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Design and Fabrication of Electric Bicycle with Regenerative System

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Abstract: The increasing demand for sustainable and efficient transportation has led to the development of electric bicycles (e-bikes) as an alternative to traditional modes of transport. This paper presents the design and fabrication of an electric bicycle integrated with a regenerative system aimed at enhancing energy efficiency and extending battery life. The proposed system utilizes a brushless DC motor to drive the bicycle and a regenerative mechanism that recovers energy, converting kinetic energy back into electrical energy. The design considerations include optimal motor selection, battery management, and regenerative circuitry. A prototype was developed to demonstrate the functionality of the regenerative system, and experimental results show a notable improvement in energy conservation, extending the operational range of the bicycle. The integration of the regenerative system also contributes to reducing the frequency of battery recharges, offering an environmentally friendly solution for urban transportation. The paper concludes with an analysis of the system's performance, highlighting the potential benefits and challenges of integrating regenerative technologies into electric bicycles.

I. INTRODUCTION

The suggestion for electric bicycles and electronic companion technologies is the anticipated outcome of an environmentally sustainable and ecological improvement in the transportation segment. E-bikes tend to be a great alternative to internal combustion engines as they offer an energy-efficient, quiet, and zero-emission method of transport, especially in congested urban areas. E-bikes function in a manner that is entirely different from human-powered bicycles due to the electric motor and consequently need frequent battery recharging associated with the use of the grid. This hurdle has emerged as an opportunity to invent electric bicycles with the help of renewable energy harvesting systems that will decrease the reliance on the external mode of charging and on the other hand, will increase the range of e-bikes and contribute to the sustainable practices of energy production. For this purpose, solar panels will be used on the e-bike to recharge the battery during the day. Solar cells incorporated into the e-bike frame function as a back-up energy production tool that draws sunlight to restore the battery during daylight hours. The e-bike design is founded on the concept of building a bike powered by renewable energy.

II. OBJECTIVES

To design and integrate a piezoelectric-based regenerative system into an electric bicycle that can efficiently capture and convert mechanical energy from road vibrations, pedaling, and other dynamic forces encountered during operation into electrical energy. To select appropriate piezoelectric materials capable of generating sufficient electrical energy under typical operating conditions of the e-bike, considering factors such as durability, energy output, and ease of integration into the bicycle structure. To compare the performance and efficiency of the piezoelectric regenerative system with traditional regenerative systems, identifying advantages and potential challenges specific to piezoelectric energy harvesting in the context of electric bicycles. To evaluate the performance of the piezoelectric regenerative system in real-world conditions, measuring its ability to recover energy, enhance battery life, and extend the operational range of the e-bike, as well as assessing the overall impact on efficiency and user experience.

III. LITERATURE REVIEW

A. Electric Bicycles, next Generation low Carbon Transport Systems

Electric bicycles (e-bikes) are rapidly gaining attention as a critical element in the shift towards low-carbon transport systems, especially in urban areas where they offer a sustainable alternative to conventional motor vehicles. This paper investigates user preferences for future e-bike features, aiming to enhance their functionality and promote wider adoption as a green mobility solution. A comprehensive survey involving 638 potential e-bike users, predominantly from Europe and North America, was conducted to evaluate the desirability of various e-bike features that could shape the next generation of these vehicles.

B. Design fabrication of e-bicycle and comparative analysis of lead acid battery and lithium ion battery

The increasing demand for sustainable and cost-effective transportation, coupled with rising fuel prices and environmental concerns, has led to a growing interest in electric bicycles (e-bikes) as a viable solution for short-distance commuting. This paper focuses on the design, fabrication, and performance evaluation of an e-bicycle that integrates an electric motor with a traditional bicycle to offer users an efficient, environmentally-friendly alternative to conventional modes of transport. The e-bike provides dual functionality, allowing users to switch between manual pedalling and motorized assistance, making it adaptable to different commuting needs .A key aspect of this study is the comparative analysis of two commonly used battery types in e-bikes: lead-acid and lithium-ion batteries. These battery types were evaluated based on several performance criteria, including energy efficiency, weight, discharge cycles, resilience to deep discharges, temperature sensitivity, lifespan, and cost. The objective was to determine the most suitable battery for e-bike applications, balancing factors such as performance, user convenience, and long-term cost-effectiveness.

C. E-bike with Regeneration

In response to the escalating demand for sustainable and efficient urban transportation, this study presents the design and implementation of an electric bicycle (e-bike) featuring regenerative braking capabilities. The primary objective is to harness the kinetic energy dissipated during braking and convert it into electrical energy, thereby recharging the e-bike's battery and improving overall energy efficiency .The e-bike is powered by a brushless DC (BLDC) motor, selected for its high efficiency and reliability. The regenerative braking system is integrated with the motor controller, enabling seamless transition between propulsion and energy recovery modes. During braking, the system engages the motor in reverse, functioning as a generator to convert kinetic energy into electrical energy, which is then stored in the battery. Comprehensive testing was conducted to evaluate the performance of the regenerative braking system under various operating conditions. Results indicate a significant improvement in energy efficiency, with the system recovering approximately 15-20% of the energy expended during acceleration phases. This energy recovery contributes to an extended range per charge and reduces the frequency of external charging, enhancing the e-bike's practicality for daily commuting.

D. How similar the usage of electric cars and electric bicycles

In the context of growing environmental concerns and the need for sustainable transportation solutions, electric vehicles (EVs) and electric bicycles (e-bikes) have gained prominence as viable alternatives to traditional gasoline-powered vehicles. This study explores the similarities and differences in usage patterns between electric cars and electric bicycles, providing insights into user behaviour, travel preferences, and the socio-economic factors influencing their adoption.

The research employs a comparative analysis of various studies and surveys to investigate key aspects of electric vehicle and e-bike usage, including trip frequency, trip distance, and user demographics. By examining a diverse range of geographic contexts, this study identifies commonalities in the motivations behind the adoption of both modes of transportation, such as environmental awareness, cost savings, and the desire for greater mobility in urban settings.

One significant finding of the study is the similarity in the profile of users for both electric cars and e-bikes, with both groups demonstrating a preference for sustainable travel options.

IV. METHODOLOGY

The working of this energy harvesting system in an electric bicycle begins with the user starting the ignition and twisting the throttle, which generates a control signal to regulate power distribution. The DC motor receives electrical energy from the battery, converting it into mechanical power that is transmitted to the wheels, propelling the cycle forward. As the rear wheel rotates, it drives a DC generator, which produces additional electrical energy that is stored in the battery. Simultaneously, the system utilizes mechanical vibrations caused by road shocks, which are converted into electricity through a piezoelectric transducer, further contributing to energy generation. Additionally, a solar panel absorbs sunlight, providing another source of electrical energy. The combined energy from the DC generator, piezoelectric transducer, and solar panel is stored in the battery, ensuring continuous power availability. This hybrid approach enhances efficiency, reduces reliance on a single energy source, and improves the overall sustainability of the electric bicycle.

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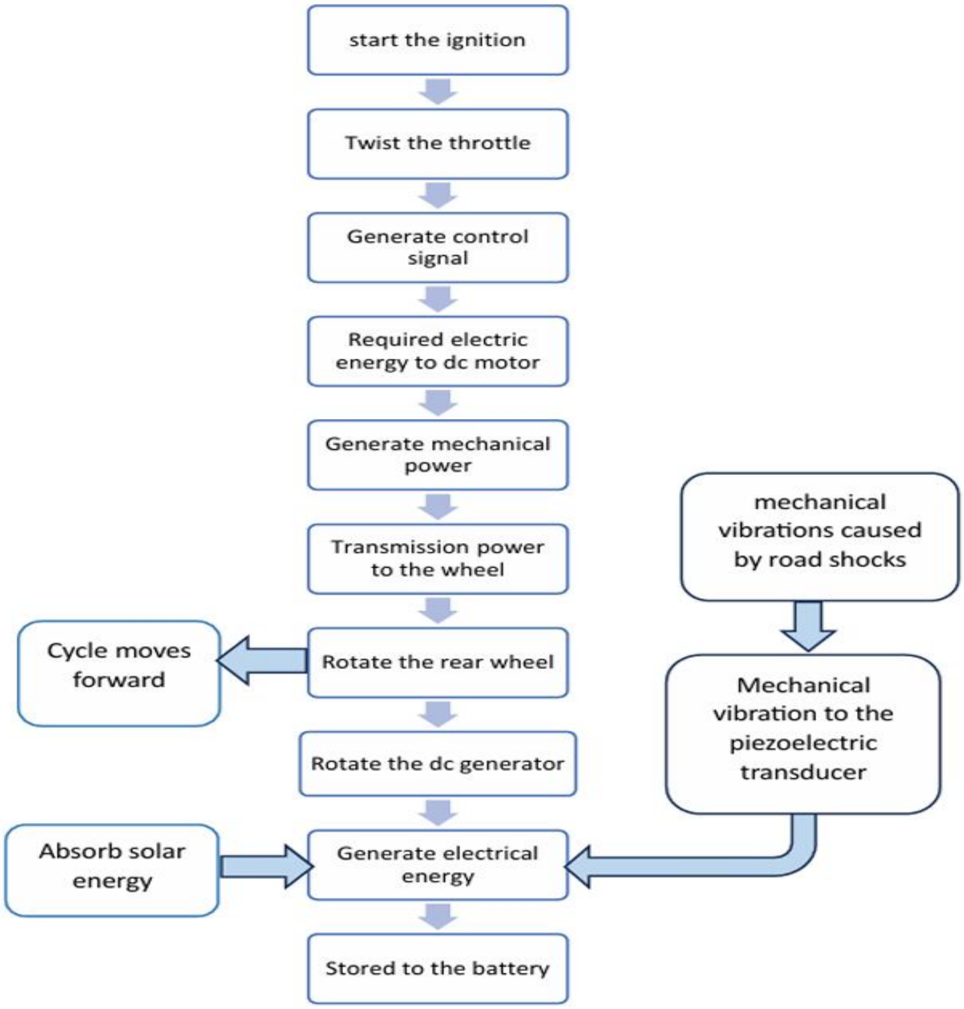

Fig. 1 Methodology

V. COMPONENTS AND DESCRIPTION

A. Dc Motor

A DC motor is an electrical motor that uses direct current (DC) to produce mechanical force. The most common types rely on magnetic forces produced by currents in the coils. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current in part of the motor. DC motors were the first form of motors widely used, as they could be powered from existing direct-current lighting power distribution systems. 14 A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing the strength of current in its field windings. Small DC motors are used in tools, toys, and appliances.

Fig. 2 Dc Motor

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B. Motor Controller

A motor controller is a device or group of devices that can coordinate in a predetermined manner the performance of an electric motor. A motor controller might include a manual or automatic means for starting and stopping the motor, selecting forward or reverse rotation, selecting and regulating the speed, regulating or limiting the torque, and protecting against overloads and electrical faults. Motor controllers may use electromechanical switching, or may use power electronics devices to regulate the speed and direction of a motor.

Fig. 3 Motor Controller

C. Throttle

The throttle mode on an electric bike is similar to a motorcycle or electric scooter, as when it is engaged the motor provides power and propels the bike forward. It gives you full power on demand with no automatic pedal assistance involved. The throttle is what allows you to sit back and enjoy a relaxing ride if you are looking to just cruise, as the bike can operate without having to pedal. On Pedego bikes, the throttle style is a half grip twist, so when the throttle is twisted towards you the bike is ready to get up and go. Other ways you can use the throttle is by safely passing others when on a bike path, accelerating yourself up a large hill, or using it to stabilize yourself as you get ready to take off on your bike.

Fig. 4 Throttle

D. Battery charger

A battery charger, recharger, or simply charger, is a device that stores energy in a battery by running an electric current through it. The charging protocol (how much voltage or current for how long, and what to do when charging is complete) depends on the size and type of the battery being charged. Some battery types have high tolerance for overcharging (i.e., continued charging after the battery has been fully charged) and can be recharged by connection to a constant voltage source or a constant current source, depending on battery type. Simple chargers of this type must be manually disconnected at the end of the charge cycle.

Fig. 5 Battery charger

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E. Battery

The integration of a Lithium-Ion Battery into the electric bicycle with a regenerative system significantly enhances the bike's energy efficiency and sustainability. By capturing and storing energy from various sources such as generator, solar power, and piezoelectric energy, the battery ensures that the e-bike remains powered with minimal reliance on external charging sources. The lithium-ion battery's high energy density, light weight, and long cycle life make it an ideal choice for powering the regenerative system, ensuring the e-bike is both environmentally friendly and cost-effective for long-term use.

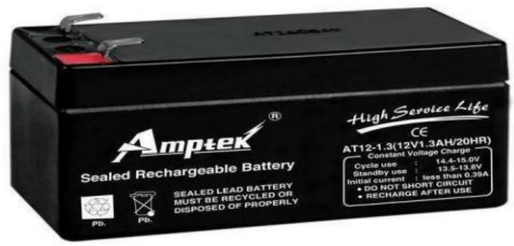

Fig. 6 Battery

F. Sprocket

The sprocket design for the electric bicycle with a piezoelectric regenerative system focuses on efficiently transferring pedaling force while integrating piezoelectric materials to harvest energy from mechanical stresses. Piezoelectric elements are strategically placed on the sprocket, which generates electrical energy as it experiences vibration and mechanical stress during cycling. The sprocket is made from durable materials, such as stainless steel or high-strength alloys, to withstand wear and tear while maintaining performance. The design also optimizes the placement of piezoelectric materials to maximize energy recovery without compromising pedaling efficiency. The harvested energy is routed into an energy management circuit connected to the e-bike's battery for storage and later use.

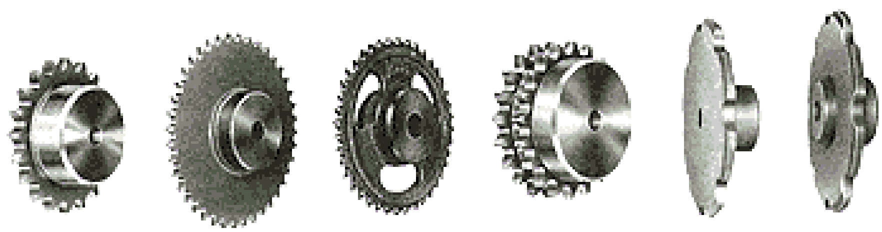

Fig. 7 Sprocket

G. Chain drive

The chain drive system is responsible for transferring mechanical power from pedalling to the wheels, and in this design, it integrates piezoelectric materials to harvest energy from the mechanical movements and vibrations of the drivetrain. Piezoelectric elements are strategically placed along the chain, sprockets, and other moving components to generate electrical energy as they experience stress during cycling. The materials used for the chain and sprockets are selected for their durability and resistance to wear, ensuring they can handle the additional forces generated by the piezoelectric system without compromising performance.

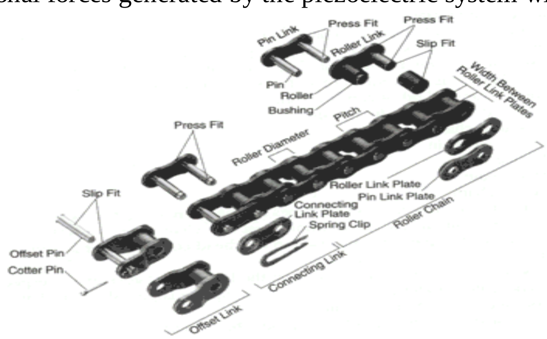

Fig. 8 Chain drive

H. Piezoelectric Transducer

Piezoelectric transducers are crucial components in the regenerative system of the electric bicycle, converting mechanical energy into electrical energy through applied stress or strain. These transducers are strategically placed at key locations on the e-bike, such as the frame, chain drive, and wheels, where vibrations and mechanical movements are most prominent. The choice of piezoelectric material, such as lead zirconate titanate (PZT) or polyvinylidene fluoride (PVDF), is essential for ensuring high energy conversion efficiency, durability, and responsiveness to dynamic forces encountered during cycling. The generated electrical energy is typically in the form of alternating current (AC) and is captured and converted into direct current (DC) through an energy harvesting circuit, which includes rectifiers and voltage regulators, before being stored in the battery. The design of the transducers is optimized to maximize energy recovery by tuning their placement and geometry to the mechanical stresses of the bike's movements.

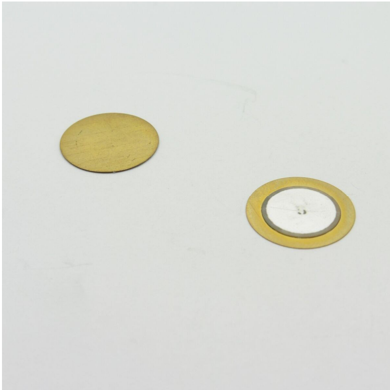

Fig. 9 Piezoelectric Transducer

I. Generator

The design and fabrication of an electric bicycle with a regenerative system using a generator focuses on enhancing energy efficiency by recovering energy and converting kinetic energy into electrical energy. The system integrates a generator into the rear wheel hub, which is activated during braking or deceleration, capturing the energy that would otherwise be lost. This mechanical energy is converted by the generator into electrical energy, which is then stored in the bicycle's battery for later use. The generator is selected for its high efficiency, lightweight design, and compatibility with the overall e-bike system, ensuring minimal impact on the bike's performance and rider experience. The regenerative mechanism with the generator, reduces the need for frequent battery recharges, extending the operational range of the bicycle.

Fig. 10 Generator

J. Solar Panel

The design and fabrication of an electric bicycle with a regenerative system utilizing solar panels aims to enhance the bike's sustainability by combining solar energy generation with energy recovery. A solar panel is integrated into the e-bike's frame to capture sunlight and convert it into electrical energy, which is stored in the battery for later use. This system is complemented by a regenerative mechanism that recovers kinetic energy during deceleration, further extending the bike's operational range. The solar panel works autonomously, providing continuous charging during daylight hours, while the regenerative system ensures that energy is efficiently stored from both solar power and the braking process.

The integration of these systems reduces the need for external charging sources, providing a more environmentally friendly and independent power solution for urban commuting. The system's performance is optimized to maintain balance between weight, efficiency, and energy output, ensuring the bicycle remains functional and easy to ride.

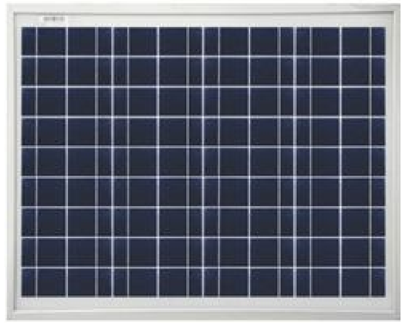

Fig. 11 Solar Panel

VI. BLOCK DIAGRAM

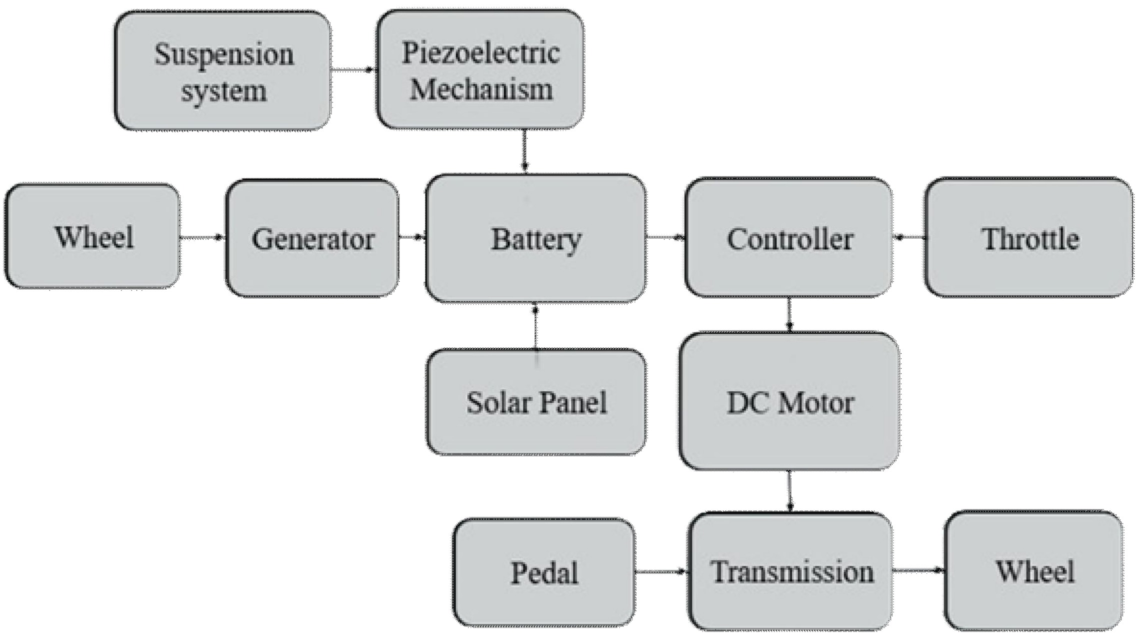

Fig. 12 Main Block Diagram

VII. WORKING

A generator, piezoelectric transducers, and a solar panel. The main power supply is a Lithium-Ion battery which charges the electric motor in order to help with pedalling, so that long-range travel and/or climbing can be performed more easily by the user. When the bicycle travels, the generator takes advantage of mechanical energy generated by the turning wheels, and it translates it into electrical electricity, which is then charged into the battery. This continuous conversion of kinetic energy into electrical energy helps to recharge the battery while riding, extending the overall range of the bike. In addition to the generator, the bicycle is equipped with piezoelectric transducers embedded in the shock absorbers and frame. These transducers translate road surface vibration, bumps and movement of the rider in electrical energy by means of the piezoelectric effect. That energy is then captured and sent to the battery, offering a secondary power recovery system while riding, even during some uneven terrain. Despite the fact that the energy that can be recaptured by the piezoelectric system is quite tiny, they are valuable to enhance both energy efficiency and sustainability of the bicycle. The photovoltaic panel on the bicycle eye acquires the solar radiation during the day and transforms it into direct current (DC) electricity. The produced energy in the solar panel is converted to and sent to the battery through a rectifier circuit, which controls the voltage to satisfy the charging parameters of the battery.

This, in turn, makes the battery reusable, even when the bike is stationary or riding during daylight, thus eliminating requests of external power. The ability to utilize solar energy for charging the battery considerably increases the sustainability of the electric bicycle, particularly for the long-range cycler. A control unit is able to optimize the power flow from the generator, piezoelectric transducers, and solar cells to the battery. The controller guarantees that all energy sources are used to the maximum without overcharging and that the battery is charged in its usable range. The controller is responsible to manage the input from these renewable energy sources, accordingly, cycling range and performance of the bicycle could be maximized, in order that the motor can be supplied with enough power to work. This regenerative system, by harnessing mechanical vibration and solar energy, decreases reliance on external charging and provides an eco-friendly approach to transport. The integration of generator, piezoelectric transducer, and solar panel makes the Electric Bicycle with Regenerative System, an energy-conserving and environmentally friendly transportation mode. In addition to the reduction of the environmental footprint, the design also enhances self-sufficiency of the bike so that it is capable of performing longer distances without the need for frequent charging. By combining these breakthrough systems, energy is continuously harvested from a wide range of energy sources and thus the electric bicycle is the solution for those who'd like to have a more sustainable and independent alternative for the way of transport. Reducing dependence on conventional grid-dependent electricity, this regenerative system provides a greener, more electrically efficient solution to conventional electrically-powered bicycles.

VIII. CONCLUSION

Design and Fabrication of Electric Bicycle with Regenerative System using generator, piezoelectric transducer and solar panel is a new approach to energy recovery and sustainability in electric transportation. By integrating three energy harvesting technologies, the system can capture and store energy from mechanical motion, vibrations and solar radiation, thus increasing the overall energy efficiency of the bicycle. The generator converts kinetic energy from the bike's movement into electrical energy, piezoelectric transducers harvest mechanical vibrations caused by road irregularities and rider movement. Solar panel captures solar energy to recharge the battery, an eco-friendly and renewable energy source. The synergy of these regenerative systems extends the bike's range and reduces dependence on external charging. With ability to charge while riding or stationary, the bicycle becomes more self-sufficient, sustainable and cost effective. Also the integration of these technologies reduces the environmental impact, a good alternative to conventional electric bicycle and other modes of transportation. The system can harvest energy from multiple sources, future of electric vehicle technology is promising especially in urban commuting and long distance travel. Energy recovery from piezoelectric transducers is incremental and overall energy production depends on sunlight exposure, but combination of these technologies in electric bicycle enhances its performance, efficiency and sustainability. In conclusion, Electric Bicycle with Regenerative System is a new and eco-friendly solution for personal transportation. Usage of generator, piezoelectric transducer and solar panel improves the bike's overall performance, autonomy and self-sufficiency, for more energy efficient and eco-friendly transportation in the future.

IX. FUTURE SCOPE

The Electric Bicycle with Regenerative System looks quite captivating and great prospects in the future. The outcome seize efficiency of the generator as well as piezoelectric transducer constituents through newfangled materials and designs could mean a significant increase in energy recovery during the operation of the bicycle. Furthermore, the concept of solar panels' integration can be further explored where photovoltaic modules are made more flexible or lighter to improve energy capture from sunlight. Also, another great idea would be discovering extra regenerative systems, such as wind turbines or kinetic energy recovery, which could upgrade the regenerative capabilities of the bike. As long as the technology continues to evolve, a cost-cutting approach along with lessons in durability will bring these systems to everyday use at an affordable price. In conclusion, the integration of these new technologies into other personal transportation vehicles, for example, electric scooters or motorcycles, would be a great way to go and would even extend their environmental and practical benefits. In general, the future area of this regenerative system raises the potential to develop clean and sustainable methods of transportation, thus the green and energy-efficient world will become a reality.

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