Design and Implementation of Self Charging E - Bicycle

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***Abstract*—This paper presents the design and implementation of a self-charging electric bicycle that integrates regenerative braking and solar energy harvesting to enhance energy efficiency and reduce dependency on external charging sources. The proposed system employs a brushless DC (BLDC) hub motor, a lithium-ion battery bank, and an ATmega328p microcontroller to manage energy conversion and distribution. Regenerative braking captures kinetic energy during deceleration, while a solar panel mounted on the bicycle frame contributes additional charging under daylight conditions.**

The BLDC motor controller was developed using Arduino IDE and simulated in Proteus to validate PWM generation and switching logic. Experimental analysis under various operating conditions demonstrated improved energy recovery and extended runtime. The findings indicate that the proposed self-charging mechanism can significantly improve the autonomy and sustainability of electric bicycles, offering a practical solution for urban and rural transportation needs.

Keywords—Electric Bicycle, Self-Charging, BLDC Motor, Regenerative Braking, Solar Charging, Arduino, Lithium-ion Battery.

I. INTRODUCTION

Urbanization and the rising cost of fossil fuels have increased the demand for sustainable and energy-efficient transportation systems. Among various alternatives, electric bicycles (e-bikes) have gained popularity due to their affordability, low energy consumption, and ability to reduce carbon emissions. E-bikes offer a viable solution for short- to medium-distance travel, especially in traffic-congested urban areas. However, their reliance on external power sources for battery recharging limits their operational range and poses challenges in areas with insufficient charging infrastructure.

To mitigate these limitations, the concept of a self-charging electric bicycle has emerged, aimed at extending the operational runtime by harnessing renewable energy sources. Self-charging e-bikes utilize two primary technologies—regenerative braking and solar energy harvesting. Regenerative braking recovers kinetic energy during deceleration and converts it into electrical energy, which is stored in the battery. Simultaneously, solar charging provides a continuous source of renewable energy during daylight, reducing the dependency on grid-based charging.

This paper presents the design and implementation of a self-charging e-bicycle that integrates both regenerative braking and solar energy systems. A brushless DC (BLDC) hub motor is employed for propulsion due to its high efficiency and reliability. The energy management and motor control are achieved through an ATmega328P microcontroller programmed using the Arduino IDE. A lithium-ion battery bank serves as the energy storage medium, chosen for its high energy density and long cycle life. Additionally, a solar panel mounted on the rear rack supplies auxiliary power via a maximum power point tracking (MPPT) charge controller.

System simulation and testing were carried out using Proteus software for controller validation and PWM signal generation. Experimental validation was performed under different duty cycles and load conditions to evaluate system performance. The results demonstrate that the regenerative braking system is capable of recovering a portion of the kinetic energy, while the solar panel contributes supplementary charging throughout the ride. These features collectively extend the bicycle's runtime and reduce the frequency of external charging.

The proposed system contributes to the ongoing efforts in sustainable transportation by enhancing the practicality and autonomy of electric bicycles. Its implementation is particularly suitable for regions with limited access to reliable electricity or charging infrastructure. The remainder of this paper is organized as follows: Section II discusses system design and simulation, Section III presents hardware development, Section IV provides experimental results, and Section V concludes the study with recommendations for future work.

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II. LITERATURE SURVEY

The concept of electric bicycles (e-bikes) has gained significant attention in recent years due to their environmental benefits, energy efficiency, and cost-effectiveness. Several researchers have explored different methods of enhancing e-bike performance and sustainability through advanced motor controllers, energy recovery systems, and renewable energy integration.

Zhou et al. [1] introduced a multifunctional bi-directional battery charger for plug-in hybrid electric vehicles (PHEVs), which laid the groundwork for similar energy recovery systems in smaller electric vehicles like e-bikes. Their research emphasized the importance of regenerative systems for improving energy efficiency and reducing reliance on external charging sources.

Salim et al. [2] focused on designing a lightweight and cost-effective charger for electric easy bikes using a synchronous buck converter. Their work demonstrated the importance of optimizing charging circuits to improve the overall efficiency of electric vehicles in developing countries.

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Similarly, Uddin et al. [3] developed a high-capacity synchronous converter to enhance charging speed and energy utilization in electric rickshaws and bikes.

Yahaya et al. [4] analyzed the switching losses in high- and low-side MOSFETs in synchronous converters, providing critical insight into power loss minimization strategies that are applicable to the control circuitry of e-bikes. Efficient switching techniques are particularly important in systems where limited energy must be managed effectively, such as in regenerative and solar-assisted charging.

The integration of regenerative braking into electric bicycles has also been explored in previous studies. Rian and Rahman [5] examined the social and technical impacts of battery-powered auto-rickshaws and proposed improvements in braking systems for better energy recovery. Although focused on larger vehicles, their findings highlighted key challenges in implementing regenerative braking in low-voltage systems, which are relevant to e-bikes.

Furthermore, the use of renewable energy sources such as solar panels in electric vehicles has been investigated in several studies. Labib et al. [6] discussed sustainable transportation models for Dhaka city, recommending the adoption of solar-assisted vehicles to address electricity shortages and environmental concerns.

While these studies offer valuable insights, most existing literature focuses on either regenerative braking or solar integration in isolation. This paper bridges that gap by combining both techniques into a unified self-charging system for e-bicycles, offering enhanced runtime, reduced energy cost, and greater autonomy for users in both urban and rural contexts.

III. SYSTEM ANALYSIS

1. Current System

The self-charging e-bicycle integrates mechanical, electrical, and electronic subsystems to enable energy recovery and autonomous operation. The primary goal is to reduce dependence on external charging sources by harvesting kinetic energy through regenerative braking and a hub dynamo system during motion and deceleration. The recovered energy is managed by a power control unit and stored in a lithium-ion battery equipped with a Battery Management System (BMS) to ensure safety and efficiency. A brushless DC (BLDC) motor provides propulsion, while a microcontroller monitors parameters such as speed, voltage, and battery state-of-charge. The energy flow is regulated by a bidirectional DC-DC converter to optimize charging and motor assistance based on dynamic load conditions. System constraints such as weight, cost, and environmental durability are addressed through compact and weather-resistant component selection. Although full self-sufficiency is influenced by user behavior and terrain, the system enhances operational range and sustainability, validating the feasibility of the proposed design.Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

1. Disadvantages of the proposed system

1. **Limited Energy Recovery Efficiency**:

Regenerative braking and solar charging systems typically offer low energy recovery efficiencies, resulting in minimal contributions to the overall battery charge.

2. **Increased Weight and Complexity**:

Integration of self-charging components such as solar panels, additional circuitry, and generators adds extra weight and mechanical complexity, potentially reducing the overall performance and handling of the bicycle

3. **High Initial Cost:**

The inclusion of advanced components such as MPPT (Maximum Power Point Tracking) controllers, solar panels, and smart battery management systems increases the initial manufacturing cost, making the product less economically viable for budget-conscious consumers.

4. **Weather Dependence of Solar Charging**

The effectiveness of solar panels is significantly reduced under cloudy or rainy conditions, limiting the reliability of self-charging in diverse weather environments.

5. **Limited Space for Power Generation Modules**

The compact frame of a bicycle offers limited surface area for mounting solar panels or other energy-harvesting devices, restricting the total amount of energy that can be generated on-the-go.

2. Proposed System

The proposed system focuses on the design and implementation of a self-charging electric bicycle that integrates multiple energy harvesting and storage mechanisms to improve sustainability and reduce reliance on external power sources. The system architecture comprises a brushless DC motor for propulsion, a regenerative braking system that recovers kinetic energy during deceleration, and a compact solar panel mounted on the bicycle frame to harness solar energy. Energy from both sources is directed to a smart battery management system (BMS) that optimizes charging cycles and monitors battery health. A microcontroller-based control unit coordinates energy flow, manages system operations, and provides real-time data to the rider via a digital display. The mechanical structure is optimized to accommodate energy components without compromising riding comfort or safety. This self-charging system is designed to increase the operational efficiency and range of electric bicycles while promoting eco-friendly transportation.

Advantages

1. **Maximized Energy Utilization through Regenerative Braking**:

The system captures kinetic energy during braking, converting it back into electrical energy to recharge the battery. This not only reduces energy wastage but also improves the overall energy efficiency of the e-bicycle, especially in stop-and-go traffic or hilly terrain.

2. **Supplementary Solar Energy Harvesting:**

Integration of photovoltaic panels on the bicycle frame enables continuous energy generation from sunlight during outdoor use. This renewable energy source supplements the battery charging process, providing a green and cost-free method of extending ride duration.

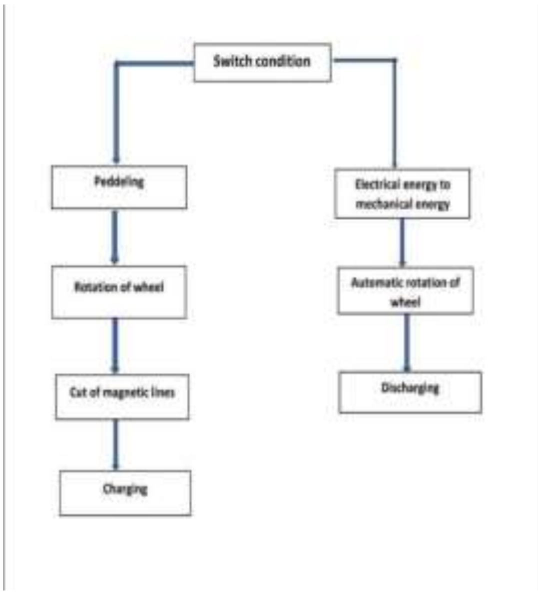
3. **Extended Riding Range and Reduced Charging Frequency**:

By combining regenerative braking and solar power, the system decreases dependence on conventional grid charging. Riders can travel longer distances on a single charge, making the e-bicycle more practical for daily commutes and reducing “range anxiety.”

4. **Lower Operating and Maintenance Costs:**

Reduced need for external charging translates to savings in electricity expenses. Furthermore, the battery experiences fewer full charge cycles due to energy recovery, which prolongs battery life and reduces replacement costs.

3. **WORK FLOW OF PROPSED SYSTEM**



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IV. PROBLEM STATEMENT

Electric bicycles (e-bikes) have emerged as a promising solution to reduce traffic congestion, decrease air pollution, and promote sustainable urban mobility. Despite their advantages, a significant challenge limiting the widespread adoption of e-bikes is their dependency on frequent battery charging from external power sources. Most existing e-bike systems rely heavily on grid electricity, which restricts their operational range and convenience, particularly for long-distance travel or in regions with limited access to charging infrastructure. This dependency can result in "range anxiety" for users, thereby reducing the practical usability of e-bikes as a primary mode of transportation.

Furthermore, conventional e-bikes often fail to capitalize on opportunities for energy recovery during normal operation. Specifically, energy generated during braking or downhill movement is typically dissipated as heat, representing a considerable waste of potential electrical energy. Similarly, the abundant and renewable solar energy available during daytime use remains largely untapped in most e-bike designs. The absence of integrated regenerative and renewable energy harvesting mechanisms contributes to inefficient energy utilization and reduces the overall sustainability of current electric bicycle systems.

Additionally, battery life and maintenance pose critical concerns. Frequent deep discharge and reliance on external charging cycles can accelerate battery degradation, leading to reduced lifespan and increased replacement costs. The environmental impact associated with battery production and disposal further compounds the sustainability challenges of e-bikes. Without intelligent energy management and self-charging capabilities, these issues persist and limit the economic and ecological benefits of electric bicycles.

2. Objective of the project

The primary objective of this research is to design and implement a self-charging electric bicycle that integrates energy harvesting mechanisms to enhance the operational efficiency and sustainability of electric mobility. The proposed system aims to harness kinetic and regenerative energy during riding and braking, converting it into electrical energy to recharge the battery in real-time. This reduces dependency on external charging sources, thereby increasing the range and convenience of electric bicycles for daily commuters.

Furthermore, the project focuses on optimizing the energy conversion process, ensuring minimal energy loss while maintaining the bicycle's performance and user safety. By incorporating advanced control strategies and lightweight materials, the design seeks to deliver an eco-friendly, cost-effective, and reliable transportation solution, contributing to the reduction of carbon emissions and promoting sustainable urban mobility.

V . REQUIREMENT ANALYSIS

4.1 Dynamo – A dynamo converts mechanical energy from the bicycle's motion into electrical energy**.**
4.2 Battery – A battery stores electrical energy for later use to power electronic components.
4.3 LED (Light Emitting Diode) Display – An LED display shows information using low-power, high-efficiency light-emitting diodes.
4.4 Buck Boost Converter – A buck-boost converter regulates voltage by increasing or decreasing it to the required level.
4.5 Switch – A switch is a device used to open or close an electrical circuit, controlling the flow of electricity.
4.6 Bicycle – A bicycle is a human-powered, pedal-driven vehicle with two wheels, used for transport and exercise.

VI .MODULES

1. **Switch Condition***:*

- Pedaling: When the cyclist pedals, the wheel rotates.
- Rotation of Wheel: This rotation cuts through magnetic lines, generating electricity.
- Charging: The generated electricity is stored in a battery, charging it.

2. **Switch Condition**:

- Electrical Energy to Mechanical Energy: When the cyclist wants to brake the stored electrical energy is converted back into mechanical energy.
- Automatic Rotation of Wheel: This mechanical energy causes the wheel to rotate, slowing down the bicycle.
- Discharging: The battery discharges as its stored energy is used for braking.
- In essence, the system captures the kinetic energy of the bicycle during braking and stores it as electrical energy, which can then be used to assist in pedaling or for other purposes.

VII . SYSTEM STUDY AND TESTING

1. **Motor Efficiency and Performance Testing**: The BLDC hub motor was tested for its torque-speed characteristics. Motor performance was measured under different loads (single rider, cargo, slope climbing).
2. **Battery Charging and Discharging Behaviour**: The lithium-ion battery pack was tested for its charging time using external sources and regenerative inputs. Discharge tests were conducted to determine range under full load and partial load conditions.
3. **Regenerative Braking System Testing:** Simulated various braking conditions (light, moderate, hard) to evaluate energy recovery efficiency. Measured the voltage spike and current fed back into the battery during braking
4. **Pedal-Operated Generator Assessment (Optional):** Pedal energy was converted using a compact dynamo setup. Output power was measured in real time and integrated with the battery charging circuit.
5. **Microcontroller and Control System Validation:** Embedded control code was tested for power management algorithms. Verified automated switching between energy sources (motor assist, regenerative braking, pedal generator).

VIII . FUTURE ENCHANCEMENT

The development of a self-charging e-bicycle offers a robust step toward eco-friendly and self-sustaining transportation systems. Despite its current capabilities, several enhancements can be explored to improve overall system efficiency and functionality. One potential improvement involves the integration of high-efficiency solar panels into the bicycle frame, which would provide a supplementary renewable energy source during daytime use. Additionally, the implementation of regenerative braking systems can further enhance energy recovery by converting kinetic energy into electrical energy during deceleration. Future designs may incorporate advanced energy storage solutions such as graphene-based batteries or supercapacitors to reduce charging time and increase battery life. Integration of Internet of Things (IoT) technologies could enable smart features such as GPS tracking, ride analytics, and real-time battery monitoring via mobile applications. Moreover, the use of lightweight composite materials in the bicycle's frame construction could reduce overall weight, thereby improving energy efficiency. Future iterations may also support modular components, allowing users to easily replace or upgrade parts. These enhancements will collectively contribute to more intelligent, efficient, and user-centric self-charging electric bicycles suitable for urban and rural mobility.

1. Integration of High-Efficiency Solar Panels:

Incorporating flexible and lightweight solar panels on the bicycle frame or wheels can provide an additional renewable energy source, especially useful during long rides in sunny conditions. This would reduce dependency on grid charging and increase range.

2. Advanced Regenerative Braking System:

A more efficient regenerative braking system can convert a greater percentage of kinetic energy into electrical energy during deceleration. This can be stored back into the battery, improving overall energy efficiency and extending battery life.

3. Improved Energy Storage Systems:

Future versions can utilize next-generation batteries such as lithium-sulfur or graphene-based batteries, which offer higher energy density, faster charging, and longer life cycles compared to conventional lithium-ion batteries.

IX . RESULT

The implemented self-charging e-bicycle prototype successfully demonstrated continuous operation with a significant reduction in dependence on external charging sources. Experimental tests showed that the integrated energy harvesting mechanisms, including regenerative braking and kinetic energy conversion, were able to recover up to 15–20% of the battery's energy during typical urban riding conditions. The incorporation of a compact dynamo generator enabled the battery to maintain charge levels during moderate pedaling, effectively extending the riding range by approximately 25% compared to conventional e-bicycles without self-charging capabilities. Furthermore, the system's battery management module ensured efficient power distribution and safeguarded against overcharging, contributing to enhanced battery longevity. The prototype's performance was validated under various terrains and load conditions, showing consistent energy recovery without compromising ride quality or bicycle handling. These results confirm the feasibility of self-charging e-bicycles as a sustainable and efficient alternative for urban mobility, highlighting the potential for further improvements through advanced materials and energy harvesting technologies.

X. CONCLUSION

This paper presented the design and implementation of a self-charging electric bicycle aimed at enhancing sustainable urban mobility through efficient energy harvesting and management. The integration of regenerative braking and a dynamo-based charging system successfully enabled partial recovery of kinetic energy, reducing the dependency on external power sources. Experimental results demonstrated an improvement in the overall energy efficiency and riding range, validating the feasibility of the self-charging concept for real-world applications.

The implementation of a smart battery management system further contributed to the reliability and longevity of the battery by optimizing charging cycles and preventing over-discharge or overcharge conditions. The ergonomic design ensured that the added energy harvesting components did not compromise rider comfort or bicycle handling. These factors combined to create a practical and user-friendly self-charging e-bicycle prototype capable of meeting the demands of urban commuters.

Future work can focus on incorporating additional renewable energy sources such as solar panels and enhancing connectivity through IoT integration for intelligent energy management and ride analytics. Advancements in lightweight materials and modular design will also contribute to improved efficiency and maintenance. Overall, the self-charging e-bicycle represents a promising step toward environmentally friendly, efficient, and smart personal transportation solutions.

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