Circuit Design of Energy Storage System With Supercapacitor As Buffer in Electric Vehicle Application

Wahyudi Wicaksono[1], M. Afif Amalul Arifidin[2], Mariana Diah Puspitasari[3], Rafi Hafizh Hawari[4], Ilham Khafid Zarkasi[5], Sunardi Sunardi[6].

[1,2,3,4,5,6] Indonesian Railways Polytechnic, Jl. Tirta Raya, Madiun, East Java 63132, Indonesia
wicaksono.tep20202148@taruna.ppi.ac.id

Abstract. Electric vehicles are increasingly in demand as an environmentally friendly solution to reducing air pollution. Reliable and efficient energy storage is critical to running electric vehicles to work optimally. With supercapacitors as a buffer in the lead-acid battery energy storage system, it can provide power quickly in meeting load requirements due to the characteristics of supercapacitors that are spontaneous in responding to power changes that occur. The research results obtained using the MATLAB/Simulink application show that the supercapacitor energy storage system can run a DC motor at 65 RPM. In contrast, without supercapacitors, it only gets 58 RPM.

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

1 Introduction

In today's modern life, electrical energy is an inevitable necessity. Current technology requires energy storage media that can store electrical energy with a large capacity[1]. 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[2]. Commonly used storage media today are batteries, with a large energy storage capacity; batteries have the disadvantage of small output in the charging or discharging process[3]. Supercapacitors are an exciting breakthrough in the energy field because of their characteristics that can carry out fast, long-lasting charging and responsive to changes in power that occur; even with these advantages, supercapacitors also have weaknesses in their relatively low storage capacity[2]. Utilizing the advantages of both energy storage media is the right solution to achieve optimal operation and integration of renewable energy systems[4].

A. Pradipta et al. (eds.), *Proceedings of the 2nd International Conference on Railway and Transportation 2023 (ICORT 2023)*, Advances in Engineering Research 231,
https://doi.org/10.2991/978-94-6463-384-9_3

2 Theoretical Aspects

Several theoretical aspects are needed to support in compiling this research. These theoretical aspects include lead-acid batteries, supercapacitors, DC motors, and buck converters.

2.1 Lead-Acid Battery

Lead-acid batteries were manufactured using lead-based electrodes and grids. Calcium is likely added as an additive to provide mechanical strength. The active ingredient formulation is some lead oxide. Batteries have their formulations to optimize performance, and the electrolyte is a solution for diluting 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)[5].

2.2 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[1]. The supercapacitor has a capacitance value much more significant than ordinary capacitors. The thing that distinguishes supercapacitors from ordinary capacitors is their structure. Unlike ordinary metal capacitors, the electrodes were based on carbon materials in supercapacitors[6].

2.3 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 the polarity of the voltage were reversed, the direction of rotation of the motor would be reversed as well. The polarity of the voltage applied to the two terminals determines the direction of rotation of the motor. In comparison, the magnitude of the voltage difference at the two terminals determines the speed of the motor[7].

2.4 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[8].

3 Method

3.1 Flowchart Diagram

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

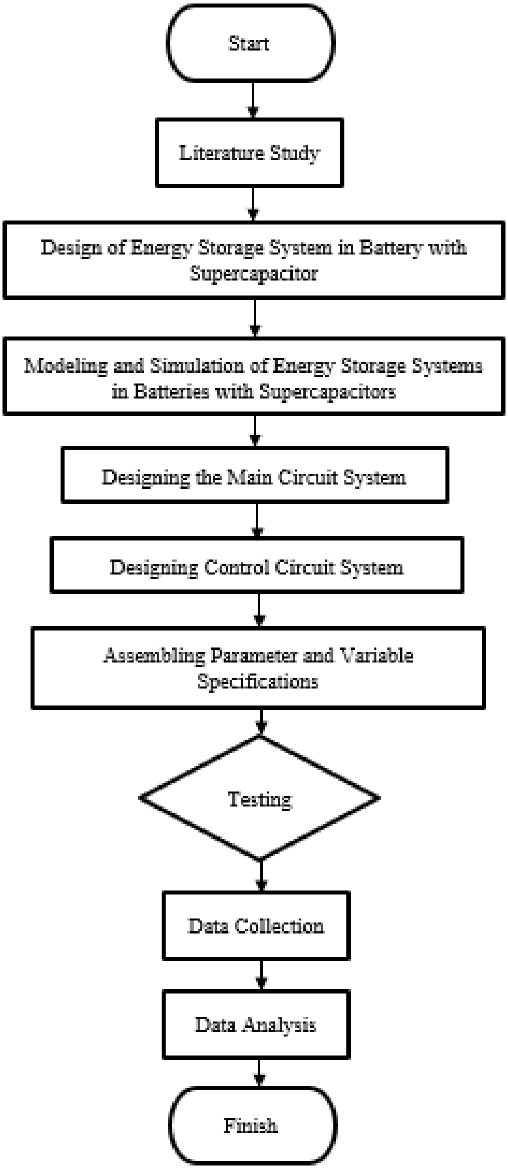

Fig. 1. Flowchart

The initial stage flowchart diagram in this research is a literature study; researchers search and find a problem by reading previous studies, then designing an energy storage system on a battery with a supercapacitor from the problem. After that, in the data collection stage, the data needed is the rotation speed of the DC motor with a supercapacitor and without a supercapacitor. After the data is collected, Analyze the differences between energy storage systems with and without supercapacitors.

3.2 Modeling Supercapacitor as Buffer in Energy Storage Systems

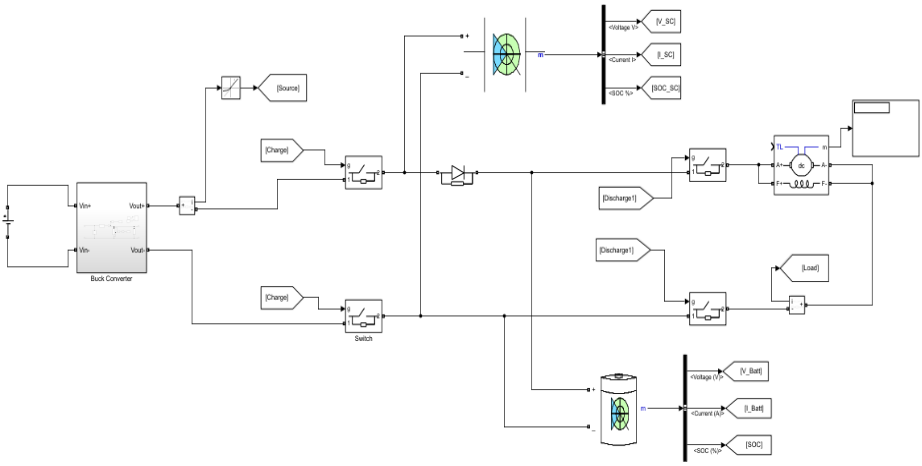

Fig. 2. Modeling Supercapacitor as Buffer in Energy Storage Systems

In preparation for this final project, researchers made a circuit that has been developed with several references that have been obtained to understand the basic principles of energy storage systems and buffers.

4 Result

4.1 Rotations Per Minute (RPM)

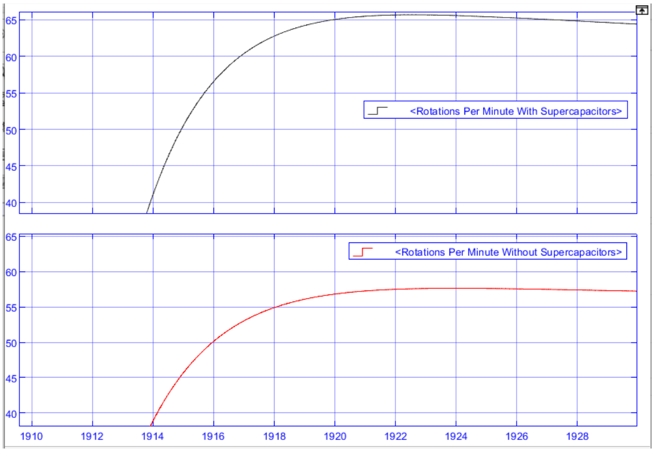

Fig. 3. Comparison of DC Motor RPM Using Lead-Acid Battery

Table 1. Lead-Acid Battery RPM Comparison Results

Rotations Per Minute on DC Motor	
Without Supercapacitor	With Supercapacitor
58RPM	65RPM

During the cut-off process on a lead-acid battery without supercapacitors, the driven DC motor only gets a rotation speed of 58 RPM. In contrast, the lead-acid battery with supercapacitors gets a rotation speed of 65 RPM.

4.2 State of Charge

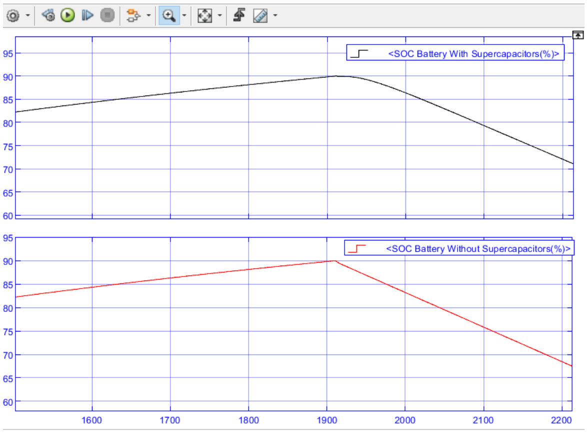

Fig. 4. SOC Comparison of Lead-Acid Battery

Table 2. Lead-Acid Battery SOC Comparison Results

State of Charge	
Without Supercapacitor	With Supercapacitor
SOC Down On Second	SOC Down On Second
At 1930 Second	At 1945 Second

When the lead-acid battery reaches the point of almost completion, the battery will cut off from the power source. The supercapacitor will act as a buffer to discharge the battery and drive the DC engine until the SOC on the supercapacitor is almost exhausted. The battery will become the leading supplier of electrical energy for the DC engine to move. When a lead-acid battery without a supercapacitor is used to drive a load or DC machine, the battery SOC will immediately decrease without any diversion to the buffer first.

5 Conclusion

Supercapacitors in the battery energy storage system can quickly make the DC motor reach peak load or maximum rotation speed. In contrast, the lead acid battery on an energy storage system with a supercapacitor DC motor can rotate at 65 RPM. In contrast, without supercapacitors, they only get 58 RPM speed due to the characteristics of supercapacitors that can provide significant power when needed to run the load. Adding supercapacitors can also make the battery last longer because the supercapacitor will meet the peak load of the load first until the power in the supercapacitor is almost exhausted, and the battery will be the leading supplier for the DC engine.

References

1. Riyanto, A. "Superkapasitor Sebagai Piranti Penyimpan Energi Listrik Masa Depan." *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, vol. 3, no. 2, 2014, pp. 56-63, doi:10.24042/jpifalbiruni.v3i2.73.
2. Suwandana, R. F., and Diah S. "Analisis Pengaruh Massa Reduktor Zinc terhadap Sifat Kapasitif Superkapasitor Material Graphene." *Jurnal Teknik ITS*, vol. 4, no. 1, 2015, doi:10.12962/j23373539.v4i1.8723.
3. Teleke, S., Oehlerking, L.J., & Hong, M. (2014). Nanogrids with energy storage for future electricity grids. *2014 IEEE PES T&D Conference and Exposition*, 1-5. doi: 10.1109/TDC.2014.6863235.
4. Atawi, I. E., Al-Shetwi, A. Q., Magableh, A. M., & Albalawi, O. H. (2023). Recent Advances in Hybrid Energy Storage System Integrated Renewable Power Generation: Configuration, Control, Applications, and Future Directions. In *Batteries* (Vol. 9, Issue 1). MDPI. https://doi.org/10.3390/batteries9010029
5. Bukhari, S. M. A. S., Maqsood, J., Baig, M. Q., Ashraf, S., & Khan, T. A. (2015, March). Comparison of characteristics--lead acid, nickel-based, lead crystal, and lithium-based batteries. In *2015 17th UKSim-AMSS International Conference on Modelling and Simulation (UKSim)* (pp. 444-450). IEEE.
6. Nurhasmia, N. "Studi Penggunaan Superkapasitor sebagai MEDIA Penyimpan Energi." *Progressive Physics Journal*, vol. 2, no. 2, 2021, pp. 79-88, doi:10.30872/ppj.v2i2.770.
7. Frank D. Petruzella., 2001, Elektronika Industri, Penerbit Andi, Penerjemah Suminto, Drs. MA., Yogyakarta.
8. Pulungan, A. B., S. Sukardi, and T. Ramadhani. “Buck Converter Sebagai Regulator Aliran Daya Pada Pengereman Regeneratif”. *Jurnal EECCIS (Electrics, Electronics, Communications, Controls, Informatics, Systems)*, vol. 12, no. 2, Nov. 2018, pp. pp. 93-97, doi:10.21776/jeeccis.v12i2.551.