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Design and development of body electrical system and controller temperature control system for electric motorcycles

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Overheating
Safety and reliability

Abstract

The rapid evolution of technology has transformed the automotive industry, transitioning from internal combustion engines to electric vehicles (EVs) to reduce greenhouse gas emissions and dependence on fossil fuels. This study focuses on developing a body electrical system for electric motorcycles by integrating components like lead-acid batteries, pulse-width modulation (PWM) controllers, waterproof DS18B20 temperature sensors, DC-DC converters, and energy-efficient LED lighting. The system is designed to comply with Indonesia's National Standards (SNI). Employing the 4D research methodology (Define, Design, Develop, Disseminate), the electrical system underwent rigorous validation and testing. Results highlight enhanced performance, improved energy efficiency, and effective thermal management. The integration of a temperature control system reduced the risk of overheating, ensuring safety and operational reliability. This research contributes to advancing EV technology, offering a framework for optimizing body electrical systems for electric motorcycles in compliance with safety and performance standards.

1 Introduction

Body Purpose The rapid advancement of technology has driven a significant transition in the automotive industry, from internal combustion engine (ICE) vehicles to electric vehicles (EVs). This shift aims to reduce greenhouse gas emissions and dependence on fossil fuels. Electric vehicles, with significantly lower emissions, offer a sustainable transportation solution while creating new economic opportunities. Governments worldwide have introduced policies and incentives, such as subsidies and investments in charging infrastructure, to support EV adoption [1–3].

In the development of electric motorcycles, key components such as electric motors, batteries, inverters, and energy management systems play a crucial role in ensuring efficiency and performance. Lithium-ion batteries remain the industry standard due to their high energy density and durability, while solid-state battery technology is being developed to enhance safety and efficiency. Advanced energy management systems further optimize energy usage, contributing to extended range and minimal energy loss [4–6].

The body electrical system is a critical component of electric vehicles, managing functions such as lighting, signaling, and safety systems. To ensure safety and reliability, this system must comply with Indonesia's National Standards (SNI), which cover aspects such as material usage, safety testing, and resistance to environmental factors like heat and vibration.

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However, many electric motorcycles today lack a cooling system for the controller, which can lead to overheating and damage during continuous use. A temperature sensor is essential for real-time monitoring of the controller's temperature and activating the cooling system when necessary. The effective integration of a cooling system significantly enhances operational efficiency and safety.

This study aims to design a reliable and efficient body electrical system for electric motorcycles that meets safety standards. By focusing on better component integration, the proposed design seeks to improve overall performance and user safety. This research is expected to contribute to advancements in EV technology, particularly in optimizing body electrical systems, addressing challenges such as thermal management, and ensuring compliance with safety standards.

2 Research Methods

The 4D model in Research and Development (R&D) is a systematic approach consisting of four main stages: Define, Design, Develop, and Disseminate. This model aims to produce valid, practical, and effective products through trials and improvements based on identified needs. This development model is commonly used in the fields of education and technology to create innovative new products and test their effectiveness before widespread implementation. Each stage in the 4D model is interconnected and continuous to ensure that the final product can be used effectively [7, 8].

This method was chosen for the study as it aligns with the requirements for designing the electrical system of an electric motorcycle, which necessitates a systematic approach to developing an effective, safe, and standards-compliant product. By utilizing the 4D model, the development of the electrical system can be carried out in stages, starting from needs analysis to testing and dissemination of results. This approach ensures that every aspect of design and implementation is thoroughly tested and refined before broader application as seen as flow diagram in Figure 1.

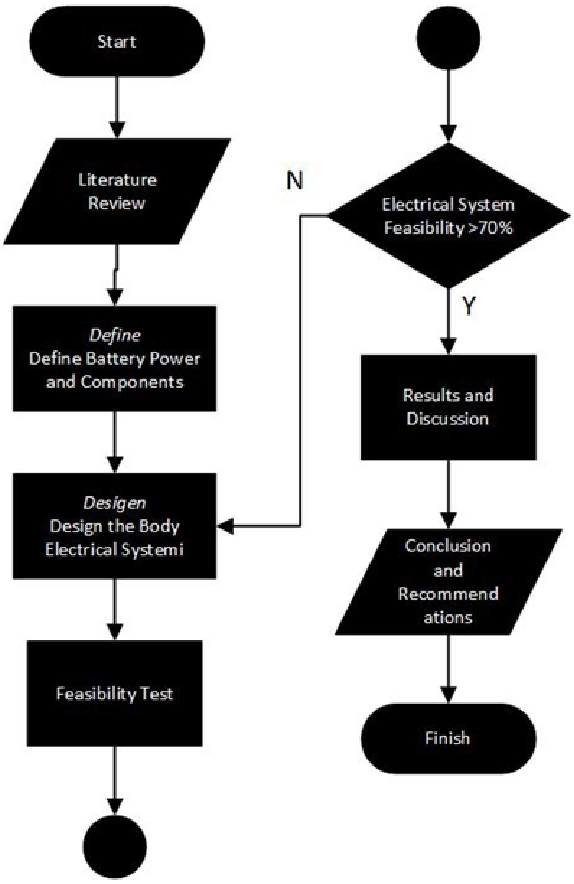

Figure 1. Flow Diagram of the Electrical System Design for an Electric Motorcycle

3 Result and Discussion

In discussion section, you should explain the result you obtain and compare it to the published paper or literature review existed. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

At this stage, the research results focus on the development of the body electrical system for electric motorcycles, which includes wiring design for several key components such as the headlamp, turn signals, horn, temperature sensor, and display panel. Each wiring system is designed to operate optimally by utilizing supporting components such as Miniature Circuit Breakers (MCBs), DC converters, fuses, and microcontrollers to ensure system stability and safety. A detailed explanation of each wiring design, including the components used and the working principle of each system, is presented as follows:

3.1 Headlight Wiring

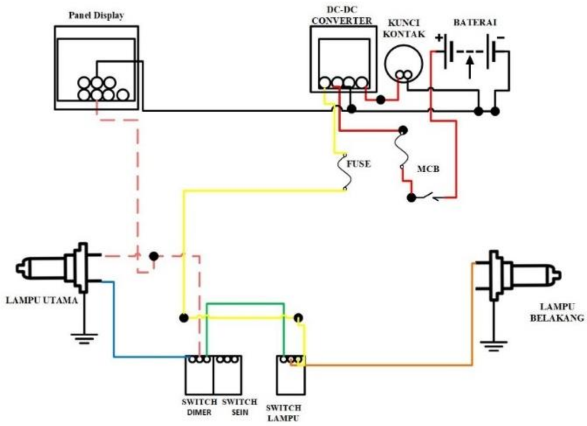

Figure 2. Headlight Wiring

The headlamp (see Figure 2) circuit consists of a battery, Miniature Circuit Breaker (MCB), fuse, ignition switch, DC converter, display panel, headlamp, taillight, dimmer switch, and light switch. The flow of electricity begins with the battery, which supplies high voltage, then passes through the MCB to protect the system from overcurrent or short circuits. Next, the current flows to the ignition switch, which controls the system's on/off state, followed by the DC converter to step down the voltage to 12V. Finally, electrical power flows to the light switch and dimmer switch, allowing for brightness adjustment (low or high beam) before reaching the headlamp.

3.2 Turn Signal Wiring

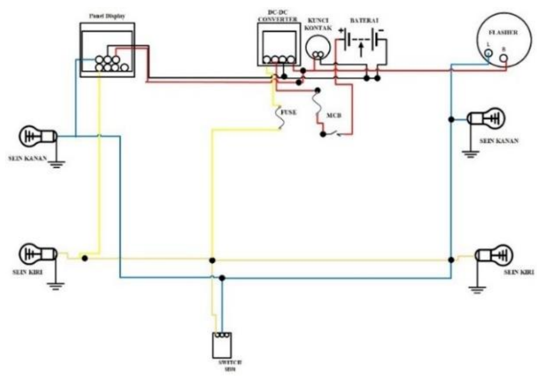

Figure 3. Turn Signal Wiring

The turn signal circuit (see Figure 3) consists of a battery, MCB, ignition switch, DC converter, fuse, turn signal switch, left and right turn signal lights (front and rear), flasher, and display panel. The flow of electricity begins from the battery, passing through the MCB to the ignition switch, and then to the DC converter. After that, the current flows through the flasher, which causes the lights to blink, followed by the turn signal switch to select either the left or right signal, and finally, the turn signal lights are activated.

3.3 Horn Wiring

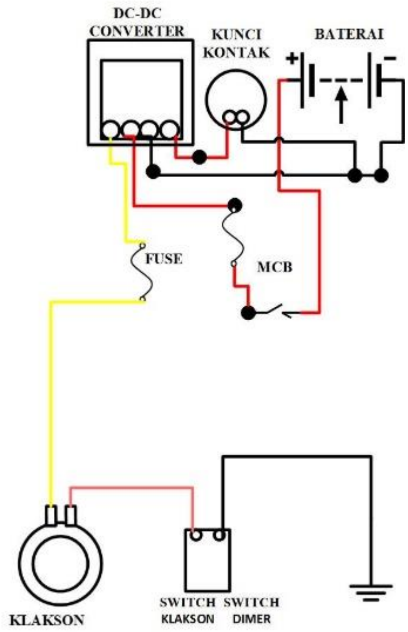

Figure 4. Horn Wiring

The horn circuit (see Figure 4) consists of a battery, MCB, ignition switch, DC converter, fuse, horn switch, and horn. The flow of electricity starts from the battery, passing through the MCB and ignition switch, then to the DC converter. Finally, the current reaches the horn switch before activating the horn.

3.4 Temperature Sensor Wiring

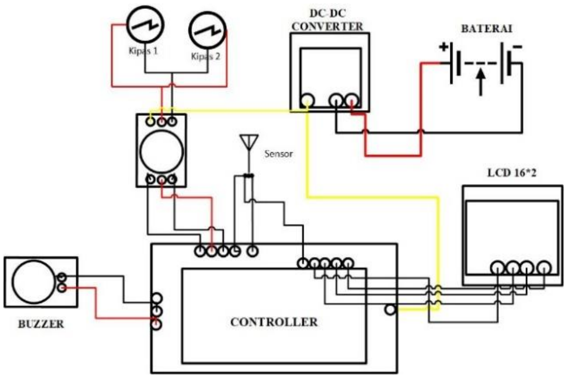

Figure 5. Temperature Sensor Wiring

The temperature sensor (see Figure 5) circuit includes a battery, DC converter, Arduino Uno controller, DS18B20 sensor, 1-channel relay, two cooling fans, LCD, and buzzer. The flow of electricity starts from the battery, passing through the DC converter to the controller, which reads data from the DS18B20 sensor. If the temperature reaches 30°C, the cooling fans activate to cool the controller. At 40°C, the buzzer sounds, warning the rider to stop and rest as the controller is overheating.

3.5 Panel Display Wiring

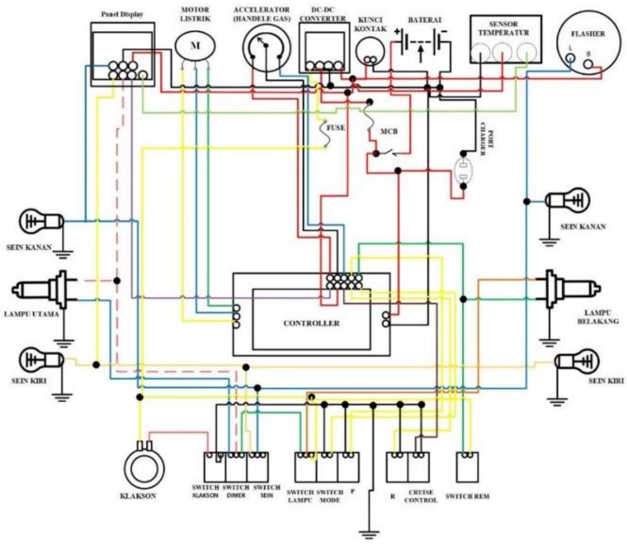

Figure 5. Panel Display Wiring

The display panel circuit (see Figure 6) integrates a battery, MCB, fuse, ignition switch, DC converter, throttle handle, electric motor, display panel, controller, turn signal lights, headlamp, dimmer switch, mode switch, cruise control switch, and brake switch. Power flows from the battery to the MCB, through the ignition switch to the DC converter, and then to the controller, which sends signals to the display panel to indicate system activity.

3.6 Electrical System Testing per Component

The measurement results of voltage, current, and power for each component are presented in Table 1, providing an overview of the performance of each electrical component.

Table 1. Electrical System Testing per Component

Component	Voltage (V)	Current (I)	Power (W)
Headlight (near)	12.56	0.83	10,4
Headlight (far)	12.78	1.00	12,78
Rear light (dim)	12.00	0.20	2,4
Rear light (brake)	12.70	0.25	3,17
Turn signals	12.00	0.84	10
Horn	12.00	1.25	15
Temperature sensor	5.00	0.15	0,75
Panel display	12.00	0.42	5,04

3.7 Electric Motorcycle Testing Without Temperature Control

The results of this test provide important information regarding the efficiency of the electric motorcycle, which can be used as a reference for design improvements or performance optimization. Table 2 presents the test results of the electric motorcycle without temperature measurements, including voltage, current, and energy consumption measurements for each type of track in Table 2.

Table 2. Electric Motorcycle Testing Without Temperature Control

Test	Measurement	Result
Flat track	Voltage (V)	63.3V
	Current (I)	2.46A
	Energy (Wh/km)	3.539
Mixed track	Voltage (V)	63.3V
	Current (I)	2.46A
	Energy (Wh/km)	3.992

3.8 Electric Motorcycle Testing with Temperature Control

In Table 3, the test results of the electric motorcycle using temperature measurements are presented for two types of tracks: straight flat tracks and mixed tracks. The measured data includes voltage, current, and energy consumption (Wh/km). By integrating temperature measurements into the analysis, this testing provides more comprehensive information to understand how environmental variables affect vehicle efficiency as seen as Table 3.

Table 3. Electric Motorcycle Testing Temperature Control

Test	Measurement	Result
Flat track	Voltage (V)	63.3V
	Current (I)	2.43A
	Energy (Wh/km)	3.75
Mixed track	Voltage (V)	63.3V
	Current (I)	2.43A
	Energy (Wh/km)	4.394

3.8 Controller Temperature Testing

The controller temperature was tested under a load of 60 kg and ambient temperature of 29°C. Results showed temperature increases with distance but remained below the safe limit of 50°C as seen as Table 4.

Table 4. Electric Motorcycle Testing Without Temperature Control

Distance (km)	Average Temperature (°C)
10	29.00
20	29.57
30	30.50
40	33.80

3.9 Validation Results

Table 5 presents the data from the product validation assessment questionnaire conducted by the validators. This assessment aims to evaluate the feasibility, quality, and technical aspects of the developed product, providing a comprehensive overview of its strengths as well as areas that require improvement.

Table 5. Validation Result

Aspect	Score
Product Completeness & Quality	4.4
Efficiency & Performance	4.6
Safety & Reliability	4.5
Presentation & Documentation	4.1

Based on the validation results, the Completeness and Product Quality aspect received a score of 88, indicating that the product is considered adequate but still has room for improvement. The Efficiency and Performance aspect achieved the highest score of 92, reflecting the product's excellence in terms of energy efficiency and functionality. Meanwhile, the Safety and Reliability aspect scored 90, signifying that the product meets good safety standards. Lastly, the Presentation and Documentation aspect received a score of 82, suggesting that while the presentation and documentation are considered good, improvements are needed to make them more informative and well-structured.

The validators provided constructive feedback on the developed product. Validator 1 stated that the product is feasible and can be used for further research, offering opportunities for future development. On the other hand, Validator 2 suggested that the electrical symbols used in the wiring design should comply with established standards such as ISO, ANSI, or JIS. This adjustment aims to align the design with international regulations, facilitating implementation and future improvements.

Discussion

Energy Consumption on a Straight and Flat Track

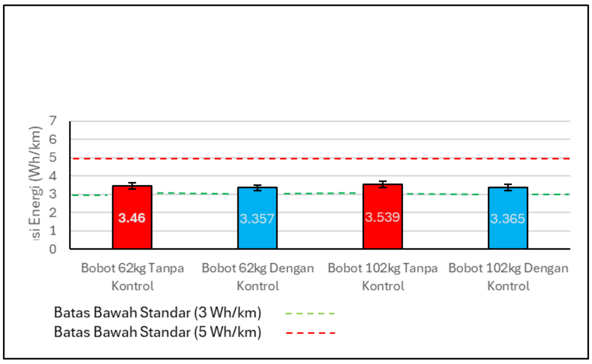

Figure 6. Energy Consumption and Efficiency

Figure 6 presents a bar chart comparing the energy consumption of the electric motorcycle Under conditions without temperature control, with a weight of 62 kg, energy consumption was recorded at 3.460 Wh/km. When the weight increased to 102 kg, energy consumption also rose to 3.539 Wh/km. Meanwhile, under conditions with temperature control, energy consumption at 62 kg was slightly lower, at 3.357 Wh/km, and experienced a slight increase to 3.365 Wh/km when the weight increased to 102 kg. The energy consumption at both 62 kg and 102 kg remained within the standard range of 3 to 5 Wh/km [9, 10].

This difference in energy consumption patterns can be explained by the effect of temperature control on the performance of the electrical system. Temperature control helps maintain the optimal temperature of key components such as the battery and electric motor, potentially improving system efficiency. This is evident in energy consumption at 62 kg, where the use of temperature control reduced energy consumption compared to conditions without control. However, at 102 kg, energy consumption remained higher despite the use of temperature control. This indicates that while temperature control helps maintain an optimal temperature, a heavier vehicle load still increases power consumption, as the electric motor has to work harder to maintain performance.

Despite the increase in energy consumption in some conditions, temperature control still provides significant benefits. This system helps stabilize component temperatures, extend the lifespan of the battery and motor, and reduce the risk of overheating, which can lead to long-term efficiency loss. Therefore, although energy consumption may increase, temperature control remains a feature that contributes to the overall reliability and durability of the system.

Mixed Track

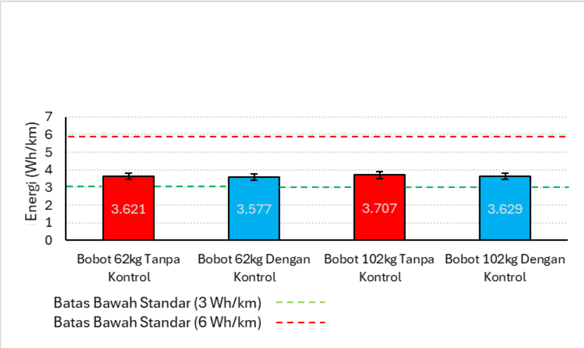

Figure 7. Mixed Track

Figure 7 illustrates a bar chart comparing the energy consumption of the electric motorcycle Under conditions without temperature control, with a weight of 62 kg, energy consumption was recorded at 3.621 Wh/km. With temperature control, energy consumption slightly decreased to 3.577 Wh/km. Meanwhile, at a weight of 102 kg, energy consumption without temperature control reached 3.707 Wh/km and decreased to 3.629 Wh/km when temperature control was used. In general, these energy consumption values remain within the standard range of 3 to 6 Wh/km [11].

The variation in energy consumption patterns is influenced by track conditions, such as inclines, declines, and speed changes due to acceleration and braking. The reduction in energy consumption for the unoccupied vehicle with temperature control indicates that the system helps maintain the optimal temperature of key components, such as the controller and battery, allowing the motor to operate more efficiently and reducing the energy used.

However, when the vehicle carries a passenger, energy consumption remains higher due to the additional load borne by the electric motor. A heavier load requires more power to maintain vehicle performance. While temperature control helps regulate component temperatures and prevent overheating, its impact on reducing energy consumption is less significant compared to when the vehicle is unoccupied. This suggests that although temperature control enhances energy efficiency, its effectiveness still depends on the vehicle's load and operating conditions.

Analysis of Temperature Control System Power Consumption

The temperature control system in an electric motorcycle significantly impacts power consumption, particularly in maintaining voltage stability and operational efficiency. Based on testing, in the without temperature control condition, the voltage difference (ΔV) was recorded at 1.0 V, whereas in the with temperature control condition, it increased to 1.9 V. Although this increase in voltage fluctuation occurs, it remains within the standard limit of $\Delta V < 2$, indicating that the electrical system remains stable. The additional load from the temperature control system, such as cooling fans, is the primary cause of this voltage fluctuation. However, since fluctuation remains within a safe range, it ensures that the electrical system's performance is not compromised [11].

Measurements of power consumption across temperature control system components and other auxiliary devices indicate the contribution of each component to the total power usage. For instance, the temperature sensor requires 0.75 W, while the display panel consumes 5.04 W. Other loads, such as cooling fans, also contribute to additional power consumption. Despite the increase in energy usage, the presence of a temperature control system provides significant benefits, including maintaining the performance of key components such as the battery and motor, as well as extending the vehicle’s lifespan. Therefore, this analysis demonstrates that the additional power consumption of the temperature control system can be regarded as an investment in enhancing system stability, reliability, and longevity.

Thermal Management

Figure 8 illustrates the changes in the temperature of an electric motorcycle controller based on travel distance and the influence of the temperature control system. The test was conducted under two rider weight conditions, 62 kg and 102 kg, with and without a temperature sensor in the controller. The results indicate that as the travel distance increases, the controller temperature rises more significantly without a sensor, whereas with a sensor, the temperature remains more stable and controlled.

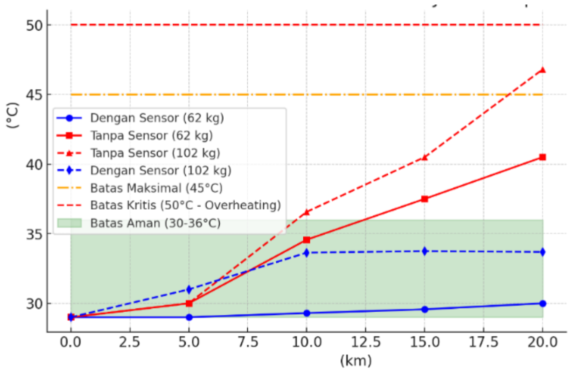

Figure 8. Graph of Controller Temperature Changes Based on Travel Distance

The testing showed that without a sensor, the temperature increased significantly as distance and load increased. At a weight of 62 kg without a sensor, the temperature rose from 30°C at 5 km to 40.50°C at 20 km, with an increase of 15.23% in the first 5 km, 8.48% at 10 km, and 8% at 15 km. In contrast, with a sensor, the temperature remained more stable, rising from 29°C at 5 km to 30°C at 20 km, with gradual increases of 1.03%, 0.92%, and 1.45% every 5 km.

At a weight of 102 kg without a sensor, the temperature increased sharply from 30°C at 5 km to 46.80°C at 20 km, with a rise of 21.90% in the first 5 km, 10.72% at 10 km, and 15.56% at 15 km. With a sensor, the temperature was more controlled, rising from 31°C at 5 km to 33.69°C at 20 km, with an initial 8.52% increase in the first 5 km, then decreasing by 0.19% at 20 km. These results indicate that without a sensor, the temperature increase is steeper, posing a risk of overheating, whereas with a sensor, the temperature remains stable or even slightly decreases, proving its effectiveness in maintaining system performance.

The controller used in this test was the WK6050AV from the Pacific E-series Classic 3-12, with an optimal operating temperature range of -10°C to 50°C and a maximum limit of 70°C. If the controller temperature exceeds this limit, the thermal protection system activates to prevent overheating. The test results showed that without a temperature sensor, the controller temperature approached the critical 50°C limit especially under heavy loads, which could trigger thermal protection. In contrast, with a sensor, the temperature remained within a safe range, ensuring optimal controller performance.

Therefore, activating the sensor at the start of the journey and using additional cooling systems, such as fans, is highly recommended to maintain an optimal temperature range, particularly under heavy loads or long-distance travel conditions.

Product Feasibility Validation

In terms of product completeness and quality, a score of 88 was obtained, indicating that the product is adequate, although there is still room for improvement. The efficiency and performance aspect received the highest score of 92, demonstrating excellence in usage efficiency and product performance. For the safety and reliability aspect, the product scored 90, indicating that safety standards have been well met. However, the presentation and documentation aspect only received a score of 82, requiring further refinement to enhance the informativeness and structure of the information provided.

Validation results from two experts showed an average score of 88, which falls into the "highly feasible" category according to the feasibility indicators in Table 1. The first validator, Febrian Arif Budiman, S.Pd., M.Pd., gave a score of 94, noting that this product has great potential for further research. Meanwhile, the second validator, Ranu Iskandar, S.Pd., M.Pd., gave a score of 82, along with a suggestion to adjust the electrical symbols to international standards such as ISO, ANSI, or JIS. The feedback from the validators has been accommodated through revisions in the system design, particularly in adjusting the electrical symbols. With these revisions, the developed product meets technical and functional aspects optimally, although some areas can still be improved.

Electrical System Maintenance

The maintenance of the body electrical system in electric motorcycles plays a crucial role in ensuring optimal vehicle performance and extending component lifespan. Therefore, structured and safety-compliant routine maintenance is necessary. The following are the steps for maintaining the body electrical system:

Inspection of Cables and Connectors

Ensure that cables and connectors are in good condition, without damage such as tearing, detachment, or corrosion.

Damaged cables or connectors can cause a decrease in system efficiency or even electrical short circuits [12].

Cleaning Switches, Connectors, and Battery Terminals

Use a specialized cleaning solution to clean switches, connectors, and battery terminals to maintain stable electrical flow.

DC-DC Converter Inspection

Conduct regular inspections to ensure that the output voltage matches the requirements of devices such as LED lights and the horn. Incorrect voltage may damage related components.

LED Light Maintenance

Regularly check the condition of LED lights, especially if their brightness starts to decrease. Ensure that the lights used comply with factory specifications for energy efficiency.

Temperature Sensor Calibration

Periodically calibrate the temperature sensor to ensure accurate temperature readings. This is crucial for preventing controller overheating, especially when the vehicle operates under high loads.

Safety Function Inspection

Check the horn, hazard lights, and other indicators to ensure they function properly.

Battery and Battery Management System (BMS) Maintenance

Ensure that there are no leaks or physical damage to the battery. The BMS must function properly to regulate charging and discharging efficiently.

Avoid excessive electrical loads to prevent overheating of the controller.

Implementation of Indonesian National Standards (SNI)

Follow safety procedures based on SNI for Rechargeable Electrical Energy Storage System (REESS) in category L electric vehicles. Conduct safety tests such as:

a. Vibration testing to ensure the REESS can withstand normal operating conditions without electrolyte leakage, component damage, or electrical short circuits.

b. Protection against external short circuits, overcharging, over-discharging, and excessive temperature.

The system must be equipped with automatic protection to prevent charging beyond the design capacity [6] (Ardika & Yogiswara, 2019).

By adhering to structured and safety-compliant routine maintenance, the body electrical system in electric motorcycles can operate optimally, safely, and efficiently.

4 Conclusion

The design and implementation of the body electrical system for electric motorcycles successfully integrate key components such as lead-acid batteries, PWM controllers, waterproof DS18B20 temperature sensors, DC-DC converters, and energy-efficient LED lighting, ensuring compliance with Indonesian National Standards (SNI) for safety and reliability. The use of energy-efficient components, such as LED lighting and a PWM controller, contributes to optimized energy consumption, with testing results confirming energy usage within the standard range for flat and mixed tracks, even with the addition of a temperature control system. Thermal management and safety are significantly improved through the integration of the DS18B20 temperature sensor and cooling system, which maintain controller operating temperatures below 50°C, preventing overheating and extending component lifespan. Voltage stability testing further demonstrates the system’s reliability, with stable performance under varying operational conditions, ensuring consistent functionality and safe operation. Expert validation yielded a high feasibility score of 88, indicating the system's readiness for implementation. Recommendations to align wiring symbols with international standards, such as ISO, ANSI, or JIS, have been incorporated to enhance broader applicability. This research provides a robust framework for optimizing body electrical systems in electric motorcycles, supporting future advancements in electric vehicle technology.

5 Acknowledgement

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