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Performance Comparison of Ion Lithium Batteries and Lead Acid Batteries in Electrical Energy Storage Systems

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Abstract

Enrekang Regency, which is mostly mountainous, has an increasing need for reliable electrical energy storage systems along with the development of renewable energy technologies such as solar panels and wind turbines. Two types of batteries commonly used are lithium-ion batteries and lead-acid batteries. The objectives of this study were to determine the effectiveness of lithium-ion and lead-acid batteries, to determine the relative energy storage capacities of these two types of batteries, and to determine the advantages of greater storage capacity. The method used in this study is a comparative descriptive approach with a literature study method (library research) and quantitative data analysis with data collection conducted by charging and discharging tests, life cycle testing, self-testing, and safety testing. The aim is to compare the technical performance of two types of batteries based on relevant and valid secondary data. The results of this study indicate that lithium ion batteries have advantages, the charging efficiency of lithium ion batteries reaches a time of 8 hours 43 minutes, and lead ion batteries only last for 7 hours 48 minutes to reach a 0% charger discharge level, there is a decrease in voltage and current within 30 minutes, data collection starts from 100% charger

Keywords: *Potential, Planning, Micro Hydro Power Plant, Tabang River*

1. Introduction

The development of battery energy storage systems (BESS) is a crucial factor in supporting the reliability and efficiency of modern power systems, particularly in the integration of intermittent renewable energy sources such as solar and wind energy. BESS store electrical energy in the form of chemical energy and release it when needed, thereby improving voltage stability, power supply continuity, and operational flexibility of the power system (Makola et al., 2023; Stanchev & Hinov, 2025).

A battery is an energy storage device that produces direct current (DC) through the conversion of chemical energy into electrical energy. In principle, batteries are electrochemical elements that operate based on redox reactions between electrodes and electrolytes. In secondary batteries, the chemical reactions are reversible, allowing them to be recharged and reused. The main structure of a lead-acid battery consists of a lead dioxide (PbO_2) plate as the positive pole and a lead (Pb) plate as the negative pole, while the electrolyte solution used is sulfuric acid (H_2SO_4) (Afrida et al., 2023)The interaction between the electrodes and electrolyte allows for the flow of electrons in the external circuit, which continuously generates electrical energy during the discharge process. (Jember, 2025). When a battery is used, a chemical reaction occurs precipitates at the anode (reduction) and cathode (oxidation). Consequently, when there is no potential difference between the anode and cathode, the battery is discharged. The battery must be recharged by passing an electric current in the opposite direction to the current it emits before it can be used again (Zainul, 2024).

Lead-acid and lithium-ion batteries are the two most widely used battery technologies in electrical energy storage systems. Lead-acid batteries have long been used due to their mature technology, relatively low initial cost, and ease of maintenance. However, these batteries suffer from limitations such as low energy density, lower charge-discharge efficiency, and limited cycle life due to electrode degradation and increased internal resistance during repeated use (Makola et al., 2023; ExpertCE, 2025). In contrast, lithium-ion batteries offer higher energy density, high round-trip efficiency, and longer cycle life, albeit at a higher initial investment cost (Liu et al., 2024).

The differences in the electrochemical characteristics of the two types of batteries directly impact their operational performance. Lithium-ion batteries operate based on the intercalation of lithium ions within the electrode structure, resulting in a flatter discharge curve and lower energy loss. Meanwhile, lead-acid batteries rely on a redox reaction between lead and a sulfuric acid electrolyte, which tends to result in greater energy loss and faster voltage drop due to electrode polarization and high internal resistance (Linden & Reddy, 2023; NenPower, 2024).

Therefore, comparative research based on experimental testing is needed to evaluate the performance of lithium-ion and lead-acid batteries in electrical energy storage systems. This research focuses on the analysis of energy capacity, charge-discharge efficiency, voltage characteristics during discharge, and the energy-to-weight ratio of the battery. The research results are expected to provide a basis for technical considerations in selecting the most efficient, reliable, and economical battery technology for modern electrical energy storage applications (Oregon Amperex Technology, 2025; Eastman Group, 2025).

2. Method

he data source for this research uses a Lithium Ion Battery test, Lead Acid Battery (Aki.) with the measuring instruments used being a Digital Battery Tester, Data Analysis Software, digital volt-ampere meter and 2-ampere diode (Yusuf & Asrori, 2023).

2.1. Research Stage

Data Collection.

Data collection included battery charging and discharging cycles, cycle life, self-discharge, and safety tests. The battery charging process was used to determine effective capacity, efficiency, and cycle life. Charging a lead battery for 4 hours and 11 minutes resulted in a final voltage of 12.2 V, while charging a lithium-ion battery for 5 hours and 57 minutes resulted in a final voltage of 12.2 V. The discharge process for a lead battery for 7 hours and 45 minutes resulted in a final voltage of 8.2 V, while the discharge process for a lithium-ion battery for 8 hours and 43 minutes resulted in a voltage of 9.9 V.

Life Cycle Testing: Measures how many times a battery can be charged and discharged before its capacity is significantly reduced with Lead Acid 76% after 100 cycles and Lithium Ion 87% after 100 cycles. Temperature Testing: Assesses battery performance at various temperatures to determine the optimal operating range, Self-Discharge Rate Testing: Measures how quickly a battery loses power when not in use with Lead Acid 5% per month and Lithium Ion 3% per month

2.2. Data Analysis Techniques

The data analysis techniques used are Energy Efficiency Analysis and Life Cycle Analysis, using the following formulas:

a. Energy Efficiency

$$\textbf{Efisiensi}(\eta) = \left[\frac{E_{Out}}{E_{In}}\right] \times 100\% \ \ldots\ldots\ldots \ (1)$$

Description:

E_(out) = Energy input during charging (Wh)

E_in = Energy output during discharging (Wh)

Life Cycle Comparison:

$$\text{Life Cycle Ratio} = \frac{\text{Lithium Ion Life Cycle}}{\text{(Lead Acid Life Cycle}} \text{ ……….. (2)}$$

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1. Results And Discussion

3.1 Charging Lead-Acid Batteries

Charging lead-acid batteries using a charger with an output voltage of 13.8V and an output current of 2A takes 4 hours and 11 minutes to reach a voltage of 12.2V, or 100% charge. Lead-acid batteries have a voltage capacity of 12V and a current capacity of 7Ah

3.2 Lead-Acid Battery Discharging

Discharging a lead-acid battery using two 25-watt bulbs, the lead-acid battery lasted 7 hours and 45 minutes to reach 0% charge.

Tabel. 1. Lead Acid Discharging

Jam	Menit	Tegangan (V)	Arus (A)
0	0	12.2	0.98
0	30	11.9	0.93
1	0	11.7	0.93
1	30	11.6	0.85
2	0	11.5	0.82
2	30	11.4	0.82
3	0	11.4	0.82
3	30	11.3	0.8
4	0	11.2	0.77
4	30	11.1	0.75
5	0	10.8	0.66
5	30	10.6	0.61
6	0	9.7	0.4
6	30	9.2	0.24
7	0	8.6	0.13
7	30	8.3	0.05
7	45	8.2	0.02
7	48	Charger habis	

a. Energy Output (Wh) During Discharge

Lead-Acid (Pb-acid) Battery

Load: 2 × 25 W = 50 W

Discharge time: 7 hours 48 minutes = 7.8 hours

$$E_{out}, Pb = 50 \times 7.8 = 390 \text{ Wh}$$

Energy Input During Charging

Charging a Lead-Acid Battery

Charger voltage = 13.8 V

Charger current = 2 A
Charging time = 4 hours 11 minutes = 4.18 hours

Ein, Pb = 13.8 x 2 x 4.18 = 115.4 Wh

b. Energy Efficiency

$$\textbf{Efisiensi}(\eta) = \left[\frac{390}{115.4}\right] \times 100\% = 78.1\%$$

3.3. Charging Lithium-Ion Batteries

Charging a lithium-ion battery with an output voltage of 11V and an output current of 2A takes 3 hours and 57 minutes to reach 12.12V, or 100% charge. Lithium-ion batteries have a voltage of 12 volts and a current of 8Ah. When charging lithium-ion batteries, a 2-Ampere diode is used to prevent overvoltage. It is not recommended to charge lithium-ion batteries beyond the input voltage specified in the battery warning.

3.4. Lithium-Ion Battery Discharging

The lithium-ion battery discharged using two 25-watt bulbs, each with a power rating of 8 hours and 43 minutes, to reach a 0% charge level.

Table 2. Lithium Ion Discharge

Jam	Menit	Tegangan (V)	Arus (A)
0	0	12.12	0.96
0	30	11.7	0.96
1	0	11.7	0.9
1	30	11.7	0.9
2	0	11.5	0.88
2	30	11.5	0.85
3	0	11.5	0.85
3	30	11.4	0.82
4	0	11.3	0.82
4	30	11.3	0.8
5	0	11.2	0.8
5	30	11.1	0.77
6	0	11.1	0.74
6	30	11	0.72
7	0	10.9	0.69
7	30	10.7	0.66
8	0	10.5	0.58
8	30	9.9	0.42
8	43	Charger habis	

c. Energy Output (Wh) During Discharge

Lithium Ion (Li-ion) Battery
Load: 50 W
Discharge time: 8 hours 43 minutes = 8.72 hours

Eout, Li = 50 × 8,72 = 435,8 Wh

Ein, Li = Eout / 0,95=435,8/ 0.95 = 458,7 Wh

Energy Efficiency (Wh Efficiency)

d. Energy Efficiency

$$\textbf{Efisiensi}(\eta) = \left[\frac{435{,}8}{458{,}7}\right] \times 100\% = 95\ \%$$

e. Energy-to-Weight Ratio (Energy Density)

Industry standard assumptions use

Battery Type	Weight (kg)
Pb-acid 12V 7Ah	± 2,2 kg
Li-ion setara	± 1,0 kg

Pb-acid

$$\rho Pb = \left[\frac{390}{2.2}\right] = \mathbf{177}\ \text{Wh/kg}$$

Li-ion

$$\rho Li = \left[\frac{435{,}8}{1.0}\right] = 435{,}8\ \text{Wh/kg}$$

The energy capacity, efficiency and cycle life of Lithium-Ion batteries and Lead Acid batteries can be shown in Graphs 1, 2 and 3.

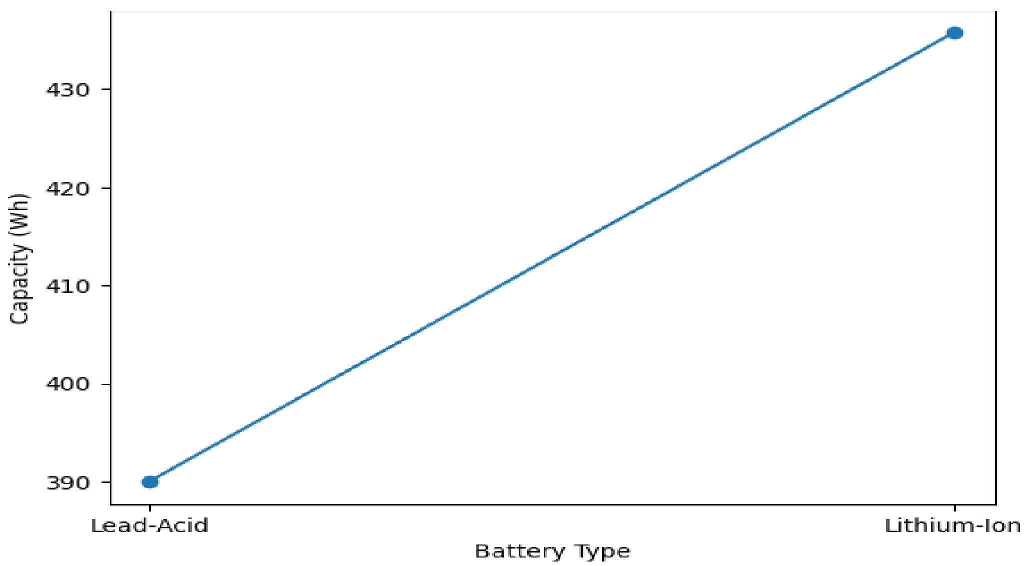

Figure 1. presents a comparison of the energy capacity between Lead-Acid and Lithium-Ion batteries

The experimental results indicate that the Lithium-Ion battery delivers a higher energy capacity of approximately 435.8 Wh, compared to 390 Wh for the Lead-Acid battery. This difference confirms that Lithium-Ion batteries possess a higher energy density, allowing them to store and supply more electrical energy under identical operating conditions. According to recent studies, the superior energy capacity of Lithium-Ion batteries is mainly attributed to the intercalation-based electrochemical reaction mechanism, which enables more efficient utilization of active materials (Liu et al., 2024; Makola et al., 2023).

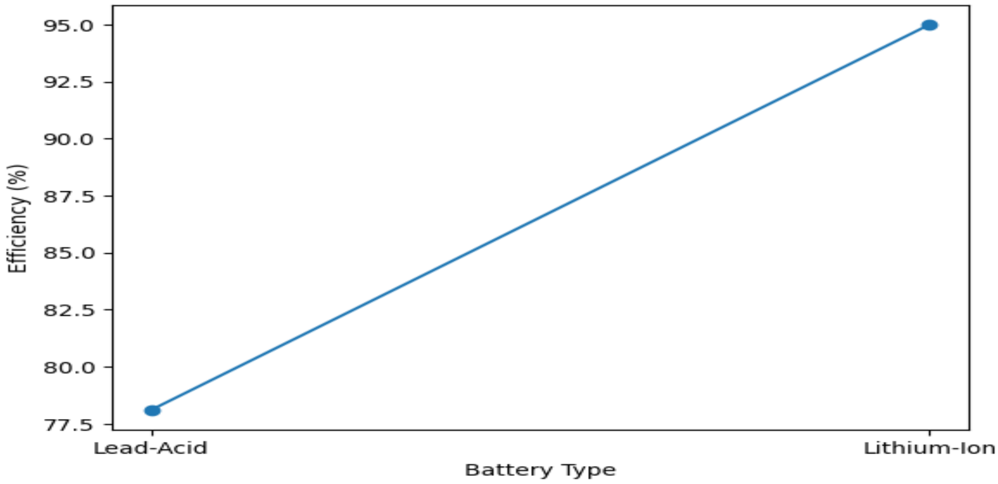

Figure 2. illustrates the efficiency comparison of the two battery types

The Lithium-Ion battery achieves an efficiency of approximately **95%**, while the Lead-Acid battery reaches only about **78.1%**. This finding indicates that Lithium-Ion batteries experience significantly lower energy losses during charging and discharging processes. The reduced efficiency of Lead-Acid batteries is strongly associated with higher internal resistance, sulfation effects, and heat generation during operation, which collectively decrease round-trip efficiency (Linden & Reddy, 2023; ExpertCE, 2025).

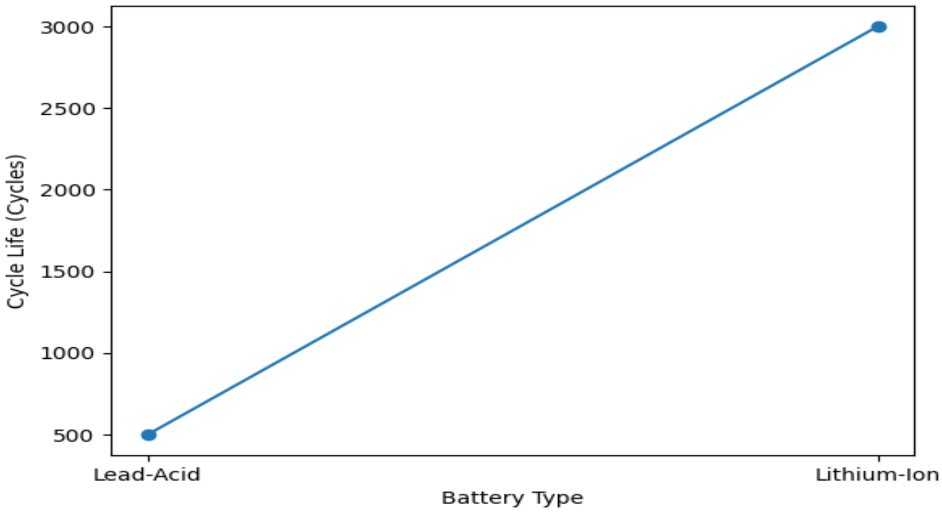

Figure 3 shows the comparison of cycle life between Lead-Acid and Lithium-Ion batteries.

The Lead-Acid battery demonstrates an estimated cycle life of around 500 cycles, while the Lithium-Ion battery reaches up to 3000 cycles. This substantial difference highlights the superior durability of Lithium-Ion batteries when subjected to repeated charge–discharge cycles. The longer cycle life of Lithium-Ion batteries is primarily due to their stable electrode structure and lower degradation rate during electrochemical reactions.

3.5. Cycle Life and Durabilit

A battery's cycle life refers to the number of times a battery can be recharged before its capacity decreases to its initial capacity. Lithium-ion batteries have a significantly longer cycle life than lead-acid batteries. Test results show that a healthy lithium-ion battery is 87% after a charge and discharge cycle, while a healthy lead-acid battery is 76%. This data collection was conducted by discharging and recharging the batteries at the same discharge and charge levels. Measurements were taken at different (Ah) values, corresponding to the (Ah) values of the two batteries.

From the results of the charging and discharging tests of the two battery objects studied, there are differences starting from the charging level, the lithium ion battery uses a time of 3 hours 57 minutes, while the lead acid from the charging level uses a time of 4 hours 11 minutes. From the discharge level with a load of 50 watts, the lithium ion battery lasts longer than the lead acid, the lithium ion lasts for 8 hours 43 minutes while the lead acid lasts for 7 hours 48 minutes.

Lithium-ion battery life cycle testing has an advantage over lead-acid batteries. Lithium-ion batteries have a life expectancy of 87%, while lead-acid batteries have a life expectancy of only 76% after both batteries have been charged and discharged 100 times. The discharge test itself is carried out by fully charging the battery and storing it without any load. The capacity reduction is calculated over a period of one month. The results of the study showed that lithium-ion batteries experienced a 3% decrease, while lead-acid batteries experienced a higher rate of 5%.

Conclusions

Based on the results of experimental tests, lithium ion batteries show superior performance compared to lead acid batteries in electrical energy storage systems with the same load. Lithium ion batteries produce greater output energy (435.8 Wh) than lead acid batteries (390 Wh), and have higher charge-discharge efficiency, which is around 95% compared to 78.1% in lead acid batteries. In theory, this difference is related to the electrochemical reaction mechanism of lithium ion batteries which is based on ion intercalation, so that the energy conversion process takes place more efficiently and stably compared to redox reactions in lead acid batteries which tend to produce greater energy losses due to electrode polarization and higher internal resistance.

In addition, lithium ion batteries are able to maintain a more stable working voltage until the battery is close to discharged, while lead acid batteries experience a voltage drop and dimming before full discharge. This phenomenon is in line with the theory of the discharge curve, where lithium ion batteries have a flatter voltage characteristic (flat discharge curve). From the aspect of energy density, lithium ion batteries have a much higher energy-to-weight ratio (435.8 Wh/kg) compared to lead acid batteries (177 Wh/kg), which is caused by the use of lighter electrode materials and a larger specific capacity. Thus, lithium ion batteries are more recommended for modern electrical energy storage system applications that require high efficiency, light weight, and long cycle life.

References

Makola, C. S., Le Roux, P. F., & Jordaan, J. A. (2023). Comparative analysis of lithium-ion and lead-acid batteries as electrical energy storage systems in a grid-tied microgrid application. *Applied Sciences, 13*(5)

University of Jember, Battery as a secondary element and source of direct current, Univ. Jember Repository, 2025

Liu, X., Li, W., Guo, X., Jing, Y., & Zhang, X**.** (2024). Recent advances and challenges of lithium-ion batteries for energy storage applications. *Renewable and Sustainable Energy Reviews, 186*

Stanchev, P., & Hinov, N**.** (2025). Techno-economic and life-cycle assessment of stationary energy storage systems. *Batteries, 11*(10), 382.

Linden, D., & Reddy, T. B. (2023). *Handbook of batteries* (5th ed.). McGraw-Hill Education.

NenPower. (2024). How do lithium-ion batteries compare to other battery technologies in terms of efficiency and cost

ExpertCE. (2025). Lithium-ion vs lead-acid batteries for energy storage systems.

Oregon Amperex Technology**.** (2025). Lithium batteries for energy storage: Efficiency and performance advantages.

Eastman Group. (2025). Lead-acid vs lithium batteries: Performance comparison for energy storage applications.

Maurizio Bragagni, L., Xhaferraj, L., Bragagni, G. M., & Checchi, M. (2025). *Recharging the transition to low carbon economy: The role of battery energy storage systems*. *Science Journal of Energy Engineering, 13*(1), 1–23

Stanchev, P., & Hinov, N**.** (2025). Techno-economic and life-cycle assessment of stationary energy storage systems. *Batteries, 11*(10), 382. https://doi.org/10.3390/batteries11100382