Analysis of Energy Storage Systems Using Lithium-Ion and Lead-Acid Batteries with Supercapacitors As Buffers

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Abstract. This research aims to compare two types of batteries, namely lithium-ion batteries and lead-acid batteries, in the application of electric vehicles. The simulation method carried out is to use the MATLAB/Simulink application to measure the performance parameters of the two types of batteries by comparing the results of state of charge, peak load current, rotations per minute of the DC engine, and peak load current. The results showed that with the lithium-ion battery, the rotations per minute of the DC motor reached 67 RPM, while the lead-acid battery only got the rotations per minute of the DC motor only 65RPM. Although the RPM provided by lead-acid batteries is relatively low compared to lithium-ion batteries, they are still relevant to use in vehicles due to their relatively low production costs.

Keywords: Batteries, lead-acid, lithium-ion, electric vehicles, energy storage systems, MATLAB/Simulink.

1 Introduction

In this global era, many issues regarding energy have emerged, ranging from new energy sources and alternative energy breakthroughs to the development of energy storage media[1]. Renewable energy sources, such as water, wind, ocean energy, biomass, and solar, can be alternative energy to replace dependence on fossil fuels that are increasingly limited in number[2]. Many countries are already utilizing renewable energy sources as power plants because they consider the impact of climate change that the use of fossil fuels can cause. In addition, the growth of renewable energy technology is also driven by the increasing price of fossil fuels and the level of CO2 emissions produced[3]. Electrical energy is a significant need that cannot be. It is advisable. to steer clear of it. Today's technologies require electrical energy storage devices[4]. Batteries are crucial as energy suppliers to all electrical components in electric vehicles. A battery is an electric cell with a highly efficient reversible electrochemical process. What is meant by reversible electrochemical reactions is that in the battery, the process of converting chemistry into electric power (discharge process) and vice versa from electric power into chemical power (charging process) using the regeneration process of the electrodes

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used, namely, by passing an electric current in the opposite polarity direction in the cell[5]. In this study, researchers will analyze the differences obtained from different types of batteries in the application of electric vehicles to determine the benefits with the addition of supercapacitors and without using supercapacitors in the MATLAB/Simulink application with several parameters that are a reference in this study.

2 Theoretical Aspects

2.1 Lithium-Ion Battery

Lithium-ion is the most widely used rechargeable battery today. Lithium-ion batteries power the devices we use daily, such as cell phones and electric vehicles. In a lithium-ion battery, lithium ions (Li+) move internally between the cathode and anode. Electrons move in the opposite direction in the external circuit[6].

2.2 Lead-Acid Battery

Lead-acid batteries were manufactured using lead-based electrodes and grids. Calcium Perhaps it is possible. It was added as an additive to provide mechanical strength. The active ingredient formulation is some lead oxide. The battery has its formulation to optimize performance. The electrolyte is a solution to dilute sulfuric acid (H2SO4). Active materials that participate in electrochemical charge/discharge include electrolyte-positive electrodes. The electrode of a fully charged battery is sponge lead (Pb), and the positive electrode is lead oxide (PbO2)[7].

2.3 Supercapacitor

Supercapacitors are electrochemical energy storage components that can store and release energy quickly, making it possible to store energy efficiently and produce high power[4]. The supercapacitor has a capacitance value much more significant than ordinary capacitors. The thing that distinguishes supercapacitors from ordinary capacitors is their structure. In supercapacitors, The electrodes utilize carbon-based materials., unlike ordinary metal capacitors[8].

2.4 Motor DC

DC (Direct Current) motors are essential electromechanical equipment that converts electrical power into mechanical power. A DC motor is a type of motor that uses direct voltage as its power source. The motor will rotate in one direction by providing a voltage difference between the terminals. If one changes the voltage polarity, the motor can rotate in the opposite direction. In comparison, the magnitude of the voltage difference at the two terminals determines the speed of the motor[9].

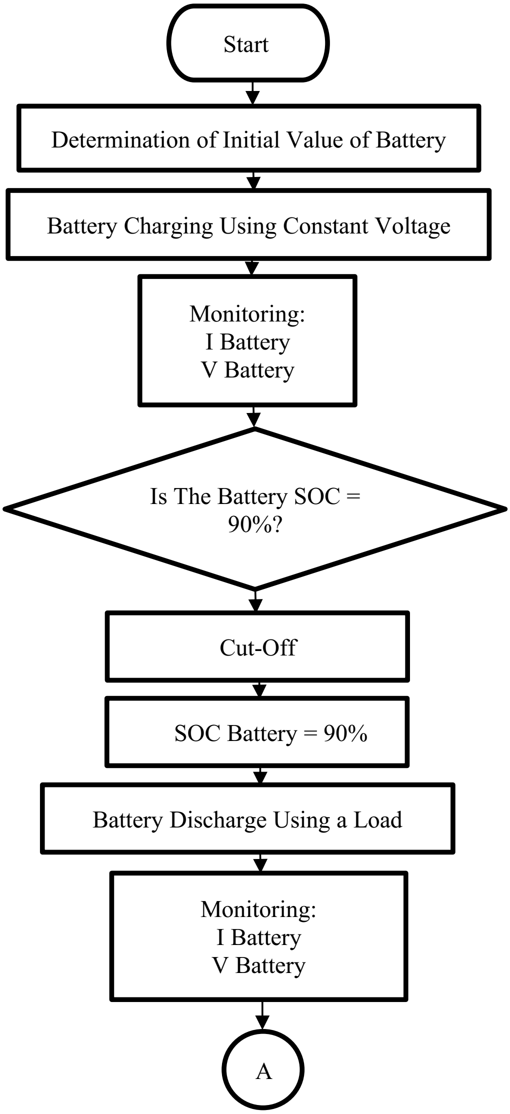
2.5 Buck Converter

The buck converter is a DC-DC converter of the voltage-lowering or step-down type. The buck converter can produce an output voltage value equal to or lower than its input voltage[10].

3 Method

3.1 Flow Diagram

This research follows the flow diagram as presented in Fig. 1



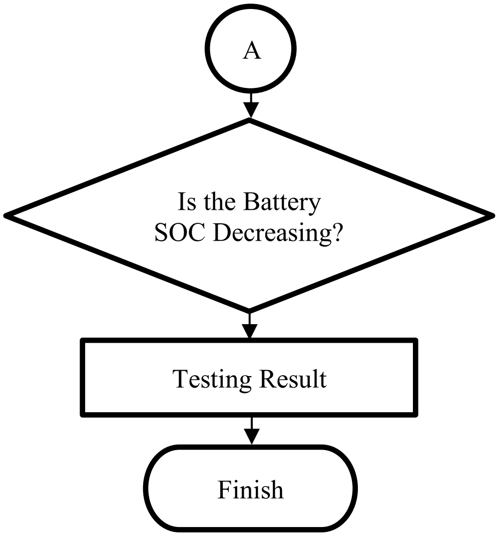


Fig. 1. Flow Diagram

90% for the supercapacitor to get space to carry out the discharge process when the battery cuts off. After that, the battery will start charging by looking at the current and voltage entering the battery and supercapacitor. When the battery has reached 90% SOC, the discharging or cut-off process will be carried out to drive the DC motor. After that, the test results stage is to collect the data from the simulation results.

3.2 Modeling Supercapacitor as Buffer in Energy Storage Systems

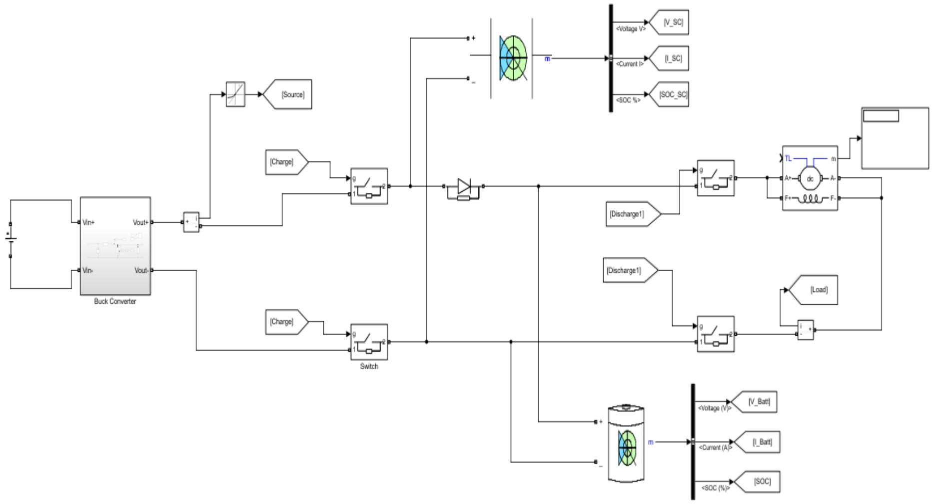


Fig. 2. Modeling Supercapacitor as Buffer in Energy Storage Systems

The final project is Getting ready for a task or situation. with the help of a newly developed circuit. Various references make understanding the basic principles of energy storage systems and buffers possible.

4 Result

4.1 State of Charge (SOC)

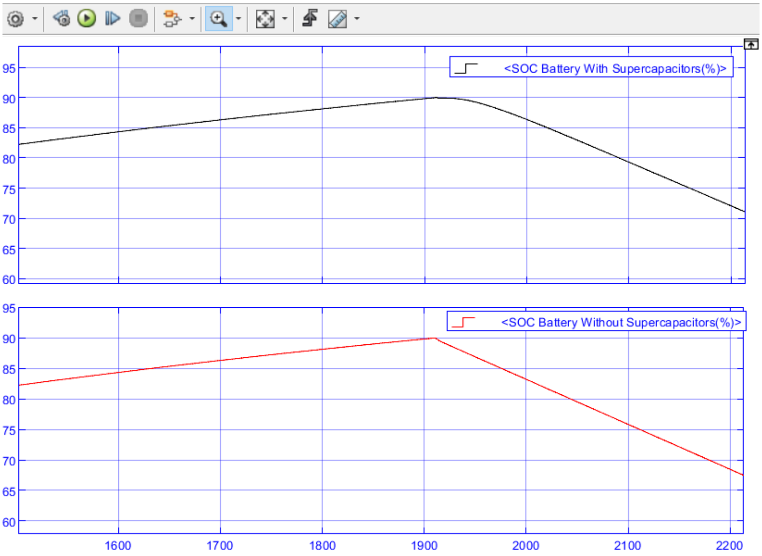


Fig 3. SOC Comparison of Lead-Acid

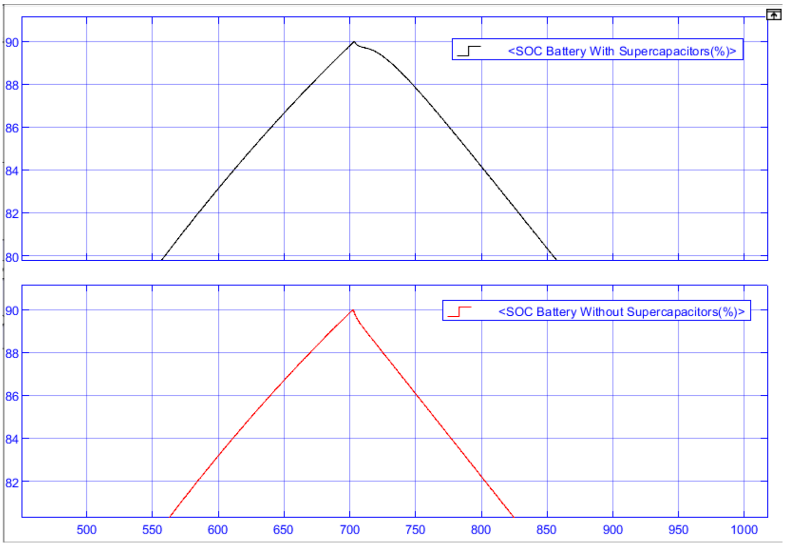


Fig. 4. SOC Comparison of Lithium-Ion.

State of Charge			
Lead-Acid		**Lithium-Ion**	
Without Supercapacitor	With Supercapacitor	Without Supercapacitor	With Supercapacitor
SOC Decreased on the Second	SOC Decreased on the Second	SOC Decreased on the Second	SOC Decreased on the Second
At 1930 Second	At 1945 Second	At 700 Second	At 725 Second

Table 1. Comparison Results of SOC Drops with Different Battery Types

In **Fig. 3**. When the lead-acid battery reaches 90% SOC, the battery will cut off from the power source and discharge to drive the DC engine until the SOC on the battery reaches the point of almost exhaustion. If a supercapacitor is absent, using a lead-acid battery to power a load immediately reduces the battery SOC. Whereas in a lead-acid battery that uses a supercapacitor, the supercapacitor will supply the load first until the power capacity stored in the supercapacitor approaches the almost exhausted position, which occurs for 15 seconds, after which the lead-acid battery will directly supply the DC motor load. In **Fig. 4**. With the addition of a supercapacitor on a lithium-ion battery type, the capacity in the battery increases by 25 seconds; after the capacity in the supercapacitor runs out, the battery will supply current to the DC motor.

4.2 Peak Battery Current

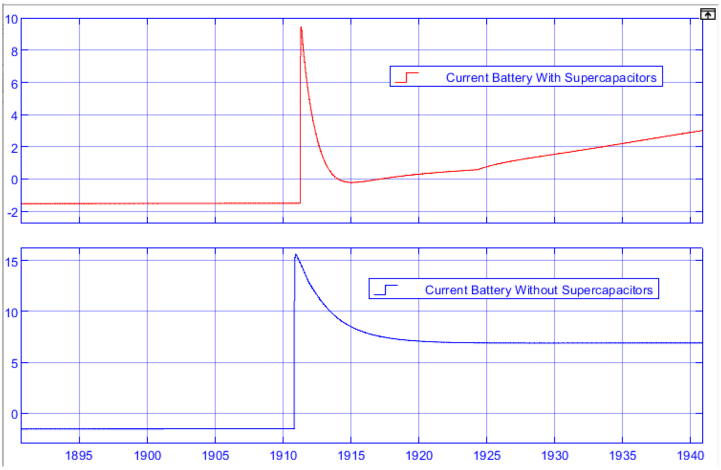


Fig. 5. Comparison of Peak Current in Lead-Acid Batteries

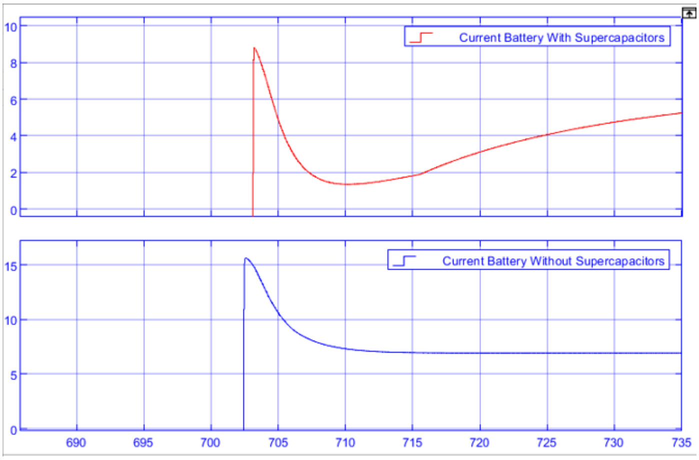


Fig. 6. Comparison of Peak Current in Lithium-Ion Batteries

Table 2. Comparison Results of Battery Peak Current with Different Battery Types

Peak Battery Current			
Lead-Acid		**Lithium-Ion**	
Without Supercapacitor	With Supercapacitor	Without Supercapacitor	With Supercapacitor
15A	9,4A	15A	8,5A

In **Fig. 5.** During the discharge or cut-off process of a lead-acid battery that lacks a supercapacitor, the battery handles the peak current directly. The current in the lead-acid battery will rise according to the required load demand of 15A. Sudden and large currents at cut-off can cause batteries with inadequate specifications to impact battery life. Meanwhile, with the help of supercapacitors during the discharge or cut-off process, the current in the lead-acid battery issued by the battery can be smaller. Because of the characteristics of supercapacitors that can meet the peak load quickly and spontaneously when needed, as well as the type of lithium-ion battery shown in **Fig. 6**. Without a supercapacitor, it can reach 15A; with a supercapacitor, it only reaches half, namely 8.5A.

4.3 Peak Load Current

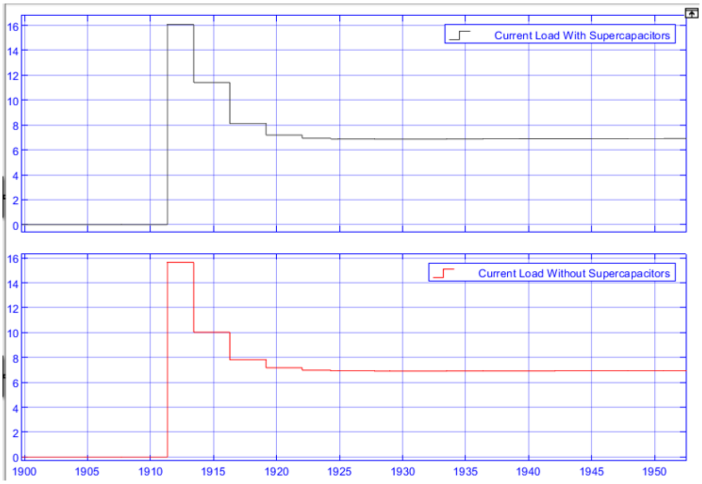


Fig. 7. Comparison of Peak Load Current of Lead-Acid Battery

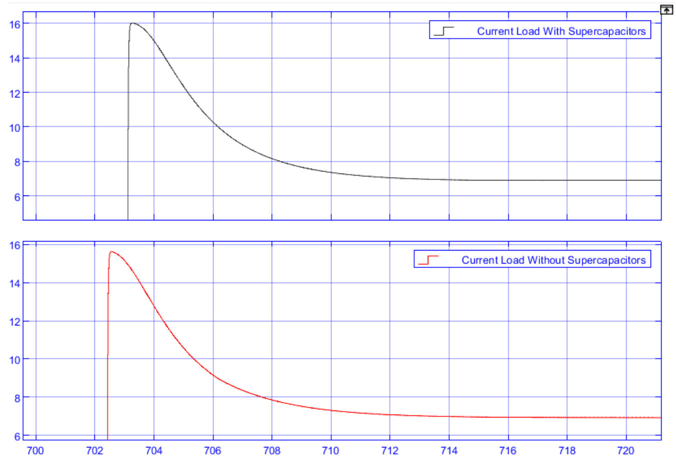


Fig. 8. Comparison of Peak Load Current of Lithium-Ion Battery

Table 3. Comparison Results of Peak Load Current with Different Battery Types

Peak Load Current			
Lead-Acid		**Lithium-Ion**	
Without Supercapacitor	With Supercapacitor	Without Supercapacitor	With Supercapacitor
15,7A	16A	15,7A	16A

In **Fig. 7.** When the lead-acid battery without supercapacitors performs a cut-off or power discharge getting 15.7A, a sudden change in load or load demand can affect the peak current on the battery; the battery needs to provide a more prominent peak current to meet the load demand from the DC motor. This high peak current can be an additional burden on the battery and can affect the life and efficiency of the battery in the long run. In contrast, the lead-acid battery with a supercapacitor can meet the peak load of 16A when there is a sudden cut-off or a sudden change in load demand; it will improve the resolution because of the supercapacitor which acts as a temporary energy storage system to drive the required load, as well as the lithium-ion battery described in **Fig. 8.**

4.4 Rotations Per Minute (RPM)

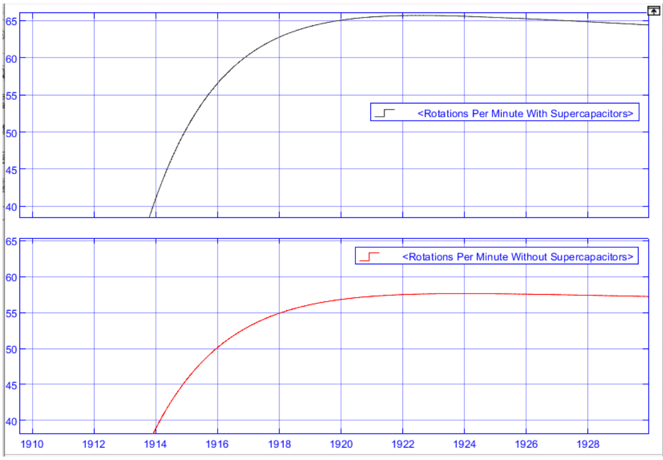


Fig. 9. RPM Comparison of Lead-Acid Batteries

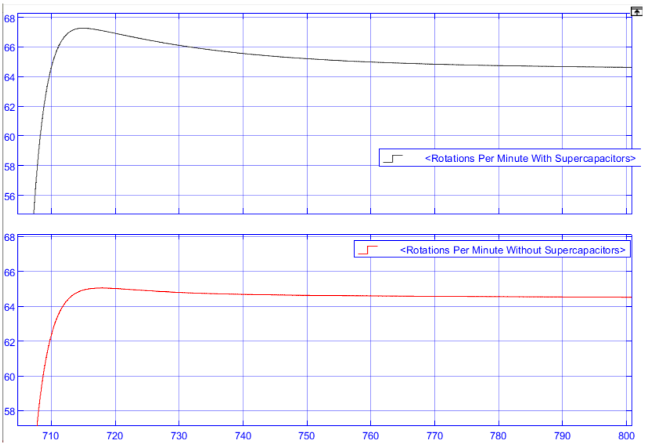


Fig. 10. RPM Comparison of Lithium-Ion Batteries

Table 4. Comparison Results of Rotations Per Minute of DC Motor with Different Battery Types

Rotations Per Minute on DC Motor			
Lead-Acid		**Lithium-Ion**	
Without Supercapacitor	With Supercapacitor	Without Supercapacitor	With Supercapacitor
58RPM	65RPM	65RPM	67 RPM

When the process of power discharge or cut-off on a lead-acid battery without a supercapacitor, the DC motor-driven speed only reaches a value of 58 RPM while the lead-acid battery with a supercapacitor reaches a value of 65RPM, while with the type of lithium-ion battery described in **Fig. 10**, without a supercapacitor can reach a value of 65 RPM, while if combined with a supercapacitor can reach a value of 67 RPM, this is influenced by the characteristics of the battery and also the influence on the supercapacitor that can meet the peak load.

5 Conclusion

1. The effect of batteries without supercapacitors and with supercapacitors is that in the presence of supercapacitors, the discharge time of lead-acid batteries increases by 15 seconds, while in lithium-ion batteries, the discharge time increases by 25 seconds, and the current that must be released to drive the load on lead-acid batteries is only 9.4A while lithium-ion batteries are 8.5A.

2. Supercapacitors can be used as a buffer in the battery energy storage system because when the battery SOC reaches 90%, the supercapacitor supplies the load first until the supercapacitor capacity is almost exhausted for 15 seconds for lead-acid batteries and 25 seconds for lithium-ion batteries, after which the battery will supply the load.
3. With supercapacitors, the efficiency of the current released by lead-acid batteries can be less, namely 9.4A, with a slight current that can increase the service life of lead-acid batteries and lithium-ion batteries that only release a current of 8.5A.
4. With supercapacitors, it can reach the maximum peak load current of 16A, which has an impact on the rotation per minute obtained, namely, with lead-acid batteries reaching 65 RPM while with lithium-ion batteries reaching 67 RPM compared to if without supercapacitors, the peak load obtained by each battery is 15.7A with the rotation per minute obtained in the use of lead-acid batteries only getting 58 RPM while lithium-ion batteries only 65RPM.

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