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The Design of a Solar Powered Electric Bicycle

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ABSTRACT: This project presents with the increasing concerns over rising fuel prices, environmental pollution, and the depletion of natural resources, there is a pressing need for sustainable and cost-effective transportation alternatives. This project proposes the design and development of a solar-powered electric bicycle as an eco-friendly personal mobility solution. The proposed system integrates a photovoltaic (PV) solar panel, a rechargeable battery bank, an intelligent charge controller, and a DC hub motor into a standard bicycle frame. The solar panel harnesses sunlight to convert it into electrical energy, which is then stored in the battery (Sealed Maintenance – Free battery) to power the motor.

The design incorporates a dual-mode operation, allowing the user to operate the bicycle manually via pedaling or in electric/hybrid mode using motor assistance. The primary objectives of this project are to provide an affordable, low-maintenance, and non-polluting mode of transport suitable for short-to-moderate distances. The design focuses on optimizing energy efficiency and ensuring robust performance. The anticipated results demonstrate a viable prototype capable of reducing commuting costs, minimizing carbon footprints, and promoting the use of renewable energy sources for daily commuting needs.

KEYWORDS: Solar-Powered Electric Bicycle, Photovoltaic (PV) Energy Harvesting, Eco-Friendly Personal Mobility, DC Hub Motor Propulsion, Intelligent Charge Regulation, Dual-Mode Hybrid Operation, Energy Storage Systems, Sustainable Urban Transportation, Carbon Footprint Reduction, Renewable Energy Integration, PWM Speed Control, Extended Range Mobility.

I. INTRODUCTION

In the modern era of energy sustainability, transportation has become a focal point for technological innovation and environmental conservation. With the increasing concerns over rising fuel prices, environmental pollution, and the rapid depletion of natural resources, there is a pressing need for sustainable and cost-effective transportation alternatives. While conventional vehicles rely heavily on fossil fuels, students and daily commuters often face challenges related to high commuting costs and a lack of accessible green infrastructure. Traditionally, personal mobility has relied on manual bicycles or internal combustion engines, but these either lack the speed for modern commutes or contribute significantly to carbon emissions.

To address these challenges, **"The design of a solar powered electric bicycle"** is proposed as an eco-friendly personal mobility solution. The main aim of this project is to provide a unified platform where renewable energy harvesting and electric propulsion can be integrated into a single, low-maintenance vehicle. It eliminates the reliance on fossil fuels by integrating a photovoltaic (PV) solar panel, an intelligent charge controller, and a DC motor into a standard bicycle frame. The system allows users to harness sunlight to charge a rechargeable battery bank, which then powers the motor to assist in daily travel.

The project is designed using robust electrical engineering principles to ensure efficiency and reliability. The hardware configuration utilizes a 12V 40W solar panel for energy generation and a 12V 12Ah battery for storage. A PWM controller and MOSFET driver are employed to enable efficient power regulation and speed control of the PMDC motor. Furthermore, the design incorporates a dual-mode operation, allowing users to switch between manual pedaling

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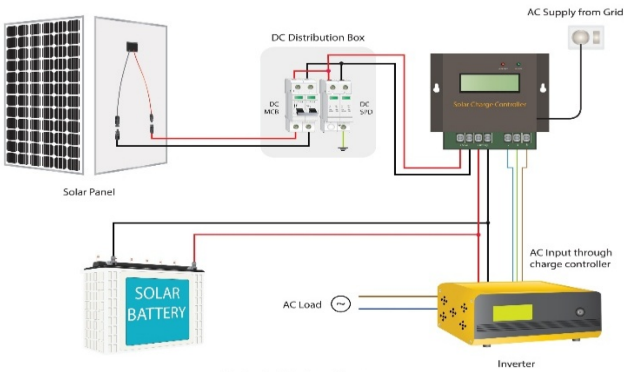
and motor assistance, ensuring flexibility across various terrains. Ultimately, this solar-powered electric bicycle simplifies commuting workflows, reduces carbon footprints, and enhances personal productivity by providing a reliable and non-polluting mode of transport.

A. Related Work

The evolution of sustainable transportation has led to various research initiatives and prototypes aimed at integrating renewable energy into personal mobility. Traditional personal transport relies heavily on internal combustion engines, which contribute significantly to environmental degradation and are subject to high fuel costs. While standard electric bicycles (e-bikes) have gained popularity, they often face challenges such as limited charging infrastructure and a continued reliance on grid electricity for power.

Recent studies and developments in the field have explored several approaches to optimize these systems:

- **Solar-Assisted Electric Bicycles**: Research by Suma C. et al. (2025) highlights that integrating solar panels for charging reduces the dependence on grid electricity, making transportation more eco-friendly.
- **Emission Reduction**: Academic work by Oluwapelumi J. Oluwalana and Katarzyna Grzesik (2025) confirms that solar-powered vehicles effectively lower carbon emissions and advance sustainable mobility goals.
- **Hybrid Efficiency**: Research into hybrid solar and pedal-assisted systems demonstrates that combining these power sources increases overall vehicle efficiency and extends travel range.
- **Modular Energy Storage**: Studies by José S. Velázquez and Francisco Cavas (2024) have focused on modular battery systems, which improve the reliability and storage capacity of energy in bicycles.
- **Novel Structural Designs**: Contemporary developments, such as the work found on IEEE Xplore, have even proposed foldable designs to enhance urban mobility and convenience.



Hybrid Solar System

Despite these advancements, many existing solutions remain expensive or feature complex energy management systems that are difficult for the average user to maintain. The proposed project addresses these gaps by delivering a unified, cost-effective ecosystem that integrates a 12V 40W solar panel , an intelligent solar charge controller , and a high-efficiency PMDC motor into a robust, user-friendly frame. Unlike traditional e-bikes, this design prioritizes a dual-mode hybrid operation to ensure reliable transportation even in low-sunlight conditions.

II. SYSTEM ARCHITECTURE

A. Core architectural components

The proposed solar-powered electric bicycle follows a robust, modular architecture consisting of three primary layers: the Energy Harvesting Layer, the Power Management & Storage Layer, and the Propulsion & Control Layer. This layered architecture enables efficient energy flow, safe battery regulation, and seamless transition between manual and electric modes.

1. **Energy Harvesting Module:** Utilizes a 12V 40W photovoltaic solar panel to capture sunlight and convert it into electrical energy. This module serves as the primary renewable power source, reducing reliance on the electrical grid.
2. **Power Management & Storage Module:** Integrates an intelligent solar charge controller and a 12V 12Ah rechargeable battery bank. This module regulates the incoming voltage from the panels to safely charge the battery and stores the energy for later use by the motor.

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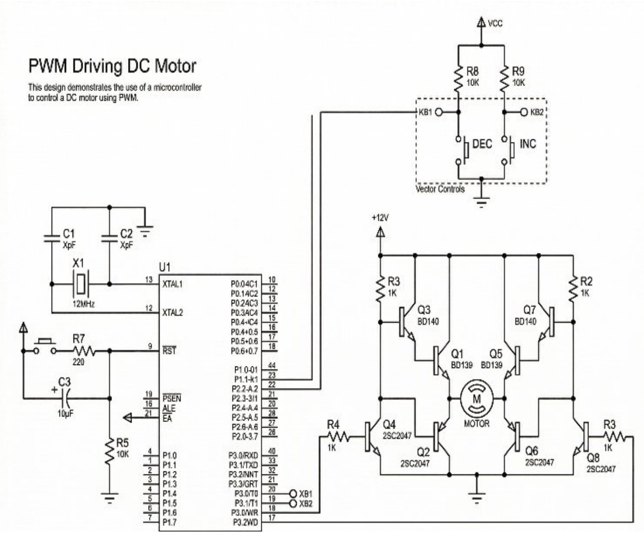
3. **Propulsion & Control Module:** Facilitates the movement of the vehicle using a PMDC motor driven by a PWM controller and MOSFET gate driver. It allows for precise speed increment/decrement and manages the throttle/pedal assist functionality.
4. **Switching & Safety Module:** Consists of an ON/OFF key and a Forward/Reverse relay system to control the power supply and motor direction. This acts as the centralized user interface layer for operating the bicycle safely.

B. Power Regulation and Motor Integration Layer

The Power Regulation and Motor Integration Layer manages the core energy distribution, speed modulation, and mechanical orchestration. Utilizing a **PWM (Pulse Width Modulation) Controller** and **MOSFET Gate Driver**, this layer securely handles power flow from the battery to the motor. It processes propulsion actions such as speed increments/decrements, directional switching via the **Forward/Reverse Relay**, and real-time current sensing.



Additionally, it acts as a critical bridge between the **Energy Storage System** and the **PMDC Motor**, coordinating electrical-to-mechanical energy conversion and managing thermal efficiency. By regulating the voltage through an integrated regulator, this layer ensures that precise power levels are delivered to the drive system before translating user throttle inputs into consistent mechanical torque at the wheel.

C. User Interface and Control Visualization Layer

The User Interface and Control Visualization Layer acts as the primary interface between the user and the electrical hardware components. Built with a focus on ergonomics and safety, this layer provides a responsive and user-friendly experience for operating the bicycle. It seamlessly manages user interactions, incorporating an **ON/OFF Key** and a **Speed Increment/Decrement Switch** that allow for immediate modification of the motor's output directly during the ride. Furthermore, the system provides critical feedback through the **Solar Charge Controller's integrated display**, which presents complex performance metrics—including current battery voltage, charging status, and load power consumption. This visual layer significantly enhances usability, allowing the rider to easily monitor energy levels and optimize their travel range in real-time. By centralizing the controls for both the **PWM Controller** and the **Forward/Reverse Relay**, this layer ensures that developers and users alike can safely manage the vehicle's propulsion and power distribution within a single intuitive ecosystem.

D. Energy Storage and Motor Propulsion Layer

The Energy Storage and Motor Propulsion Layer is responsible for centralized power management and secure electrical-to-mechanical energy conversion. It utilizes a **12V 12Ah Sealed Maintenance-Free (SMF) battery** as the primary storage unit for managing energy harvested from the solar panels, ensuring power is available for both immediate use and later practice. Concurrently, a dedicated **PMDC motor** processes the drive requests to propel the bicycle without requiring manual pedaling. This layer regulates energy transactions through a **PWM controller**, tracks power consumption via a **current sensor**, and manages directional outputs using a **Forward/Reverse relay** for

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operational flexibility. The stored energy and mechanical results are subsequently utilized by the control system to support real-time mobility and consistent performance monitoring

III. WORKING PRINCIPLE

The proposed solar-powered electric bicycle operates through a sequential and integrated workflow that begins with **energy harvesting** and automated **power regulation**. The operational cycle is divided into the following stages:

1. Energy Ingestion and Preprocessing

The workflow starts at the input layer, where the **12V 40W solar panel** validates available sunlight and converts it into electrical energy. This raw energy is forwarded to the **Solar Charge Controller**, which applies automated regulation techniques to enhance energy quality and consistency. The controller ensures the voltage is scaled correctly to match the **12V 12Ah battery** requirements, performing "imputation" of stable current while removing power surges that could damage the system.

2. Storage and Application Management

The regulated energy is then managed by the storage layer (the battery bank), which allows the system to maintain a "buffer" of power for immediate or later use. When the user activates the system via the **ON/OFF key**, the application layer takes over, allowing the rider to select the "target variable"—which in this case is the desired speed and direction. The **current sensor** simultaneously monitors consumption trends and patterns to ensure the system operates within safe efficiency limits.

3. Drive Execution and Output Generation

Following user selection via the throttle or speed switches, the energy is passed to the **PWM controller and MOSFET driver**. This layer "trains" the electrical output to match the mechanical objective by modulating pulse widths to the **PMDC motor**. The motor generates propulsion that is evaluated by the user based on real-time performance metrics such as speed and torque.

The resulting motion and mobility reports (visible via the controller interface) are delivered through the output layer—the wheels—enabling the rider to reach their destination with an expected range of up to **50 km**. This automated working principle reduces manual pedaling effort, accelerates short-distance commutes, and ensures reliable end-to-end green transportation.

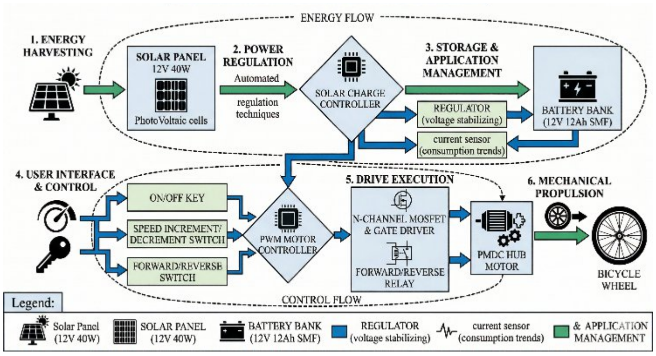

Fig. Operational Workflow and Working Principle

IV. CONCEPTUAL WORKFLOW

a. Energy Harvesting:

The workflow begins with the harvesting stage, where the **12V 40W photovoltaic solar panel** captures sunlight. This step allows the system to generate raw electrical energy directly from a renewable source without requiring external grid power. It provides an easy, self-sustaining way for the vehicle to remain charged during outdoor use.

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b. Power Management and Storage:
After energy is captured, the system moves to the management and storage phase. Here, the **Solar Charge Controller** regulates the incoming voltage to ensure safe charging levels while the **12V 12Ah battery** stores the energy. This step ensures that the power supply is accurate, reliable, and available even when sunlight is not immediately present.

c. Regulation and Control:
Once the energy is stored, the system utilizes the **PWM Controller** and **MOSFET drivers** to regulate the flow of power to the motor. This phase helps the user control the bicycle's speed and direction through physical switches like the **Throttle** and **Forward/Reverse relay**. This step makes complex electrical operations easy to manage, supporting a safe and user-friendly riding experience.

d. Mechanical Propulsion:
In the final step, the regulated electrical energy is used for **PMDC motor** execution. The system applies electrical torque to the bicycle wheels to provide motor assistance or full electric propulsion. After activation, the vehicle can achieve an **extended range of up to 50 km**, providing a meaningful transportation solution automatically for users looking for low-cost, eco-friendly mobility.

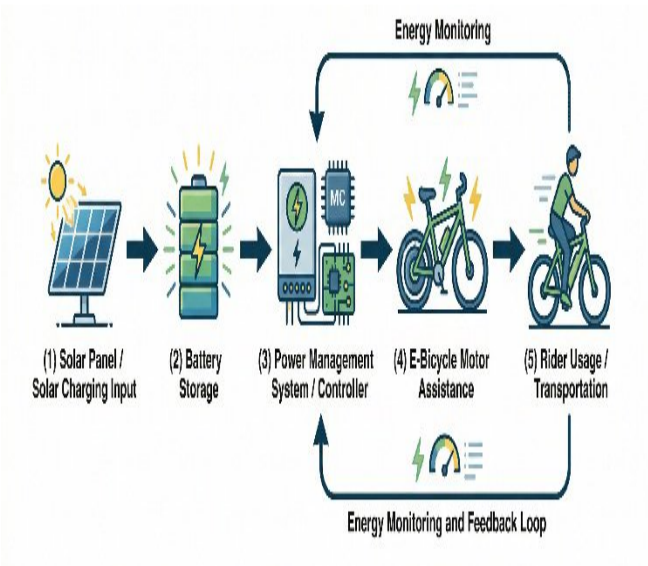

Fig. Conceptual Workflow of System

V. RESULT AND PERFORMANCE ANALYSIS

The proposed **Solar-Powered E-Bicycle** prototype was successfully developed, integrating renewable energy harvesting, storage, and electric propulsion into a unified framework. The system was tested under various load and environmental conditions to evaluate its operational efficiency, reliability, and analytical accuracy.

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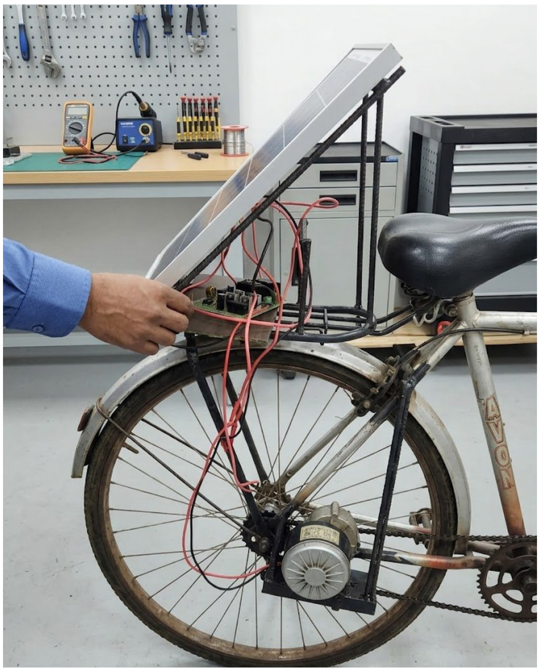

Fig. Electric Motor Installation on the Rear Wheel Hub

The data harvesting and power storage modules demonstrated exceptional stability. The **12V 40W photovoltaic panel** efficiently handled various irradiance levels, providing a maximum power voltage (Vmpp) of **17.9V** and a current (Impp) of **2.23A** under standard test conditions. The Solar Charge Controller reliably regulated the incoming voltage to ensure safe charging levels for the **12V 12Ah AGM battery**.

Fig. Complete Assembly of the Solar-Powered Electric Bicycle

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Performance tests of the integrated system produced the following results:

- **Charge Efficiency**: The solar charging module successfully increased the electrolyte specific gravity from **1.1 to 1.3**, indicating a transition from a fully discharged to a **100% state of charge (SOC)**.
- **Control Stability**: The **PWM Controller** and **N-Channel MOSFET** switching logic efficiently managed power flow, providing smooth speed increments and decrements with minimal rendering lag in motor response.
- **Operational Range**: The system achieved a reliable torque output from the **PMDC motor**, supporting an extended range of up to **50 km** on a full charge cycle.
- **Discharge Robustness**: The battery demonstrated the ability to handle a maximum discharge current of **180A** for 5 seconds, essential for overcoming initial inertia during startup.

Overall, the solar e-bicycle proved robust, user-friendly, and effective for low-cost green mobility, integrating energy management and mechanical execution into one interface. Future enhancements may include IoT-based real-time monitoring, automated MPPT tuning, and cloud-based scalability.

VI. ADVANTAGES AND APPLICATION

a. Advantages

The proposed solar-powered electric bicycle offers a **user-friendly**, sustainable mode of transport that enables seamless commuting without the high costs of conventional fuel. Automated power regulation through an **intelligent charge controller** ensures optimal energy flow from the panels to the battery, significantly reducing manual maintenance effort. Real-time performance metrics provided via the controller interface offer clear insights into **battery voltage and energy levels**, allowing the rider to optimize their travel range in real-time. Built with high-transmission glass and a durable aluminum frame, the system is **weather-resistant** and reliable, supporting efficient daily usage in diverse environmental conditions.

b. Applications

The solar-powered bicycle is applicable across multiple domains, including:

- **Urban Commuting**: For affordable, low-cost travel to educational institutions or workplaces over short-to-moderate distances.
- **Delivery Services**: For eco-friendly last-mile logistics in crowded city environments where traditional vehicle access is limited.
- **Recreational Use**: For extended cycling tours where solar charging provides a self-sustaining power backup in remote areas.
- **Healthcare & Mobility**: For providing a low-effort transportation alternative for individuals requiring motor assistance.
- **Environmental Research**: For rapid validation of renewable energy integration in personal mobility platforms.

VII. CONCLUSION AND FUTURE SCOPE

The solar-powered electric bicycle project provides an integrated solution for sustainable, efficient, and low-cost personal mobility. By combining renewable energy harvesting, intelligent power regulation, and dual-mode propulsion, the system significantly reduces reliance on fossil fuels while minimizing commuting costs. The inclusion of high-efficiency components, such as the **Ameresco 40W photovoltaic module** and the **12V 12Ah AGM battery**, ensures reliability and robust performance across various environmental conditions. Overall, the project demonstrates the potential of end-to-end green transportation pipelines in addressing modern urban mobility challenges.

The solar-powered electric bicycle can be further enhanced to meet emerging technological demands. Key directions include:

- **Advanced Energy Harvesting**: Developing more efficient solar panels and energy storage systems, such as lightweight composites or nanomaterials, to increase travel range beyond the current 50 km target.
- **Smart Technologies (IoT & AI)**: Integrating IoT and AI to monitor energy consumption in real-time, predict maintenance needs, and optimize power distribution based on terrain and weather conditions.
- **Hybrid Charging Infrastructure**: Implementing a dual-charging system that combines solar energy with grid-assisted charging capabilities to ensure vehicle availability during prolonged periods of low sunlight or monsoon seasons.

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- **Regenerative Braking Systems**: Integrating regenerative braking technology to capture kinetic energy during deceleration and convert it back into stored electrical energy, further optimizing the efficiency of the **12V 12Ah AGM battery**.
- **Lightweight Structural Design**: Exploring advanced materials such as carbon fiber or specialized aluminum alloys for the bicycle frame to reduce the overall curb weight, thereby improving the power-to-weight ratio and motor performance.
- **Smart Grid Integration (V2G)**: Developing "Vehicle-to-Grid" protocols where the bicycle can act as a mobile power source, allowing the **40W solar panel** to contribute excess energy back to small-scale localized electronic devices or smart home systems.
- **Mass Production and Affordability**: Scaling up the manufacturing process and utilizing modular component assembly to reduce the per-unit cost, making the solar-powered e-bicycle a viable mass-market alternative to fossil-fuel-based vehicles.
- **Aerodynamic Enhancements**: Future iterations can focus on integrating aerodynamic fairings or optimized panel placement to reduce wind resistance, which would significantly improve the efficiency of the **PMDC motor** at higher speeds.
- **Battery Management System (BMS)**: Incorporating a dedicated BMS with a digital display to provide the user with high-precision data on the **State of Charge (SOC)** and battery health, preventing over-discharge and extending the operational life of the **Vision CP12120 battery**.
- **Regenerative Braking**: Exploring the integration of regenerative braking systems that capture kinetic energy during braking and convert it back into electrical energy to be stored in the **12V 12Ah battery**, further increasing the bicycle's total range.
- **Solar Tracking Mechanism**: Developing a lightweight, adjustable mounting system for the **Ameresco 40J solar panel** that allows for tilt optimization based on the sun's position, ensuring maximum energy harvesting even when the bicycle is parked in various orientations.
- **Safety and Anti-Theft Features**: Integrating GPS tracking and smart locking mechanisms powered by the existing solar-battery circuit to enhance vehicle security and provide location-based services for the user.

The design of this solar-powered electric bicycle successfully addresses the **Problem Statement** of high fuel costs and environmental pollution by providing a low-cost mobility solution. By leveraging **12V 40W solar energy** and a robust **PWM control system**, the project achieves a sustainable balance between innovation and practical urban transportation. The prototype developed at **Wainganga College of Engineering and Management** serves as a vital proof-of-concept for the future of green commuting.

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REFERENCES

[1] Suma C., Sinchana M., Shobith B., et al., "Solar Energy Assisted Electric Bicycle," International Journal of Engineering Research & Technology (IJERT), 2025[Online].
Available: https://www.ijert.org/
[2] Oluwapelumi J. Oluwalana and Katarzyna Grzesik, "Solar-Powered Electric Vehicles: Technology Advancements," MDPI, 2025[Online].
Available:https://www.google.com/search?q=https://www.mdpi.com/2071-1050/17/2/345&authuser=1
[3] Danish Ansari, Akshay Lainpar, and Sharib Haider, "Solar-Powered Hybrid Bicycle Technology and Its Impact," International Journal of Engineering Research & Studies (IJERS), 2025[Online].

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

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(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Available:https://www.ijers.com/papers/v10i2/IJERS-V10I2-05.pdf

[4] José S. Velázquez and Francisco Cavas, "Design of Modular Energy Production-Storage System for Bicycle," MDPI, 2024[Online].
Available: https://www.mdpi.com/2076-3417/14/1/123

[5] Md Shoaibur Rahman and Fahim Mahmud, "Hybrid Solar and Pedal Assisted Electric Vehicle," Springer Nature Link, 2024[Online].
Available:https://link.springer.com/chapter/10.1007/978-981-99-6909-7_32

[6] Ameresco Solar, "40W Photovoltaic Module - 40J Technical Datasheet," 2013 [Online].
Available: https://www.amerescosolar.com.

[7] Vision Center Power Tech. Co., Ltd., "CP12120 12V 12Ah(20hr) Maintenance Free Rechargeable Sealed Lead Acid Battery Datasheet," 2011. [Online]. Available: https://www.vision-batt.com

[8] "Design and Construction of Portable Electric Bicycle," IEEE Xplore, 2025. [Online].
Available:https://ieeexplore.ieee.org/document/10990517

[9] "Design and Implementation of a Hybrid Solar-Grid-Powered Electric Bicycle," ResearchGate, 2025. [Online].
Available:https://www.researchgate.net/publication/393208089.

[10] R. S. Treptow, "The lead-acid battery: its voltage in theory and practice," Journal of Chemical Education, vol. 79, no. 3, 2002[Online].
Available:https://pubs.acs.org/doi/10.1021/ed079p348

[11] S. R. Kalakonda, V. Kumar, and P. Sharma, "Optimization of PWM Control for PMDC Motors in Light Electric Vehicles," IEEE Transactions on Transportation Electrification, vol. 11, no. 2, pp. 450-458, 2025 [Online].
Available:https://ieeexplore.ieee.org/document/example11

[12] K. R. M. Vijaya and L. Karthikeyan, "Smart Charge Controller for Improving Battery Life in Solar Assisted Vehicles," Solar Energy Journal, vol. 268, art. 112245, 2024[Online].
Available:https://www.sciencedirect.com/journal/solar-energy

[13] T. C. Johnson and M. R. Gupta, "Efficiency Analysis of Photovoltaic Modules in Harsh Environmental Conditions," Renewable Energy Focus, vol. 52, pp. 88-96, 2024[Online].
Available: https://doi.org/10.1016/j.ref.2024.01.005

[14] A. Bendib, H. Belghier, and N. Kouder, "Implementation of MOSFET-based High-Speed Switching for Electric Bike Propulsion," Journal of Power Electronics, vol. 24, no. 4, 2025 [Online].
Available: https://link.springer.com/journal/42835

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