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Towards Sustainability: The Self-Charging Electric Bike - Harnessing Energy for Eco-Friendly Transportation



Abstract: - The quest for sustainable transportation solutions has intensified with the growing concerns over environmental degradation and energy consumption. In response, the self-charging electric bike emerges as a promising innovation, offering an eco-friendly alternative for urban commuting. By integrating regenerative braking and solar power technologies, this self-sustaining vehicle can harness kinetic and solar energy to charge its batteries, thereby extending its range and reducing reliance on grid electricity. This paper explores the design, functionality, and potential environmental impacts of the self-charging electric bike. Through a comparative analysis with conventional electric bikes and traditional bicycles, its advantages in terms of energy efficiency, cost-effectiveness, and carbon footprint reduction are elucidated. Additionally, considerations regarding infrastructure requirements and user adoption are discussed. The self-charging electric bike represents a significant step towards sustainable transportation, aligning with global efforts to mitigate climate change and promote greener lifestyles.

Keywords: Sustainability, Self-Charging, Electric Bike, Energy, Eco-Friendly, Transportation).

I. INTRODUCTION (*HEADING 1*)

The exponential growth of the global vehicle fleet since the early 1970s has been staggering, with an annual expansion rate reaching 16 million vehicles [1]. This surge in vehicular presence has been accompanied by a parallel surge in fuel consumption, painting a concerning picture of escalating environmental impact [2]. Projections indicate that if this trajectory remains unchecked, the world's roads will accommodate over one billion vehicles [3] by 2025. However, this rapid proliferation of transportation infrastructure comes at a significant cost to the environment, notably marked by the alarming rise in greenhouse gas emissions [4].

In light of the mounting concern over transportation-related emissions, governments and policymakers worldwide are urgently seeking strategies to reverse this unsettling trend [5]. The imperative to curb emissions and mitigate the environmental fallout of transportation has ignited a wave of innovation aimed at fostering sustainable alternatives [6]. Within this landscape of urgency and innovation, the concept of self-charging electric bikes emerges as a promising solution, offering a glimmer of hope for eco-friendly urban mobility [7].

Against the backdrop of burgeoning vehicle numbers and escalating fuel consumption, the self-charging electric bike stands out as a beacon of sustainable transportation technology [8]. By leveraging renewable energy sources and incorporating regenerative technologies, this innovative mode of transport has the potential to usher in a paradigm shift in urban mobility [9]. Its ability to harness energy from the environment, coupled with its eco-friendly operation, positions it as a viable solution for reducing the environmental footprint of transportation [10].

This paper aims to delve into the design, functionality, and environmental implications of the self-charging electric bike. By examining its transformative potential within the context of mounting transportation challenges and the urgent need for sustainable solutions, we seek to shed light on its role in shaping the future of urban

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mobility. Through a comprehensive exploration, we endeavor to unveil the promises and possibilities offered by this innovative mode of transportation in fostering a greener, more sustainable world.

1.1 Contributions

The novel contributions of this study are:

1. Introduction of plug-in hybrid technology to the two-wheeler sector, offering potential reductions in petroleum consumption and urban emissions.
2. Proposal of a control strategy tailored for plug-in electric two-wheelers, aimed at optimizing all-electric range and fuel economy.
3. Evaluation of energy requirements, mass, and initial cost of battery packs for accommodating daily travel needs of plug-in electric two-wheelers in the Indian context.
4. Investigation into the impact of driving cycles and all-electric range on battery parameters, with analysis across three distinct battery types and driving scenarios.

2. Literature Review

In Nguyen et al. [11] (2024), the incorporation of artificial intelligence and the internet of things into the traffic system has facilitated the emergence of innovative technologies like autonomous vehicles or unmanned aerial vehicles, which contribute to the reduction of traffic accidents and the liberation of human driving time. However, the improvement involves the use of multiple sensor devices that need external power sources. As a result, pollution occurs, as do increases in manufacturing costs. Therefore, the quest to develop sustainable energy remains a formidable obstacle. Triboelectric nanogenerators (TENGs) have emerged as a possible solution for addressing this problem owing to their exceptional performance and simple design. The article explores the use of TENG-based self-power sensors and their potential applications in the field of transportation. Furthermore, the data collected for the study might aid readers in enhancing their comprehension of the benefits linked to the use of these technologies to promote their creative ability

In Nguyen et al. [12] (2022), the energy can be converted to power using small electronic devices. Vibration is a common energy source in our surroundings and can be transformed into electrical energy using different transduction mechanisms: electrostatic, electromagnetic, piezoelectric, and triboelectric generators. A piezoelectric nanogenerator (PENG) and triboelectric nanogenerator (TENG) are two electrical power harvesting devices for converting the vibration from the surrounding to electrical energy. Several eco-friendly and biocompatible components have been employed in the fabrication of the PENG and TENG for multiple application including chemical sensors, pressure sensors, and biomedical appliances. The review elaborates the application of different smart materials as the TENG and PENG for the conversion of mechanical or vibrational energy to electrical energy for varied applications.

II. In Trinh et al. [13] (2023), the review comprehensively examines the recent advancements in TENG (Triboelectric nanogenerators) technologies for harnessing mechanical waste energy sources, with a primary focus on their sustainability and renewable energy attributes. It also delves into topics such as optimizing tribo-surface structures to enhance output performance, implementing energy storage systems to ensure stable operation and prolonged usage, exploring energy collection systems for efficient management of harvested energy, and highlighting practical applications of TENG in various contexts. The results indicate that TENG technologies have the potential to be widely applied in sustainable energy generation, renewable energy, industry, and human care in the near future.

III. Stecula et al. [14] (2023) outline four objectives in their literature review: O1: Identify trends, emerging technologies, and applications of AI in the energy field; O2: Provide current insights into AI's use in energy-related applications; O3: Gain a comprehensive understanding of AI-driven urban energy solutions; O4: Explore future directions, emerging trends, and challenges in AI-driven energy solutions. Their paper enhances understanding of AI's transformative potential in urban energy management, offering insights for researchers and practitioners. AI is utilized in homes for heating, cooling, lighting, window control, home devices, and energy management. In urban infrastructure, AI contributes to enhancing electric vehicle charging, reducing emissions, developing smart grids, and efficient energy storage. Challenges include balancing comfort and efficiency in smart homes, ensuring device compatibility, preventing energy consumption increases, managing renewable sources, and coordinating energy usage.

- IV. Harivardhagini et al. [15] (2024) develop an adaptive bicycle prototype with a manual charging mechanism for renewable energy, addressing environmental concerns and the need for eco-friendly transportation. The study aims to showcase human power as a viable alternative to non-renewable energy by converting cycling's rotational force into electrical energy. This energy is stored in a specialized battery and utilized to power the bicycle with an electric motor's assistance. The methodology involves constructing and testing a prototype, analyzing mechanical components, electrical conversion, and battery efficiency. Controlled experiments evaluate the bicycle's functionality and effectiveness in self-charging without external power, showing successful integration with an average energy conversion efficiency. The adaptive bicycle offers a sustainable solution for short-distance commuting, minimizing environmental impact and promoting eco-friendly travel. This innovative approach emphasizes the integration of renewable energy into transportation, reducing reliance on non-renewable sources.
- V. Binzaid et al. [16] (2024) research proposes a pioneering hybrid solution. In response to these formidable challenges, an innovative hybrid energy and freshwater generation system is developed using solar PV and Sustainable Energy Generating Pad (SEGP) technology integrated into road infrastructure. Thus, a combined station is established and embedded within the road pavement. The multifunctional station serves as a charging hub for electric bikes and mobile devices while simultaneously generating freshwater, contributing to alleviating water and energy scarcity. This integrated hybrid energy solution holds the potential to be a game-changer, addressing the pressing concerns of water and energy scarcity while actively contributing to global sustainability endeavors. Its innovative approach and multifaceted utility offer a promising pathway toward a greener and more sustainable world.
- VI. Olabi et al. [17] (2023) offers a comprehensive evaluation of micromobility, highlighting its pivotal role in advancing Sustainable Development Goals (SDGs). Micromobility emerges as a potent contributor to SDG 3, fostering good health and well-being by curbing toxic emissions and mitigating traffic accidents. Additionally, its impact resonates across various fronts: SDG 8 sees benefits through reduced transportation footprint, SDG 11 witnesses improved urban sustainability via enhanced accessibility and air quality, and SDG 12 gains from heightened resource efficiency and reduced transportation footprint. Furthermore, micromobility's alignment with SDG 13 underscores its contribution to climate action by lowering greenhouse gas emissions. Notably, the analysis underscores a conspicuous literature gap, particularly concerning energy management and storage within the micromobility sphere. Emphasizing the potential of emerging renewable energy and storage technologies, the review underscores their pivotal role in bolstering micromobility sustainability and, consequently, advancing the SDGs.
- VII. Kabir [18] (2024) research introduces a hybrid system integrating solar PV and SEGP technology into road infrastructure, serving as a charging hub for e-bikes and freshwater generation. The study evaluates renewable energy efficiency, water generation, and purification technologies, alongside economic considerations. With a calculated ROI of 2.60 years within a 10-year project lifetime, the initiative represents a paradigm shift toward sustainable resource management, contributing to global sustainability efforts.
- VIII. Grzesiuk et al. [19] (2023) employed a diagnostic survey method, designing a questionnaire based on literature review findings. 490 representatives of Generation Z participated. They conducted qualitative analysis, followed by correlation analysis using Pearson's chi-square test, Cramer's V, and the Contingency Coefficient. Data normalization enabled examination of correlations using Pearson's test and analysis of relationships based on regression results. Results showed energy-related sustainable behaviors in acquiring, using, and disposing of electrical appliances, as well as mobility-related energy-conserving behaviors, influence perceptions of energy-efficient mobility solutions. City administrations could use these findings to implement energy-conserving solutions and plan activities tailored to Generation Z's attitudes and behaviors.
- IX. Abdullah-Al-Mahbub et al. [20] (2022) highlights the present status of various forms of solar energy progress in Bangladesh, such as solar parks, solar rooftops, solar irrigation, solar charging stations, solar home systems, solar-powered telecoms, solar street lights, and solar drinking water, which can be viable alternative sources of energy. The review helps decision-makers and investors realize Bangladesh's up-to-date solar energy scenario and plan better for the development of a sustainable society.

Table 1: Summary of Research gap				
Ref No.	Author/Year	Method	Finding	Research Gap
[11]	Nguyen et al. (2024)	Literature Review	Explores TENG-based self-power sensors in transportation	Need for sustainable energy solutions in transportation
[12]	Nguyen et al. (2022)	Review	Explores PENG and TENG applications	Potential for eco-friendly energy harvesting solutions
[13]	Trinh et al. (2023)	Review	Examines advancements in TENG technology	Need for optimization and practical applications of TENG
[14]	Stecula et al. (2023)	Literature Review	Examines AI's role in urban energy management	Gaps in understanding AI-driven urban energy solutions
[15]	Harivardhagini et al. (2024)	Experimental Study	Develops adaptive bicycle prototype for renewable energy	Need for more efficient renewable energy integration in transportation
[16]	Binzaid et al. (2024)	Research Proposal	Proposes hybrid energy and freshwater generation system	Need for innovative solutions addressing water and energy scarcity
[17]	Olabi et al. (2023)	Literature Review	Assesses micromobility's role in achieving SDGs	Lack of literature on energy management and storage for micromobility
[18]	Kabir (2024)	Research	Introduces hybrid system integrating solar PV and SEGP	Need for economic viability and feasibility studies for integrated sustainable solutions
[19]	Grzesiuk et al. (2023)	Survey	Analyzes Generation Z's energy-related behaviors	Gap in understanding attitudes towards energy-efficient mobility solutions
[20]	Abdullah-Al-Mahbub et al. (2022)	Review	Highlights solar energy progress in Bangladesh	Need for further development and utilization of solar energy in Bangladesh

2.1 Research gap

The literature review identifies various research gaps in sustainable transportation and energy solutions, including the need for more efficient renewable energy integration, optimization of emerging technologies like TENG, and innovative solutions addressing water and energy scarcity. Additionally, there's a gap in understanding attitudes towards energy-efficient mobility solutions and opportunities for further development and utilization of solar energy in specific regions.

3. Problem statement

The transition towards electric vehicles (EVs) signifies a pivotal stride in curbing urban emissions and curbing petroleum consumption. Yet, the application of plug-in hybrid electric vehicle (PHEV) technology within the

two-wheeler realm remains largely uncharted. This oversight stifles the potential for substantial decreases in transportation emissions and reliance on petroleum. Therefore, there's an urgent call to bridge this gap by introducing plug-in hybrid technology to two-wheelers, presenting a sustainable avenue for urban mobility that concurrently bolsters fuel efficiency and diminishes environmental impact. This study endeavors to confront this challenge head-on by devising a control strategy tailored for plug-in electric two-wheelers, while scrutinizing the viability and advantages of such innovation concerning daily travel requisites and battery performance, particularly within the Indian landscape.

4. Objectives

The novel objectives of this study are:

1. To integrate plug-in hybrid technology into the two-wheeler sector, aiming to enhance fuel economy and reduce urban emissions.
2. To devise and implement a tailored control strategy for plug-in electric two-wheelers, focusing on optimizing both all-electric range and fuel efficiency.
3. To assess the energy requirements, mass, and initial cost of battery packs necessary to meet the daily travel needs of plug-in electric two-wheelers in the Indian market.
4. To analyze the impact of driving cycles and all-electric range on battery performance across various battery types and driving scenarios, providing insights for optimization and improvement.

5. Proposed Methodology

The primary components needed for the project are a readily accessible battery-powered bike, a secondary battery pack, a bank of super capacitors, a dynamo setup, a system for managing the battery's power, a circuit for connecting the various components, and so on.

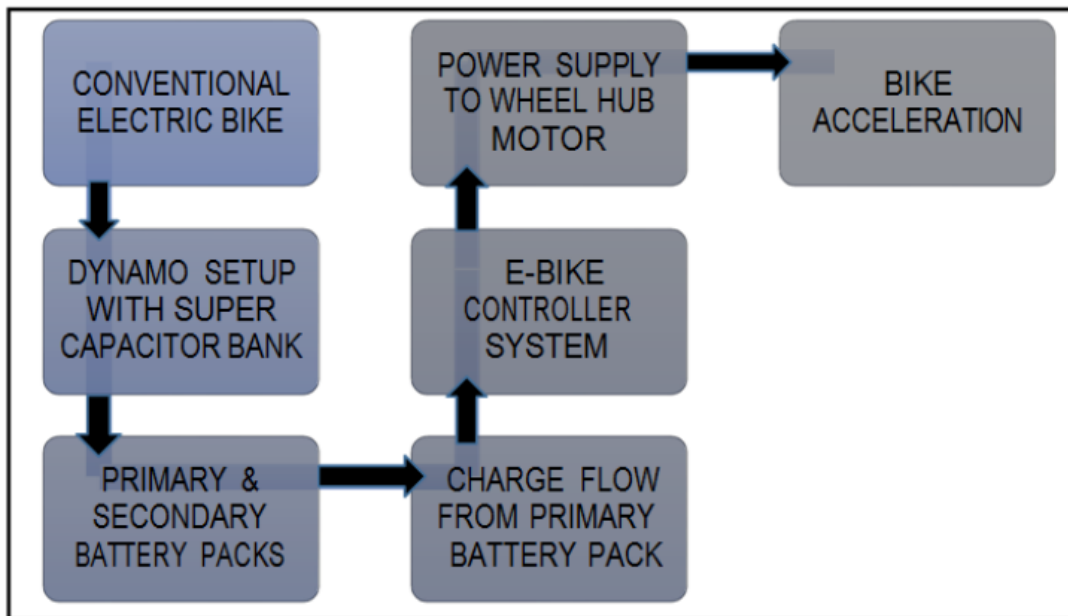


Fig 1: Proposed Methodology

5.1 Circuit connection

The suggested electric bike model's operating principle is comparable to that of a standard electric bike, with the exception of certain minor enhancements to battery technology, charging techniques, and the utilization of power from an external dynamo setup.

Figure 2 depicts the circuit connection of the whole bike configuration for illustration purposes. The setup of a dynamo, depicted in yellow in the illustration, is an electromechanical device that uses electromagnetic activity to transform mechanical motion—specifically, rotating motion—into electrical energy. For this, we use electromagnetic induction and the faraday law. The red dots here represent the banks of capacitors, the most

important part of the system for charging the secondary batteries, because of their ability to maintain a constant current in the secondary battery pack. There is voltage fluctuation in the system, which might harm the battery packs, because high current flows from the dynamo to the packs when the speed is high and low current flows the other way around. Hence, it accepts both high and low currents and sends a consistent current to the battery pack.

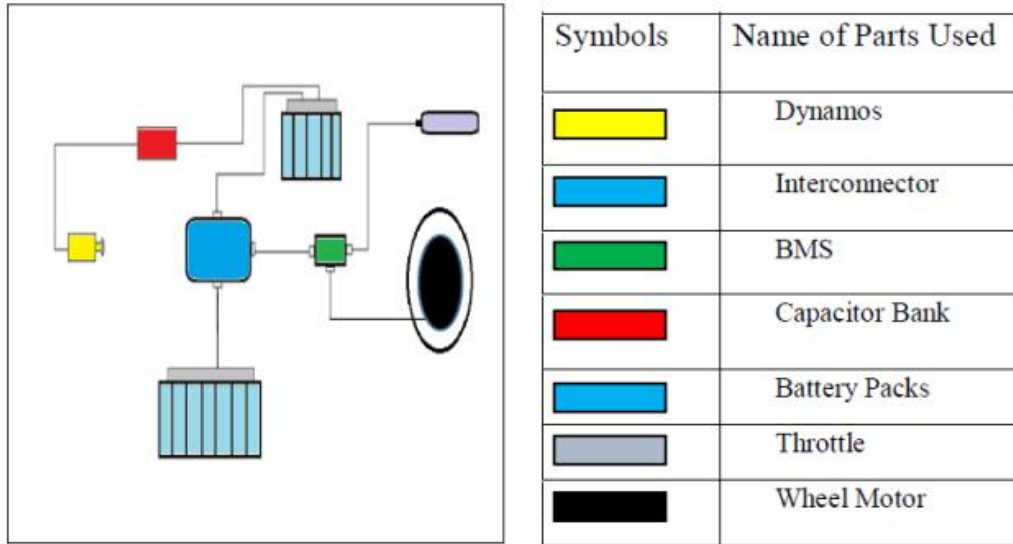


Fig 2: Circuit connection and working principle

6. Results

6.1 Battery Pack Configuration and Charging Calculation

The battery packs are made up of 26 lithium ion batteries that are connected in parallel. Because each battery can be charged to a maximum of 4.20 volts, even though their nominal voltage is between 3.6 and 3.7 volts, we may claim that their maximum charging capacity is 4.20 volts. We are utilizing lithium ion batteries of the 18650 variety for the battery pack. The 18 and 65.0 in the battery symbolise the 18 mm diameter and 65.0 mm length variant cells, respectively. The total voltage and real capacity when connected in parallel is in range from 39 to 54.6 volts and 2200 to 3300 mAh, respectively. Battery, on the other hand, can hold up to a thousand watts. The charger requires an input voltage of 70V-300V AC-47 - 63 Hz, 2.2 Ampere max., a float voltage of 68.5V, $\pm 0.5V$, and a boost voltage of 73.5V, $\pm 0.5V$, in order to charge it. The output voltage is equivalent to $2.7A \pm 0.1A$.

6.2 Dynamo Calculations

An electromechanical device known as a dynamo uses the principle of electromagnetic induction to transform mechanical rotation into electrical energy. For simplicity and cost-effectiveness, we are currently employing a dynamo with specs of 6 volts and 3 watts. We acquire varied readings from the ammeter under different load and speed conditions during testing. For example, when we run at a speed of about 5 km/h, we get an output voltage of 1.3 V. As the speed increases, so does the output voltage. At an average speed of about 15 km/h, we achieve a maximum output of about 4.7 volts. We can accomplish the expected output despite numerous losses, such as friction between the wheel and dynamo.

6.3 Capacitor Calculations

To store electrical energy in an electric field, an electronic component known as a capacitor can be passively connected to two terminals. A capacitor's effect is called capacitance. Capacitors are components that are specifically made to increase the amount of capacitance in a circuit, however capacitance already exists between any two electrical conductors that are close together. With respect to the power consumption and dynamo configuration, we are making use of three 2.7V 500f capacitors.

6.4 Problem Formulations

It is clear from the reviewed literature that not a single bike or vehicle has been transformed into a completely electric and regenerative one. Hybrid vehicles were the most groundbreaking invention in the automotive industry when electric vehicle technology was first being developed. Vehicles that can draw power from both conventional and non-traditional sources are known as hybrids. Electricity and fossil fuels are typically used for this. Hybrid vehicles were developed to address the issue of pollution created by internal combustion engines. This won't be able to stop pollution entirely, but it will help a lot. When everything is perfect, vehicles with internal combustion engines (IC engines) require gasoline. This results in the loss of energy. This sparked the idea of completely electric automobiles, which, in an ideal world, would drastically cut fuel use and pave the way for a civilization free of pollution.

Different people have contributed in different ways to this type of model; for example, one person has suggested improvements to technology surrounding lithium ion batteries, another has suggested ways to charge super capacitors, and so on. This project incorporates all of the aforementioned techniques, including riding an electric bike, installing a dynamo system on the front wheel to charge the bike's secondary battery with super capacitors and lithium-ion primary batteries, and many more related technologies. To address the fact that no electric car currently in development is completely electric and regenerative, our project centers on developing a self-charging mechanism. Recharging the battery packs allows the bike to continue going by converting energy lost to friction and kinetic energy produced by wheel spin. Which means it'll be more efficient than regular cars while still being simple to operate. The project encountered numerous challenges when it was in the development phase because it is the cutting edge of automotive technology. We had a lot of trouble with electrical setup because I am a mechanical engineer. Unfortunately, we were unable to procure the necessary components, such as the lithium-ion battery and nickel strip. We had to place an order from a different city because acquiring those parts was a real hassle. Nickel strip in particular proved difficult to procure. Similarly, a lot of other parts were difficult to procure, and even if we did, the cost made it difficult for us to use them. When the project is finished, we will have charging stations that are readily available and free for customers to use. Locating a charging station has become more challenging due to the rapid evolution of this technology. There ought to be plenty of electricity stations, just like gas stations. The Indian government has reportedly begun enforcing new policies on electric vehicles. With the goal of reducing pollution, the government is implementing a plan to install charging stations and other infrastructure for electric bikes in large cities such as Mumbai, Delhi, Bangalore, etc.





Fig 3: Finished model

7. Conclusion

The concept of e-bikes not only aims at reducing environmental pollution but also focuses on conserving fossil fuels for future generations. By employing swappable battery packs, charging time is minimized, enabling users to travel longer distances with ease. The integration of a Dynamo setup allows for the secondary battery to be charged on the go, eliminating the need for individual charging sessions as required for primary batteries. This approach not only reduces charging costs significantly but also extends the traveling range. By leveraging efficient battery technology and charging methods, there is a tangible opportunity to reduce overall costs and mitigate pollution associated with transportation needs.

In a few years, electric vehicles will have surpassed internal combustion engine vehicles in terms of popularity. Constant demand is depleting fossil fuel reserves, which in turn is driving up prices. A wide variety of terrifying events are befalling people. Carbon pollution is causing new kinds of these to emerge. We can eliminate vehicle-related pollution by switching to renewable energy. Therefore, electric bikes are a positive step toward rescuing the planet. The technology we're utilizing is more than enough to dominate the road and triumph over vehicles powered by internal combustion engines. Improved efficiency and torque are possible outcomes of exploring alternative battery technologies that require less charging conditions (i.e., less time to charge). A bike's top speed can be increased by advancements in wheel motor technology. A variety of technologies, such as a dynamo setup and capacitor connection, can enhance the secondary battery pack's charging time and condition. Improved dynamos have the ability to maximize voltage output. The millage and range of battery packs could be improved with the use of increased number of cells

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