https://doi.org/10.14669/AM/191492

COMPREHENSIVE REVIEW ON EVOLUTION, PROGRESSION, DESIGN, AND EXPLORATION OF ELECTRIC BICYCLE

SATHISH DHANDAPANI[1], THIRUNAVUKKARASU RAJA[2], VEERAMANIKANDAN MURUGAN[3], JEGADHEESWARAN SELVARAJ[4], VIJAYAKUMAR RATHINASAMY[5]

Abstract

Many countries are moving to electric vehicles for daily transportation due to the scarcity of fossil fuels and the pollution emissions from internal combustion engines. The most promising technique to manage environmental pollution and energy security is the employment of electric vehicles. The electric bicycle is gaining an abundance of attention due to the various advantages of electric vehicles. Recently, people started using electric bicycles on a regular basis, and it is a suitable option for shorter daily rides. The present study was conducted using the Scopus database, which included an analysis of all papers pertaining to the content of electric bicycles up until the year 2023. The literature review delves into the profound impact and numerous benefits of electric bicycles, highlighting their potential for revolutionizing transportation. This exploration is informed by advancements in design and construction, offering insights into optimal electric bicycle development. One promising avenue for sustainability involves integrating solar technology into these vehicles, reducing reliance on conventional energy sources, and addressing environmental concerns. Discussions encompassed diverse aspects, including operation principles, throttle variations, commutation systems, self-charging

[1] Mechanical Engineering, Dr.N.G.P. Institute of Technology, Coimbatore, India, e-mail: sadhirash@gmail.com, ORCID: 0000-0002-9494-0508

[2] Mechanical Engineering, SRM Institute of Science and Technology, Ramapuram Campus, Chennai, India, e-mail: thirunaarasu821@gmail.com, ORCID: 0000-0001-9319-3005

[3] Mechanical Engineering, SRM Institute of Science and Technology, Ramapuram Campus, Chennai, India, e-mail: veera.thermal@gmail.com, ORCID: 0000-0002-9255-382X

[4] Mechatronics Engineering, Bannari Amman Institute of Technology, Sathyamangalam, India, e-mail: jegadheeswaranphd@gmail.com, ORCID: 0000-0002-2540-0487

[5] Mechanical Engineering, Dr.N.G.P. Institute of Technology, Coimbatore, India, e-mail: vijoybe@gmail.com, ORCID: 0000-0001-5311-4800

mechanisms, health advantages, and solar-powered electric bicycles. To address this, the goal is to create universally acceptable electric bicycles to broaden their appeal and dispel misconceptions. In order to provide scientists and researchers with beneficial information to further optimize electric bicycles, the research fields pertaining to electric bicycles are reviewed in accordance with previous studies.

Keywords: electric vehicle; electric bicycles; energy security; sustainability

1. Introduction

The scarcity of fossil fuels has led to high costs and increased demand for them around the world. As a result, the top producers demand that fossil fuel prices be met. It impacts the lives of regular people. Additionally, the environment and people are impacted by the pollution from fossil fuel-powered vehicles. Vehicles with internal combustion engines also have an impact on the environment and its inhabitants due to noise pollution. The Indian government unveiled a plan to regulate internal combustion engine vehicles' exhaust emissions. The Bharath stage is the method. There are three Bharath stages in operation, namely 3, 4, and 6. India is currently in Bharath Stage 6, which means that internal combustion engine emissions from gasoline-powered vehicles are less than those of Bharath Stage 4 emissions. The pollution limit of BS4 is not more than 1.5 g/kWh, and the pollution limit of BS4 is not more than 1.5 g/kWh. Diesel engine vehicles are not selected in BS6 norms because diesel engine vehicle manufacturers can't reduce tailpipe emissions. Only the petrol engines are selected according to the BS6 norms. But still, we can't reduce the tailpipe emissions to zero. In addition, the pollution limit for BS4 is limited to 4 g/kWh, rather than 1.5 g/kWh. Because diesel engine vehicle manufacturers are unable to reduce tailpipe emissions, these vehicles are not allowed to operate under BS6 norms. The only engines chosen to meet BS6 standards are petrol ones. However, we are still unable to completely eliminate tailpipe emissions.

This is the location where the electric car made its debut. Electric cars have no tailpipe emissions, and they also don't produce any noise pollution. Electric bicycles are ideal for daily commutes, such as trips to nearby gyms, stores, and schools. Cycling is best suited for shorter commutes because we can't pedal for very long before we get tired. This is where the electric bicycle made its debut. By utilizing a motor, battery, and throttle type, we are able to travel a greater distance than with a regular, conventional, or traditional cycle.

Combine those parts to create an electric bicycle. An electric bicycle is not the same as a regular bicycle. Conventional bicycles can only be operated manually, but electric bicycles can be operated both manually and with a motor. In the paper [23] the author expressed that electric bicycles are becoming more popular due to their convenient mode of transportation. The majority of nations, including China, the United States, Switzerland, the Netherlands, and Japan, use electric bicycles for daily transportation. An electric bicycle promotes better

https://doi.org/10.14669/AM/191492

health. Because it is smaller, anyone can handle an electric bicycle with ease. People prefer to use this for their daily commutes as a result. In the paper [123] the author demonstrated that the greenhouse gas (GHG) emissions of electric vehicles (EVs) were significantly influenced by the chosen system boundary for analysis, whether it encompassed the well-to-wheel perspective or the entire vehicle lifecycle. They observed that GHG emissions assessed on a well-to-wheel basis were lower compared to those calculated over the vehicle's entire lifespan. The author of publications [13] conducted a model-based investigation aimed at projecting the potential reduction in GHG emissions from EVs in Switzerland, considering the influence of weather conditions such as temperature and precipitation. Their findings suggested that for a notable impact on GHG emissions, individuals should be willing to use EVs at temperatures around 10°C. In the paper [103] devised a regenerative power control system tailored for a pure electric bicycle (EB), employing a permanent magnet brushless DC motor housed within the EB wheel. The author of publications [24] demonstrated a model-based design and real-time simulation approach for a pure EB using RT-LAB and Simulink. They utilized SimPowerSystem, a Matlab/Simulink toolbox, to model and simulate the power components. The author of publications [37] conducted a simulation study employing proportional-integral (PI) and fuzzy controllers in Matlab/Simulink to develop an effective speed control mechanism for a brushless direct current (BLDC) hub motor situated within an EB wheel. As per the paper [69], electric motor-assisted bicycles in the United States are limited to a maximum power of 750 W, whereas in Europe, India, and Japan, the maximum power is capped at 250 W. Pedelecs prove particularly beneficial for individuals residing in hilly terrains or for riders seeking both assistance and the opportunity to enhance their health through exercise. The author of publications [43] conducted simulations and experimental investigations into the operational efficiency of an electric bicycle (EB) coupled with a semi-automatic transmission. This setup allowed for control of driving power through both pure electric and power-assisted modes. In the publication [96] also explored an EB configuration incorporating a blend of pure electric and power-assisted modes. In the publications [114] the researchers explored the technological advancements and market dynamics of LPG-fueled vehicles in this comprehensive overview.

2. Research Methodology

Various scientists and investigators expressed that in the area of research, development, and the practical implementation of electric bicycles, they discovered a notable lack of public awareness in these domains. This article provides valuable insights, especially for the new investigators optimizing the performance of the electric bicycle.

The article's inception involved desk research, a common starting point for academic inquiries. Academic research typically commences with a thorough examination of existing data, including previous studies, an evaluation of the current knowledge landscape, and a meta-analysis of relevant literature. While such extensive methods may not always be

https://doi.org/10.14669/AM/191492

deemed essential in business contexts, it's advisable to initiate research endeavours with at least a foundational level of inquiry. This preliminary step enables researchers to gain a deeper understanding of the subject matter and its surrounding context, facilitating the formulation of more pertinent questions and the efficient selection of research methodologies and data sources for subsequent investigations. Desk research is predominantly utilized in competitive analysis, serving as a swift means to derive crucial insights vital for business decision-making, particularly in market analysis.

The next step of the research involved determining the current state of EV technologies, commonly known as the "state of the art." This term encompasses the current status of a specific technology or the most cutting-edge advancements in a particular field of science or art. Within academic research, it specifically entails analyzing documents to showcase the latest developments in EV production and utilization. This analysis aims to compile a variety of sources, ideas, concepts, and opinions, which the researcher will either corroborate or refute based on their findings. Such information is crucial for fostering a critical understanding of the subject matter and for generating new knowledge to advance theoretical perspectives.

This article reviews the progression of electric bicycles over the past few years, from the application of hybrid machinery made of conventional batteries and engines to the final product's marketability and future effects. An extension study will be paid to the various energy-supply mechanisms and the motors that employ them to propel. Moreover, the technologies that appeal to smooth transportation and accelerate the performance of bicycles are examined. Furthermore, this system complies with foreseeable challenges and offers the best techniques for resolving them.

3. Overview of Electric Bicycle Usage in the World

3.1. Technologies in E-Bicycle

In the paper [111] examined that in electric bicycles, posture and straight-line tracking are used for the features of future development, and the final assembly is shown in Figure 1. Here, there are two strategies used to stabilize the posture of the bicycle, namely trajectory control and lateral velocity. Experimental investigation concluded that the steering function controller (trajectory controller) is more powerful than the lateral velocity controller in straight-path tracking of the bicycle.

https://doi.org/10.14669/AM/191492

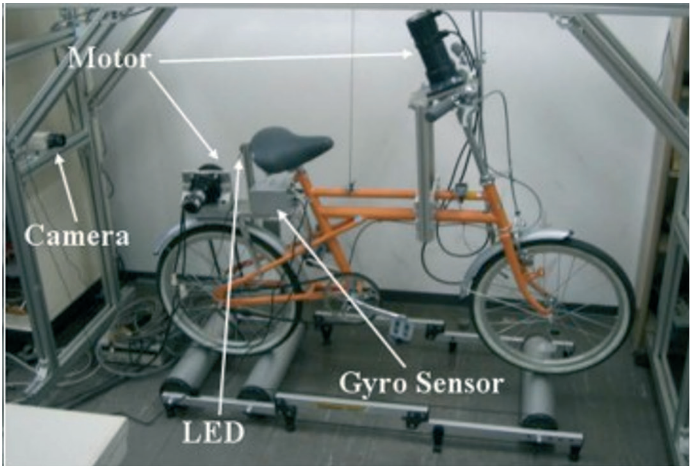

Fig. 1. Assembly of straight line and posture tracking e-bicycle

The author of publications [21] introduced a novel reinforcement-learning-based assisted power management (RLAPM) system with a focus on quality-of-riding (QoR) for human-electric hybrid bicycles (pedelecs). By dynamically adjusting the motor power based on the riding environment, RLAPM ensures QoR, encompassing safety and comfort while enhancing battery energy utilization. Simulations and experimental results highlight the RLAPM's effectiveness, demonstrating a 24% improvement in comfort and a notable 50% enhancement in energy utilization compared to other pedelec-assisted power methods in urban riding scenarios. In the paper [1] discussed the limitations of conventional constant assistance algorithms in power-assisted electric bicycles (pedelecs) and introduced a novel control strategy. Focused on minimizing tracking errors in varying environmental conditions, the approach integrates feedforward and feedback components into the electric motor torque. It evaluates the methodology on an innovative pedelec prototype, demonstrating enhanced riding comfort and energy utilization compared to traditional assistance methods. In the paper [104] introduced an innovative charging management-based intelligent control strategy designed to maximize external charging benefits and extend the range of electric bicycles and vehicles. It tailors the control approach to diverse urban road characteristics, employing constant power control on arterial roads and power follower control on expressways. It contributes valuable insights into intelligent control strategies for optimizing extended-range EV performance and energy management. In Figure 2, the wiring diagram of the Graphic Positioning System is shown. The author of publications [87] expressed that the GPS is used to locate the bicycle. The GPS cycle computer system can also provide speed, mileage, and other parameters. Get the information and turn it into an ASCII code [80]. Collected the data from the CV file, uploaded it to the Google disk, and monitored those parameters as mentioned above. The GPS application calculated the travelled distance to be 11.94 km, a difference of 28 m, and an average speed of 63.8 km/h as at night [124, 131].

https://doi.org/10.14669/AM/191492

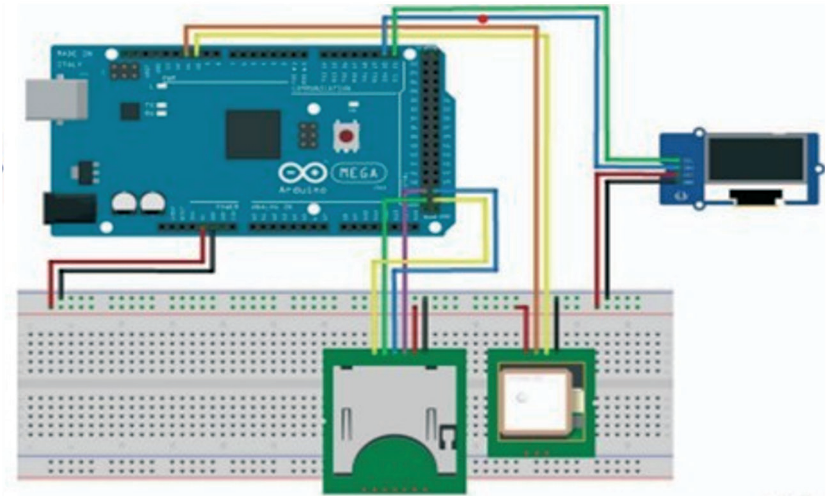

Fig. 2. Wiring diagram of GPS cycle computer

In Figure 3, there is a system that can detect accidents and notify urgent care clinics [106]. A MARG type of sensor is used to detect the bicycle. A support vector algorithm detects fall accidents. 34 trails have been conducted, each of which includes cycling status and fall status segments.

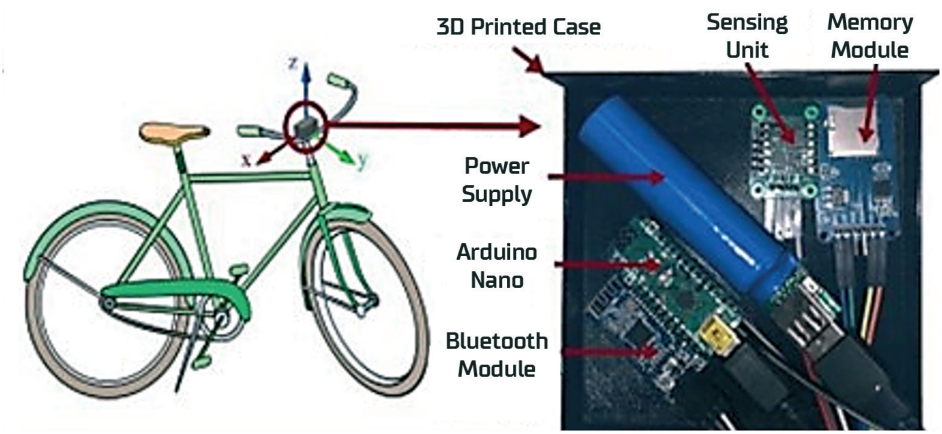

Fig. 3. Accident detection components

In the paper [119] proposed an innovative fuzzy logic control strategy incorporating human-bike interaction for electric bicycles, featuring a novel transmission mechanism and intelligent control system. Leveraging a load cell-based mini-sensor system, the study employs

https://doi.org/10.14669/AM/191492

data-based system identification for transfer function determination. Through simulations and experimental validation, the proposed fuzzy PID and hybrid fuzzy control algorithms exhibit superior performance in terms of response time and speed control, highlighting their effectiveness in ensuring driving comfort and safety in electric bicycle applications.

In the paper [90] article details the design and fabrication process of an electric vehicle specifically catered to meet the needs of physically challenged individuals. It explores innovative adaptations and features aimed at enhancing accessibility, comfort, and safety for users with mobility impairments. By addressing the unique requirements of this demographic, the research aims to promote inclusivity and independence in personal transportation.

3.2. Design and Fabrication of E-Bicycle/Development of E-Bicycle

The author of publications [26] introduced an innovative brushless DC motor driver for electric bicycles, outlining its hardware and software design. It successfully achieves speed control, over-current protection, and battery under-voltage protection, demonstrating effective control and suitability for electric bicycle applications. It contributes to enhancing the performance and safety of electric bike systems, showcasing their practicality and potential impact in the field. In Figure 4, the electric bicycle frame mechanical model is shown [125], designers pay more attention to the frame than any other component. The second thing is the battery. The main thing on the frame is to allocate the battery and proper weight distribution, as well as shortlist the power supplies for the components. The configuration of an electric bicycle is defined by two data points: geometry data and topological data. A frame for the electric bicycle that distributes the weight equally has been designed.

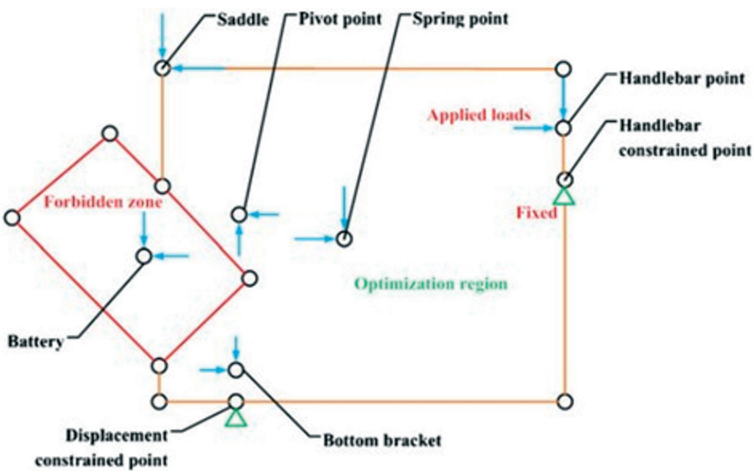

Fig. 4. Electric bicycle frame mechanical model

https://doi.org/10.14669/AM/191492

In the paper [60] introduced an innovative combination of a standard geared bicycle with an electric power motor cum alternator, providing riders the flexibility to choose between electric motor assistance and manual pedaling. With a focus on reducing effort during climbing and rough terrain, the design emphasizes eco-friendly transportation. The system's adaptability for various age groups aligns with its intended use as an inter-college transportation solution, promoting the concept of "green energy" and aiming to minimize automobile use within the campus. In the paper [112] examined the electric vehicle industry, focusing on the cost-effective design and manufacturing of lightweight electric vehicle prototypes. With the rising demand for electric vehicles due to fossil fuel scarcity and emission regulations, cost-efficient solutions are crucial. The paper introduces innovative methodologies, including motor synchronization theorems, gear ratio optimization, and simplified suspension-steering kinematics, all aimed at creating a low-cost, lightweight prototype. The author of publications [16] introduced an innovative inductive lane design for wirelessly transferring power to electric bicycles (e-bikes), showcasing initial test results. The system employs oblong primary coils embedded in the ground, activated by high-frequency alternating current and RFID authentication. The e-bike's powertrain harvests energy from the lane through a secondary coil around its rear wheel. When away from the inductive lane, stored energy sustains on-board power. The prototype's feasibility demonstrates potential applications for lightweight electric vehicles, presenting a low-cost, sustainable urban mobility variant. In the paper [72] proposed the need for high-technology solutions to address fossil fuel shortages and combat climate change. The block diagram of E-cycle requirements is shown in Figure 5. Electric bicycles (e-bikes) emerge as a promising and sustainable alternative for mobility and transportation, offering features like efficiency, compactness, electric power, comfort, and lightweight design. The focus on e-bikes as a visionary solution highlights their potential to create a better world for future generations, making them a versatile and advantageous mode of transportation.

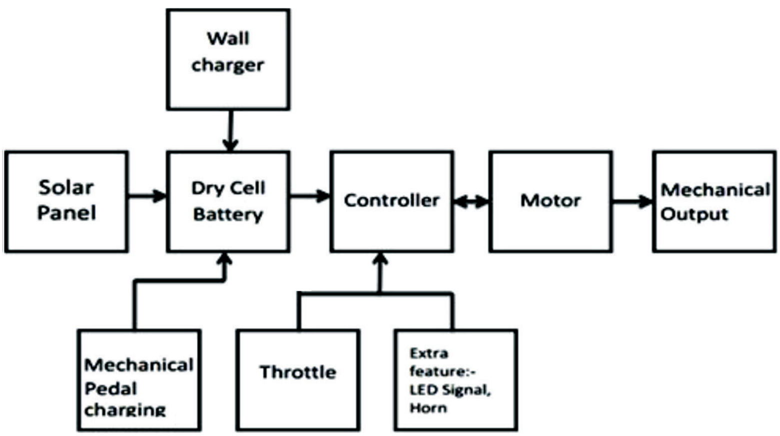

Fig. 5. Block diagram of e- cycle

https://doi.org/10.14669/AM/191492

The author of publications [66] discussed stress analysis and design optimization of a custom bicycle frame using Pro/ENGINEER digital solid modeling CAD software. Through wireframe and solid structure analysis, various bicycle frame types are examined, highlighting the superior rigidity of the diamond-type frame. Additionally, it explores the mechanical properties of AZ60/Al_2O_3p magnesium metal matrix nanocomposites, achieving levels comparable to those of A16061 aluminum after equal channel angular extrusion. This comprehensive investigation contributes valuable insights into enhancing bicycle frame design and material selection. In the paper [14] experimented with a finite element analysis (FEA) model for electric trike frames, incorporating modifications for battery packs and passenger loads. It evaluates various steel tube profiles, including circular, oval, and square, to optimize safety and ease of assembly. Through FEA simulation and validation with experimental methods, the research identifies the oval tube with a diagonal size of 56.6x40 mm and 1.65 mm thickness as the most effective, providing recommendations for the redesign of electric bicycle frames for improved safety and performance. In the publication [95] fabricated the electric bicycles registered during the Second World War because of the shortage of large motorized vehicles. Electric cycles began to be promoted in 1973 due to the oil crisis. In the year 1992, they used nickel-cadmium batteries. In the publication [55] suggested an efficient automated development process, developed by the Institute for Automotive Engineering at RWTH Aachen University, that customizes electric vehicle transmissions based on demand. This approach presents an opportunity to reduce overall vehicle costs by optimizing transmission design and potentially using smaller batteries. In the paper [117] explained the assessment of alternative battery pack designs for electric vehicles (EVs), with a focus on safety, energy absorption, and packaging efficiency. By employing the finite element method and crash simulations, the study compares a commercially available battery pack structure with alternative geometric concepts. Evaluating geometric considerations and crashworthiness indicators, the research provides insights into optimizing EV performance beyond crash scenarios, offering valuable contributions to the evolving landscape of battery pack design for enhanced safety and efficiency. The author of publications [54] fabricated the best design and performance for electric bicycles and made their electric bicycles a front-wheel ride by using a 500W brushless DC motor (BLDC) motor, classifying the electric bicycles into two types: pedelec and throttle types. Pedelec types of bicycles have low-power electric motors, and throttle types have high-power electric motors. Detailed information for electric bicycle components has been provided.The author of publications [56] experimented with a systematic design process that considers material properties to minimize energy consumption, utilizing vehicle simulations to calculate consumption. Moreover, mathematical models of key components like the traction motor and battery are employed for precise estimations. In the paper [79] suggested the pressing need for affordable and efficient electric bikes, as shown in Figure 6. In response to the growing number of cars on the road worldwide and the increasing reliance on fuels derived from oil.It emphasizes the environmental benefits of electric bikes and aims to design a superior, cost-effective electric bike for everyday commuting. Through comprehensive market research and benchmarking, it contributes to the development of a smarter and more eco-friendly mode of transportation, aligning with the demand for sustainable mobility solutions.

https://doi.org/10.14669/AM/191492

Fig. 6. Complete assembly of e-cycle

The author of publications [5] utilized the pressing issues of rising fuel prices and increasing urban pollution, prompting the exploration of alternative energy sources for vehicles. Electric bicycles offer a practical solution by integrating an electric motor with traditional bicycle components, providing a convenient and eco-friendly mode of transportation. The description of the dissertation project involving a 250 W hub motor and lead-acid batteries underscores the practical implementation of such solutions, contributing to the advancement of electric bike technology. In the paper [7] the evolution of bicycles, once regarded as traditional recreational items, has transformed them into essential, eco-friendly urban transport. Fueled by rising pollution and fuel costs, electric bicycles emerge as crucial support for sustainable personal mobility, integrating motors and advanced technology to ease commuting while addressing environmental concerns. In the publication [88] discussed that the electric bicycle is initially in a stationary state; if we need to move it from that state, we need to pedal or throttle the bicycle. An electric cycle uses electric power to move, and we can also run the cycle with the pedal. In electric bicycles, the major components are classified into two types such as frame and battery. The outcome of the paper is the working principle of the electric bicycle. In the paper [89] the author examined and effectively demonstrated the computational aspects and practical implementation of the MMS E-Bike, covering both electrical and mechanical systems. The construction process, focusing on battery, BLDC motor, and electronic commutator integration, results in a cost-effective and lightweight E-Bike capable of achieving speeds up to 25 mph, particularly in hilly terrain. The outcome is that the emphasis on rider comfort and ergonomic design enhances the E-Bike's appeal and functionality, making it a promising addition to the electric bike market. In the paper [98] the author explained the concept of an electric bicycle as an eco-friendly alternative, emphasizing its role in reducing fuel consumption and emissions. The focus is on delivering electromagnetic momentum to a traditional bicycle through a powerful motor and rechargeable battery. The motivation to design a battery-operated bike aligns with the broader responsibility to diminish reliance on fuel-consuming vehicles, promoting sustainable and efficient electric transportation.The author of publications [31] examined the escalating environmental impact of transportation.

https://doi.org/10.14669/AM/191492

This study proposes leveraging plug-in electric vehicles (PEVs) to reduce fossil fuel consumption. Focusing on the challenge of establishing charging infrastructure, it introduces a novel approach utilizing excess energy from smart street lights powered by renewable solar energy. Through IoT monitoring and control, the paper outlines a system where PEVs are charged from connected street light batteries, offering a sustainable solution for electric vehicle charging. Simulated in MATLAB/SIMULINK, the results showcase the viability and efficiency of this integrated approach. In the publication [44] fabricated a cost-effective portable electric bicycle kit that combines pedaling and electric motor modes, aiming to reduce rider fatigue and extend travel range. By incorporating an external drive electric motor, it offers a solution to enhance the riding experience and cover longer distances on a single charge. The integration of solar power and DC-DC conversion further contributes to sustainable and energy-efficient transportation, emphasizing a shift towards preserving fossil fuels. The project underscores innovation in electric vehicle technology. In the paper [35] the author explained the outlines of a comprehensive approach to conceiving a product from inception to final presentation to customers. It involves market analysis, innovation assessment, component integration, stylistic considerations, CAD modeling, and effective communication. The methodology, encompassing QFD, benchmarking, and design for X, offers a systematic and efficient framework for product development, ultimately leading to prototyping and testing. In the publication [32] fabricated a comprehensive project on designing and analyzing a foldable electric bicycle chassis. It covers key project phases such as market research, literature review, design, analysis, and observations. Recognizing the evolving landscape of electric bicycles, the study emphasizes their ecological benefits, reduced maintenance, and noise levels. The focus on foldability addresses the demand for compact urban transportation solutions, aligning with the dual advantages of the E-Bike-blending features of bicycles and motorcycles for efficient, pollution-free commuting. The author of publications [4] discussed the growing shift in the automobile sector towards electrical energy to combat environmental challenges. Focusing on electric bikes as a viable solution for congested megacities like Dhaka, the study delves into chassis design and analysis. Utilizing triangulation for optimal structural strength, the research employs the advanced FEA software ANSYS for numerical simulations. The validated numerical methodology enables the prediction of dynamic performance, contributing to confident exploratory designs in the development of electric bikes for urban transportation. In the publication [84] expressed the design and simulation of bicycle frames in Creo Parametric and Marc Mentat software, comparing materials (steel, aluminum, and carbon). emphasizes how simulation results guide engineers in selecting optimal materials and optimizing frame geometry for desired stiffness and rider comfort. In the paper [19] the author discussed the multifaceted process involved in designing and fabricating an electric bicycle with an auto-recharging mechanism. It emphasizes crucial steps, including selecting an appropriate electric motor and battery system, integrating them into the bicycle frame through custom fabrication, and developing an auto-recharging mechanism. It underscores the importance of testing, fine-tuning, and implementing safety measures, offering a comprehensive perspective on the intricate engineering considerations for creating an innovative and sustainable electric bicycle.

https://doi.org/10.14669/AM/191492

3.3. Solar Bicycle

The author of publications [25] discussed the growing importance of renewable energy, particularly in the context of the surging global population and linearly increasing energy demands. Focusing on the solar-powered electric bike, the study emphasizes the potential of this technology to save non-renewable sources and increase energy efficiency. By storing solar energy in batteries and utilizing a PMDC motor for propulsion, the solar-powered electric bike introduces an eco-friendly alternative, with benefits including reduced charging time and simplified maintenance compared to conventional AC-powered electric bikes. The author of publications [65] employed Solid Works to design a solar-powered electric bike structure, evaluating various installation methods and concluding that optimal placement involves front and rear frame solar panels with a solar tracking device. Integration with ANSYS through graphical data conversion enables finite element analysis, assessing strength and stiffness in static analysis, and determining vehicle body frequency via modal analysis. In the paper [58] the author proposed a solar panel to recharge the battery. By using solar panels, the battery charging cycle will be minimized. It is also called a solar-assisted bicycle. Fabricating a solar bicycle reduces the time of charging and improves the battery life by using solar panels. In the paper [78] the author fabricated the solar energy to charge the bicycle with solar panels. The solar charge controller is shown in Figure 7. A Hall Effect sensor is used to measure the speed of the bicycle, and it provides a top speed of (35–40) km/h. It can travel up to 40 kilometers, and the charging time of the battery and panels is between 3 and 6 hours.

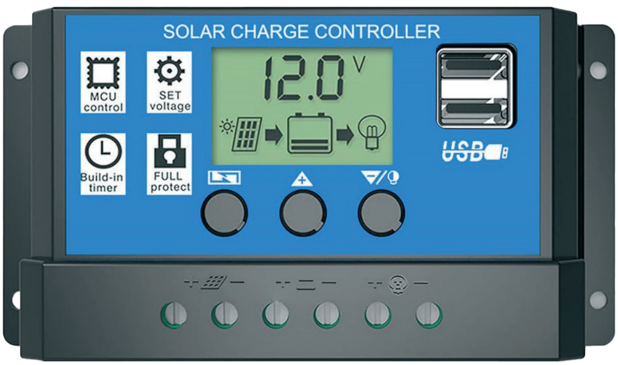

Fig. 7. Solar charge controller

In Figure 8, the block diagram of the Solar E-cycle the author [40] expresses the pivotal shift towards battery-powered electric bikes as a sustainable and eco-friendly mode of transportation, replacing polluting internal combustion engines. It addresses the challenges of charging infrastructure and outlines the potential for solar-powered vehicles to further reduce carbon emissions. The project's objective is to develop a hardware model of a solar

https://doi.org/10.14669/AM/191492

electric bicycle, emphasizing its role in promoting greener and more sustainable urban mobility. It highlights the ongoing efforts to tackle environmental concerns and enhance personal transportation options in cities.

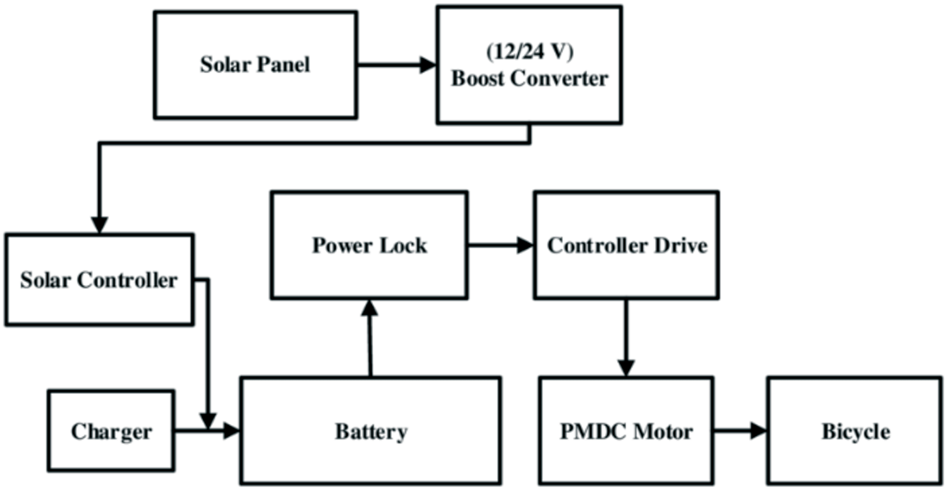

Fig. 8. Block diagram of solar e-cycle

The author of publications [107] examined the upgrade of the dual charge method to charge an electric bicycle. So, here we get another upgrade for charging the bicycles by using solar panels and a dynamo to charge the bicycles. Here, we need (15–20) miles per hour of speed to charge a 15 V battery. In the paper [59] the author introduced two types of controllers to control the solar panel voltage and motor: battery, dynamo, indicator, brake, brake lights, and charging port. This electric bicycle is suitable for both rural and urban areas. Using different types of controllers increases the battery life, and we charge our mobiles by using an AC adapter. The outcome was quite effective for daily use and was done at a much faster rate with less energy utilized.

3.4. Performance/Evaluation

The author of publications [76] expressed that there are three different types of throttle systems in an electric bicycle. Thumb throttle, twist the throttle, and push the button. The motor can be fixed at the front and rear ends. An electric bicycle can climb up to a 6% slope. Two different types of motors are also used in electric bicycles. The result provides the study of electric bicycle components. In the paper [50] the author analyzed the energy usage efficiency of the EVS-XL 2000 electric vehicle (EV) across various domestic and foreign driving cycles. Introducing novel concepts like "interval usage percentage of energy efficiency" and

https://doi.org/10.14669/AM/191492

"exertion degree of energy efficiency," it explores the impact of driving cycles on electromotor efficiency and the distribution of running status. The findings emphasize the significant influence of driving cycles on the exertion degree of electromotor energy efficiency, highlighting the variability in efficiency distributions, control system performance, and driving range across dissimilar driving cycles. The author of publications [3] suggested an optimization model employing simulated annealing to determine specifications for a hybrid solar-diesel-battery power generation system, aiming to strike a balance between life cycle cost and CO_2 emissions. Applied to a residential colony in India, the optimized configuration involves 89% PV inclusion and 11% diesel fraction, with specific parameters yielding minimum life cycle cost and CO_2 emissions. It contributes to optimal design for similar environmental conditions, and future work is suggested to explore the impact of PV array tilt angle and probabilistic performance analysis in conjunction with system reliability assessment. In the paper [71] the author introduced an innovative nonlinear control strategy for electric bicycles, aiming to automatically adjust motor assistance to maintain a desired heart rate. Incorporating rider inputs like heart rate, torque, and cadence, the control algorithm utilizes both feedforward and feedback components. Environmental factors are treated as disturbances to be rejected. It develops and validates a nonlinear heart rate response model through test rides, employing a modified electric bicycle, and presenting simulation and experimental results to demonstrate the controller's performance across various heart rate profiles. In the paper [53] the author suggested that the motor is the costlier component in the electric bicycle. Most e-cycles have BLDC motors, and the loss comparisons of benchmark outer-rotor BLDC motors, SRMs, and SynRM at maximum speed are shown in Figure 9. Here is a case study of changing the reluctance motor instead of the BLDC motor for cost reduction. The result of using a reluctance motor is that it needs a large dimension to produce the required torque, and the designed reluctance motors are heavier in weight and torque ripple.

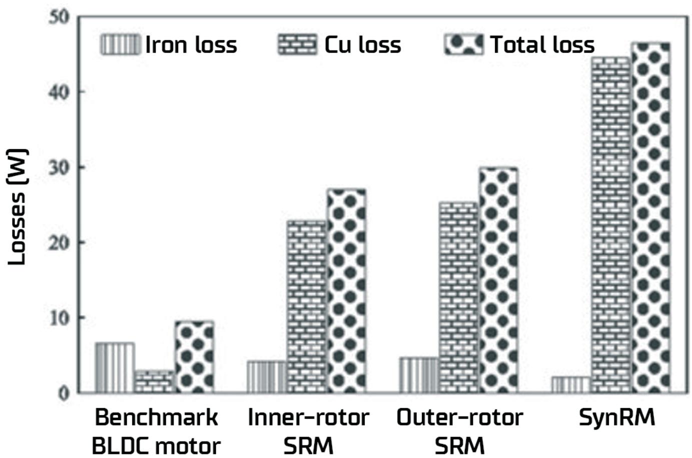

Fig. 9. Loss comparisons of benchmark outer-rotor BLDC motor, SRMS and SynRm at maximum speed

https://doi.org/10.14669/AM/191492

The author of publications [22] utilized real-time challenges in achieving optimal fuel consumption for hybrid electric vehicles (HEVs) by introducing a novel power-split strategy based on linear quadratic optimal control. To overcome the need for prior knowledge of driving cycles, this approach utilizes a quadratic performance index and two rules to ensure battery state-of-charge sustainability and fuel efficiency. Simulations in ADVISOR demonstrate the strategy's effectiveness across diverse driving conditions, closely approaching the fuel economy achieved by optimal control methods based on Pontryagin's minimum principle while significantly reducing computational complexity. The author of publications [42] proposed the performance of electric bicycles, emphasizing their environmental benefits. It employs simulation and experimentation, considering key parameters like the rider's mass, wind speed, and slope. Dynamic equations are solved using MATLAB-Simulink, guiding motor power selection. The experimental study, conducted with LabVIEW programming, validates simulation results, contributing to the development of efficient electric bicycles. In the paper [100] the author examined EVs, conducting a comprehensive investigation into a novel powertrain system comprising four independently driven in-wheel traction motors. It evaluates the energy efficiency of the system under various operational modes and driving cycles, employing a rule-based power management controller. The author of publications [41] expressed the dynamic performance and electric consumption of an electric bicycle through both simulation and experimental approaches. Using MATLAB-Simulink, dynamic and battery models are employed to analyze the impact of operating conditions such as air density and slope. The results reveal improved performance and reduced electric consumption with lower air density and slope. Experimental findings align with simulation results, indicating potential for developing a more efficient electric bicycle. Future work aims to explore additional input parameters for a comprehensive analysis. In the paper [109] the author suggested the environmental performance of plug-in hybrid electric vehicles (PHEVs) in reducing greenhouse gas emissions and gasoline consumption. Utilizing year-long data from 153 PHEVs in California, the study systematically analyzes deviations in the utility factor (UF) from the SAE J2841 standard. Charging behavior, daily VMT distribution, efficiency in charge depleting mode, annual VMT, and effective CD range are identified as key factors influencing UF disparities, providing valuable insights into the real-world impact of driving and charging behaviors on PHEV performance. In the paper [64] the author explored the reliability and performance advantages of a liquid rocket engine employing an electric pump cycle, exemplified by the Rutherford engine developed by Rocket Lab. It involves a thorough analysis and comparison with other cycles for small-sized low-thrust rocket engines, demonstrating the feasibility of electric-pump cycles in achieving lower dry mass and superior performance, particularly evident in specific impulse and speed increments, even at low thrust levels. The analysis program incorporates improved mass estimation reliability, enhancing the understanding of this innovative propulsion technology. The author of publications [45] examined the crucial research aspects of modeling complete polymer electrolyte membrane fuel cell (PEMFC) power systems, encompassing air and hydrogen supply, fuel cell stack, electrical components, and a 75 kW vehicle. Utilizing MATLAB and Simulink, the dynamic model incorporates a brand-new electric motor's efficiency map and assesses the system's performance

https://doi.org/10.14669/AM/191492

during the New European Driving Cycle (NEDC). While revealing instabilities in the air supply system during transient operation, the study affirms that the obtained stack characteristics align with prior research, and the vehicle's energy consumption performance is noteworthy. In the paper [15] the author utilized the appropriate electric motor for electric vehicles as a pivotal challenge for manufacturers, as it profoundly impacts overall propulsion system performance. Utilizing Advanced Vehicle Simulator software, it compares the torque characteristics of the induction motor with those of two permanent magnet motors designed for the same purpose. It contributes valuable insights into motor selection for light electric vehicle applications. The author of publications [127] discussed the role of the cell cycle Cyclin E gene (CCNE) in the ovarian development of Exopalaemon carinicauda. Through cloning and expression analysis, the research reveals that CCNE is highly expressed during various stages of ovarian development, peaking in stage III. Knocking down CCNE expression impacts the vitellogenin (VG) gene, indicating a positive correlation between CCNE and VG. The phylogenetic tree suggests a close relationship between E. carinicauda and Penaeus monodon. In situ hybridization highlights abundant CCNE expression in the ova, suggesting its regulatory role in nutrient accumulation and transport in the ovaries.The author of publications [29] expressed the production of low-carbon electrofuels using a reverse water gas shift and Fischer-Tropsch synthesis process, modeling jet, diesel, and naphtha. Leveraging nuclear energy for its consistent supply and low emissions, the process achieves high carbon conversion and energy efficiency. Lifecycle greenhouse gas emissions are estimated using the GREET model, showing promising results with steam coproduct credit. Economic analysis for different nuclear power plant capacities indicates competitive minimum fuel selling prices, offering insights into the viability of large-scale e-fuel production as a sustainable alternative to conventional petroleum fuels.

3.5. Battery and Converter

The author of publications [10] examined the critical role of power electronic circuits (PECs) in modern electric vehicles, focusing on DC-AC inverters and DC-DC converters. It underscores the evolving need for high-power bidirectional DC-DC converters in future electric vehicles, providing an overview of various converter topologies and their applications in battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and fuel cell vehicles (FCVs). This comprehensive review serves as a valuable resource for understanding the state-of-the-art technology in electric vehicle power management. In the publication [62] expressed the potential for synthesizing nanosize carbon materials in substantial quantities over short durations through electric explosions in liquids. Investigations into the law of nano-carbon generation through repeated cycles reveal a fluctuating pattern, approaching zero, indicating a correlation between material mass and hydrocarbon chain atoms, energy input per pulse, and the number of treatment cycles. The findings underscore the viability of the electric explosion method for efficient nanocarbon synthesis at a macroscale. In the paper [68] the author proposed a smart boost converter system for electric bicycles shown in Figure 10.

https://doi.org/10.14669/AM/191492

The system retrofits a front hub motor onto a regular geared bike and uses a microcontroller-based boost converter to manage power between the battery and supercapacitor. The results demonstrate improved uphill acceleration and extended battery life, particularly on hilly terrain, though the challenge of bi-directional regenerative braking is noted.

Fig. 10. Boost converter with control circuit

The author of publications [6] explained a novel capacity fade model for lithium-ion batteries, built upon the single particle model (SP model) originally proposed by Doyle et al. This model effectively captures the mechanisms of active material loss in the cathode and the formation of the solid electrolyte interphase (SEI) in the anode, leading to capacity degradation and increased resistance.The author of publications [33] examined the global supply chain of raw materials for EV batteries, with a focus on the security and supply of lithium for lithium-ion battery production. State-of-the-art matrix analysis (SAM) categorizes literature into key areas, including resources, supply and demand, geopolitics, and recycling. It also presents a lithium supply chain model to assess technical, geopolitical, and economic factors impacting lithium supply across various life cycle stages. It enhances the understanding of EV lithium supply chain issues, aiding engineering managers in decision-making.The author of publications [74] introduced a versatile life cycle tester for batteries, highlighting its capability to assess cycle life with the provision for various battery sizes. The circuit's main limitation lies in the need for a suitable power supply and load for discharging, but this can be addressed for larger batteries. The tester enables faster life cycle testing by adjusting time and current, reducing manual supervision. Compared to existing models, it offers continuous current variation, digital display, electronic timers, and quick fault-finding, enhancing flexibility and efficiency in battery testing and evaluation. In the paper [36] the author explored the use of technology forecasting using data envelope analysis (TFDEA) to predict future EV battery performance. The study compares these forecasts to the performance objectives set by the US Department of Energy (DOE) and concludes that existing battery technology improvements won't meet DOE's range goals. This highlights the need for new battery technology to align with DOE specifications for

https://doi.org/10.14669/AM/191492

longer EV trip ranges. In the paper [63] the author explained an innovative energy management control strategy for HEVs, combining dynamic programming with preview driving cycle information. Addressing the non-causal nature of dynamic programming, the study leverages recent driving cycle prediction algorithms to optimize energy management. The proposed rule-based strategy, incorporating dynamic programming calculations, demonstrates enhanced fuel economy across various standard driving cycles. It contributes to the advancement of efficient and globally optimal energy management solutions for HEVs, integrating predictive driving cycle information for improved performance. The author of publications [67] suggested an innovative approach to developing an "Electric Bicycle System" that transforms traditional bicycles into electric ones, incorporating regenerative braking and BLDC motor control. It emphasizes real-time sensing and crowd-sourcing to enhance the cycling experience and promote urban design. While electric bikes are gaining popularity worldwide, they address challenges related to design, range, recharging, and battery management, providing insights into the potential feasibility and utility of such electric cycles within existing transportation systems. In the paper [93] explained the critical issue of estimating fuel consumption by employing personalized driving cycles derived from real-world GPS-based data. Departing from standardized driving cycles, the study investigates the impact of varied driving styles and vehicle types on fuel economy for conventional vehicles and HEVs. The results reveal substantial variations in fuel consumption, highlighting the influence of driving scenarios. Additionally, the application of the Equivalent Consumption Minimization Strategy (ECMS) for HEVs demonstrates significant fuel consumption reductions in urban driving scenarios. It contributes valuable insights into enhancing the accuracy of fuel economy estimates based on personalized driving behavior and real-world driving conditions. In the paper [102] the author experimented with the importance of a battery management system (BMS) for electric bikes, emphasizing its role in preventing battery degradation. The proposed BMS effectively regulates and monitors battery conditions, ensuring a well-balanced battery system and protection against various issues. Test results demonstrate its ability to maintain accurate voltage, current, and temperature readings with minimal error, making it a valuable component for enhancing electric bike performance. In the paper [77] the author discussed the growing prominence of direct current (DC) systems in the internal power grid of electric vehicles (EVs). Focusing on a pure DC grid circuit with a battery storage system (BSS), the study employs a flyback DC-DC converter for efficient BSS utilization. Evaluating the dynamic and control performances of the combined system, including the BSS, flyback converter, and DC motor, it employs a small-signal-based control method. Simulations using MATLAB validate the effectiveness of the proposed strategy, showcasing promising results in managing voltage and current signal fluctuations in the context of EV-grid circuits. In Figure 11, the intention to use battery swapping is shown. The paper [130] proposed a data drive about swapping the batteries in electric bicycles and provided the regional swapping stations for swapping the batteries. According to the statistics on swapping batteries, 60% of the residents are open to trying battery swapping, 35% are price-sensitive, and 5% are reluctant to swapping batteries.

https://doi.org/10.14669/AM/191492

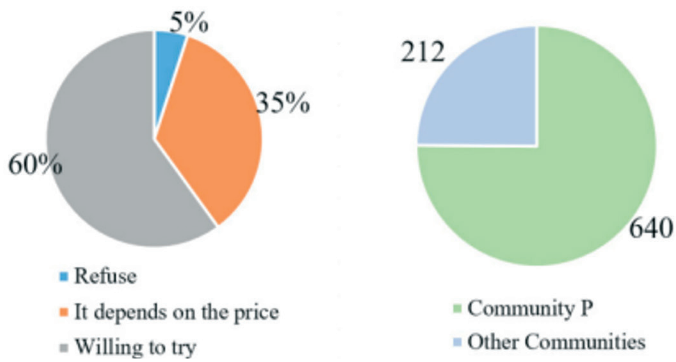

Fig. 11. Potential intention to use battery swapping

The author of publications [70] emphasized the pressing global need to develop technology in the transportation sector, particularly for electric bikes, to address the escalating concerns of fossil fuel overuse, pollution, and global warming. The charging and discharging process of a lithium-ion battery is shown in Figure 12. Analyzing global research trends reveals a significant increase in publications since 2008, with China, India, and the USA emerging as key contributors. Recognizing the environmental consciousness of these countries, it suggests that electric bikes, powered by lithium-ion batteries, present a viable and sustainable solution for transforming the transport industry, offering enhanced performance anda longer life cycle.

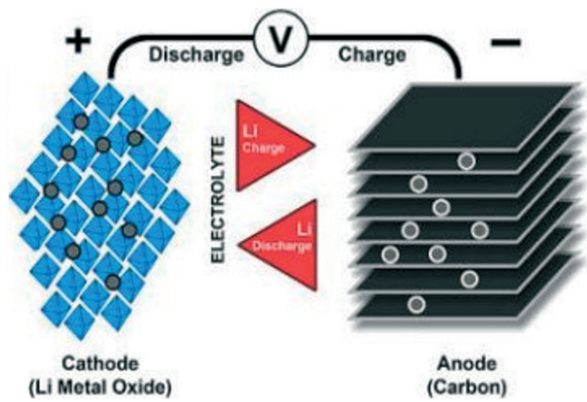

Fig. 12. Charging and discharging process of lithium-ion battery

In the paper [99] the author examined the integration of battery and ultracapacitor technologies in a hybrid energy storage system (HESS) to enhance the EV driving range. It provides a genetic algorithm to optimize EV drivetrain parameters and components. In the paper [128] the

https://doi.org/10.14669/AM/191492

author expressed the benefits of a HESS comprising a battery and supercapacitor for electric vehicles, emphasizing a driving condition-adaptive rule-based energy management strategy (EMS). Through computer simulations and semi-physical rapid control prototype tests, the HESS with EMS proves more effective than a single battery, stabilizing battery status during propulsion and regeneration modes while enhancing energy efficiency. It further incorporates a dynamic degradation model to demonstrate the economic viability of the HESS by prolonging battery lifetime, offering valuable insights for optimized energy storage in electric vehicles. The author of publications [121] utilizing the critical challenge of accurate state of charge (SOC) estimation in lithium-ion batteries for electric vehicles, this paper introduces a robust model based on an independently recurrent neural network (IndRNN). Leveraging experimental datasets from lithium nickel cobalt aluminum oxide cells, the proposed model demonstrates superior performance in capturing non-linear battery behavior compared to conventional techniques. Comparative analyses with gated recurrent unit (GRU) and long short-term memory (LSTM) architectures underscore IndRNN's higher accuracy, showcasing minimal root mean square error and mean absolute error across diverse temperature conditions in electric vehicle drive cycles. In the paper [75] the author introduced the Unified Level Shifted PWM (UniLS-SPWM) for multilevel inverters, addressing issues of low-frequency ripples and drifts in DC-link voltages that impact load voltage harmonics. Leveraging feed-forward terms and a variable frequency scheme, UniLS-SPWM effectively compensates for load current waveform distortions. MATLAB simulations and experimental results highlight the technique's ability to generate a pure sinusoidal load voltage, demonstrating its robust performance in unbalanced and hybrid operational scenarios. It contributes a promising modulation approach for improving loads current Total Harmonic Distortion (THD) in diverse practical applications.

3.6. Charging and Power Management

The author of publications [48] fabricated the dual-chargeable method; the battery gets charged. Using an alternator, the dual-chargeable system works, and the rest of the work is the same as with the other electric bicycles. The result of using a dual-chargeable system shows that a fully charged battery obtained (10–51) km/h. When coming down the hill, the charging can be achieved in 1 hour. In the publication [9] expressed the feasibility of having a magnetic coupler within the kickstand for wireless charging of electric bicycles, the different types of kickstands used for wireless charging, and which stand gives more efficiency in charging an electric bicycle. The study emphasizes the impact of interfering materials on charging efficiency and highlights the importance of achieving high transfer efficiency and safety while meeting weight, cost, and size requirements. The block diagram of the charging system is shown in Figure 13. In the paper [47] the author proposed an improved bridgeless boost Power Factor Correction (PFC) topology for electric vehicle charging systems, emphasizing high power factor and efficiency. Utilizing one-cycle control in the pre-regulator, the proposed approach is analyzed through simulation and experimentation. Results demon-

https://doi.org/10.14669/AM/191492

strate a power factor exceeding 0.99, low total harmonic distortion, improved efficiency, and stabilized output voltage. The simplicity and reliability of the control circuit make it a promising solution for enhancing the performance of electric vehicle charging systems, offering potential advancements in DC/DC circuit design.

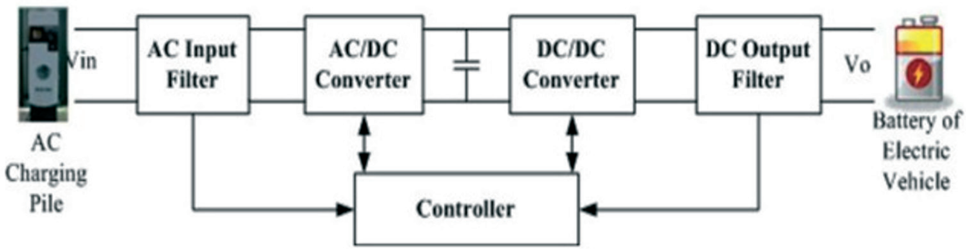

Fig. 13. Block diagram of charging system

In the paper [27] the author introduced a thing called a control algorithm that is used when the rider pedals the pedals. Some form of energy is generated, which is saved into the battery pack and used when the rider loses his energy. The experimental setup is shown in Figure 14. The control algorithm is charge-sustaining. The charge-sustaining system provides the efficiency of urban cycling, and this approach is capable of maintaining the charge and avoiding depletion.

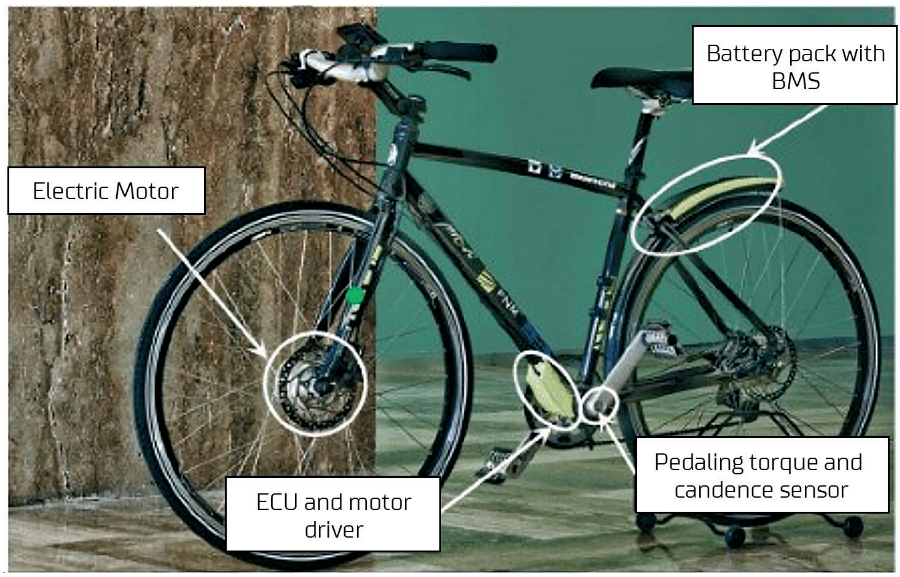

Fig. 14. Experimental setup of charge-sustaining electric bicycle

https://doi.org/10.14669/AM/191492

The author of publications [110] examined the inefficiencies of Combined Cycle Gas Turbine (CCGT) power plants in arid climates, such as the United Arab Emirates, where rising ambient temperatures and supplementary firing contribute to power loss and reduced thermal efficiency. It advocates for solar hybridization, proposing integrated solar combined cycle (ISCC) plants as a promising solution to enhance overall efficiency and mitigate carbon emissions. Utilizing EBSILON Professional for simulation, the research demonstrates that ISCC plants outperform other configurations, highlighting their potential as an intermediate step toward optimizing renewable energy integration in power generation. In the publication [30] proposed a blended strategy that incorporates real-time driving pattern recognition, enabling adaptive control to enhance PHEV performance and maximize the utilization of electrical energy resources. The author of publications [108] suggested an innovative power management strategy for series PHEVs, addressing the critical aspects of battery state of charge and power requirements. This contribution adds valuable insights to the field of PHEV power management, aligning with the growing demand for eco-friendly transportation solutions. In the paper [116] the author explored advancements in electric vehicles (EVs), focusing on the integration of batteries and supercapacitors to enhance power consumption and address electrochemical challenges. The hybrid system approach, treating the battery and supercapacitor as distinct units, offers improved energy cycling and capability. It synthesizes recent research on EV applications, emphasizing the synergy between battery and supercapacitor technologies to optimize performance and address energy demands in electric vehicles. The author of publications [8] experimented with an innovative battery charging system for electric vehicle charging stations, leveraging pulse-voltage and pulse-current techniques. The design refines a non-dissipative pulse-current DC-DC stage, optimizing control for versatile voltage levels. The design, a novel pulse-voltage DC-DC stage, mitigates abrupt power fluctuations associated with the pulse-voltage method. In the paper [61] the author examined a three-port dual-boost DC-DC converter in a HEV with a dual-motor drive system to enhance fuel efficiency and minimize carbon dioxide emissions. The Dual Drive Hybrid Electric Vehicle (DDHEV) integrates a photovoltaic (PV) system/plug-in, a dual drive system, and a power management algorithm to optimize fuel efficiency. Simulation and experimental results in MATLAB/Simulink demonstrate the effectiveness of the proposed PV-DDHEV, showcasing improved stability and reduced power consumption with the dual motor drive system operated by the TPDB. The author of publications [49] understood the critical need to combat fossil fuel overuse, pollution, and global warming through innovative transportation technology. Electric bicycles, powered by lead-acid batteries, offer a sustainable solution with superior performance and longevity. The focus on enhancing battery life and utilizing a dynamo for power recycling presents a holistic approach to greener and more efficient transportation, potentially marking a significant breakthrough in the industry. In the paper [38] the author fabricated a self-charging method used to charge the battery while the cycle is moving. The block diagram of self-charging is shown in Figure 15. Using this method, we get additional power and use it for the cycle to ride. The diagram shows a clear definition of the self-charging method. This electric bicycle is more efficient to run for longer rides than a conventional electric bicycle.

https://doi.org/10.14669/AM/191492

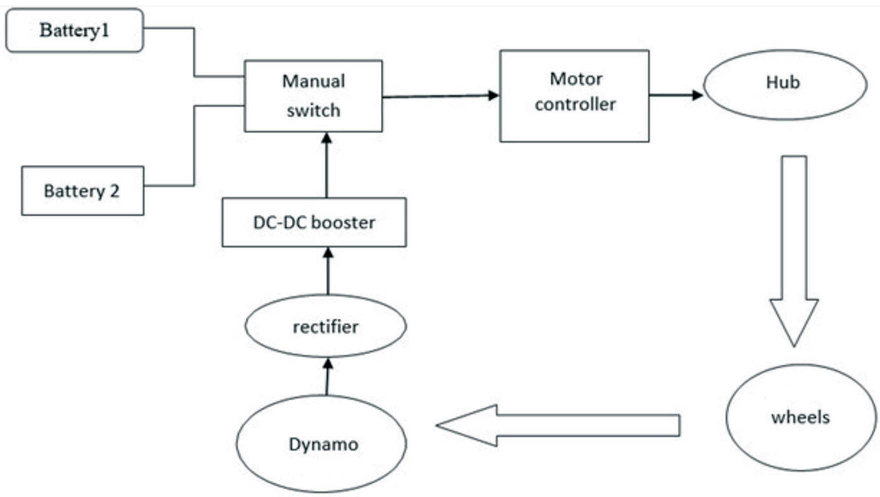

Fig. 15. Block diagram of self-charging

In the paper [2] the author presents a comprehensive examination of electric vehicle charging stations' architectures within microgrids, exploring key criteria, power converter technologies, and control strategies. By dissecting these elements, it sheds light on the intricate ecosystem of EV charging infrastructure within microgrid networks, essential for sustainable energy management. The author of publications [51] explores the development and implementation of a smart electric vehicle charging station tailored for residential complexes. It investigates the integration of advanced technologies to optimize charging efficiency, user convenience, and grid interaction, addressing the specific needs and challenges of residential settings. By examining the design, functionality, and benefits of such systems, it aims to facilitate the adoption of electric vehicles in residential communities.

3.7. Commutation of E-Bicycle

In the paper [94] the author explained different electric vehicles, such as electric cars, motorcycles, and bicycles, used for commutes and transportation that are dominated by China. The health consequences are an important concern among e-bike riders. In Canada, the 2000 projects were examined. 83% of people felt safer on an e-bike than on a conventional bicycle. The author of publications [101] delves into Edward Thomas's "In Pursuit of Spring (1914)" as a bicycle travelogue, positioning it as a precursor to the modern sociological perspective. Emphasizing the significance of bicycle mobility in shaping the sociological gaze, it contrasts it with urban flanerie and pedestrian travel. Thomas's exploration of Southern England reflects a contemporary take on modernity, drawing parallels to earlier journeys while utilizing the unique human-powered mobility of the bicycle for introspec-

https://doi.org/10.14669/AM/191492

tion and addressing existential questions, echoing influences on later writers like Robert Frost, Samuel Beckett, and Flann O'Brien. In the publication [81] expressed that electric bicycle sales soared from 30 000 to 30 million in China. In Holland, sales grew up to 30% in 2015. Pedelec-type electric bicycles are a broader category. Using the pedal type gives a good physical and health benefit to the rider. In the paper [120] the author discussed how electric bicycles are performed in Belgium with older adults (>65 years). Here we get the conclusion from older adults in an interview process. The older adults give their experience with electric bicycles and the benefits of the electric cycle; older women are scared of riding injuries, and older men feel safer on electric bicycles. In the paper [97] the author utilized the urban freight delivery challenges by comparing cost trade-offs between Electric Assist (EA) cargo bicycles and traditional box delivery trucks. The box-type cargo bicycle is shown in Figure 16. Through data collection and a literature review, it models delivery routes in Seattle, considering variables such as distance, stops, and parcel volumes. The findings highlight conditions favoring EA cargo bikes, demonstrating their cost-effectiveness for short distances, high residential density, and low delivery volumes per stop, providing valuable insights for sustainable urban logistics solutions.

Fig. 16. Box type cargo bicycle

The author of publications [73] examined the unique travel dynamics of electric-assist bicycles (e-bikes) compared to conventional bicycles, focusing on speed and road-grade dynamics. Analyzing data from 1451 utilitarian bicycle trips in Vancouver, the research reveals that, beyond higher average speeds, e-bike trips exhibit significantly greater speed dynamics. This nuanced understanding of microscopic cycling behavior has implications

https://doi.org/10.14669/AM/191492

for vehicle and facility design, as well as health evaluations, highlighting the distinctive features of e-bike travel dynamics. In the paper [92] the author explained the rise of e-cycles in European countries and the prediction of how many electric cycles will tend to be sold in the years 2018 to 2030. In 2006, electric cycles represented only 1% of Switzerland. But in 2019, it had increased to 36%. The Netherlands is the country that has the highest model share of cycling. In the paper [28] the author examined the crucial aspect of e-bike adoption by examining the influence of weather conditions on daily commuting choices in an e-cycling incentive program in the Netherlands. Reveals how weather conditions affect the use of e-bikes. This research highlights the significance of weather-related challenges in promoting e-bikes for daily commuting, particularly for individuals with limited alternative transportation options during inclement weather. The author of publications [113] discussed the cargo-type electric cycles used in the United States and California. These types of cycles play a vital role among parents and caretakers. Parents used electric cargo bikes over cars to commute their children to school. These types of electric cargo cycles can easily commute on hills. In the paper [86] the author experimented in Curitiba, Brazil, sheds light on the challenges faced by urban managers in reconciling micro-mobility and urban tourism within cycle-inclusive policies. These include the underutilization of cycling infrastructure, heightened traffic risks for cyclists, and a predominant focus on technical bicycle projects over safety measures. The author of publications [129] discussed the impact of factors on the stressful work pressure and crash involvement of delivery e-bike riders in China. Utilizing a bivariate ordered probit (BOP) model, it explores the simultaneous influence of working conditions and crash incidents. Results reveal associations with variables such as the number of orders, delivery time, rider age, risky riding behaviors, punishment severity for traffic violations, and familiarity with traffic regulations. It establishes a positive correlation between stressful working conditions and crash involvement, contributing valuable insights to enhance safety and working conditions in the delivery industry. The author of publications [18] Limited research exists on developing driving cycles for e-rickshaws, particularly in rural and urban settings combined. This study addresses this gap by collecting real-world driving data for 100 trips using a high-end GPS data logger. Two methodologies, random selection and k-means clustering, are compared for creating an e-rickshaw driving cycle (ERDC). The findings highlight the superiority of k-means clustering in systematically representing traffic conditions and offer valuable insights for modeling e-rickshaw performance in terms of energy consumption and driving characteristics, crucial for comparisons with conventional fossil-fuel vehicles. In the paper [52] the "E-Cargo Bike: Accompanying Research" project complements the SERVUS initiative by scientifically analyzing the requirements for a new urban cargo bicycle with electric drive, as shown in Figure 17. Through agile development and production processes, prototypes are created, allowing evaluation by users at events like IAA 2021. It extends to tracking experiments with various sensor setups, offering insights into electric cargo bike capabilities and their interactions with Munich's transportation infrastructure, including considerations of trajectory shapes, travel times, and the impact of bicycle infrastructure on mixed traffic modes.

https://doi.org/10.14669/AM/191492

Fig. 17. Cargo bicycle

In the paper [82] explored the usage of electric bicycles in urban areas as a bigger deal than in rural areas. Most people in rural areas like to use the electric cycle for their daily commutes to eliminate the daily traffic. Most of the Netherlands' conventional bicycle riders are three times more open or willing to use an electric cycle. In the paper [91] examined the electric cycle-sharing systems that have spurred the need for comprehensive analyses of their environmental impact. It focused on Lisbon, Portugal, and conducted a life cycle analysis to evaluate the ecological footprint of shared e-scooters. Production accounts for over 70% of environmental impacts, while vehicle use contributes 17%. The author of publications [46] employed the lifecycle assessment (LCA) methodology to evaluate various scenarios for waste printed circuit board (PCB) disposal, a critical component of global electronic waste (e-waste). Examining the environmental impacts of recycling overseas versus in Australia, it identifies Scenario 2 (integrated material and energy recovery) as the optimal approach for waste PCB recycling locally. It underscores the potential environmental gains, reduced impact categories, and positive outcomes in human toxicity when choosing local recycling over overseas options, providing valuable insights for future policies, investment decisions, and resource recovery supply chain optimization.The author of publications [57] explored the environmental impact of the FITGEN e-axle, a novel functionally integrated electric vehicle powertrain developed under the European H2020 FITGEN project. Employing Life Cycle Assessment (LCA) methodology, the study compares the FITGEN e-axle to the 2018 State-of-the-Art (SotA) e-drive, as well as traditional diesel and petrol powertrains. The findings reveal a 10% reduction in climate impacts and improved energy efficiency for the FITGEN powertrain, contributing valuable insights to efforts to mitigate emissions and advance sustainable powertrain technologies for electric vehicles. In the paper [39] expresses the growing adoption of micromobility solutions globally and emphasizes the need for improved design to tackle issues of reliability and total cost of ownership (TCO). Combining literature synthesis

https://doi.org/10.14669/AM/191492

with a detailed case study of a shared e-bike provider, the research presents a systematic Design for Reliability (DIR) linked to the TCO approach. The findings offer valuable insights for the electric micromobility sector, suggesting avenues for longitudinal studies, multiple case analyses, and prescriptive assessments of the proposed design methodology.

3.8. Health Benefits and Physical Activity

The author of publications [11] explained the comparison of an electric bicycle and a conventional bicycle. Compared the two bicycles in two different ways and also monitor the rider's health. The flat route has a longer distance, whereas the hilly route has a shorter distance but is sloped. Comparatively, the electric bicycle reduces the lower commute, easily climbs on the hill, and offers more exercise intensity than the conventional bicycle. In the paper [105] discussed the public health implications of e-bike use in Norway, addressing concerns about potential substitution effects that could offset the benefits of increased cycling. Combining a cross-sectional and quasi-experimental design, it explores hedonistic values associated with e-bike interest and assesses changes in physical activity pre- and post-purchase. The findings suggest that, contrary to concerns, the introduction of e-bikes in the Norwegian cycling population does not lead to a substantial substitution effect. Instead, the net effect appears positive, particularly among individuals with lower pre-existing levels of physical activity. The author of publications [12] expressed that e-cycling leads to a reduction in activity volume and intensity over the same distance compared to conventional cycling and also provides high intensity to promote positive health outcomes. The author of publications [126] examined the impact of Pedestrian Countdown Signal Devices (PCSDs) on electric bicycle riders' behavior at signalized intersections, focusing on red light violations (RLVs) and early start actions. It employs descriptive analyses and binary logic models to assess various factors influencing these behaviors. The results demonstrate the effectiveness of PCSDs in reducing RLVs while also highlighting an increase in early start maneuvers. It underscores the importance of potential countermeasures, such as redesigning PCSDs, to enhance safety for electric bicycle riders at intersections, offering valuable insights for urban planners and policymakers. The author of publications [20] introduced that there is another type of electric bicycle there, i.e., the Electric Mountain bike. This isn't as famous or popular as the other two types of electric bicycles. Still, this type has been well known in Europe for many years, but it's still emerging in Europe. In the paper [122] examined the injury mechanism of electric cyclists in collisions with right-turning trucks, employing Pc-Crash for injury assessment. Through dynamic response simulations, it identifies two distinct processes: initial impact with the truck, followed by the electric bicycle and cyclist being thrown and crushed. The study builds a multi-rigid-body truck model to calculate the crushed part, which is crucial for assessing injury severity. Analyzing various damage indices, it emphasizes the correlation between cyclist crushing and fatal injuries, underscoring the importance of reducing the likelihood of such events to enhance the safety of electric cyclists.

https://doi.org/10.14669/AM/191492

3.9. Integration of DC Motor

In the paper [17] expressed that the motor should be small in size and also provide more efficiency. The cross-sectional view of an axial-field permanent-magnet DC motor is shown in Figure 18. The battery and motor should not occupy more space. The function of the motor is to eliminate mechanical commutators and moving parts.

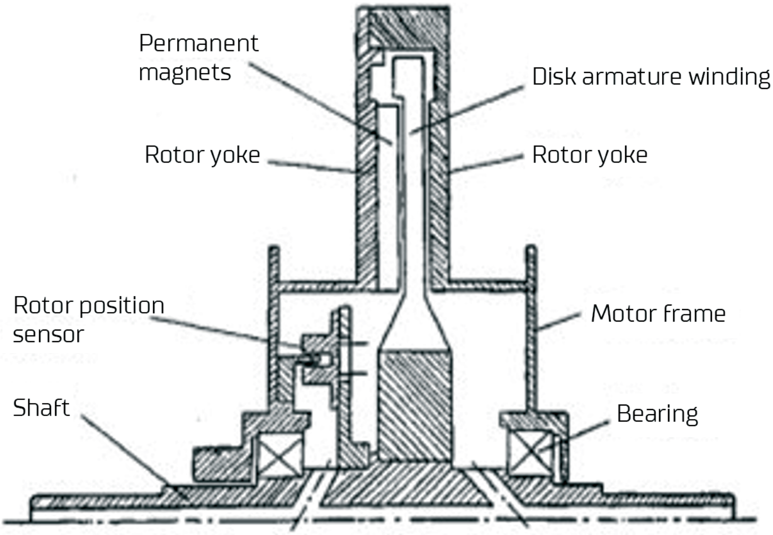

Fig. 18. Cross-sectional view of axial-field permanent-magnet BLDC motor

The author of publications [118] proposed the design and optimization of a brushless DC (BLDC) motor for electric bicycle applications, adhering to the EN15194 European Standard and market constraints. Investigating slot/pole ratios and winding configurations employs analytical solvers and finite element method (FEM) analyses. Evaluation criteria include torque production, weight, efficiency, and ease of manufacture. The resulting prototype motor, aligned with a standard bicycle, undergoes an experimental study to validate the design's effectiveness, contributing to the advancement of electric bicycle motor technology. In the paper [115] expressed the crucial role of transmission control in enhancing the performance of electric vehicles, emphasizing the necessity for precise gear-shifting control. Introducing a dedicated Transmission Control Unit (TCU), the paper details its functional modules, including signal processing and motor control circuits. Through hardware-in-the-loop simulation tests and a rigorous 150,000 km road test, the TCU design demonstrates its effectiveness in achieving accurate measurement, coordinated actuator actions, and swift, reliable gear shifts, contributing to the overall efficiency of electric vehicle systems. In the paper [83] examined the VDI Guideline 2206 and the V-model to design an electric hybridization kit for manual transmission motorcycles. Through multidisciplinary input, it proposes a three-mode

https://doi.org/10.14669/AM/191492

control system for enhanced fuel efficiency and reduced emissions, demonstrating feasibility through a functional model on a motorcycle and showcasing a substantial decrease in internal combustion engine use, thus offering a promising solution to environmental concerns in the motorcycle segment. In the paper [34] proposed that most of the e-cycles are re-manufacturing by using the ease of disassembly method. The AEG motor disassembly result is shown in Figure 19. Used products are restored to their original position by five things. Reassembly or re-manufacturing is used to control the waste. The work concluded that the electric bicycles examined can be disassembled without significant damage if all the necessary tools are available.

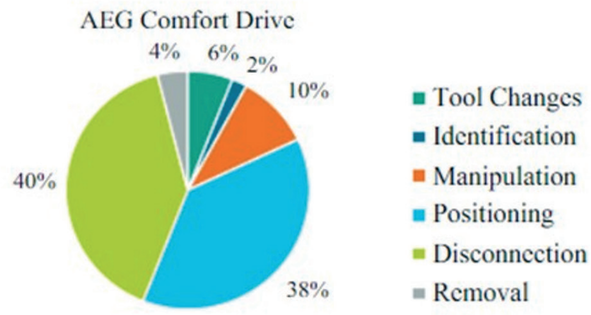

Fig. 19. Results of the disassembly of the electric bicycle motor

In the paper [85] delves into the conceptual design and material analysis of a BLDC motor tailored for electric vehicle applications. It employs Finite Element Analysis (FEA) tools to scrutinize performance, efficiency, and durability, crucial for advancing EV propulsion technology.

4. Gap Analysis and Suggestions

The concentration on two stabilization strategies may limit the exploration of additional methods beneficial for enhancing tracking and posture stability in electric bicycles. Discrepancies between stepper motor and magnetic sensor measurements compared to those of the engine and GPS cycle engine suggest potential issues with component calibration or accuracy. Considering the high cost and susceptibility to damage of torque sensor technology directly attached to the pedal, an alternative approach involving sensor-less control techniques based on a disturbance observer is discussed. The provided information lacks technical details on specially designed drives and operating cycles, omitting factors influencing efficiency and how various electric bicycle types are handled. While cost savings are highlighted, a comprehensive economic analysis accounting for upfront expenses, ongoing costs, and long-term savings is absent. Essential details regarding the solar bicycle's economic

https://doi.org/10.14669/AM/191492

feasibility and affordability are crucial. The document falls short in providing comprehensive performance metrics, focusing only on charging times and maximum speed without addressing total energy consumption, braking effectiveness, and acceleration. Despite mentioning the average electrical output of the dynamo during a 30-minute ride, crucial metrics like energy conversion efficiency, charging time, and the impact on the electric bicycle's overall range are missing. The practicality of the Dynamo system in real-world situations and its potential effects on user experience are not explored.

Go beyond trajectory control and lateral velocity in the research to investigate a wider range of stabilization strategies. Carry out extensive trials in various real-world settings to evaluate how the selected strategies function in various circumstances, such as varied terrain, speeds, and environmental elements. Make sure that all of the parts are calibrated, paying particular attention to the stepper motor, magnetic sensor, engine, and GPS cycle engine. To ensure precise measurements, make sure they are calibrated consistently. In addition, it is required to look into more affordable options for torque sensors that are as reliable as conventional ones. It should also look into strong, long-lasting designs that reduce damage risk and guarantee affordability and longevity for broader use. Give more thorough technical information about the drives' unique design, effectiveness, and ability to accommodate different kinds of electric bicycles. Perform a thorough comparative study of the electric bicycle drive systems currently in use, methodically assessing each system's technical features, effectiveness, and performance under various operating conditions. Compare the environmental impact of conventional vehicles and the solar bicycle in a thorough assessment. To prove the financial advantages, do a comprehensive economic analysis that takes into account the whole cost of ownership, which includes the initial investment, ongoing maintenance expenses, and possible long-term savings. Conduct and present a thorough performance analysis that includes acceleration tests, braking effectiveness, and total energy consumption. Add a section outlining the dual-chargeable electric bicycle's effects on the environment, taking into account things like sustainability, recyclability, and life cycle assessment. Provide a more thorough performance analysis that addresses the energy conversion efficiency, the length of time needed to charge the bike under various circumstances, and the effect on the bike's overall range. Give a thorough technical explanation of the dynamo system, covering its parameters, efficiency measures, and the principles of power generation and transfer. Make a detailed comparison with other technologies or current models of self-charging electric bicycles.

5. Conclusion

The literature review highlights the many benefits and potentially revolutionary effects of electric bicycles. A thorough understanding of how electric bicycles should be made has been made possible by the design and construction of these vehicles. A viable option that provides an environmentally responsible and sustainable means of powering these bikes

https://doi.org/10.14669/AM/191492

is the incorporation of solar technology into electric bicycles. This invention contributes to reducing dependency on traditional energy sources while simultaneously addressing environmental issues. The integration of advanced technologies, such as accident detection sensors, GPS cycles, posture and straight-line tracking, and pedal torque sensors, has significantly improved the overall performance and range of electric bicycles. It underscores the pivotal role of commutation systems in enhancing the efficiency and performance of electric bicycles, ultimately contributing to the broader goals of sustainable transportation. The evolution from traditional brushed motors to more sophisticated brushless counterparts reflects a concerted effort to mitigate energy losses, reduce maintenance requirements, and enhance overall system reliability. Furthermore, the health benefits associated with electric bicycles, including increased physical activity, improved physical health, and reduced emissions, emphasize the broader positive impact that these vehicles can have on individuals and communities alike. As concerns about environmental sustainability and personal well-being continue to grow, electric bicycles stand out as a promising solution that aligns with both environmental and health-conscious goals.

6. Nomenclature

BEV – Battery Electric Vehicles
BLDC – Brushless DC Motor
CCGT – Combined Cycle Gas Turbine
DDHEV – Dual Drive Hybrid Electric Vehicle
DIR – Design for Reliability
EB – Electric Bicycle
ECMS – Equivalent Consumption Minimization Strategy
ERDC – E-Rickshaw Driving Cycle
EV – Electric Vehicles
FCV – Fuel Cell Vehicle
FEA – Finite Element Analysis
FEM – Finite Element Method
GHG – Greenhouse Gas
GPS – Graphic Positioning System
GRU – Gated Recurrent Unit
HESS – Hybrid Energy Storage System
HEV – Hybrid Electric Vehicles
IndRNN– Independently Recurrent Neural Network
ISCC – Integrated Solar Combined Cycle
LCA – Lifecycle Assessment
NEDC – New European Driving Cycle
PCB – Printed Circuit Board
PCSD – Pedestrian Countdown Signal Devices

https://doi.org/10.14669/AM/191492

PEMFC – Polymer Electrolyte Membrane Fuel Cell

PFC – Power Factor Correction

PHEV – Plug-in Hybrid Electric Vehicles

QoR – Quality-of-Riding

RLAPM – Reinforcement-Learning-Based Assisted Power Management

RLV – Red Light Violations

SAM – State-of-the-Art Matrix Analysis

SEI – Solid Electrolyte Interphase

SOC – State of Charge

TCU – Transmission Control Unit

TFDEA – Technology Forecasting Using Data Envelopment Analysis

TOC – Total Cost of Ownership

UF – Utility Factor

7. Reference

[1] Abagnale C, Cardone M, Iodice P, Strano S, Terzo M, Vorraro G. Model-based control for an innovative power-assisted bicycle. Energy Procedia. 2015;81:606–617. https://doi.org/10.1016/j.egypro.2015.12.045.

[2] Abraham DS, Verma R, Kanagaraj L, Raman SRGT, Rajamanickam N, Chokkalingam B, Sekar KM, Mihet-Popa L. Electric vehicles charging stations' architectures, criteria, power converters, and control strategies in microgrids. Electronics. 2021;10(16):1895. https://doi.org/10.3390/electronics10161895.

[3] Agarwala N, Kumarb A, Varun. Sizing analysis and cost optimization of hybrid solar-diesel-battery based electric power generation system using simulated annealing technique. Distributed Generation & Alternative Energy Journal. 2012;27(3):26–51. https://doi.org/10.1080/21563306.2012.10531122.

[4] Arnob FF, Khan S, Bhuiyan HK. Design, Fabrication and Analysis of Chassis for Electric Bike. International Journal of Innovative Research in Science, Engineering and Technology. 2022;3(4):25– 31. https://doi.org/10.35248/ ijirset.22.3(4).25-31.

[5] Ashok G, Chandrika K, Revanth P, Yoganandha CH, Vandana D. Design and Implementation of Electric Assisted Bicycle with Attached Dynamo. International Journal of Multidisciplinary Research. 2020;6(11):309–315. https://doi.org/10.36713/epra2013.

[6] Baek KW, Hong ES, Cha SW. Capacity fade modeling of a Lithium-ion battery for electric vehicles. International Journal of Automotive Technology. 2015;16(2):309–315. https://doi.org/10.1007/s12239-015-0033-2.

[7] Bansal R, Sharma A, Ali M, Shrivastav P, Yadav V, Mandloi S, Dhanotia R. Design and fabrication of electric bicycle. Advances and Applications in Mathematical Science. 2020;20(1):25–36.

[8] Bayati M, Abedi M, Gharehpetian GB, Farahmandrad M. Two designs for DC–DC stage of electric vehicle charging stations. Electrical Engineering. 2020;102(4):2389–2399. https://doi.org/10.1007/s00202-020-01017-3.

[9] Beh HZZ, Covic GA, Boys JT. Investigation of magnetic couplers in bicycle kickstands for wireless charging for electric bicycles. IEEE Journal of emerging and selected topics in power electronics. 2015;3(1):87–100. https://doi.org/10.1109/JESTPE.2014.2325866.

[10] Bellur DM, Kazimierczuk MK. DC-DC converters for electric vehicle applications. Electrical Insulation Conference and Electrical Manufacturing Expo. 2007;286–293. https://doi.org/10.1109/EEIC.2007.4562633.

https://doi.org/10.14669/AM/191492

[11] Berntsen S, Malnes L, Langaker A, Bere E. Physical activity when riding an electric assisted bicycle. International journal of behavioral nutrition and physical activity. 2017;14(1):1–7. https://doi.org/10.1186/s12966-017-0513-z.

[12] Bourne JE, Sauchelli S, Perry R, Page A, Leary S, England C, Cooper AR. Health benefits of electrically-assisted cycling: a systematic review. International journal of behavioral nutrition and physical activity. 2018;15(116):1–15. https://doi.org/10.1186/s12966-018-0751-8.

[13] Bucher D, Buffat R, Froemelt A, Raubal M. Energy and greenhouse gas emission reduction potentials resulting from different commuter electric bicycle adoption scenarios in Switzerland. Renewable and Sustainable Energy Reviews. 2019;114:109298. https://doi.org/10.1016/j.rser.2019.109298.

[14] Cahyono SI, Anwar M, Diharjo K, Triyono T, Hapid A, Kaleg S. Finite element analysis of electric bicycle frame geometries. AIP Conference Proceedings. 2017;1788(1):030084. https://doi.org/10.1063/1.4968337.

[15] Camargos PH, Caetano RE. A performance study of a high-torque induction motor designed for light electric vehicles applications. Electrical Engineering. 2022;104(2):797–805. https://doi.org/10.1007/s00202-021-01331-4.

[16] Cardoso LAL, Martinez MC, Melendex AAN, Afonso JL. Dynamic Inductive Power Transfer Lane Design for E-Bikes. IEEE 19th International Conference on Intelligent Transportation Systems. 2016;2307–2312. https://doi.org/10.1109/ITSC.2016.7795928.

[17] Chan TF, Yan LT, Fang SY. In-wheel permanent-magnet brushless dc motor drive for an electric bicycle. IEEE Transactions on energy conversion. 2002;17(2):229–233. https://doi.org/10.1109/TEC.2002.1009473.

[18] Chandrashekar C, Agrawal P, Chatterjee P, Pawar DS. Development of E-rickshaw driving cycle (ERDC) based on micro-trip segments using random selection and K-means clustering techniques. International Association of safety Sciences research. 2021;45(4):551–560. https://doi.org/10.1016/j.iatssr.2021.07.001.

[19] Chandrawanshi R, Kumar RR, Alam R, Chandra A, Kumar A. Design and fabrication of an Electric Bicycle with Auto Recharging Mechanism. International Journal of Creative Research Thoughts. 2023;11(3):750–753.

[20] Chaney RA, Hall PC, Crowder AR, Crookston BT, West JH. Mountain biker attitudes and perceptions of eMTBs (electric-mountain bikes). Sport Sciences for Health. 2019;15(3):577–583. https://doi.org/10.1007/s11332-019-00555-z.

[21] Chaoming HSU, Liu CT, Chan DY. A reinforcement-learning-based assisted power management with QoR provisioning for human–electric hybrid bicycle. IEEE transactions on industrial electronics. 2012;59(8):3350–3359. https://doi.org/10.1109/TIE.2011.2141092.

[22] Chen Y, Zhou J, Dai WP, Hu E. Application of improved bridgeless power factor correction based on one-cycle control in electric vehicle charging system. Electric Power Components and Systems. 2014;42(2):112–123. https://doi.org/10.1080/15325008.2013.846440.

[23] Cheon DS, Nam KH. Pedaling torque sensor-less power assist control of an electric bike via model-based impedance control. International journal of automotive Technology. 2017;18(2):327–333. https://doi.org/10.1007/s12239-017-0033-5.

[24] Choi Y, Kim YE, Moon HS, Son YW. Model Based Design and Real-Time Simulation of the Electric Bike using RT-LAB and Simulink. SAE Technical Paper Series. 2013;1–8. https://doi.org/10.4271/2013-01-0110.

[25] Chouhary MB, Talpur S, Zafar T, Hussain M, Raza A, Zuberi HH. Solar Powered Electric Bike. European International Journal of Science and Technology. 2016;5(1):77–82.

[26] Cong J. Design of Electric Bicycle Controller. Computer and Information Science. 2009;2(2):126–130. https://doi.org/10.5539/cis.v2n2p126.

[27] Corno M Berretta D., Spagnol P, Savaresi SM. Design, control, and validation of a charge-sustaining parallel hybrid bicycle. IEEE Transactions on Control Systems Technology. 2016;24(3):817–829. https://doi.org/10.1109/TCST.2015.2473821.

[28] De Kruijf J, Van Der Waerden P, Feng T, Bocker L, Van Lierop D, Ettema D, Dijst M. Integrated weather effects on e-cycling in daily commuting: A longitudinal evaluation of weather effects on e-cycling in the Netherlands. Transportation research part A: policy and practice. 2021;148:305–315. https://doi.org/10.1016/j.tra.2021.04.003.

[29] Delgado HE, Cappello V, Zang G, Sun P, Ng C, Vyawahare P, et al. Techno-economic analysis and life cycle analysis of e-fuel production using nuclear energy. Journal of CO2 Utilisation. 2023;72:102481. https://doi.org/10.1016/j.jcou.2023.102481.

[30] Denis N, Dubois MR, Dube R, Desrochers A. Blended power management strategy using pattern recognition for a plug-in hybrid electric vehicle. International Journal of Intelligent Transportation Systems Research. 2016;14(2):101–114. https://doi.org/10.1007/s13177-014-0106-z.

[31] Divyapriya S, Amedha A, Vijayakumar R. Design of Solar Smart Street Light Powered Plug-in Electric Vehicle Charging Station by Using Internet of Things. The Institution of Engineers (India): Series B. 2021;102(3):477–486. https://doi.org/10.1007/s40031-021-00548-y.

[32] Dorugade P, Jadhav P, Kolhe P, Mane H, Sangle U, Pardeshi K. Design & Analysis of foldable E-Bicycle. International Research Journal of Engineering and Technology. 2022;9(6):2928–2933.

[33] Egbue O, Long S. Critical issues in the supply chain of lithium for electric vehicle batteries. Engineering Management Journal. 2012;24(3):52–62. https://doi.org/10.1080/10429247.2012.11431947.

[34] Erdmann JG, Koller J, Brimaire J, Dopper F. Assessment of the disassemblability of electric bicycle motors for remanufacturing. Journal of Remanufacturing. 2023;13(2):137–159. https://doi.org/10.1007/s13243-023-00124-1.

[35] Frizziero L, Freddi M, Bucchi G, Coltelli L, Leon-Cardenas C. Electric Bike Product Conception and Styling According to Design Trends. Designs. 2022;6(3):42. https://doi.org/10.3390/designs6030042.

[36] Gibson E, Van Blommestein K, Kim J, Daim T, Garces E. Forecasting the electric transformation in transportation: the role of battery technology performance. Technology Analysis & Strategic Management. 2017;29(10):1103–1120. https://doi.org/10.1080/02564602.1994.11437486.

[37] Hadi KA, Kuncheria JT. Simulation study of FPGA based energy efficient BLDC hub motor driven fuzzy controlled foldable e-bike. International Journal for Scientific Research & Development. 2015;3(7):554–558.

[38] Harikiran CH, Rithvik R, Deekshitha M. Fabrication of self-charging. Technix International Journal for Engineering Research - International research journal. 2023;10(6):382–390.

[39] Heimes HH, Kampker A, Kehrer M, Gerz J, Marzolla R, Zancul E. Design for Reliability and Total Cost of Ownership: the case of electric micromobility. Procedia CIRP. 2023;119:302–308. https://doi.org/10.1016/j.procir.2023.02.137.

[40] Hema Latha K. Design and Development of Solar Powered Vehicle. International Journal of Engineering Research & Technology. 2019;8(8):608–615. https://doi.org/10.17577/IJERTV8IS080267.

[41] Hung NB, Lim O. A simulation and experimental study of dynamic performance and electric consumption of an electric bicycle. Energy Procedia. 2019;158:2865–2871. https://doi.org/10.1016/j.egypro.2019.01.937.

[42] Hung NB, Sung J, Kim K, Lim O. A simulation and experimental study of operating characteristics of an electric bicycle. Energy Procedia. 2017;105:2512–2517. https://doi.org/10.1016/j.egypro.2017.03.723.

[43] Hung NB, Sung J, Lim O. A simulation and experimental study of operating performance of an electric bicycle integrated with a semi-automatic transmission. Applied Energy. 2018;221:319–333. https://doi.org/10.1016/j.apenergy.2018.03.195.

[44] Inchara GV, Mamatha Rani CN, Zamani R, Sheila H. Conversion of traditional bicycle to electric bicycle.International Journal of Creative Research Thoughts. 2022;10(6):252–256.

[45] Isikli F, Surmen A, Gelen A. Modelling and performance analysis of an electric vehicle powered by a PEM fuel cell on New European Driving Cycle (NEDC). Arabian Journal for Science and Engineering. 2021;46(8):7597–7609. https://doi.org/10.1007/s13369-021-05469-y.

[46] Islam MDT, Iyer-Raniga U. Life cycle assessment of e-waste management system in Australia: Case of waste printed circuit board (PCB). Journal of Cleaner Production. 2023;418:138082. https://doi.org/10.1016/j.jclepro.2023.138082.

[47] Islam S, Hossain RI, Amin SS, Ferdous AKM, Azad AAM. Implementation of Torque Sensor Technology in Electric Bicycle with Solar Charging Kit. IEEE Region 10 Symposium. 2020;718–721. https://doi.org/10.1109/TENSYMP50017.2020.9230825.

[48] Jadoun RS, Choudhary SK. Design and fabrication of dual chargeable bicycle. Innovative systems design and engineering. 2014;5(8):30–40.

[49] Jagannati VM, Abilash C, Reddy SY, Dinesh L, Prasad PD, Hemasai R. Self-chargeable e-bicycle using dynamo. International Research Journal of Modernization in Engineering Technology and Science. 2023;5(4):1286–1289.

[50] Ji F, Xu L, Wu Z. Effect of driving cycles on energy efficiency of electric vehicles. Science in China Series E: Technological Sciences. 2009;52(11):3168–3172. https://doi.org/10.1007/s11431-009-0265-3.

[51] Kannapiran E, Joshi K, Chougale RK, Rana N, Neeraja B, Kaur C. Smart Electric vehicle charging Station for Residential Complex. Proceedings of the 2022 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems, ICSES. 2022;183502. https://doi.org/10.1109/ICSES55317.2022.9914182.

[52] Keler A, Kessler L, Fehn F, Bogenberger K. Movement Patterns of Electric Cargo Bike Commuters–First Insights from Field Experiments and Trajectory Analyses. Proceedings of the ICA. 2021;4:1–4. https://doi.org/10.5194/ica-proc-4-58-2021.

[53] Kerdsup B, Fuengwarodsakul NH. Performance and cost comparison of reluctance motors used for electric bicycles. Electrical Engineering. 2017;99(2):475–486. https://doi.org/10.1007/s00202-016-0373-6.

[54] Keseev VP. Electric bicycle design experience and riding costs. 2020 7th International Conference on Energy Efficiency and Agricultural Engineering. 2020;1–4. https://doi.org/10.1109/EEAE49144.2020.9279070.

[55] Kieninger D, Hemsen J, Koller S, Uerlich R. Automated design and optimization of transmissions for electric vehicles. MTZ worldwide. 2019;80(11):88–93. https://doi.org/10.1007/s38313-019-0126-9.

[56] Kim DM, Jung YH, Cha KS, Lim MS. Design of Traction Motor for Mitigating Energy Consumption of Light Electric Vehicle Considering Material Properties and Drive Cycles. International Journal of Automotive Technology. 2020;21(6):1391–1399. https://doi.org/10.1007/s12239-020-0131-7.

[57] Koroma MS, Costa D, Puricelli S, Messagie M. Life Cycle Assessment of a novel functionally integrated e-axle compared with powertrains for electric and conventional passenger cars. Science of the Total Environment. 2023;904:166860. https://doi.org/10.1016/j.scitotenv.2023.166860.

[58] Kumar DR, Prasad PG, Santhosh S, Raja CV. Solar powered electric bicycle. International research journal of engineering and technology. 2019;6(3):4422–4424.

[59] Kumar R. Solar bicycle project. Journal of student research. 2022;11(3). https://doi.org/10.47611/jsrhs.v11i3.2758.

[60] Kumar VV, Karthik A, Roshan A, Kumar AJ. Design and Implementation of Electric Assisted Bicycle with Self Recharging Mechanism. Proceedings of International Conference on Innovations & Advances in Science. Engineering and Technology. 2014;3(5):485–492.

[61] Kumaresan J, Govindaraju C. Development of a Power Management Algorithm for PV/Battery Powered Plug-In Dual Drive Hybrid Electric Vehicle (DDHEV). Electric Power Components and Systems. 2020;48(1-2):70–85. https://doi.org/10.1080/15325008.2020.1736212.

[62] Kuskova NI, Boguslavskii LZ, Smal'ko AA, Zubenko AA. Obtaining nanocarbon using the electric-discharge treatment method of organic liquids. Surface Engineering and Applied Electrochemistry. 2007;43(4):269–275. https://doi.org/10.3103/S1068375507040072.

[63] Lee H, Jeong J, Park YI, Cha SW. Energy management strategy of hybrid electric vehicle using battery state of charge trajectory information. International Journal of Precision Engineering and Manufacturing-Green Technology. 2017;4(1):79–86. https://doi.org/10.1007/s40684-017-0011-4.

[64] Lee J, Roh TS, Huh H, Lee HJ. Performance analysis and mass estimation of a small-sized liquid rocket engine with electric-pump cycle. International Journal of Aeronautical and Space Sciences. 2020;22(1):94–107. https://doi.org/10.1007/s42405-020-00325-z.

[65] Li XY, Chiu YJ, Sun KK, Li SB, Su D. The Design of Solar Bike. 7th International Conference on Management, Education, Information and Control. 2017;156:78–84. https://doi.org/10.2991/meici-17.2017.18.

[66] Lin CC, Huang SJ, Liu CC. Structural analysis and optimization of bicycle frame designs. Advances in Mechanical Engineering. 2017;9(12):1–10. https://doi.org/10.1177/1687814017739513.

[67] Madhavi N, Shirke M, Kharpade P, Shaikh M, Bandewar A. Battery Charged Power Cycle. International Journal of Scientific & Engineering Research. 2018;9(5):109–114.

[68] Manoj E, Isa D, Arelhi R. Supercapacitor/battery hybrid powered electric bicycle via a smart boost converter. World Electric Vehicle Journal. 2010;4(2):280–286. https://doi.org/10.3390/wevj4020280.

[69] McLoughlin IV, Narendra IK, Koh LH, Nguyen QH, Seshadri B, Zengh W. Campus mobility for the future: the electric bicycle. Journal of Transportation Technologies. 2012;2:1–12. https://doi.org/10.4236/jtts.2012.21001.

[70] Mehtre VV, Kumar P, Samule KF, Verma A. Electric Bike using Lithium ION Battery. International Research Journal of Engineering and Technology. 2020;7(7):662–666.

[71] Meyer D, Zhang W, Tomizuka M, Senner V. Heart rate regulation with different heart rate reference profiles for electric bicycle riders. Procedia Manufacturing. 2015;3:4213–4220. https://doi.org/10.1016/j.promfg.2015.07.398.

[72] Mithesh M, Budhvani MK, Sapovadiya KM, Pansuriya DH, Chirag DA. Design & Development of E-Bike-A Review. Iconic research and engineering journals. 2017;1(5):36–43.

[73] Mohamed A, Bigazzi A. Speed and road grade dynamics of urban trips on electric and conventional bicycles. Transportmetrica B: Transport dynamics. 2019;7(1):1467–1480. https://doi.org/10.1080/21680566.2019.1630691.

[74] Mondal A, Saha H. Low Cost Digital Battery Life Cycle Tester. Institution of Electronics and Telecommunication Engineers Technical Review. 1994;11(5-6):347-–351. https://doi.org/10.1080/02564602.1994.11437486.

[75] Mouselinos TP, Syrigos SP, Tatakis EC. A unified confined band pwm with duty cycle and frequency compensation for multilevel inverters. IEEE Journal of Emerging and Selected Topics in Industrial Electronics. 2023. https://doi.org/10.1109/JESTIE.2023.3313061.

[76] Muetze A, Tan YC. Electric bicycles – "A performance evaluation". IEEE industry applications magazine. 2007;13(4):12–21. https://doi.org/10.1109/MIA.2007.4283505.

[77] Musasa K, Muheme MI, Nwulu NI, Muchie M. A simplified control scheme for electric vehicle-power grid circuit with DC distribution and battery storage systems. African Journal of Science, Technology, Innovation and Development. 2019;11(3):369–374. https://doi.org/10.1080/20421338.2018.1527888.

[78] Nagwe SS, Sangale V, Sangale T, Sapkale J, Singh A. Solar E-Bicycle. International Journal of Advance Research and Innovative Ideas in Education. 2019;5(1):590–596. https://doi.org/16.0415/IJARIIE-9492.

[79] Nigam P, Sahu D, Bisen AM. Design and Development of Modern Electric Bike. International Journal of Engineering Research & Technology. 2020;9(11):527–535. https://doi.org/10.17577/IJERTV9IS110270.

[80] Patil MB, Patil SD, Saankapal RS, Patil AP, Rajput OA, Shinde SS. Self power generating electric bike. International Journal of Advance Research, Ideas and Innovations In Technology. 2020;6(3):525–530.

[81] Peterman JE, Morris KL, Kram R, Byrnes WC. Pedelecs as a physically active transportation mode. European journal of applied physiology. 2016;116(8):1565–1573. https://doi.org/10.1007/s00421-016-3408-9.

[82] Plazier P, Weitkamp G, Van den Berg A. E-bikes in rural areas: current and potential users in the Netherlands. Transportation. 2023;50(4):1449–1470. https://doi.org/10.1007/s11116-022-10283-y.

[83] Polanía-Restrepo S, Jaramillo-Gonzalez S, Osorio-Gomez G. Electric hybridization kit for modification of a manual transmission motorcycle. International Journal on Interactive Design and Manufacturing. 2020;14(2):587–594. https://doi.org/10.1007/s12008-020-00649-w.

[84] Pompas L, Brumercík F, Kucera L, Smetanka L. Design of a Bicycle's Structural Components and a Comparison of Their Characteristics in Steel, Aluminum and Carbon. Communications – Scientific Letters of the University of Zilina. 2023;25(3):259–267. https://doi.org/10.26552/com.C.2023.061.

[85] Chandran P, Mylsamy K, Umapathy P. Conceptual design and material analysis of BLDC motor using FEA tools for electric vehicle applications. Tehnicki vjesnik. 2022;29(3):1010–1018. https://doi.org/10.17559/TV-20210425201219.

[86] Procopiuck M, Segovia YNS, Procopiuck APV. Urban cycling mobility: management and urban institutional arrangements to support bicycle tourism activities study from Curitiba, Brazil. Transportation. 2021;48(4):2055–2080. https://doi.org/10.1007/s11116-020-10121-z.

[87] Radoslav B, Moroslav K, Guzan M, Tomcikova I, Melnykov V. GPS cycle computer. International Conference on Modern Electrical and Energy Systems. 2017;256–259. 10.1109/MEES.2017.8248904

[88] Ramadhan A., Dinata R: Development of electric bicycle and its impact on the environment. IOP Conf. Series: Materials Science and Engineering. 2021, 1122, 012054(1-8). https://doi.org/10.1088/1757-899X/1122/1/012054.

[89] Ramash KK, Anandhi TS, Vijayakrishna B, Mohanty M, Siva Ramkumar M, Shivappa HA, et al. Modified Mechanical Structure Electric Bike Design Computation and Prototype Model Implementation. Advances in Materials Science and Engineering. 2021;2021:3673172. https://doi.org/10.1155/2021/3673172.

[90] Ramash KK, Aswin K, Hariharan S, Rilwan SM, Poonkundran T, Vinothni A, et al. Design and Fabrication of Electric Vehicle for Physically Challenged Person. International Journal of Innovative Technology and Exploring Engineering. 2019;8(10):4297–4300. https://doi.org/10.35940/ijitee.J1064.0881019.

[91] Reis AF, Baptista P, Moura F. How to promote the environmental sustainability of shared e-scooters: A life-cycle analysis based on a case study from Lisbon, Portugal. Journal of Urban Mobility. 2023;3:100044. https://doi.org/10.1016/j.urbmob.2022.100044.

[92] Rerat P. The rise of the e-bike: Towards an extension of the practice of cycling?. Mobilities. 2021;16(3):423–439. https://doi.org/10.1080/17450101.2021.1897236.

[93] Rios-Torres J, Liu J, Khattak A. Fuel consumption for various driving styles in conventional and hybrid electric vehicles: Integrating driving cycle predictions with fuel consumption optimization. International Journal of Sustainable Transportation. 2019;13(2):123–137. https://doi.org/10.1080/15568318.2018.1445321.

[94] Rose G. E-bikes and urban transportation: emerging issues and unresolved questions. Transportation. 2012;39(1):81–96. https://doi.org/10.1007/s11116-011-9328-y.

[95] Salmeron-Manzano E, Manzano-Agugliaro F. The Electric bicycle: Worldwide research trends. Energies journal. 2018;11(7):1894. https://doi.org/10.3390/en11071894.

[96] Sharma Y, Banker P, Raikwar Y, Chauhan Y, Sharma M. R&D on Electric Bike. International Research Journal of Engineering and Technology. 2018;5:610–614.

[97] Sheth M, Butrina P, Goodchild A, McCormack E. Measuring delivery route cost trade-offs between electric-assist cargo bicycles and delivery trucks in dense urban areas. European transport research review. 2019;11(1):1–12. https://doi.org/10.1186/s12544-019-0349-5.

[98] Shiva Kumar D, Rajasekhar G, Rabu D. Design and Fabrication of E-Bike. Journal of Engineering Science. 2021;12(1):45–48. https://doi.org/10.15433.JES.2021.V12I01.43P.7.

[99] Silva LCA, Eckert JJ, Lourenco MA, Silva FL, Correa FC, Dedini FG. Electric vehicle battery-ultracapacitor hybrid energy storage system and drivetrain optimization for a real-world urban driving

scenario. Journal of the Brazilian Society of Mechanical Sciences and Engineering. 2021;43(5):1–15. https://doi.org/10.1007/s40430-021-02975-w.

[100] Sleptsov MA, Omara AM. Simulation of the Movement of an Electric Vehicle in the Standard Cycle. Russian Electrical Engineering. 2019;90(2):167–173. https://doi.org/10.3103/S1068371219020135.

[101] Smethurst P. A flaneur on wheels? Bicycle mobility and the sociological gaze in Edward Thomas's In Pursuit of Spring. Studies in Travel Writing. 2014;18(3):249–263. https://doi.org/10.1080/13645145.2014.940707.

[102] Soeprapto S, Hasanah RN, Taufik T. Battery management system on electric bike using Lithium-Ion 18650. International Journal of Power Electronics and Drive Systems. 2019;10(3):1529–1537. http://doi.org/10.11591/ijpeds.v10.i3.pp1529-1537.

[103] Somchaiwong N, Ponglangka W. Regenerative power control for electric bicycle. SICE2006 SICE-ICASE International Joint Conference, Korea 2006. https://doi.org/10.1109/SICE.2006.314654.

[104] Song W, Zhang X, Tian Y, Xi LH. A charging management-based intelligent control strategy for extended-range electric vehicles. Journal of Zhejiang University-Science A. 2016;11(17):903–910. https://doi.org/10.1631/jzus.A1600036.

[105] Sundfor HB, Fyhri A. A push for public health: the effect of e-bikes on physical activity levels. BMC public health. 2017;17:1–12. https://doi.org/10.1016/j.jth.2023.101752.

[106] Tabei F, Askarian B, Chong JW. Accident Detection System for Bicycle Riders. IEEE Sensors Journal. 2021;21(2):878–885. https://doi.org/10.1109/JSEN.2020.3021652.

[107] Tagde D, Ingle P, Rangari S, Dongre G, Upadhye N. Solar powered electric cycle. International journal of advanced research in science, communication and technology. 2022;2(6):448–455. https://doi.org/10.48175/IJARSCT-4276.

[108] Taherzadeh E, Javadi S, Dabbaghjamanesh M. New optimal power management strategy for series plug-in hybrid electric vehicles. International Journal of Automotive Technology. 2018;19(6):1061–1069. https://doi.org/10.1007/s12239-018-0104-2.

[109] Tal G, Raghavan SS. Plug-in hybrid electric vehicle observed utility factor: Why the observed electrification performance differ from expectations. International Journal of Sustainable Transportation. 2020;16(2):105–136. https://doi.org/10.1080/15568318.2020.1849469.

[110] Talukder P, Soori PK. Integration of Parabolic Trough Collectors with Natural Gas Combined Cycle Power Plants in United Arab Emirates. International Conference on Smart Grid and Clean Energy Technologies. 2015;62–69. https://doi.org/10.1109/ICSGCE.2015.7454270.

[111] Tanaka Y, Murakami T. A study on straight-line tracking and posture control in electric bicycle. IEEE Transactions on Industrial Electronics. 2009;56(1):159–168. https://doi.org/10.1109/TIE.2008.927406.

[112] Tanik E, Parlaktas V. Design of a very light L7e electric vehicle prototype. International Journal of Automotive Technology. 2015;16(6):997–1005. https://doi.org/10.1007/s12239-015-0102-6.

[113] Thomas A. Electric bicycles and cargo bikes-Tools for parents to keep on biking in auto-centric communities? Findings from a US metropolitan area. International journal of sustainable transportation. 2021;16(7):637–646. https://doi.org/10.1080/15568318.2021.1914787.

[114] Kivevele T, Raja T, Pirouzfar V, Waluyo B, Setiyo M. LPG-fueled vehicles: An overview of technology and market trend. Automotive Experiences. 2020;3(1):6–19. https://doi.org/10.31603/ae.v3i1.3334.

[115] Tian F, Sui L, Zeng Y, Li B, Zhou X, Wang L, et al. Hardware Design and Test of a Gear-Shifting Control System of a Multi-gear Transmission for Electric Vehicles. Automotive Innovation. 2019;2(3):212–222. https://doi.org/10.1007/s42154-019-00072-2.

[116] Udhaya Sankar G, Ganesa Moorthy C, RajKumar G. Smart storage systems for electric vehicles – a review. Smart Science. 2018;7(1):1–15. https://doi.org/10.1080/23080477.2018.1531612.

[117] Uerlich R, Sanalkumar KA, Bokelmann T, Vietor T. Finite element analysis considering packaging efficiency of innovative battery pack designs. International Journal of Crashworthiness. 2020;25(6):664–679. https://doi.org/10.1080/13588265.2019.1632545.

https://doi.org/10.14669/AM/191492

[118] Ustun O, Tanc G, Kivanc OC, Tosun G. In Pursuit of Proper BLDC Motor Design for Electric Bicycles. 2016 XXII International Conference on Electrical Machines (ICEM), IEEE. 2016;1808–1814. https://doi.org/10.1109/ICELMACH.2016.7732769.

[119] Uyar O, Cunkaş M, Karaca H. Enhanced intelligent control with adaptive system for electrically assisted bicycle. Engineering Science and Technology and International Journal. 2022;30:101047. https://doi.org/10.1016/j.jestch.2021.08.004.

[120] Van Cauwenberg J, De Bourdeaudhuij I, Clarys P, De Geus B, Deforche B. E-bikes among older adults: benefits, disadvantages, usage and crash characteristics. Transportation. 2018;46(6):2151–2172. https://doi.org/10.1007/s11116-018-9919-y.

[121] Venugopal P, Vigneswaran T, Sofana SR. State of charge estimation of lithium batteries in electric vehicles using IndRNN. Institution of Electronics and Telecommunication Engineers Journal of Research. 2021;69(5):2886–2896. https://doi.org/10.1080/03772063.2021.1906770.

[122] Wei L, Tan Y, Liu H, Pu Y. Electric cyclist injury of the collision between right turn of truck and electric bicycle. Computer methods in biomechanics and biomedical engineering. 2021;24(13):1463–1472. https://doi.org/10.1080/10255842.2021.1892662.

[123] Weiss M, Dekker P, Moro A, Scholz H, Patel MK. On the electrification of road transportation – a review of the environmental, economic, and social performance of electric two-wheelers. Transportation Research Part D: Transport and Environment. 2015;41:348–366. https://doi.org/10.1016/j.trd.2015.09.007.

[124] Xia C, Zhang C. Real-time optimization power-split strategy for hybrid electric vehicles. Science China Technological Sciences. 2016;59(5):814–824. https://doi.org/10.1007/s11431-015-5998-6.

[125] Xiao D, Liu X, Du W, Wang J, He T. Application of topology optimization to design an electric bicycle main frame. Structural and Multidisciplinary Optimization. 2012;46(6):913–929. https://doi.org/10.1007/s00158-012-0803-7.

[126] Yu R, Zhao H, Zhang C, Wang Z. Analysis of risk-taking behaviors of electric bicycle riders in response to pedestrian countdown signal devices. Traffic injury prevention. 2019;20(2):182–188. https://doi.org/10.1080/15389588.2018.1542138.

[127] Zhang S, Pang Z, Gao J, Dai Q, Liu X, Shen Y, et al. Functional analysis of the cell cycle protein E gene (ccne) in ovarian development of the white ridgetail prawn, Exopalaemon carinicauda. Aquaculture Reports. 2023;32:10171. https://doi.org/10.1016/j.aqrep.2023.101716.

[128] Zheng C, Wang Y, Liu Z, Sun T, Kim N, Jeong J, et al. A hybrid energy storage system for an electric vehicle and its effectiveness validation. International Journal of Precision Engineering and Manufacturing-Green Technology. 2021;8(6):1739–1754. https://doi.org/10.1007/s40684-020-00304-5.

[129] Zhou J, Shen Y, Guo Y, Dong S. Exploring the factors affecting electric bicycle riders' working conditions and crash involvement in Ningbo, China. Journal of Traffic and Transportation Engineering. 2023;10(4):633–646. https://doi.org/10.1016/j.jtte.2021.12.006.

[130] Zhu H, Pei Z. Data-driven layout design for regional battery swapping stations for electric bicycles. IFAC-PapersOnLine. 2020;53(5):13–18. https://doi.org/10.1016/j.ifacol.2021.04.078.

[131] Zuev D. E-bike as a technological innovation system in China: transition to the stage of institutionalized certainty?. Applied Mobilities. 2020;5(3):251–270. https://doi.org/10.1080/23800127.2020.1764237.