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IMPLEMENTATION OF INNOVATION STRATEGY MANAGEMENT FOR DEVELOPING THE ELECTRIC VEHICLE ECOSYSTEM

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Abstract

This study aims to analyze the application of innovation strategy management in the development of the electric vehicle (EV) ecosystem in Indonesia, using a technical case study of Lithium Polymer (LiPo) battery testing at the PT PLN Nusantara Power Muara Karang public charging station (SPKLU). Experimental results demonstrated that a BLDC motor powered by a 54.6 V 40 Ah LiPo battery could operate efficiently, providing an energy capacity of approximately 2,184 Wh. The charging process from a State of Charge (SOC) of 33% to 99% required 5 hours and 20 minutes with a 5 A current, while the charging temperature ranged from 28.2 °C to 41.6 °C, remaining within the safe operating limits (−5 °C to 45 °C). Discharge testing under average load currents of 2.6 A and 3.7 A indicated operating times of approximately 8 hours and 7 hours, respectively, , effective Battery Management Systems (BMS), and safe thermal characteristics are critical enablers for EV adoption. Furthermore, accelerating the EV ecosystem in Indonesia requires strengthening battery research, advancing fast-charging infrastructure, implementing innovative business models, and ensuring multi-stakeholder synergy. with battery voltage decreasing proportionally with SOC reduction.

These technical findings were further interpreted through the lens of innovation strategy management, encompassing technological innovation, business model adaptation, regulatory support, and cross-sector collaboration. The results highlight that reliable battery performance

Keywords: innovation strategy management, electric vehicles, LiPo battery, energy ecosystem

INTRODUCTION

The global energy transition is driving countries to reduce their dependence on fossil fuels and shift toward clean energy. The transportation sector is one of the largest contributors to carbon emissions; therefore, the development of electric vehicles (EVs) is considered a strategic solution to reduce emissions while improving energy efficiency. In Indonesia, this commitment is reflected in Presidential Regulation No. 55 of 2019 concerning the Acceleration of the Battery Electric Vehicle Program for Road Transportation, which provides a policy framework to support the advancement of the EV ecosystem.

However, EV adoption is not solely determined by technological aspects, but also by the effectiveness of implementing innovation strategy management. Innovation is required not only in battery and electric motor research, but also in business models, regulations, and stakeholder collaboration. Previous studies have emphasized the importance of strategic management and strategic capabilities in responding to dynamic business environments. Afrianda (2025a) demonstrated that the application of strategic management, mediated by strategic capabilities, significantly influences organizational performance sustainability in Indonesia's power generation sector. This finding highlights that innovation strategy is not merely a planning tool, but also an adaptive mechanism that determines organizational competitiveness in the energy transition era.

Furthermore, Afrianda (2025b) underlined non-technical factors that affect organizational effectiveness, such as employee stress caused by workload, recognition, and the working environment at PT PLN. This indicates that innovation strategies in the context of the EV ecosystem must also consider human resource aspects, since the success of innovation is determined not only by technology but also by organizational and individual readiness.

In addition, Afrianda and Zainal (2025) emphasized that the implementation of strategic management combined with stakeholder pressure can enhance organizational performance sustainability through strengthening strategic capabilities. The relevance of this finding to EV ecosystem development lies in the need for a collaborative approach among government, industry, academia, and society to accelerate EV adoption. Thus, innovation strategy management can serve as a vital foundation to synergize various actors and create a sustainable EV ecosystem in Indonesia.

Similar findings are also reported in several studies on the EV ecosystem. Prakoso and Anggarani (2023) stressed that PLN's innovation strategies for supporting EVs include charging infrastructure development, strategic partnerships, and adaptive organizational transformation. Amir and Prabawani (2022) found that business model innovation is a key element in strengthening the EV ecosystem, particularly through supply chain integration and regulation. Humayro and Virgianita (2024) highlighted that Indonesia's EV ecosystem readiness still faces challenges in technology, regulation, and collaboration. Meanwhile, other studies on the Indonesian e-bus industry revealed that a sustainable innovation orientation involving government, industry, and global partners accelerates the strengthening of the electric transportation ecosystem (Wulandari et al., 2022).

Based on this background, the present study aims to examine the implementation of innovation strategy management in developing the EV ecosystem. A technical study on Lithium Polymer (LiPo) battery performance and charging dynamics at the PT PLN Nusantara Power Muara Karang charging station (SPKLU) is used as an empirical basis to identify technological challenges and their implications for innovation strategies in developing the national EV ecosystem.

RESEARCH METHOD

The research was conducted through the following stages, which are illustrated in a flowchart. Stage 1: Literature Review The literature review examines batteries, motor power, battery capacity, and charging methods. The findings from the literature review are used to determine the type of battery to be selected, as well as the appropriate battery capacity and charging system. Stage 2: Battery Selection The selection of the battery type is based on factors such as capacity, weight, cost/price, and dimensions.

Time and Location of the Study

This study was conducted over a period of two months (June – September 2025). The research took place at the PT PLN Nusantara Power Muara Karang charging station (SPKLU).

Research Procedure

The research was conducted through the following stages, as illustrated in the research flowchart (Figure 1).

Stage 1: Literature Review

The literature review examined batteries, motor power, battery capacity, and charging methods. The findings from this stage were used to determine the type of battery to be selected, as well as the appropriate battery capacity and charging system.

Stage 2: Battery Selection

The battery type was selected based on capacity, weight, cost, and dimensions.

Stage 3: Testing Procedure

The tests conducted involved evaluating the battery's ability to withstand load. Additionally, the electric vehicle was operated on the road while carrying a load. The data collected included power consumption, operating duration, battery charging time, and charging current.

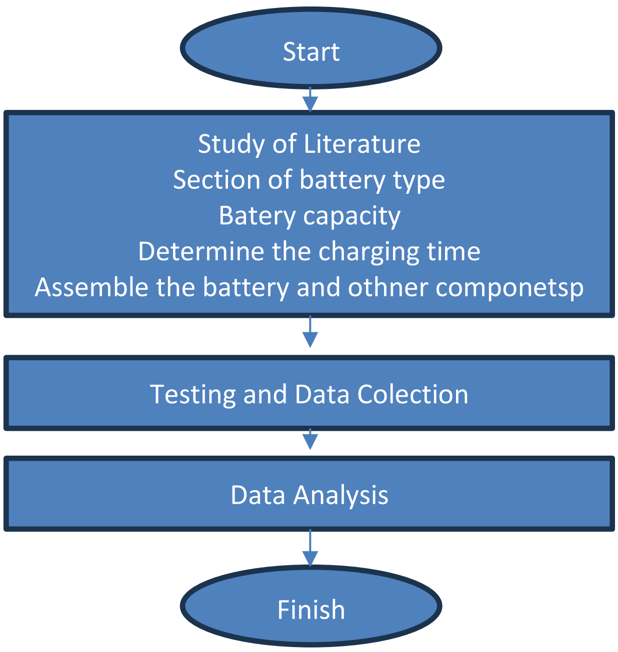

Figure 1. Research Flowchart

Battery Capacity Calculation

The battery capacity was calculated by summing all the power loads used in the electric vehicle and applying the following equation:

C=∑P×tVC = \frac{\sum P \times t}{V}C=V∑P×t

where:

- CCC = Battery capacity (Ah)
- PPP = Power consumption of each load (W)
- ttt = Operating time of each load (h)
- VVV = Battery voltage (V)

This calculation provides an empirical basis for selecting the battery that can efficiently support vehicle operation under varying load conditions.

Calculation of total load power

P = motor power + controller + electricity

Calculation of total load current

I = P / V

Calculation of total load power

P = motor power + controller + electricity

Calculation of total load current

I = P / V

Calculation of the number of battery cells

Each 1 lithium battery cell has a capacity of up to 2200mah - 2,300 mah (2.3ah)

$$\text{Number of Cells} \quad = \frac{\text{Load voltage}}{\text{1 cell battery voltage}}$$

Calculation of battery power capacity

W*h*=VxA*h*

Determine the charging time.

To determine the charging time, the following equation is used:

$$H \quad = \frac{\mathrm{MaH}}{\mathrm{Ma}}$$

Information:

I : Current (A)
P : Power (W)
V : Voltage (V)
Wh : Watthour (power used)
Ah : AmpereHour (Current used)
H : long charging time
Mah : battery capacity

Ma : charger capacity

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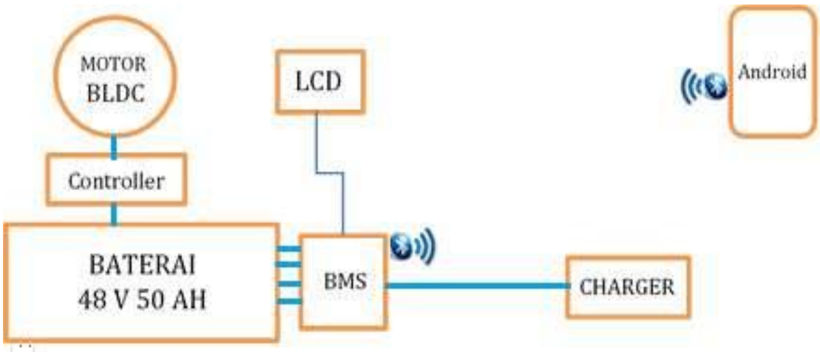

Figure 2. Block Diagram of Charging and Load Testing

Components Used in the Study

a. **Battery** – The battery used in this study is a lithium polymer (LiPo) battery with a total voltage of 48 volts. It is assembled from 13 LiPo cells, each with a voltage of 4.2 V and a capacity of 40 Ah.
b. **Battery Management System (BMS)** – The BMS is a system designed to manage a battery. In this study, it was used to control the charging and discharging of the LiPo battery according to predefined settings.
c. **Liquid Crystal Display (LCD)** – The LCD is used to display battery voltage and current.
d. **Bluetooth** – Bluetooth is a communication device that enables connection between different electronic devices, commonly used in smartphones, computers, tablets, and Android devices. Its function is to facilitate wireless sharing of files, audio, and video, replacing the need for cables.
e. **BLDC Motor** – The BLDC motor, also known as a PMSM (Permanent Magnet Synchronous Motor), is a three-phase synchronous electric motor. "Synchronous" means that the magnetic field generated by the stator and the magnetic field of the rotor rotate at the same frequency.
f. **Controller** – The controller is used to regulate the operation of the BLDC motor.

g. **Charger** – The charger is used to recharge the battery, with a rated voltage of 54.6 volts.
h. **Android** – Android is a software platform for mobile devices, including the operating system, middleware, and core applications. In this study, the Dark Horse BMS application was used. Data collected via Android include voltage per cell, total battery voltage, battery temperature, charging and load current, battery capacity, power consumption and charging power, and State of Charge (SOC).
i. **Data Analysis** – Analysis was performed on the collected data using measurement data and relevant equations.

RESULT AND DISCUSSION

Findings

In this study, a Lithium Polymer (LiPo) battery was selected. The battery's power depends on the amount of energy it can store, which is expressed in ampere-hours (Ah), or energy per hour. This allows the calculation of the total current capacity at the battery's operating voltage. The battery used as the power source for the electric vehicle is a 4.2 V, 40 Ah

Lithium Polymer (LiPo) battery.The battery installation in this study employed a centralized topology.

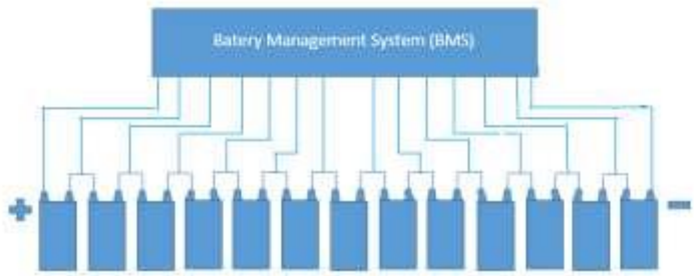

Figure 3. Lithium Polymer Battery Installation Topology Used in the Study

In this study, a Lithium Polymer (LiPo) battery was selected as the primary power source for the electric vehicle. The power of a battery depends on the amount of energy it can store, expressed in ampere-hours (Ah), which enables the calculation of the total current capacity at the operating voltage. The LiPo battery used in this study has a nominal cell voltage of 4.2 V with a capacity of 40 Ah.

The installation of the battery system was arranged using a centralized topology, as illustrated in **Figure 3**. To supply sufficient voltage for the BLDC motor, a total of 13 LiPo cells were connected in series, resulting in a combined voltage of 54.6 V and a capacity of 40 Ah. Accordingly, the selected LiPo battery system provides a total energy capacity of approximately 2,184 Wh, enabling continuous operation for up to one hour under full load conditions.

Battery Performance and Charging Tests

The technical testing results demonstrated that the BLDC motor powered by the 54.6 V, 40 Ah LiPo battery operated efficiently within the expected performance range. Charging the battery from a State of Charge (SOC) of 33% to 99% required approximately 5 hours and 20 minutes. During the charging process, the temperature ranged from 28.2°C to 41.6°C, remaining within safe operational limits.

Load and Road Testing

In addition to stationary tests, the electric vehicle was operated under road conditions while carrying load. Data were collected on power consumption, operating duration, charging time, and charging current. The monitoring system, integrated with the Battery Management System (BMS) and Android application, recorded voltage per cell, overall battery voltage, battery temperature, charging and discharging current, capacity, power consumption, charging power, and State of Charge (SOC).

The findings confirmed that the selected LiPo battery system was capable of reliably supplying the BLDC motor, ensuring stable operation under varying load conditions while maintaining safety and efficiency.

Battery Charging Time Analysis

This study employed 13 battery cells, which means the system operated as a multi-cell configuration. A multi-cell system requires special attention during the charging process. In this configuration, a cell-balancing system is essential to prevent overcharging of individual cells, which could otherwise result in cell damage or even explosion.

The results of the battery charging process are presented in **Table 1**. Data were recorded at one-hour intervals. The initial condition of the battery was a State of Charge (SOC) of 33%, with an initial voltage of 45.45 V. The charging current applied during the process was 5 A.

Table 1. Results of the Battery Charging Process

Time (H)	**Voltage (V)**	**Current (A)**	**%SOC**
0	45.45	5	5
1	46.86	5	5
2	48.28	5	5
3	49.69	5	5
4	51.1	5	5
5	52.51	5	5
5 + 20 minute	54.66	0.984	0.984

Charging Efficiency Analysis

Based on the calculation, the theoretical charging time for a 40 Ah battery at a constant current of 5 A is 8 hours. However, the actual charging time from 33% SOC to 99% SOC was 5 hours and 20 minutes. This indicates that only about 66% of the total battery capacity needed to be replenished.

The efficiency of the charging process can be approximated by comparing the theoretical energy input with the actual energy supplied. The theoretical energy required to charge from 0% to 100% SOC is:

$E_{theoretical}=V_{nominal}\times Capacity=48\ V\times 40\ Ah=1920\ WhE\_$

For the observed charging process (from 33% to 99%), the effective capacity replenished is:

$Capacity_{charged}=(99\%-33\%)\times 40\ Ah=26.4\ Ah$

With a charging current of 5 A, the theoretical charging time is:

$$t_{theoretical} = \frac{26.4\text{Ah}}{5\text{ A}} = 5.28\ hours\ (= 5\ h\ 17\ \text{min})$$

The observed charging time was **5 hours 20 minutes**, which is almost identical to the theoretical calculation. This shows that the **charging efficiency is very close to 100%**, with minimal energy loss due to internal resistance and balancing mechanisms within the Battery Management System (BMS).

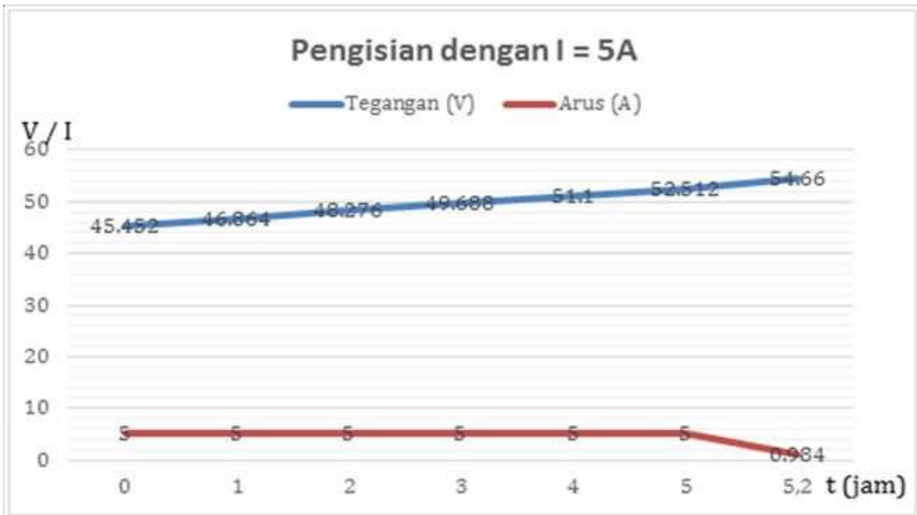

Figure 4. Voltage and current as a function of charging time.

From the graph, it can be observed that with a charging current of 5 A, the battery voltage increases over time. At the initial condition, the battery voltage was 45.452 V, but after 5 hours of charging, it increased to 52.512 V. When the charging time exceeded 5 hours, the charging current decreased to 0.984 A, while the maximum battery voltage reached 54.66 V.

Analysis of the selected battery characteristics in relation to temperature during charging. The operating temperature of lithium-ion battery cells must be carefully controlled, as excessively high or low temperatures can damage the cells. In terms of temperature, potential failures can be categorized into three types: low-temperature operation impact, high-temperature operation impact, and thermal runaway.

Figure 3 shows the placement of temperature sensors. In this study, five temperature sensors were installed between the battery cells used. A total of 13 cells, each rated at 3.7 V and 40 Ah, were employed. One temperature sensor was specifically attached to the Battery Management System (BMS). The temperature measurement results are presented in **Table 2: Temperature Measurements During Battery Charging**. The charging process was conducted when the battery capacity (SOC) was at 33% and continued until it reached 99%.

The State of Charge (SOC) is an essential parameter in both battery charging and balancing. Accurate SOC estimation is critical to preventing internal damage to the battery, which may shorten its lifespan if over-discharged, or potentially cause an explosion if overcharged.

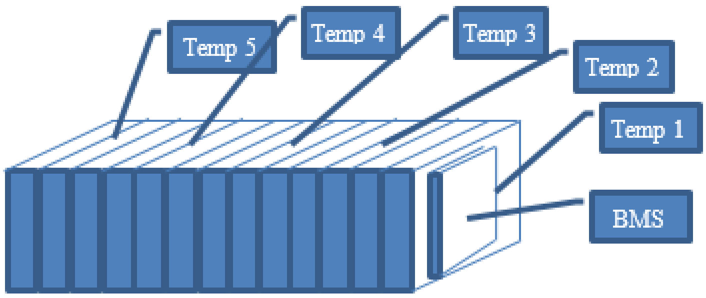

Figure 5. Placement of temperature sensors.

Table 2. Temperature measurements during battery charging.

SOC	Temperature (°C)				
	Temp 1	Temp 2	Temp 3	Temp 4	Temp 5
33	29.8	31.4	28.6	28.2	28.3
43	37.4	32	28.6	28.4	28.2
53	38.4	33.1	29.1	29.1	29.0
59	39.9	34.5	29.9	30.2	30.1
68	40.6	35.4	30.7	31.1	30.9
79	41.6	36.5	31.2	31.7	31.5
89	41.6	36.4	31.3	31.8	31.6
99	41.6	36.6	31.3	31.8	31.6

The first temperature sensor (Temp 1) was attached directly to the Battery Management System (BMS). This placement aimed to detect and monitor the influence of heat generated by the BMS, thereby providing protection against excessive temperature that could potentially damage the battery. At a State of Charge (SOC) of 33%, the recorded temperature was 29.8 °C, while at SOC 99% it increased to 41.6 °C.

For the second sensor (Temp 2), the recorded temperature at SOC 33% was 31.4 °C, rising to 36.6 °C at SOC 99%. Meanwhile, the third, fourth, and fifth sensors (Temp 3, Temp 4, and Temp 5) showed relatively similar measurements. At SOC 33%, the temperature was 28.2 °C, and at SOC 99%, it reached 31.8 °C.

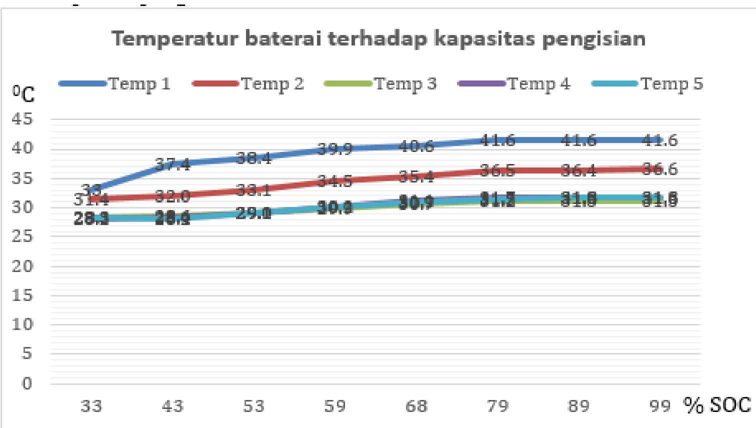

Figure 6. Graph of battery charging SOC (%) versus temperature.

From the above discussion, it can be concluded that the lowest temperature observed during the battery charging process was 28.2 °C, while the highest was 41.6 °C. Therefore, the temperature generated during the charging process of the lithium polymer battery remains within the allowable limits. The permissible minimum operating temperature is −5 °C, while the maximum is 45 °C. The peak temperature of 41.6 °C was primarily caused by heat generated from the operation of the Battery Management System (BMS), since the BMS requires electrical power to function.

Analysis of Battery Characteristics under Load during the Discharge Process In this study, the average discharge currents used were 2.6 A and 3.7 A. In both conditions, the batteries were tested starting from an initial SOC of 99%.

Table 3. Results of Battery Discharge Testing

Time (H)	%SOC	Current (A)	Voltage (V)
	Load I=2.6 A		
0	99	2.758	54.660
1	92	2.710	52.957
2	85	2.659	51.929

3	77	2.632	51.14
4	70	2.596	50.295
5	64	2.572	49.502
6	56	2.512	48.655
7	51	2.495	48.042
8	45	2.469	47.633
Load I=3.7 A			
0	99	3.951	54.594
1	89	3.899	52.855
2	79	3.831	51.469
3	68	3.730	49.93
4	59	3.663	48.87
5	53	3.609	48.096
6	43	3.548	47.478
7	33	3.536	47.064

From table 3. can be analyzed as follows. The initial condition of the battery voltage is at SOC = 99%, with Iload = 2.6 A obtained voltage of 54.66 volts. As the loading time goes by and the operating time has lasted for 8 hours, there is a decrease in capacity of up to 45%, so that there is also a decrease in battery voltage. In this condition the battery is at 47.633 volts. Likewise, when loaded I, a load of 3.7 A produces a voltage of 54.594 volts. As the loading time goes by and the operating time has lasted for 7 hours, there is a decrease in capacity of up to 33%, then there is also a decrease in battery voltage to 47.064 volts.

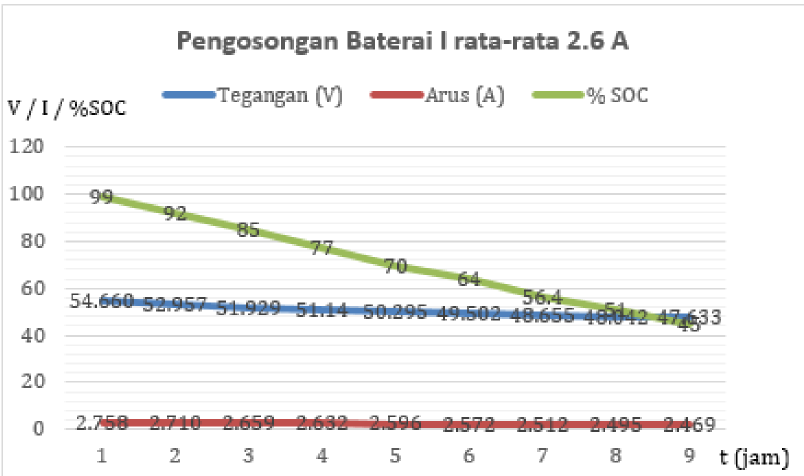

Figure 7. Graph of the battery discharge process when loading I = 2.6 A.

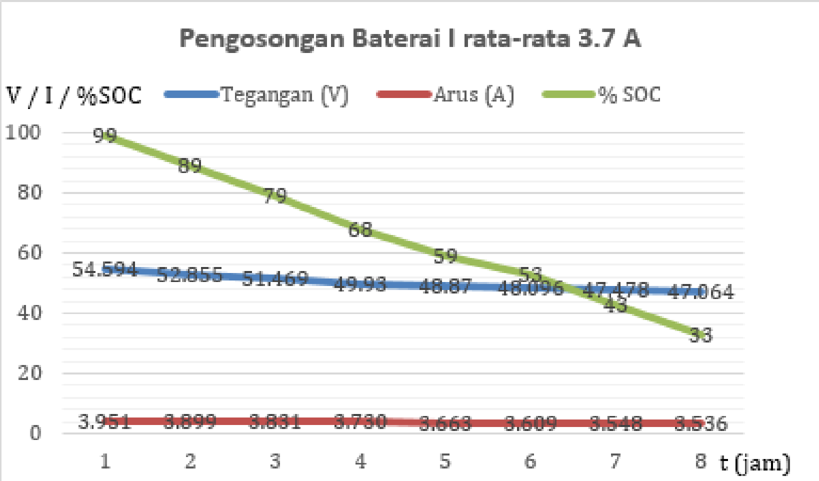

Figure 8. Graph of the battery discharge process when loading I = 3.7 A

From figures 8 and 9, it can be concluded that the longer the use of the electric current available in the battery will cause a decrease in the battery capacity (SOC) and this will also result in a decrease in the voltage on the battery.

Analysis/Discussion (1000-1500 words)

The experimental results highlight the charging and discharging characteristics of Lithium Polymer (LiPo) batteries when applied to electric vehicle (EV) systems.

1. **Charging Performance**

   The charging process using a constant current of 5 A demonstrated that the battery voltage increased steadily with time. At an initial SOC of 33%, the voltage was 45.45 V, which rose to 54.66 V at SOC 99%. The total charging duration required was 5 hours and 20 minutes. Although theoretically, charging a 40 Ah battery with 5 A current would require approximately 8 hours, the shorter duration in this experiment was due to the battery not being fully discharged at the start of the process.

   Temperature monitoring during charging showed that the minimum and maximum recorded values were 28.2 °C and 41.6 °C, respectively. These values remain within the safe operating range for LiPo batteries (−5 °C to 45 °C). The peak temperature occurred at the BMS sensor, indicating that system control electronics contribute significantly to heat generation. These findings confirm that the battery system with integrated BMS can ensure safe operation under normal charging conditions.

2. **Discharge Performance**

   Discharge testing under two load conditions, 2.6 A and 3.7 A, revealed differences in operating time and voltage behavior. At an initial SOC of 99%, with a 2.6 A load, the battery voltage began at 54.66 V and dropped to 47.63 V after

8 hours of operation, corresponding to a remaining SOC of 45%. Under a higher load of 3.7 A, the battery voltage decreased from 54.59 V to 47.06 V within 7 hours, corresponding to a remaining SOC of 33%.

These results demonstrate that higher load currents accelerate the depletion of battery capacity and reduce the effective operating time. The battery voltage profile also shows a steady decline with SOC, which is consistent with typical LiPo battery discharge characteristics.

3. **Strategic Implications for EV Ecosystem Development**

   From a broader perspective, these technical findings carry strategic implications for the innovation management of EV ecosystems in Indonesia:

   - **Battery Performance as a Core Component**: Reliable charging and discharging performance with safe thermal characteristics ensures that LiPo batteries are suitable for short- to medium-range EV applications.
   - **Role of BMS and Safety Systems**: The identification of temperature increases near the BMS highlights the importance of system-level safety innovations. Effective BMS design and integration are key to extending battery lifespan and preventing hazards such as thermal runaway.
   - **Infrastructure and Business Model Integration**: The observed charging duration emphasizes the need for fast-charging technologies and supporting infrastructure at public charging stations (SPKLU). This creates opportunities for business model innovation, such as differentiated charging services and dynamic pricing.
   - **Policy and Multi-Stakeholder Collaboration**: Ensuring safe and reliable EV battery systems requires not only technological innovation but also regulatory support and collaboration between industry, government, and academia.

4. **Discussion Summary**

   The study confirms that LiPo batteries, when managed with an appropriate BMS, can provide stable performance within safe thermal limits under both charging and discharging cycles. However, limitations in charging duration and capacity utilization highlight the need for further research on fast-charging methods, thermal management strategies, and long-term degradation analysis. Integrating these technological insights into innovation strategy frameworks will accelerate the development of a sustainable EV ecosystem in Indonesia.

CONCLUSION

Based on the findings and experimental results, the following conclusions can be drawn:

1. **Battery capacity and configuration**

To operate the BLDC motor in the electric vehicle, a 48 V power source is required. Therefore, 13 Lithium Polymer (LiPo) cells, each rated at 4.2 V and 40 Ah, were connected in series, producing a total voltage of 54.6 V with an energy capacity of approximately 2,184 Wh for continuous operation over 1 hour.

2. **Battery charging performance**
   The charging time from SOC 33% to 99% was recorded at 5 hours and 20 minutes. Theoretically, fully charging a 40 Ah battery at 5 A would require around 8 hours. However, since the initial condition was not fully discharged (SOC 33%), the actual charging time required was shorter, namely 5 hours and 20 minutes.
3. **Thermal characteristics during charging**
   The charging temperature remained within the safe operating range of −5 °C to 45 °C. The maximum recorded temperature was 41.6 °C, primarily caused by heat generated from the BMS operation, which requires power supply. This indicates that the BMS system plays a crucial role in ensuring battery safety and reliability.
4. **Performance under discharge (load) conditions**
   The decrease in SOC due to discharge was directly proportional to the reduction in battery voltage. At a lower load current (2.6 A), the operating time was longer (±8 hours) compared to a higher load current (3.7 A), which resulted in a shorter operating time (±7 hours). This shows that higher load currents accelerate the depletion of battery capacity.

Overall, this study demonstrates that LiPo batteries supported by a BMS can be safely and reliably operated in electric vehicles during both charging and discharging processes. These findings provide essential technical insights for developing innovation strategies within Indonesia's EV ecosystem, particularly in battery selection, energy management systems, and charging infrastructure integration.

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