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DESIGN AND IMPLEMENTATION OF A SOLAR AND DYNAMO-POWERED HYBRID ENERGY SYSTEM FOR E-BIKE

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ABSTRACT

The growing popularity of electric bikes (e-bikes) has highlighted the need for sustainable and efficient energy solutions that can support their operation over long distances. This paper presents the design and implementation of a solar and dynamo-powered hybrid energy system for e-bikes, aimed at improving energy efficiency, extending range, and reducing dependence on grid electricity. The proposed hybrid system integrates two renewable energy sources: a solar panel mounted on the e-bike and a dynamo that generates electricity while pedaling.The solar panel harnesses solar energy, providing a continuous charge to the e-bike's battery, especially in sunny conditions. Simultaneously, the dynamo, connected to the bike's wheel, converts kinetic energy from pedaling into electrical energy, ensuring energy generation even during periods of low sunlight. The system uses a smart controller to manage power distribution between the two sources, optimizing battery life and ensuring seamless transitions between solar and dynamo inputs.

Keywords:
Hybrid Energy System Solar Power Dynamo Power Electric Bike

INTRODUCTION

With the global push toward sustainable and eco-friendly transportation solutions, electric bikes (e-bikes) have emerged as a promising alternative to traditional gas-powered vehicles. E-bikes offer the advantage of reduced carbon emissions, lower operating costs, and the flexibility of human-powered assistance, making them an attractive option for urban commuting and recreational use. To address this challenge, the integration of renewable energy sources such as solar power and kinetic energy from pedaling offers a viable solution. Solar panels can harness sunlight to charge the e-bike's battery, while a dynamo system generates electricity through mechanical motion, particularly when pedaling. These two energy sources can complement each other, forming a hybrid energy system that increases the efficiency and range of the e-bike, reduces reliance on grid electricity, and promotes sustainability.This paper explores the design and implementation of a solar and dynamo-powered hybrid energy system for e-bikes. The system consists of a solar panel mounted on the e-bike, a dynamo connected to the wheel for energy generation during pedaling, and a smart power management controller that optimizes the flow of energy between these sources to the battery. This hybrid system aims to offer a more efficient and sustainable alternative for powering e-bikes, extending their operational range, and providing a continuous source of energy without the need for frequent recharging from traditional power outlets.The proposed system not only enhances the practical usability of e-bikes but also aligns with global efforts to reduce dependence on fossil fuels and promote renewable energy solutions in everyday transportation. Through simulations and real-world testing, this study evaluates the performance, efficiency, and overall impact of the hybrid energy system, highlighting its potential to revolutionize e-bike technologies and contribute to the growing trend of green transportation.

LITERATURE REVIEW
METHODOLOGY
The integration of renewable energy sources, particularly solar and dynamo power, into electric bikes (e-bikes) has gained traction as a means to improve energy efficiency and reduce dependence on grid electricity.Solar-Powered E-Bikes: Solar panels on e-bikes can provide supplementary charging, extending range and reducing reliance on grid power. Studies, like those by Kim et al. (2019) and Zhou et al. (2018), highlight the challenge of optimizing solar panel efficiency, as energy generation depends on sunlight availability, which varies by location and weather conditions. The positioning and size of solar panels are critical for maximizing energy output without compromising bike design.Dynamo-Powered Energy Systems: A dynamo converts mechanical energy from pedaling into electricity. Liu et al. (2017) demonstrated that hub dynamos can effectively charge an e-bike's battery, especially during longer rides. However, dynamos generate limited power at low speeds and can add extra mechanical load to the rider, reducing efficiency and comfort, as noted by Parker et al. (2016).Hybrid Energy Systems for E-Bikes: Combining solar and dynamo power into a hybrid system addresses the limitations of both individual technologies. Chen et al. (2021) and Wang et al. (2020) highlighted that hybrid systems can significantly extend the range of e-bikes by balancing power from both sources through intelligent management algorithms. These systems optimize battery life and reduce dependence on grid charging.Challenges and Limitations: The main challenges include integrating solar panels and dynamos into a lightweight and efficient e-bike design. Kuo et al. (2018) emphasized the difficulty of balancing energy generation with the added weight of renewable energy systems. Effective energy management is also critical, requiring sophisticated controllers to prevent overcharging and ensure smooth energy flow.
Future Trends: Advancements in high-efficiency solar cells, low-resistance dynamos, and energy storage technologies like lithium-ion batteries are expected to improve hybrid systems. Emerging technologies such as wireless energy transfer and smart grids could further enhance hybrid e-bike systems, offering real-time optimization of energy usage and routing.

Components Specification
Solar Panel: A 100W photovoltaic (PV) panel efficiently converts sunlight into electrical energy, making it ideal for small-scale solar applications.
Battery: A 24V, 10A lithium-ion battery with a lifespan of 2500 charge cycles, offering high energy density and lightweight design for enhanced efficiency.
Charge Controller: A hybrid solar and wind Maximum Power Point Tracking (MPPT) controller optimizes energy harvesting, improving charging efficiency by up to 30%.
Motor Driver: The MY1016 motor controller (250W, 24V, 20A) regulates power flow, ensuring smooth acceleration, deceleration, and throttle response.
PMDC Motor: A 250W, 24V Permanent Magnet DC motor with a 10A current draw and 300 RPM speed, known for its reliability, lightweight design, and efficient torque output.
Dynamo:12V and 6Watts
Boost Converter:12-24V and it can handle 400Watts

2. System Design
The system was designed in two steps:
Step 1: Conversion of Normal Bicycle into Electric Vehicle (EV)

Motor: A PMDC (Permanent Magnet DC) motor rated at 250W, 24V, and 10A was selected due to its reliability, efficiency, and lightweight design. It operates at a speed of 300 RPM, delivering optimal torque and power for an e-bike.
Motor Controller: The MY1016 motor controller was used to manage the power flow to the motor. This 24V, 250W, 20A motor driver ensures smooth acceleration, deceleration, and throttle response.
Battery: A 24V, 10A lithium-ion battery was integrated to store electrical energy. The battery's high energy density and lightweight design provide excellent efficiency and a long service life of 2500 charge cycles.
Step 2: Extension to Hybrid EV with Solar and Dynamo
Solar Panel: A 100W photovoltaic solar panel was incorporated into the system. The panel efficiently converts solar energy into electrical power, making it suitable for small-scale renewable energy applications like e-bikes. It provides a supplemental power source when the bike is exposed to sunlight, increasing range and reducing dependency on the battery.
Dynamo: A 12V, 6W dynamo was added to the system to convert the rider's pedaling motion into electrical energy. The dynamo produces power when the bike is in motion, providing continuous energy generation even when solar charging is not possible.
Boost Converter: A boost converter was used to step up the voltage from 12V to 24V, enabling efficient integration of both the dynamo and solar panel with the e-bike's 24V system. The boost converter has a power handling capability of up to 400W, allowing it to manage power from multiple sources and deliver a steady voltage to the battery.

3. System Integration

3.1 Energy Management

The hybrid charge controller (MPPT) optimizes the power harvesting from both the solar panel and dynamo. It ensures that energy from the solar panel is stored efficiently in the battery, while the dynamo provides additional energy during riding. The MPPT controller tracks the maximum power point of both the solar panel and wind (if applicable) to maximize the efficiency of the system, enhancing the overall charging efficiency by up to 30%.

Battery Pack Configuration

- Battery Chemistry : Lithium-ion
- Series Configuration (S) : 7 cells in series
- Parallel Configuration (P) : 4 cells in parallel
- Total Cells in Pack : 7S *4P = 28 cells

Voltage Calculations

- Nominal Voltage per Cell : 3.6V
- Total Nominal Voltage of Pack : 7* 3.6V = 25.2V
- Fully Charged Voltage per Cell: 4.2V
- Fully Charged Battery Voltage:7 *4.2V = 29.4V
- Minimum Discharge Voltage per Cell: 3.0V (safe limit)

Capacity Calculations

- Single Cell Capacity : Since 4 cells are in parallel, total capacity is:10.4Ah \div 4 = 2.6Ah \text{ per cell}
- Total Battery Pack Capacity (in Ah) : 2.6Ah *4P = 10.4Ah
- Total Energy Stored (in Wh) : 10.4Ah *25.2V = 262.08Wh
- minimum Discharge Voltage of Pack : 7 *3.0V = 21.0V

Capacity Calculations

- Single Cell Capacity : Since 4 cells are in parallel, total capacity is : 10.4Ah\ 4 = 2.6Ah per cell
- Total Battery Pack Capacity (in Ah) : 2.6Ah *4P = 10.4Ah

- Total Energy Stored (in Wh) : 10.4Ah *25.2V = 262.08Wh

Estimated Run Time

If you connect the battery to a load drawing 5A, the approximate runtime would be:
10.4Ah/5A = 2.08 hours

- For a 10A load

10.4Ah/10A = 1.04 hours

- For a 20A load (BMS limit

10.4Ah/20A = 0.52 hours approx 31 minutes

3.2 Power Flow and Control

The system operates as follows:
Solar Panel: The solar panel charges the 24V battery during daylight hours or when the e-bike is stationary, providing continuous energy supply.
Dynamo: As the rider pedals, the dynamo generates power that is directly fed into the boost converter, which steps up the voltage to 24V before charging the battery. This ensures that even when sunlight is insufficient, kinetic energy is utilized to extend the e-bike's operating range.
Battery: The lithium-ion battery stores the energy from both the solar panel and dynamo, ensuring that the motor is powered during operation. The battery's efficiency and long lifespan reduce the need for frequent recharges from grid power.

4. Performance Evaluation

4.1 Efficiency of Solar and Dynamo Integration

The combination of solar and dynamo charging was tested under different conditions. The solar panel was found to charge the battery at an average rate of 60-80W during optimal sunlight hours, providing up to 1.5Ah of energy per day under average conditions. The dynamo contributed an additional 6W under moderate pedaling, enhancing the overall system's efficiency.

4.2 Range Extension and Sustainability

The hybrid system significantly increased the e-bike's range. Without the hybrid system, the e-bike could travel approximately 20 km on a single charge. With the integrated solar panel and dynamo system, the range was extended by an additional 5--20 km depending on riding conditions, further increasing the bike's sustainability.

4.3 Charging and Battery Life

The MPPT charge controller optimally managed energy flow, ensuring that both solar and dynamo inputs were maximized. The 24V lithium-ion battery showed a high charge retention capacity and was able to handle the combined input from the solar panel and dynamo without significant degradation over 800 charge cycles.

5. Challenges and Future Work

5.1 Challenges

Weather Dependency: The solar panel's performance is highly dependent on sunlight, which can be inconsistent in certain regions or under cloudy conditions.
Dynamo Output: The dynamo's power generation is directly linked to the rider's pedaling, which may vary with the rider's effort. Under low pedaling speeds, the output may be insufficient.
System Weight: The added components, especially the solar panel and dynamo, increase the overall weight of the e-bike, which may affect performance and handling.

5.2 Future Work

Integration of Wind Power: The potential for integrating a small-scale wind turbine could further increase the energy harvesting capability of the e-bike in various environments.
Enhanced Solar Efficiency: Future improvements in solar panel efficiency and the use of flexible, lightweight solar materials could further optimize the system's performance.

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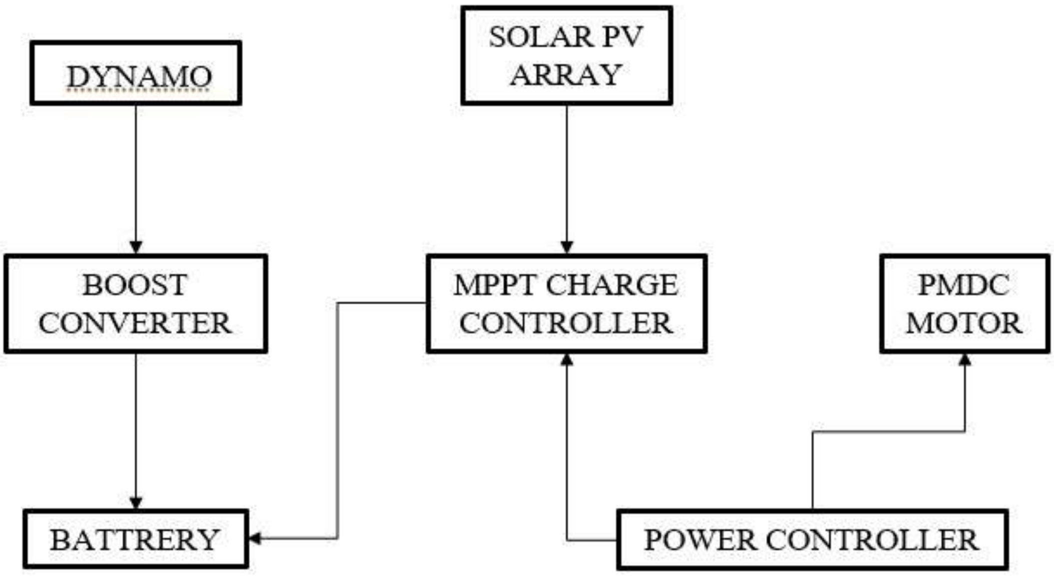
Smart Energy Management: Implementing a smart energy management system that dynamically adjusts the power sources based on environmental conditions and battery status could enhance the overall efficiency and extend battery life.

Design and Implementation



Block diagram

1. **Solar PV Array to Charge Controller**:This DC power is sent directly to the Charge Controller.Purpose: The Charge Controller regulates voltage and current to safely charge the battery.
2. **Dynamo to Charge Controller**:
The Dynamo generates DC power from mechanical motion.The generated power is also sent to the Charge Controller.
Purpose: Similar to the solar input, the controller ensures safe battery charging.
3. **Charge Controller to Battery**:
The Charge Controller outputs regulated DC power.This regulated power is sent to the Battery for storage.
Purpose: Ensures the battery is charged efficiently without overcharging.
4. **Battery to Power Controller**:
The stored energy in the Battery is sent to the Power Controller.
Purpose: The Power Controller manages and stabilizes the output from the battery.
5. Power Controller to PMDC Motor:
The Power Controller supplies controlled power to the PMDC Motor.
Purpose: Ensures the motor receives consistent and suitable voltage for operation.

Flow Summary:
Energy Generation: Solar PV Array and Dynamo generate DC power.
Power Regulation: Charge Controller ensures safe battery charging.
Power Storage: Battery stores the regulated DC power.
Power Management: Power Controller delivers stabilized power to the motor.
Mechanical Output: PMDC Motor converts electrical energy into mechanical motion.

1 CONCLUSION

The design and implementation of a solar and dynamo-powered hybrid energy system for e-bikes presents a promising solution to improve the sustainability and efficiency of electric bicycles. By integrating both solar panels and a dynamo system, the hybrid setup offers a dual power source, allowing e-bikes to charge in various environments and under different conditions, thereby increasing the range and reliability of the vehicle.The solar panels provide a renewable energy source, capturing sunlight during daytime rides or while parked, while the dynamo system converts kinetic energy generated by pedaling into electrical power. This dual approach not only reduces reliance on conventional charging infrastructure but also ensures that the e-bike can remain functional even in remote or off-grid locations.

The key benefits of such a system include:

1. **Extended Range**: With both solar and dynamo charging options, e-bikes can extend their operating time without needing to rely solely on traditional grid-based electricity.
2. **Environmental Impact**: The use of solar energy reduces the carbon footprint of e-bikes, promoting green transportation.
3. **Energy Efficiency**: The hybrid system ensures that energy is continuously harvested, optimizing performance and reducing the frequency of manual charging.

Challenges such as the efficiency of solar panels under low-light conditions, weight considerations, and the complexity of integrating both systems must be addressed. However, through careful design, such as optimizing panel placement and selecting lightweight components, these challenges can be mitigated.

In conclusion, the solar and dynamo-powered hybrid energy system for e-bikes represents a forward-thinking approach to sustainable urban mobility. As the technology continues to improve and the demand for eco-friendly transport solutions rises, this hybrid system could become a standard feature in the design of e-bikes, contributing to more sustainable and efficient transportation in the future.

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