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DESIGN OF BUCK CONVERTER FOR HYBRID ELECTRIC BIKE

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ABSTRACT

Hybrid Electric Bikes (HEBs) require efficient power conversion to ensure stable voltage regulation, optimal battery utilization, and enhanced performance. This paper presents the design and implementation of a Buck Converter, which steps down the battery voltage to match the motor's operational requirements while minimizing energy losses. The proposed system integrates a digital monitoring system for real-time voltage tracking, enhancing operational efficiency, reliability, and safety. By ensuring stable voltage regulation, the converter prevents fluctuations that could impact motor performance and battery health. The digital interface provides continuous voltage monitoring, enabling early fault detection and preventive maintenance, thus improving the overall longevity of the system. The optimized power conversion topology enhances energy efficiency, extending the bike’s operational range and making it more suitable for practical applications. With an emphasis on improved energy management and sustainability, this design contributes to the advancement of Hybrid Electric Bike technology, ensuring a more reliable and eco-friendly transportation solution for the future.

Keywords: Buck Converter, Hybrid Electric Bike (Heb), Voltage Regulation, Digital Monitoring, Energy Efficiency

I. INTRODUCTION

Hybrid Electric Bikes (HEBs) integrate an electric motor with a conventional pedaling system to enhance efficiency, reduce fuel consumption, and lower emissions. A stable and efficient power supply is crucial for ensuring smooth motor operation, making a reliable DC-DC conversion system essential. The Buck Converter, a step-down voltage regulator, plays a key role in maintaining a consistent and optimal voltage level for the motor, preventing performance fluctuations. Unlike traditional linear regulators, Buck Converters offer significantly higher efficiency by minimizing power losses and reducing heat generation, thereby extending battery life. As the demand for energy-efficient transportation grows, research into advanced DC-DC converters has gained momentum, with the Buck Converter emerging as a promising solution for HEBs. This study focuses on designing an optimized Buck Converter to enhance power management, improve energy utilization, and integrate a digital monitoring system for real-time voltage tracking, ensuring improved reliability and sustainability in Hybrid Electric Bikes.

II. PROPOSED SYSTEM

The proposed system involves designing a Buck Converter to regulate the 48V battery voltage for a 48V, 250W motor, ensuring stable and efficient power delivery. By stepping down the voltage as required, the converter optimizes energy utilization while minimizing power losses. To enhance reliability, a digital monitoring unit is integrated, enabling real-time tracking of voltage levels and performance metrics, which helps in early fault detection and proactive maintenance. The design focuses on improving power conversion efficiency through optimized switching techniques that reduce heat dissipation and voltage fluctuations, thereby enhancing overall system performance. A microcontroller-based monitoring system continuously analyzes and displays voltage levels, providing users with crucial operational insights. Additionally, the lightweight and compact design makes it ideal for Hybrid Electric Bike applications, ensuring minimal space consumption while maintaining high efficiency. By implementing an advanced power management strategy, the system extends battery life, enhances energy efficiency, and delivers a reliable power supply for sustainable and high-performance electric bike operation.

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III. BLOCK DIAGRAM

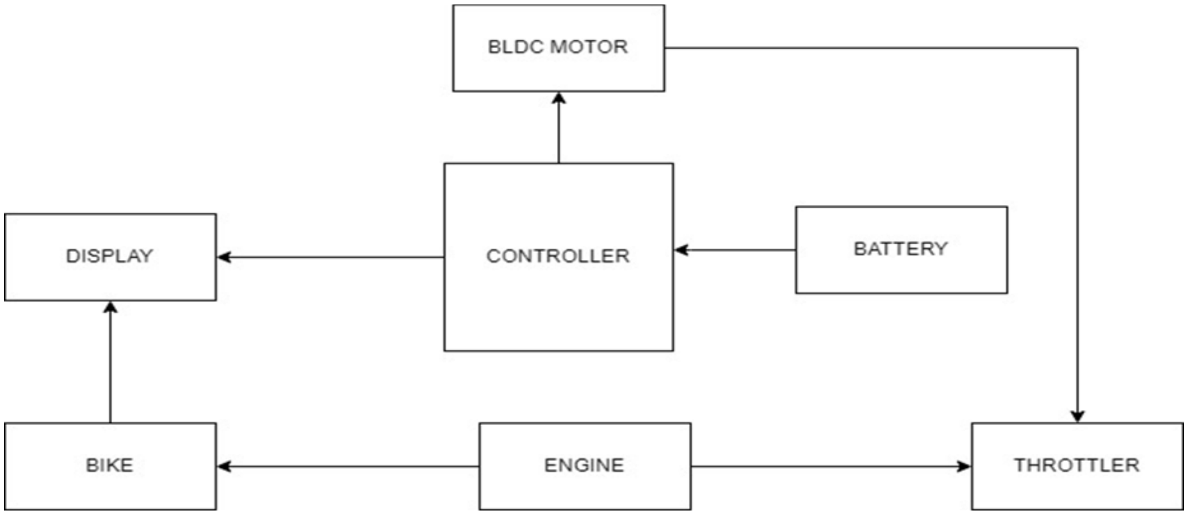

Figure 1: Block Diagram of Proposed System

Figure 1 shows that the Hybrid Electric Bike system consists of a controller, BLDC motor, battery, throttle, engine, bike, and display. The controller regulates power distribution between the battery and motor while processing throttle input. The display provides real-time system information, ensuring efficient energy management and smooth operation of the bike.

IV. SIMULATION ANALYSIS

The Simulink model represents a Buck Converter used in a Hybrid Electric Bike to step down 48V battery voltage to 12V for auxiliary loads. It includes a MOSFET switch, diode, inductor, and capacitor for efficient voltage regulation. A pulse generator controls switching. The Powergui block ensures accurate simulation. Voltage measurement and scope blocks analyze efficiency, stability, and performance for bike applications.

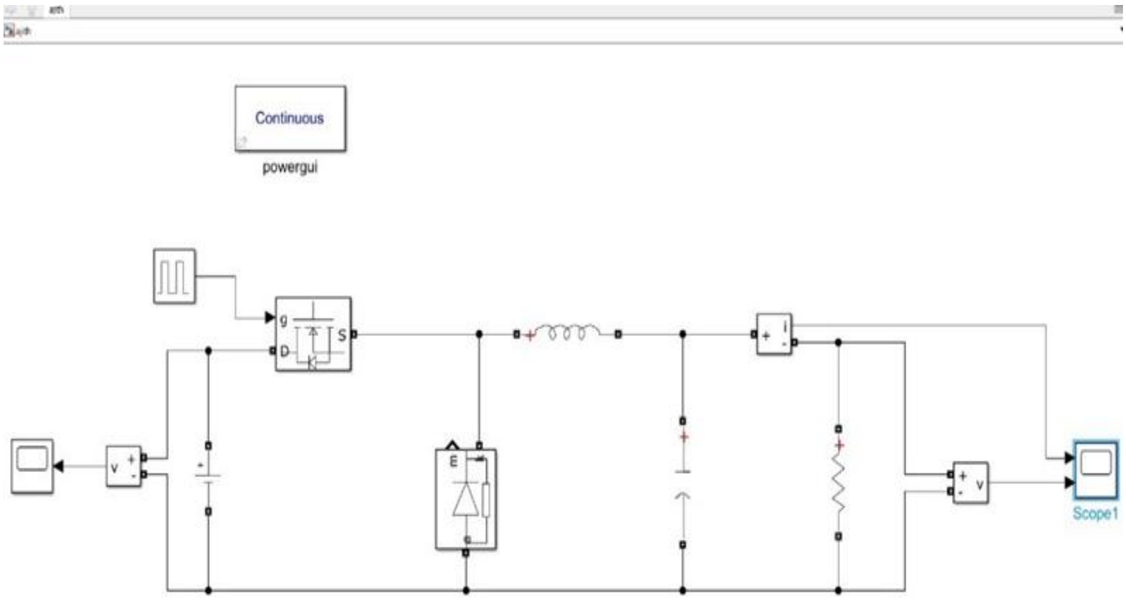

Figure 2: Buck Converter Simulation for Hybrid Electric Bike

Figure 2 shows the Simulink model of a Buck Converter, designed to step down 48V to 12V for a Hybrid Electric Bike. It includes a MOSFET switch, diode, inductor, and capacitor for efficient voltage regulation. A pulse generator controls switching, and a Powergui block ensures accurate simulation. Voltage and current measurement blocks monitor system performance and efficiency.

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Figure 3: Input Voltage Waveform

Figure 3 shows the **input voltage waveform** of the **Buck Converter** for the **Hybrid Electric Bike** simulation. The waveform is a **steady DC voltage at 48V**, as expected from the battery source. The consistent voltage level ensures a stable power supply to the converter, allowing proper step-down operation to **12V** for auxiliary loads.

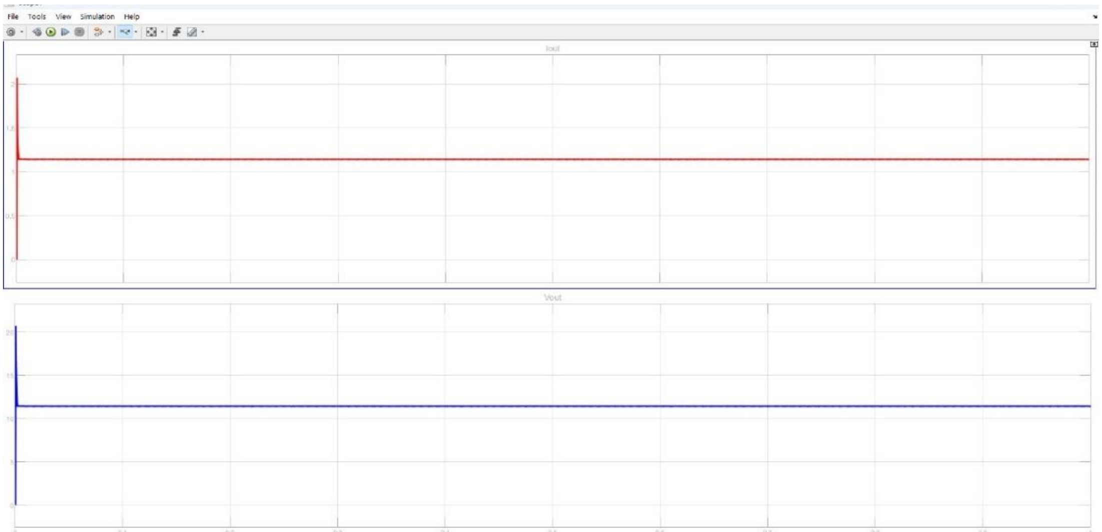

Figure 4: Output Voltage and Current Waveforms

Figure 4 shows the output voltage and current waveforms of the Buck Converter for the Hybrid Electric Bike simulation. The output voltage (Vout) stabilizes at approximately 12V after an initial transient response, while the output current (Iout) reaches a steady-state value. This confirms the converter's proper step-down operation from 48V to 12V, ensuring reliable power delivery to auxiliary loads.

V. WORKING PRINCIPLE

The Buck Converter operates using pulse-width modulation (PWM) control to regulate the output voltage by switching a MOSFET on and off. When the MOSFET is turned ON, current flows through the inductor, storing energy in its magnetic field. When the MOSFET is turned OFF, the inductor releases the stored energy to the load through a freewheeling diode, ensuring a continuous power supply. The output voltage is determined by adjusting the duty cycle of the PWM signal, allowing precise control over the power delivered to the motor. This efficient DC-DC conversion reduces energy losses and improves battery utilization. Additionally, a digital monitoring system is integrated to track real-time voltage levels and system performance. This system provides continuous feedback, enabling early fault detection, optimizing energy management, and ensuring reliable operation. By maintaining stable voltage regulation, the Buck Converter enhances motor efficiency and contributes to the overall performance and sustainability of Hybrid Electric Bikes.

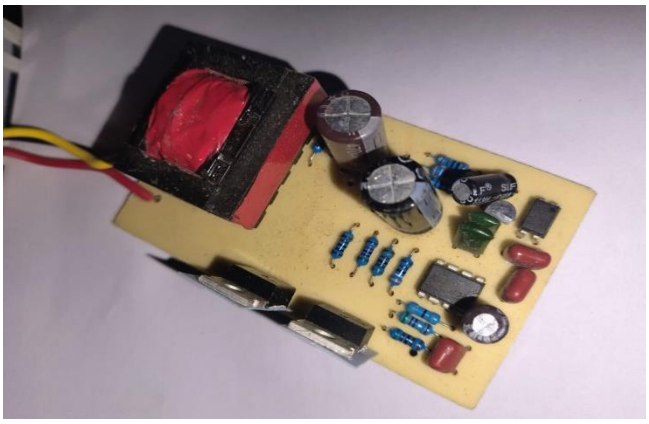

Figure 5: Buck Converter

Figure 5 shows that the Buck Converter circuit consists of an inductor, capacitors, resistors, diodes, and MOSFETs, ensuring efficient voltage step-down. The transformer and switching components regulate output voltage, minimizing losses. This compact design optimizes power conversion, enhancing energy efficiency and stability for Hybrid Electric Bike applications.

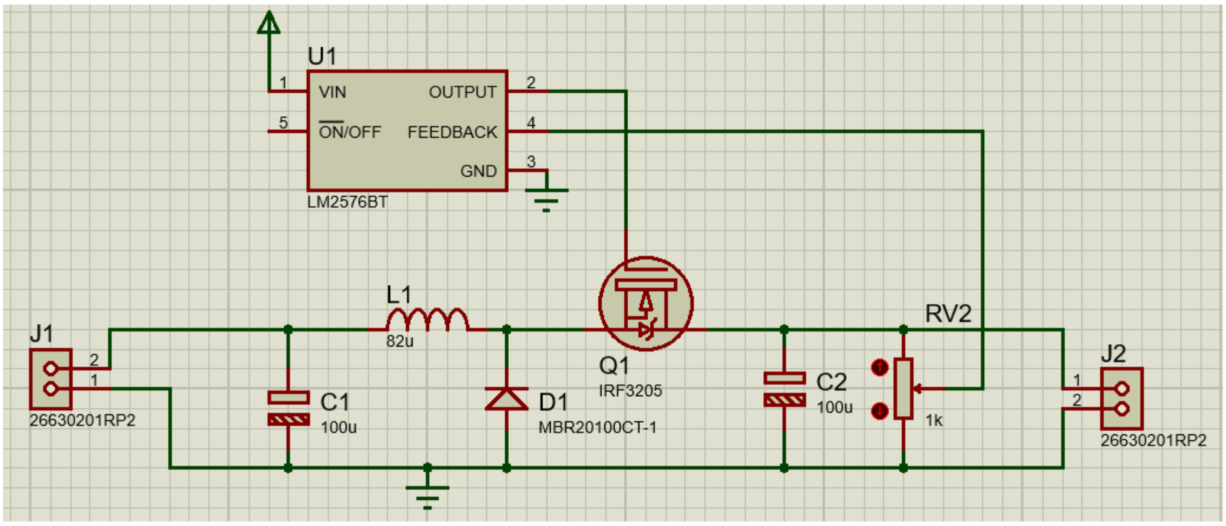

Figure 6: Circuit Diagram

Figure 6 shows that the buck converter circuit utilizes the LM2576BT regulator to step down the input voltage efficiently. It consists of an inductor (L1), a Schottky diode (D1), a MOSFET (Q1), and capacitors (C1, C2) for voltage regulation. A potentiometer (RV2) is used to adjust the output voltage.

VI. RESULT AND DISCUSSION

The designed Buck Converter effectively steps down the 48V battery voltage to provide a stable and regulated output suitable for the 48V, 250W motor. The system ensures efficient power conversion, minimizing energy losses and enhancing overall battery utilization. By implementing an optimized switching technique, the converter achieves high efficiency, reducing heat dissipation and improving the longevity of the power electronics components. The integration of a real-time digital monitoring system allows continuous tracking of voltage levels and system performance, enabling early fault detection and proactive maintenance. Experimental results validate the converter's ability to maintain stable voltage regulation even under varying load conditions, ensuring smooth motor operation without fluctuations. The proposed system demonstrates reliability in Hybrid Electric Bike applications, providing a compact, lightweight, and efficient power management solution. Additionally, the monitoring system enhances user awareness by displaying critical voltage parameters, contributing to improved safety and operational efficiency. The table below presents key performance parameters, including efficiency, voltage stability, and response time under different operating conditions.

Table 1: Result Statistics

Parameter	Value
Input Voltage	48V
Battery Capacity	28Ah
Motor Power	250W
Motor Current	250W / 48V = **5.2A**
Estimated Run Time	28Ah / 5.2A ≈ **5.4 hours**

The result statistics are shows in Table 1. The designed Buck Converter effectively regulates the voltage for the 48V, 250W motor. The estimated motor current is 5.2A, and the system provides an approximate run time of 5.4 hours with a 28Ah battery. This ensures stable performance and efficient energy utilization for Hybrid Electric Bikes.

VII. MAPPING OF SUSTAINABLE DEVELOPMENT GOALS

- **SDG 7 – Affordable and Clean Energy:** Enhancing energy efficiency in electric transportation reduces reliance on fossil fuels.
- **SDG 9 – Industry, Innovation, and Infrastructure:** Improving power electronics supports the development of sustainable mobility solutions.
- **SDG 11 – Sustainable Cities and Communities:** Encouraging the adoption of eco-friendly transportation alternatives.
- **SDG 12 – Responsible Consumption and Production:** Promoting sustainable battery utilization and recycling practices.
- **SDG 13 – Climate Action:** Reducing emissions through optimized electric bike systems contributes to a cleaner environment.

VIII. CONCLUSION

The proposed Buck Converter enhances power conversion efficiency in Hybrid Electric Bikes by ensuring stable voltage regulation and minimizing energy losses. By integrating a digital monitoring system, real-time voltage tracking is achieved, allowing for improved system reliability, early fault detection, and better energy utilization. Experimental validation confirms the converter's ability to maintain consistent performance under varying load conditions, demonstrating its effectiveness in electric bike applications. The optimized design contributes to extending battery life, reducing heat dissipation, and improving overall operational efficiency. This research supports the development of sustainable and energy-efficient transportation solutions by addressing critical power management challenges in electric mobility. Future advancements could explore AI-driven control strategies to further optimize power distribution and efficiency. Additionally, incorporating advanced semiconductor materials, such as SiC or GaN, could enhance switching performance, reduce thermal losses, and improve overall system compactness, making Hybrid Electric Bikes even more efficient and practical for widespread adoption.

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