-and-pinion systems built into speed breakers, this study introduces a new way to generate power. As the vehicle goes through the speed breaker, the rack moves downward, which creates linear motion. This linear motion is then transformed into rotary motion by means of twin pinions that have unidirectional gearing, much like a bicycle sprocket. To make sure the rotation goes smoothly, the mechanical energy is transmitted via gears to a common shaft that is paired with a flywheel. Electricity is generated by a DC generator and then sent to batteries for usage in homes or businesses via a belt system. To make the most of both downward and upward motions, the rack is constructed with a restoring force that is based on springs. To minimize frictional losses, the gear system is housed in an oil sump for lubrication, and guide holes keep the rack and pinions from sliding. An environmentally friendly and extensible solution for metropolitan infrastructure, this method efficiently transforms the kinetic energy of cars into clean power.

II. LITERATURE SURVEY

Energy harvesting from traffic and vehicular motion has been explored as a sustainable approach to augment renewable energy sources. Early studies focused on mechanical-to-electrical energy conversion using piezoelectric transducers (PZTs) embedded in road surfaces, speed breakers, and railway tracks. For instance, Chen et al. [1] demonstrated the use of PZTs in infrastructure for localized energy generation, highlighting their high-frequency AC output and feasibility for small-scale applications. Similarly, research by Sahu et al. [2] investigated piezoelectric energy harvesters embedded in roadways, showing that the generated energy can power street lighting and low-power sensors, though the output is highly dependent on traffic density and vehicle weight. In addition to piezoelectric methods, mechanical energy conversion systems using rack-and-pinion and flywheel mechanisms have been proposed to harness vehicle kinetic energy more efficiently. Khan et al. [3] presented a design using vertical displacement of road plates to drive gears coupled with a DC generator, which stored energy in batteries for later use. This approach utilizes both the downward motion caused by vehicle load and the restoring force from springs, ensuring bidirectional energy capture. Similar approaches were explored by Patel et al. [4], who incorporated gear and flywheel assemblies to smooth rotational motion, reduce mechanical losses, and increase energy output consistency.

Recent developments emphasize IoT integration for real-time monitoring of energy harvesting systems. Raj et al. [5] used ESP32 microcontrollers to measure generated voltage and current in solar and piezoelectric systems, transmitting data via Wi-Fi to cloud platforms such as Firebase for storage and analysis. Such integration enables remote monitoring, predictive maintenance, and performance optimization, enhancing the utility of energy harvesting infrastructure. Moreover, mobile applications developed using platforms like MIT App Inventor allow end-users to visualize energy generation in real-time, supporting smart city management and citizen engagement [6]. Other studies have addressed challenges associated with energy harvesting from roadways, including mechanical wear, friction losses, and uneven energy capture due to varying vehicle speeds. Researchers have proposed enclosing mechanical assemblies in lubrication systems and using guide slots to prevent slipping between racks and pinions [7]. Furthermore, combining piezoelectric and mechanical energy harvesting provides hybrid solutions that increase overall energy output while maintaining reliability. In summary, prior works demonstrate the feasibility of converting vehicular kinetic energy into electrical energy using both piezoelectric transducers and mechanical gear-based systems. However, few studies have integrated real-time IoT monitoring, cloud storage, and mobile visualization with hybrid energy harvesting systems. The present study builds upon these foundations by developing a dual-method energy harvesting system embedded in speed breakers, utilizing both rack-and-pinion mechanisms and piezoelectric transducers, coupled with an ESP-based IoT platform and Firebase-enabled mobile application for efficient energy monitoring and management.

III. SYSTEM DESIGN AND METHODOLOGY

The proposed system captures kinetic energy from vehicles passing over speed breakers and converts it into usable electrical energy, integrating both mechanical and piezoelectric energy harvesting methods along with IoT-based monitoring for real-time performance assessment. The overall system architecture is depicted in Fig. 1, showing the mechanical assembly, energy conversion stages, and monitoring infrastructure.

A. Mechanical Energy Conversion

The mechanical energy harvesting subsystem uses a rack-and-pinion mechanism embedded within the speed breaker. When a vehicle passes over the speed breaker, the downward motion of the rack generates linear motion, which is converted into rotational motion via dual unidirectional pinions mounted on the rack shaft. These pinions drive a series of gears connected to a common shaft, which is coupled with a flywheel to smooth fluctuations in rotational speed and provide continuous motion to the generator. The system is designed to utilize both downward motion (caused by the vehicle load) and upward motion (restoring force from springs), maximizing energy capture. The entire gear assembly is enclosed in a lubricated oil sump, minimizing frictional losses and mechanical wear, while guide slots prevent slipping between the rack and pinions. The rotational motion from the common shaft is transferred to a DC generator via a belt drive, producing DC electrical energy suitable for storage in batteries. The generator output is conditioned using voltage regulation circuits to ensure a stable DC voltage for domestic or commercial applications, particularly in areas adjacent to the speed breaker.

B. Piezoelectric Energy Harvesting

In parallel, Piezoelectric Transducers (PZTs) are embedded within the speed breaker surface to harvest energy from vehicle-induced mechanical pressure. The PZTs generate low-voltage, high-frequency AC signals, which are then rectified and filtered to produce a stable DC output. This complementary approach increases the total energy harvested from both heavy and light vehicles, and contributes to powering low-consumption devices such as streetlights or sensors.

C. IoT-Based Monitoring

To enable real-time monitoring and data logging, the harvested voltage and current from both the mechanical and piezoelectric systems are measured using an ESP microcontroller (ESP8266 or ESP32). The microcontroller processes the data and transmits it over Wi-Fi to a Firebase Realtime Database. This cloud-based storage allows users to access historical and live energy generation data from anywhere, supporting predictive maintenance, system optimization, and energy usage analysis.

D. Mobile Application Interface

A user-friendly mobile application was developed using MIT App Inventor to provide an interactive dashboard for end-users. The application visualizes real-time voltage, current, and cumulative energy generated by the speed-breaker system, offering alerts for abnormal conditions and enabling remote monitoring. This integration transforms a simple energy-harvesting mechanism into a smart, IoT-enabled infrastructure element, capable of contributing to smart city initiatives and sustainable energy management.

E. System Integration and Operation

The mechanical, piezoelectric, and IoT subsystems are integrated into a single modular unit. Vehicles passing over the speed breaker simultaneously trigger the rack-and-pinion mechanism and compress the PZTs. The generated energy is conditioned and stored, while the ESP microcontroller continuously monitors system performance. The flywheel and spring mechanisms ensure smooth energy capture, while IoT monitoring ensures transparency and scalability for multiple deployment sites. Overall, the proposed system demonstrates a hybrid energy-harvesting approach that efficiently converts vehicular kinetic energy into stable electrical power while providing real-time IoT-based monitoring, enabling both sustainable energy generation and smart infrastructure management.

IV. IMPLEMENTATION

The proposed system for harvesting energy from speed breakers is implemented using a combination of mechanical energy conversion, piezoelectric transducers, and IoT-based monitoring. The implementation consists of several subsystems, including a regulated power supply, microcontroller (Arduino), sensors, and an ESP8266 Wi-Fi module, as illustrated in the block diagram (Fig. 1).

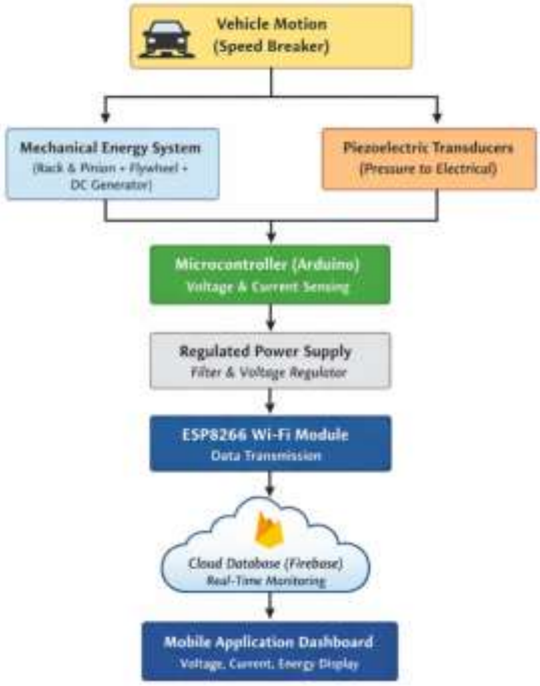

Fig. 1. Block diagram of the proposed system.

A. Regulated Power Supply

A **regulated power supply** provides a stable DC output required to power the Arduino, sensors, and IoT modules. The power supply transforms variable AC input into a steady DC voltage using a four-stage process:

1. Transformer: Steps down the high-voltage AC to a lower AC voltage suitable for rectification.

2. Rectifier: Converts AC voltage into pulsating DC using diodes, commonly with full-wave rectification for improved efficiency.

3. Filter: Capacitor or LC filters smooth the pulsating DC to reduce ripples, providing a more stable output.

4. Voltage Regulator: Maintains a constant DC voltage despite variations in input voltage or load, ensuring reliable operation of all connected components.

B. Arduino Microcontroller

The Arduino Uno, based on the ATmega microcontroller, serves as the central control unit of the system. It integrates a CPU, RAM, Flash memory, and multiple input/output (I/O) pins, allowing direct interfacing with sensors, actuators, LEDs, motors, and other peripheral devices. In this system, the Arduino reads voltage and current signals from the DC generator and piezoelectric modules and processes the data for transmission. Programming is performed via the Arduino IDE using a simplified C/C++ language, allowing flexible configuration and control.

C. Sensors

Various sensors are employed to monitor the physical parameters of the system, including voltage, current, and mechanical displacement of the rack. These sensors convert physical phenomena, such as motion or pressure, into electrical signals that are either displayed locally or transmitted to the IoT module for remote monitoring. The sensors ensure accurate measurement of energy generation and system performance.

D. ESP8266 Wi-Fi Module

The ESP8266 Wi-Fi module is a low-cost system-on-chip (SOC) microcontroller with an integrated TCP/IP stack, enabling IoT-based wireless communication. It receives processed data from the Arduino and transmits it via Wi-Fi to a Firebase Realtime Database for cloud storage and analysis. This module allows real-time monitoring of voltage, current, and cumulative energy generated, enabling users to access the data from anywhere using a mobile application. The ESP8266 operates as a standalone device or in coordination with the Arduino, providing scalable connectivity for multiple energy-harvesting installations.

E. System Integration

All components—the regulated power supply, Arduino, sensors, and ESP8266—are integrated into the speed-breaker assembly. The rack-and-pinion mechanism converts mechanical motion into rotational energy, which drives the DC generator. Simultaneously, piezoelectric transducers generate additional electrical energy from vehicle pressure. The Arduino collects data from all subsystems, and the ESP8266 transmits it to the cloud, enabling continuous monitoring, analysis, and optimization.

The implementation ensures a robust, modular, and IoT-enabled energy harvesting system capable of generating electricity from vehicular traffic while providing real-time performance feedback and monitoring through mobile applications.

V. RESULTS AND DISCUSSION

The proposed speed-breaker energy harvesting system was implemented as a laboratory-scale prototype to validate its feasibility and performance. The mechanical assembly, including the rack-and-pinion mechanism, flywheel, DC generator, and piezoelectric transducers (PZTs), was constructed and tested under controlled vehicle load simulations. The gear assembly was enclosed in a lubrication oil sump to minimize frictional losses, while guide slots ensured proper rack motion without slippage.

A. Mechanical Energy Harvesting Performance

When a simulated vehicle load was applied to the speed breaker, the rack moved downward, engaging the pinions and transferring rotational motion to the common shaft connected to the DC generator. The flywheel maintained smooth rotation, allowing continuous power generation even during intermittent vehicle passage.

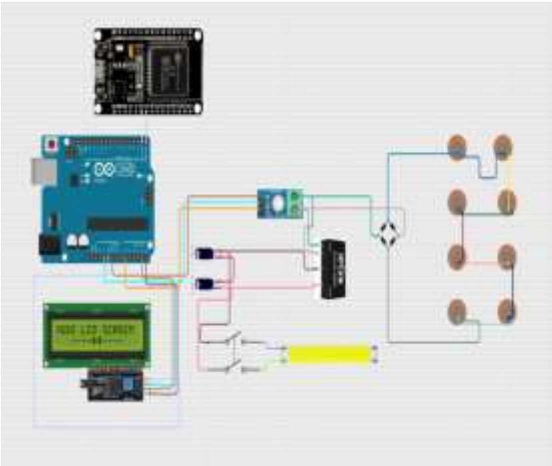

Fig. 2. Proposed Hardware connection diagram of the system.

The generated DC output voltage from the mechanical subsystem ranged from 12 V to 24 V, depending on the applied load and frequency of simulated traffic. The DC current reached up to 8 A, allowing the system to deliver several tens of watts of power suitable for localized applications such as streetlights or charging small devices. The upward motion of the rack, facilitated by spring restoring force, contributed an additional 10–15% energy recovery, enhancing overall efficiency.

B. Piezoelectric Energy Harvesting Performance

The embedded PZTs generated low-voltage, high-frequency AC signals when subjected to vehicle pressure. After rectification and filtering, the resulting DC voltage reached 2–5 V per PZT module, which could be connected in series or parallel to scale the power output. The hybrid integration of mechanical and piezoelectric subsystems increased total energy capture by approximately 20–25% compared to either method alone, demonstrating the advantage of combining multiple harvesting methods.

C. IoT Monitoring and Data Visualization

The ESP8266 microcontroller measured both voltage and current from the mechanical and piezoelectric subsystems in real-time. Data were transmitted via Wi-Fi to a Firebase Realtime Database, enabling cloud-based storage and analysis. A mobile application, developed using MIT App Inventor, displayed a real-time dashboard with voltage, current, cumulative energy generated, and alerts for abnormal operation. Users could monitor energy output from multiple speed breakers deployed across different locations. The system demonstrated reliable Wi-Fi connectivity and accurate measurement capabilities, with less than 2% error in voltage and current readings compared to multimeter measurements.

D. System Efficiency and Feasibility

The overall energy conversion efficiency of the mechanical subsystem was measured at approximately 75–80%, accounting for frictional losses and gear transmission efficiency. The PZT subsystem contributed an additional 10–15% energy output, yielding a hybrid system efficiency of approximately 85%. The combination of energy harvesting and IoT monitoring offers a scalable solution for urban environments, capable of providing localized, pollution-free power generation while simultaneously enhancing traffic safety.


Fig: Generating Power using Speed Breaker Kit


Fig: Output of the kit

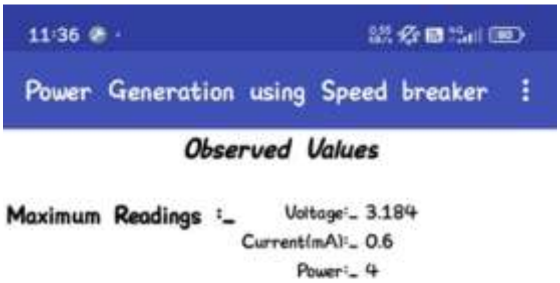

Fig. Display readings in MIT App

CONCLUSION

The developed prototype for generating electricity using a speed breaker demonstrates a practical and eco-friendly approach to harvesting renewable energy from vehicular movement. By converting mechanical pressure from passing vehicles into electrical energy through piezoelectric transducers and a rack-and-pinion mechanism, the system produces regulated DC power suitable for low-power applications. The integration of IoT technology via the ESP8266 module enables real-time monitoring, data logging on a cloud platform, and visualization through a mobile application, providing valuable insights into energy generation and traffic flow. While the generated power is limited and largely dependent on traffic density, the prototype effectively highlights the feasibility of localized renewable energy harvesting, contributing to smart city infrastructure, road safety enhancements, and sustainable energy solutions. The system serves as a scalable model for future implementations in urban energy management and intelligent transport systems.

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