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Performance Analysis of LiFePO4 Batteries as a Replacement for Motorcycle Accumulators

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ABSTRACT

Conventional motorcycle batteries, including wet and maintenance-free types, suffer from limited lifespan, sulfation issues, and high maintenance requirements. This study proposes a LiFePO4 battery pack as a superior alternative, integrating a real-time monitoring system for enhanced performance tracking. Compared to conventional batteries, the developed system offers longer cycle life, improved thermal stability, and reduced maintenance. The battery pack consists of LiFePO4 cells (3.2V 6Ah) arranged in a 4-series 1-parallel configuration, delivering a 12V 6Ah output while maintaining compatibility with standard motorcycle battery dimensions. Experimental testing validates the system's ability to monitor current, voltage, and temperature parameters effectively. The integration of a data logging system further ensures long-term reliability and optimization of battery performance. This research contributes to advancing motorcycle battery technology by enhancing durability, safety, and real-time performance monitoring.

Keywords: LiFePO4, motorcycle battery, real-time monitoring, battery performance

1. INTRODUCTION

A vehicle is a means of transportation on the road, consisting of motorized and non-motorized vehicles. A motorized vehicle is any vehicle driven by mechanical equipment in the form of an engine or motor. The battery, or accumulator, plays an important role in motorized vehicles by providing the electrical power needed to operate various electrical systems in the vehicle [1]. Among its functions are providing energy for the engine starter, stabilizing voltage, and supplying electrical power to the vehicle's systems, such as the lights and other electronic systems.

The types of batteries commonly used in conventional vehicles are wet batteries and maintenance-free batteries, also known as dry batteries. Dry batteries do not require refilling with battery water; however, over time, the voltage of dry batteries decreases due to the reduction of sulfuric acid solution in each cell. Therefore, dry batteries are typically used only once. Based on the electrolyte solution, batteries are classified into lead-acid batteries and alkaline batteries (NiCd). The typical lifespan of a conventional battery is around 2 years. Used conventional batteries have a harmful impact on the environment, including environmental damage caused by chemicals during use and disposal.

To reduce environmental impact, large-scale recycling processes can be implemented [2], [3], [4]. However, unfortunately, not all consumers have the competence and awareness needed to support environmentally sustainable recycling processes. One possible effort to reduce environmental impact is the development of technology that uses batteries as a replacement for conventional batteries [5].

There are many types of batteries that are currently being developed, including lithium-ion, lead-acid, Nickel Cadmium (Ni-CD), and Nickel Metal Hydride (Ni-MH) batteries [6]. Among these, lithium-ion batteries are more widely used in electronic devices, particularly the lithium iron phosphate (LiFePO4) type [7], [8]. This battery has characteristics such as higher energy density [9], [10], high power density, a long life cycle [11], [12], and a relatively smaller size and weight [13],[14], [15]. LiFePO4 also has excellent energy storage stability (lasting up to 10 years or more). Another advantage of LiFePO4 batteries is fast charging [16], a high mass-to-energy ratio [17], and no memory effect [18], allowing them to produce high power density.

However, at present, battery modules as a replacement for conventional batteries have not been widely developed. Therefore, the creation of battery modules as a substitute for conventional batteries, equipped with current, voltage, and temperature monitoring systems, is highly needed now [19]. The monitoring system plays a crucial role in tracking these three parameters in real-time to ensure safety and security, maintain components, improve energy efficiency, and monitor power quality [20].

The scope of research on the development of battery modules as a replacement for motorcycle batteries includes components, technology, and performance aspects. Research findings on the development of battery modules as a replacement for motorcycle batteries from the component aspect include studies comparing the development of Li-Ion battery technology. The research shows that LiFePO4 batteries have the longest life cycle and offer the potential for component recycling to extend the battery's lifespan [21]. Another study related to other component aspects compares Li-Ion batteries based on the specific chemicals used. The research findings indicate that significant energy in lithium-ion batteries is found in the LiFePO4 type [22].

Research on the development of battery modules as a replacement for motorcycle batteries, from the technological aspect, includes studies on the design of control and monitoring tools for battery charging. The research findings show that the monitoring system is capable of monitoring both charging and discharging, as well as tracking the battery's electrical power [23]. Another study compares electrical measurements between different devices using a smart meter application. The research findings show that the use of a monitoring system can provide measurements with an error rate of less than 5% [24].

Several studies have evaluated the performance of different types of batteries and found that LiFePO4 batteries have the highest efficiency compared to wet cell and maintenance-free batteries, resulting in better overall performance. One of the studies compared the performance of lithium-ion batteries integrated with a solar power network (PLTS). The results showed that Lead Acid batteries could store energy with a maximum power of 4×10^5 W, Nickel Cadmium batteries 6.5×10^5 W, Nickel Metal Hydride batteries 8.5×10^5 W, and lithium-ion batteries 10×10^5 W. The findings indicate that lithium-ion batteries are capable of storing energy with the highest power capacity [25]. Another study compared Lithium Iron Phosphate (LiFePO4) batteries with dry and wet cell batteries. The results indicated that Lithium Iron Phosphate (LiFePO4) batteries had the highest efficiency at 96.02%, followed by wet cell batteries at 92.22%, and dry cell batteries at 84.76% [26].

Studies on energy storage capacity further indicate that LiFePO4 batteries can store higher power compared to other battery types, making them suitable for motorcycle applications. The battery to be implemented in this research is a lithium battery of the LiFePO4 type, with specifications listed in Table 1.

Table 1. Specifications of the LiFePO4 Battery

Battery Specifications	
Battery type	$LiFePO_4$
Cell dimensions	32650
Capacity per cell	6Ah
Voltage per cell	3,2V
Maximum charging voltage	3,65V
Use of voltage breakers	2,5V
Charging method	CC-CV
Filling temperature parameters	10 ºC - 45 ºC
Usage temperature parameters	-20 ºC - 65 ºC

Despite these promising characteristics, a significant research gap remains in developing modular LiFePO4 battery systems specifically designed for motorcycles, particularly in integrating real-time monitoring systems for current, voltage, and temperature. Addressing this gap is essential to enhancing battery safety, efficiency, and longevity in motorcycle applications. This study aims to develop and analyze the performance of a LiFePO4 battery module as a direct replacement for motorcycle accumulators. The proposed system features a 12V 6Ah LiFePO4 battery pack (4-series 1-parallel configuration), designed to match the form factor of conventional motorcycle batteries. Additionally, a real-time monitoring system is integrated to track key operational parameters, ensuring optimal performance, safety, and user awareness. By addressing this technological gap, this study contributes to advancing sustainable battery technology in the transportation sector, offering a longer-lasting, more efficient, and environmentally friendly alternative to conventional lead-acid batteries.

2. RESEARCH SIGNIFICANCE

The development of electric vehicle accumulators using lithium-ion batteries significantly contributes to the field of manufacturing science. These contributions include advancements in battery technology for electronic components supporting electric vehicles, management systems that enhance product efficiency, optimization processes, and automation in the motor vehicle manufacturing industry.

This research focuses on the technological development of motorcycle batteries and their real-time electrical monitoring (current, voltage, temperature). The study of using LiFePO4 batteries as a replacement for conventional accumulators demonstrates its impact on reducing environmental effects, enhancing energy sustainability, and supporting the transition toward a more sustainable society based on renewable energy.

3. RESEARCH METHODS

This study employs an experimental method. The steps involved begin with a literature review and the identification of requirements for motorcycle accumulators using LiFePO4 batteries integrated with a monitoring system. Subsequently, the process includes designing the accumulator, creating a schematic design of the electronic circuitry, and developing a 3D design for the accumulator casing. The accumulator and casing designs are created using Fusion software, while the schematic design of components is developed using EasyEDA software. Programming is carried out using Arduino Nano. The research flowchart is illustrated in Fig. 1.

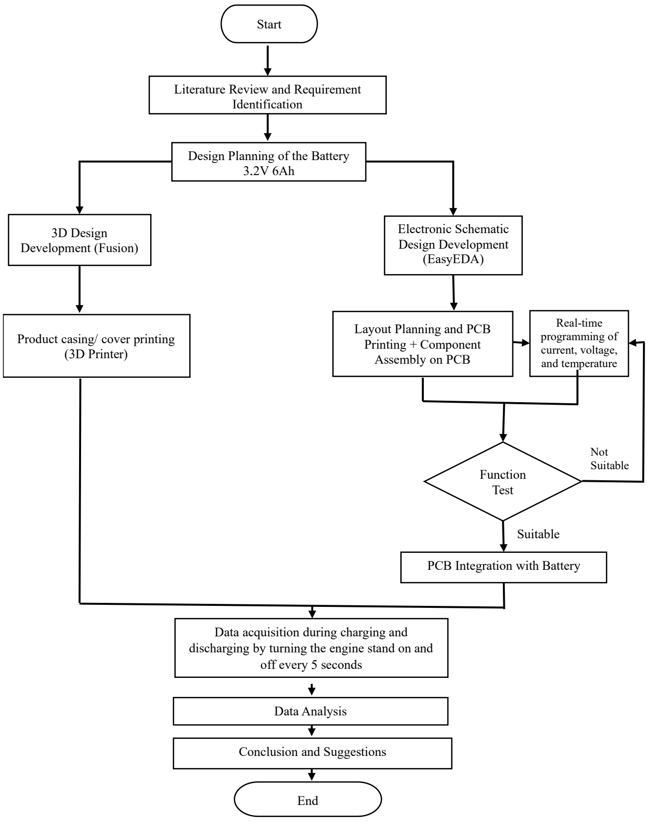

Fig 1. Research Flowchart

3.1 Material

The material used in this study are as follows:

a. LiFePO4 Battery, each cell has a voltage of 3.2 Volts and a current of 6 Amperes. In this research, four batteries are connected in series, resulting in a total of 12 Volts and 6 Ampere,
b. Current Sensor Type ACS758, this sensor is capable of measuring currents up to 100 Amperes, which is crucial since the exact current output during the starting process of the battery is unknown. Using a sensor with lower specifications may lead to unreadable data, especially in injection system vehicles, and could damage the sensor,
c. Voltage Sensor, this sensor can measure voltages ranging from 0V to 25V, which is sufficient to monitor the battery output voltage of 13V,
d. Temperature Sensor Type LM35, this sensor operates with a power supply between 4V and 30V and consumes less than 60 µA of current, making it suitable for use in a battery monitoring system,
e. OLED Display (Organic Light Emitting Diode), used to display sensor readings clearly with a minimalist design, making it easy to place,
f. Battery Management System (BMS) 4S20A, 12V, used to manage, monitor, and protect the lithium-ion battery pack [27],
g. SD Card Reader Module, this module supports input voltages of 4.5V – 5.5V and is compatible with micro SD and micro SDHC cards,
h. Memory/SD Card with 8GB Capacity, used for storing data transferred to the memory or SD card,
i. Microcontroller Arduino, the Arduino Nano Atmega 168P is used in this research due to its relatively small dimensions compared to Arduino Uno,
j. Cables, used to connect the battery to the microcontroller.

3.2 Experimental Procedure

The development of the battery as an accumulator was designed using Fusion 360 software. The design was developed based on the technical specifications of a two-wheeled motor vehicle accumulator, with dimensions of 113 mm in length, 70 mm in width, and 89 mm in height. This accumulator utilizes LiFePO4 battery cells with a specification of 3.2V 6Ah, arranged in a configuration of 4 cells in series and 1 in parallel, resulting in a total output of 12V 6Ah. Design of the battery as an accumulator is shown in Fig. 2.

Fig 2. Design of the battery as an accumulator

The electronic design in this study was created using the online platform EasyEDA.com. After accessing the website, users are prompted to register an account to gain access to the schematic and PCB layout design menu. The next step, after completing the registration and logging into EasyEDA.com, is to proceed with the schematic design process within the EasyEDA Designer menu. The microcontroller programming is conducted using the C++ programming language. In this study, the programming is focused on real-time output data of current, voltage, and temperature, which are also stored in a data logger.

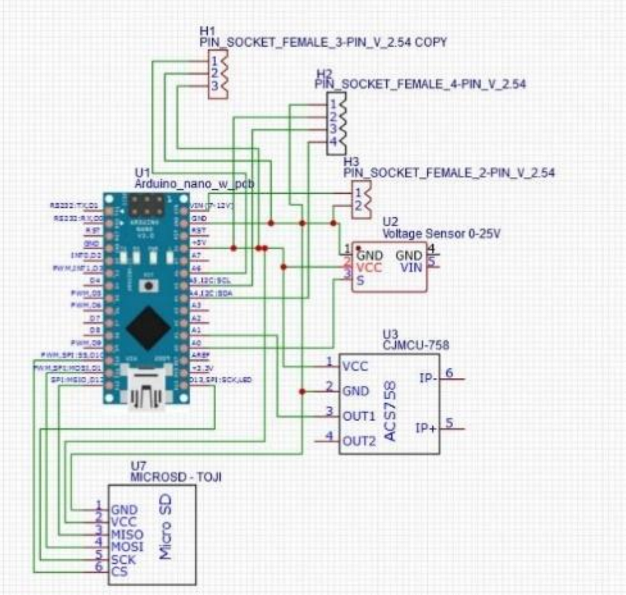

Fig 3. Schematic Design

The assembly of LiFePO4 battery components as an accumulator for motor vehicles with a monitoring system for current, voltage, and temperature consists of several stages. First, the selection of LiFePO4 battery cells is performed based on the capacity and specifications required for the vehicle, specifically 3.2V 6Ah. The battery cells are then configured in a 4-series 1-parallel arrangement to achieve the desired voltage and capacity of 12V 6Ah and are connected using spot welding.

Once the battery pack is assembled, the next step is to connect the Battery Management System (BMS) to each battery cell to monitor the voltage of each cell and balance the charge [28]. Next, the current sensor, voltage sensor, and temperature sensor are connected to the microcontroller (Arduino Nano in this study). The Arduino Nano is programmed to collect data from all sensors and display the information in real-time [29], [30], with the data also being shown on an LCD screen. After all components are connected and the monitoring system functions properly, the final step is to enclose the entire assembly within a casing.

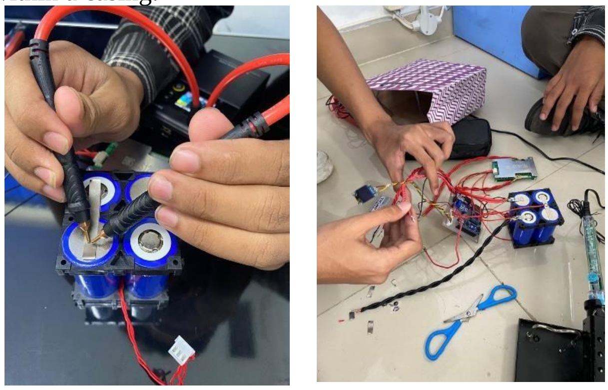

Fig 4. Component Assembly Process

The testing of the LiFePO4 battery components as an accumulator was conducted under real-world conditions, specifically on a motorcycle or engine stand. Temperature testing involved monitoring changes in the battery's temperature during vehicle operation. The collected temperature data helps ensure that the battery does not overheat. Current and voltage testing was performed by repeatedly turning the engine stand on and off every 5 seconds to simulate the dynamic conditions frequently encountered during real-world accumulator use. This process aimed to evaluate the performance of the 12V 6Ah LiFePO4 battery under varying load cycles.

4. RESULTS AND DISCUSSION

LiFePO4 batteries feature a positive electrode made of lithium iron phosphate, which provides better thermal and chemical stability compared to other types of lithium batteries. When the motorcycle is started, the LiFePO4 battery delivers electric current through the vehicle's circuit, supplying sufficient power to drive the starter motor and other electronic components. The integrated monitoring system continuously measures the battery's current, voltage, and temperature during operation. This data is collected and analyzed in real-time by a microcontroller programmed to monitor the battery's condition and ensure operation remains within safe limits. If any irregularities occur, such as excessive temperature rise, significant voltage drop, or abnormal current, the system will issue a warning or automatically cut off the power flow to prevent damage to the battery or other motorcycle components. Additionally, the collected data is stored in a data logger for further analysis, assisting in preventive maintenance and improving battery performance.

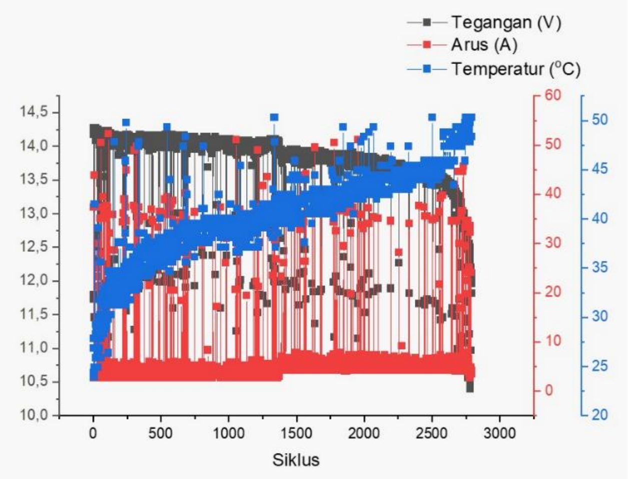

Fig 5. Data logger samples of current, voltage, and temperature of the LiFePO4 battery

Fig. 5 illustrates the comparison of current, voltage, and temperature in a LiFePO4 battery used as a motorcycle starter battery during the testing process. Based on the analysis of the test results, the voltage parameter exhibited a relatively stable pattern, ranging between 12V and 14V throughout the testing cycle. Although the voltage showed slight fluctuations, it generally remained within the usable range for motorcycle starter applications. This stable voltage trend indicates that the battery is capable of maintaining consistent power output despite variations in current and temperature. The current parameter (A) displayed higher fluctuations compared to voltage. The current often experienced significant drops, particularly below 20A, which reflects the variable load encountered by the battery during the starting process. This fluctuation pattern is normal, as the motorcycle starter requires a high initial current, followed by a decrease as the motor system stabilizes in operation. The third parameter, temperature (°C), showed a gradual increase during the testing cycle, starting from approximately 20°C and reaching over 50°C by the end of the cycle. This consistent rise in temperature indicates an increase in the battery's internal resistance over time, leading to heat generation during use. Despite the temperature increase, it remained below the safe threshold (approximately 65°C), demonstrating that the battery's thermal management system functions effectively. The comparison of these three parameters concludes that, despite fluctuating current and rising temperature, the voltage remained relatively stable, indicating good battery performance.

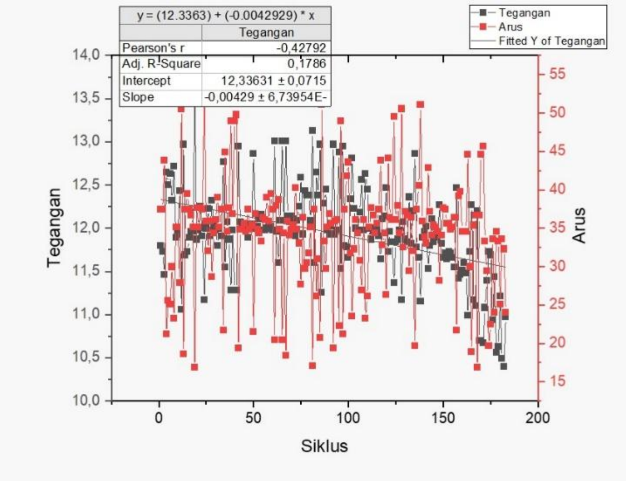

Fig 6. Data logger average of testing results of the LiFePO4 battery

Fig. 6 illustrates the relationship between current (A) and voltage (V) during the testing of the LiFePO4 battery as a motorcycle starter battery. The graph shows how each parameter changes over time throughout the testing process. The red points represent the current parameter, with the test results indicating significant fluctuations in current during the testing. The current alternates between negative (discharge) and positive (charge), reflecting the battery's charge and discharge cycles [31]. At certain points, the positive current spikes sharply, possibly due to heavy loads or increased energy demands. At the beginning of the test, the current tends to be higher, with some peaks approaching 55 amperes. However, as the cycles progress, the current appears to stabilize within a lower range, approximately 20 to 35 amperes. The black points represent the voltage parameter. The test results indicate an average voltage of around 12.5 volts, which gradually decreases as the number of cycles increases. Although there are substantial oscillations in each cycle, a clear downward trend can be observed. Based on the provided regression equation, the voltage decreases linearly with a slope of -0.00429 per cycle, meaning the voltage drops by approximately 0.00429 volts per cycle. Pearson's correlation coefficient (r) between voltage and cycles is -0.42792, indicating a moderate negative correlation between cycles and voltage. This implies that as the number of cycles increases, the voltage tends to decline. The battery's voltage remains within a relatively stable range, suggesting voltage stability despite fluctuations in current and temperature.

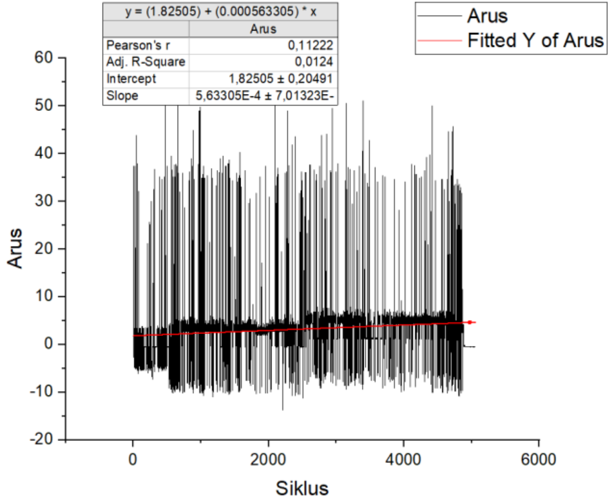

Fig 7. Current During the Start of the LiFePO4 Battery

Figure 7 illustrates that the current fluctuates significantly, particularly during the initial cycles, with spikes exceeding 40 amperes and instances of negative current, likely due to regenerative effects or transient responses within the battery system. While most current values remain in the 0 to 10-ampere range, the significant fluctuations suggest that during startup, the battery experiences highly variable loads. The ability of the battery to deliver high peak currents while also exhibiting notable variations can be attributed to rapid charge-discharge transitions, variations in motor load, and transient response characteristics of the electrical system. Despite the fluctuations, the overall trend of current shows a slight increase over successive cycles, as reflected by the positive slope (0.000563305) in the linear regression analysis. However, this increase is minimal and does not significantly impact the operational performance of the battery. Additionally, Pearson's correlation coefficient (r = 0.11222) indicates a very low correlation between current and the number of cycles, implying that the startup current remains relatively stable over time. This suggests that the battery maintains its current delivery capability without significant degradation, even after prolonged cycling. The stability of the LiFePO4 battery in maintaining its current performance highlights its suitability for motorcycle starter applications, where reliability in high-current discharge is essential.

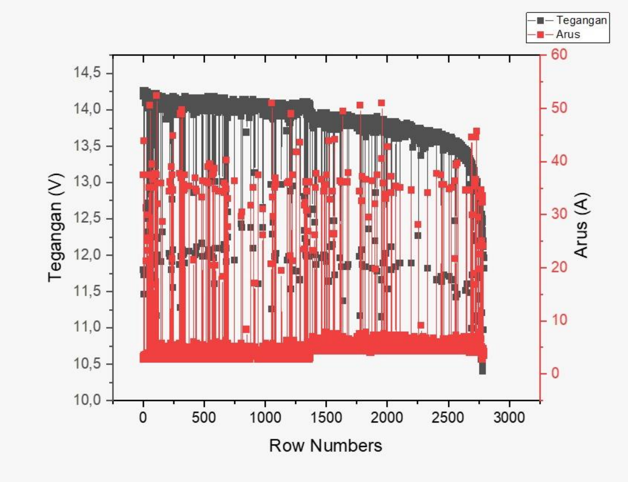

Fig 8. Voltage Drop During the Start of the LiFePO4 Battery

A deeper examination of the voltage behavior in Figure 8 reveals that, at the beginning of the test, the battery voltage ranges from 13.5 to 14 volts, indicating a nearly full charge state. However, substantial current fluctuations are observed, ranging from 0 to over 50 amperes. These high fluctuations occur due to the dynamic nature of the startup process, where sudden increases in load demand cause rapid current draw, leading to momentary voltage drops. This behavior is typical in battery-powered systems, where voltage stability is influenced by sudden load variations. As the test progresses, particularly around the 2500–3000 cycle mark, a noticeable voltage drop occurs, decreasing from approximately 14V to around 11V. This voltage decline suggests a reduction in battery capacity over extended use, which could be attributed to increased internal resistance, gradual electrode degradation, or thermal effects affecting battery efficiency. The fluctuations in current throughout the test cycles, with peaks exceeding 50 amperes at certain points and near-zero readings at other times, indicate dynamic variations in load conditions, including periods of inactivity or minimal load demand. The observed trends highlight important considerations for the long-term use of LiFePO4 batteries in motorcycle starter applications. While the battery initially demonstrates stable voltage and current performance, the gradual voltage decline over extended cycling suggests potential long-term capacity fading. This can be mitigated through optimized battery management strategies, such as improved thermal regulation, balanced charge-discharge cycles, and periodic maintenance to reduce internal resistance buildup. The resilience of the battery in maintaining its high-current delivery despite these changes reinforces its potential as a replacement for conventional lead-acid batteries, offering advantages in durability, efficiency, and reduced maintenance requirements.

5. CONCLUSIONS

The design of the developed LiFePO4 battery technology demonstrates high efficiency in utilizing the available motorcycle battery space with dimensions of 113mm x 70mm x 89mm. The integrated monitoring system helps maintain battery operation within safe limits, ensuring longer battery life and consistent performance. The implementation of the LiFePO4 battery as a motorcycle starter battery has proven to enhance the efficiency and reliability of the motorcycle's electrical system. This battery reduces the overall vehicle mass and contributes to improved fuel efficiency. Its ability to operate safely under various environmental conditions (such as high temperatures) makes it a superior solution compared to conventional batteries for the energy needs of two-wheeled vehicles.

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7. AUTHOR CONTRIBUTIONS

Conception and design: Nila Alia, Fengky Adie
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Approval of final publication: Nila Alia, Widjanarko
Resources, technical and material supports: Fengky Adie
Supervision: Fengky Adie, Eva Weddakarti

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