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A Review On Energy Generation From Speed Brakers

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Abstract: The increasing demand for sustainable energy has driven the exploration of innovative solutions to generate renewable energy. This research aims to harness energy from vehicular movement using innovative technologies embedded in speed breakers to generate renewable electricity. By utilizing piezoelectric materials, rack-and-pinion mechanisms, and hybrid energy systems, the platform optimizes energy conversion for powering urban infrastructure. The integrated IoT-based monitoring system dynamically adjusts to traffic density and environmental factors, ensuring efficient energy usage. This sustainable energy solution not only addresses the rising energy demands but also supports smart city initiatives by powering streetlights, IoT devices, and other low-voltage applications. Designed with scalability and cost-effectiveness in mind, the platform provides a renewable, adaptive, and eco-friendly alternative to conventional power systems, promoting energy independence and reducing environmental impact. Its potential lies in creating self-sustaining urban ecosystems while aligning with global sustainability goals.

Keywords- Sustainable Energy, Piezoelectric Sensors, Speed Breakers, Energy Harvesting, Rack-and-Pinion Mechanism, Renewable Energy Systems, IoT Integration.

I. Introduction

The growing energy demand and environmental challenges have intensified the need for sustainable alternatives to traditional power sources. Urban areas, with their dense traffic, offer a unique opportunity to harness energy through innovative methods such as speed breaker-based energy harvesting systems. These systems utilize the kinetic and mechanical energy generated by vehicles to produce electricity, providing a renewable solution for powering essential infrastructure like streetlights and IoT devices. Piezoelectric materials, such as Lead Zirconate Titanate (PZT), and mechanical systems like rack-and-pinion mechanisms have been extensively studied for their efficiency in converting mechanical stress into electrical energy. Hybrid systems further enhance energy output by combining multiple energy harvesting techniques. Recent advancements in IoT technology have enabled real-time monitoring and optimization of these systems, making them adaptable to traffic patterns and reducing maintenance costs. This paper consolidates insights from seven studies to analyse the design, implementation, and scalability of these systems. By evaluating their performance and cost-effectiveness, the research highlights the potential of speed breaker-based systems to contribute to sustainable energy goals in urban settings.

II. LITERATURE REVIEW

2.1 Piezoelectric Energy Harvesting: Integrating Materials and Applications for Sustainable Energy Solutions

Piezoelectric energy harvesting has attracted increased attention because of its potential for converting mechanical stress into electrical energy, through the piezoelectric effect, by generating a voltage due to induced polarization in response to the stress [1,2]. Material development and realistic applications have reached new levels based on systemic reviews and real-life practices.

Lead Zirconate Titanate remains the most popular in this material class because of high piezoelectric constant along with feasibility of production by methods involving sintering [1]. Environmental implications and fragility encouraged further explorations into other classes like SPN and PVDF having flexibility and compatibility but very low coupling factors [1]. PZT sensors widely find applications in energy harvesting industries and roadways with their toughness under high mechanical stresses [2]. Transducer design such as cantilever beams, cymbal types, stack designs result in the optimization of energy conversions for particular application. Example: In Roadway systems, PZT sheets embedded in speed-breakers have the potential of converting automobile stress into electrical breakers can transform vehicular stress to electrical energy. One PZT sensor, when there is a 750 N load on it can produce 104 V. For example, heavy vehicles like buses can generate energy up to 1000 V [2]. The generated energy is conditioned by the help of rectifiers and DC-DC converters, stored in batteries [2]. The thin-film technologies and MEMS integration that allow miniaturizing and improving energy harvesting devices for low-power electronics applications such as wearables and implants are on the materials side. Techniques such as epitaxial growth and hybrid material formulations improve energy conversion efficiency and device longevity [1]. Nonetheless, challenges such as low voltage generation at non-resonant frequencies and mechanical degradation under stress persist [1][2]. In practical implementations, such as speed breakers, rubber padding is used to manage deflections and protect PZT plates, enhancing durability. Calculations reveal that using multiple plates in parallel can significantly increase energy output. For example, a speed breaker system with 10 PZT plates produces sufficient voltage to charge standard batteries, demonstrating the feasibility of this approach [2].

The integration of piezoelectric systems into real-world infrastructure underscores potential for sustainable energy harvesting. Future research will be directed to material optimization, circuit efficiency and scalability in order to enhance performance as well as expand applicability [1][2].

2.2 Harnessing Energy Through Piezoelectric Speed Breakers

Piezoelectric materials are transforming the way that energy can be harvested from vehicle traffic stress as mechanical stress turned into usable electrical energy

These systems rely on the piezoelectric effect, where specific materials develop an electric charge when put under mechanical stress. Lead Zirconate Titanate (PZT) is considered the best material because it is highly sensitive and can generate the highest voltage output of up to 104V when subjected to heavy loads of vehicular traffic, compared with other materials such as PVDF that give relatively very low outputs [6][2]. These studies also highlight the importance of efficient sensor configurations, hybrid series-parallel configurations balancing both current and voltage. Sensors should be placed underneath high-pressure zones, such as speed breakers, to optimize energy capture [6].

One such example was in one experiment, single PZT plates were shown to generate substantial voltage when placed under a 750N force and scale linearly with multiple plates in parallel [2]. In another, direct relationship was observed between applied weight and energy output from the device; a heavy bus created up to 1000V of electricity, implying scalability of the device in high traffic regions [6].

Energy retrieved can be stored into the power banks for other street-lighting purposes as well as charging devices making it appropriate for both city and outback environments. Results highlighted the feasibility of piezoelectric systems towards the mainstream realization of sustainable sources of power due to their ease of embedding infrastructure [6][2].

2.3 Hybrid Energy Harvesting through Speed Breakers: Mechanisms and Efficiency

The idea of hybrid energy harvesting by speed breakers is that it converts vehicular kinetic energy into electrical energy through mechanical and electromagnetic systems. This not only caters to the increasing energy demands but also provides a sustainable and environmentally friendly solution for urban infrastructure [3][4].

Rack-and-pinion mechanisms form the backbone of these systems, converting the vertical motion of a speed breaker into rotational energy. This rotary motion powers an AC or DC generator, generating electrical energy. For example, one of the systems showed an energy output of 123.16 watts per stroke with a 400 kg load and other pneumatic mechanisms adding 100.85 watts by exploiting air pressure, resulting in a total of 224 watts per event [3]. Other enhancements include flywheels, which maintain constant speed and helical springs, restoring motion, to further enhance the energy harvesting process [4]. Advanced materials and hybrid technologies have been applied to enhance efficiency. Graphene-coated piezoelectric transducers and electromagnetic systems possess enhanced durability and power output for high-traffic applications. Hybrid designs that combine piezoelectric and electromagnetic systems exhibit superior energy conversion rates, capturing kinetic and vibrational energy [5]. Energy management is a strong focus point. Supercapacitor-based systems ensure seamless energy supply through the use of excess power at peak time hours for later utilization. Therefore, it enhances reliability and optimizes performance under different traffic conditions [4][5]. The use of IoT-driven monitoring and adaptive control systems further enhances efficiency through the real-time analysis and regulation of energy harvesting parameters considering the flow of traffic [5]. These innovations make hybrid energy harvesting through speed breakers a promising method for powering applications in urban facilities such as street lighting, traffic signals, and local loads.

2.4 Utilization of Speed Breaker Energy Harvesting in Urban Infrastructure

Vibrations from speed breakers have been proven feasible sources of energy for supplementing urban energy needs. These systems use the kinetic energy offered by moving vehicular traffic to provide renewable power to small-scale applications such as street lighting and traffic management systems [3][4]. The integration of energy harvesting mechanisms with intelligent automation systems makes them more applicable in urban settings. For instance, LDRs and Raspberry Pi controllers enable dynamic street lighting control through adjusting illumination based on ambient light conditions. Such automation ensures energy efficiency by minimizing wastage and reducing reliance on conventional power grids [4].

Hybrid models have exhibited strong potential along with mechanical systems. Renewable sources like solar panels can be combined with speed breaker mechanisms, which will significantly increase the energy produced along with system resilience. The model is most effective in an urban scenario where the density of traffic is fluctuating; there will always be an essential supply of energy [5]. Comparative studies indicate that the advanced systems are more efficient and productive. A suggested system was said to have an energy conversion efficiency of 82.9%, which is higher than the earlier designs that were between 75% and 78% [5]. The use of high-efficiency components, such as piezoelectric materials and graphene-based technologies, enhances the longevity and output of these systems, making them ideal for high-traffic regions. These systems would be integrated in future research with the technologies of a smart city to enhance their adaptability and operational efficiency. Advanced energy storage solution, for instance, supercapacitors, will also further support scalability of these systems by optimizing power distribution at both peak and off-peak hours [3][5].

2.5 IoT-Based Speed Breaker for Sustainable Energy Generation

Employing a rack-and-pinion mechanism integrated with piezoelectric generators, the system converts the vehicle's motion mechanical energy into electrical energy. This addresses the twin aims of saving energy and generation of electricity in a more sustainable manner. The design is spring-based, compressing under the weight of passing vehicles. It converts linear motion into rotational motion by attached gears. This rotational energy drives the shaft of the generator, producing electrical power that is stored in rechargeable battery packs for later use. Calculations show that 1800 vehicles passing the speed breaker can fully charge a 7200-watt battery pack. The prototype has an efficiency of about 82% as a result of careful integration of components like 3kW dynamos and high-capacity batteries. Besides, the system has a payback period of 3 years and 8 months, making it economically viable for large-scale implementation. Its modular design makes it scalable and adaptable to different traffic conditions, ranging from busy highways to lower-capacity zones like toll booths or drive-throughs.

This innovative approach provides a sustainable energy solution while minimizing the dependency on conventional fossil fuels, making it a vital step toward addressing modern energy challenges [7].

III. FUTURE RESEARCH ASPECTS

3.1 Hybrid Energy Harvesting Systems Integration

By combining several energy harvesting techniques, such as piezoelectric sensors, rack-and-pinion mechanisms as a mechanical system, and pneumatic turbines, much more energy can be produced in a much more efficient way. These different technologies integrated into one hybrid system could capture energy from many sources, thereby providing more reliable and continuous power output, especially for places with changing traffic patterns. Future studies must be designed toward the realization of systems in a seamless cost-effective fashion combining these technologies, whereby the energy harvest is optimally captured, based on real-time data of the traffic.

3.2 Next-Generation Piezoelectric and Mechanical Systems Based on Advanced Materials

On-going research for advanced materials, such as lead-free composites, nanomaterials, and 3D printed piezoelectric material could lead to more effective and long-term energy-harvesting systems. Develop piezoelectric materials that display much increased energy conversion rates with additional satisfactory mechanical properties to boost efficiency in energy harvesting systems; particularly in environments characterized with heightened mechanical stress. Alternatively, further research into the realm of exploring advanced piezoelectric polymer or hybrid organic-inorganic composites may yield feasible prospects for large-scale implementations through reducing expense considerably.

3.3 Real Time Adaptive Energy Harvesting based on IoT Integration

The future research area is in IoT-based systems that dynamically adjust energy harvesting based on real-time traffic conditions. Advanced sensors and controllers can be integrated to monitor traffic flow, vehicle weight, and speed, allowing energy harvesting systems to optimize performance on the fly. These systems could utilize data from IoT devices to not only maximize energy output but also predict peak traffic times and adjust energy storage and distribution accordingly. The use of cloud computing and edge processing to manage the data would enhance the scalability and real-time functionality of these systems.

3.4 Improved Energy Storage Solutions

Future research might look into more efficient ways to store electricity from the speed breakers by the means of advanced energy storage technologies, including high-efficiency supercapacitors, solid-state batteries, and energy-dense lithium-ion technologies. They have to be designed so as to be able to face intermittent generation and still ensure fast charge/discharge cycles. Research for the development of scalable cost-effective storage systems is, therefore, important in such applications to ensure that energy is always available for continued usage in street lighting, for instance, or even traffic monitoring.

3.5 System Durability and Environmental Impact

With the deployment of energy harvesting systems in outdoor, high-traffic environments, the durability research for these systems is essential. The development of robust weather-resistant materials and protective coatings for piezoelectric sensors and mechanical components will enable long-term sustainability of the systems. Similarly, studies on the environment and ecological footprint of such systems, including the disposal methodologies of components, will be important for this technology's sustainable growth.

IV. CONCLUSION

The exploration of speed breaker-based energy harvesting systems has a great potential to meet the global demand for sustainable energy solutions. These innovations, through piezoelectric materials, rack-and-pinion mechanisms, and hybrid energy systems, effectively convert vehicular kinetic energy into renewable electricity. The integration of IoT-based monitoring systems further optimizes efficiency, adaptability, and scalability, making these systems ideal for powering urban infrastructure such as streetlights and IoT devices. Speed breaker energy harvesting systems, with their development in material science, energy storage, and automation technologies, offer a low-cost, environmentally friendly, and self-sustaining alternative to traditional sources of energy. They fit into global sustainability goals in the sense that they promote energy independence and lower environmental impact. Hybrid systems, optimization of the components, and integration into cities will continue to propel the acceptance of these new solutions toward the development of smarter and greener cities.

IV. REFERENCES

[1] Aabid, A.; Raheman, M.A.; Ibrahim, Y.E.; Anjum, A.; Hrairi, M.; Parveez, B.; Parveen, N.; Mohammed Zayan, J. “A Systematic Review of Piezoelectric Materials and Energy Harvesters for Industrial Applications.” Sensors 2021, 21, 4145.
[2] S. Joglekar, V. Gole, and A. Sambhus, "Energy Generation in Speed Breakers by Using Piezoelectric Sensors," International Research Journal of Engineering and Technology (IRJET), vol. 8, no. 6, pp. 4273–4275, 2022.
[3] Y. Zhao, X. Li, and Z. Wang, "Hybrid Power Generation Using Speed Breaker," Journal of Sustainable Energy Solutions, vol. 9, no. 4, pp. 55–58, 2024.
[4] A. Bhatia, S. Agarwal, R. Sharma, and P. Thakur, "Sustainable Energy Generation from Speed Breakers for Smart Street Lighting Application," Renewable Energy and Urban Infrastructure Journal, vol. 12, no. 6, pp. 145–152, 2022.
[5] P. Singh, V. Sharma, and K. Agarwal, "Electrical Power Generation Using Speed Breaker Mechanism: An Innovative Approach to Energy Harvesting," International Journal of Engineering Research and Technology, vol. 7, no. 5, pp. 12–18, 2024.
[6] Ranjan, S., Rakesh, N., Irshad, S., Gulhane, M., & Kaur, M. (2024). “Prototype Specification for a Speed Breaker to Generate Electricity”. In Proceedings of the 11th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), Amity University, Noida, India, March 14-15, 2024.
[7] Marwah, R., Kunjir, M., Jeble, A., & Sutar, A. “Generation of Electricity Using Piezoelectric Speed Breakers.” International Engineering Research Journal (IERJ), Special Issue 3, pp. 22-24. ISSN 2395-1621.
[8] Shalini, S., Sheela, S., Taj, S., & Bagalatti, M. R. (2024). Vulnerabilities in Internet of Things and Their Mitigation with SDN and Other Techniques. In CRC Press eBooks (pp. 279–288).
[9] S. S, S. S, A. S, B. P, G. C and R. K S, "An Effective Counterfeit Medicine Authentication System Using Blockchain and IoT," 2023 4th International Conference for Emerging Technology (INCET), Belgaum, India, 2023, pp. 1-5, doi: 10.1109/INCET57972.2023.10170622
[10] T. J. Lakshmi, Shalini S., Sheela S., Saakshi P.. WSN with IoT Using Raspberry Pi as a Tool for Communication. International Journal of VLSI Circuit Design & Technology. 2023;01(01):34-42. https://journals.stmjournals.com/ijvcdt/article=2023/view=125918
[11] Umeda, M.; Nakamura, K.; Ueha, S. "Analysis of the Transformation of Mechanical Impact Energy to Electric Energy Using Piezoelectric Vibrator." Japanese Journal of Applied Physics, 1996, 35, 3267–3273.
[12] Sodano, H.A.; Inman, D.J.; Park, G. "A Review of Power Harvesting from Vibration Using Piezoelectric Materials." The Shock and Vibration Digest, 2004, 36, 197–205.
[13] Jiang, X.; Li, Y.; Li, J.; Wang, J.; Yao, J. "Piezoelectric Energy Harvesting from Traffic-Induced Pavement Vibrations."
Journal of Renewable and Sustainable Energy, vol. 6, no. 4, pp. 043110, 2014.
[14] Gholikhani, M.; Roshani, H.; Dessouky, S.; Papagiannakis, A.T. "A Critical Review of Roadway Energy Harvesting Technologies." Applied Energy, vol. 247, pp. 146–164, 2019.