

Lithium batteries/supercapacitor and hybrid energy storage systems

Huang Ziyu

*National University of Singapore, Singapore
huangziyu0915@163.com*

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Abstract: This paper mainly introduces electric vehicle batteries, as well as the application of supercapacitors, and then discusses the current research situation for hybrid energy storage systems, with a view to gaining a certain understanding and analysis. Finally, we conducted the simulation, which is based on simulink software, comparing the SOC of supercapacitor and lithium battery, current and voltage analysis, as well as the simulation of hybrid energy storage system at different speeds of the car.

1. Introduction

With the increasing excessive consumption of petrochemical energy and environmental pollution worldwide, a new round of energy revolution featuring the large-scale development and utilization of renewable energy and the rapid development of new-energy vehicles is booming. However, no matter it is clean power generation from renewable energy represented by solar energy and wind energy, or driving of new energy vehicles dominated by pure electric vehicles, energy storage devices are indispensable for energy conversion, storage and use. According to the characteristics of energy storage, energy storage devices can be divided into energy storage technology and power storage technology. Energy storage devices mainly include lead-acid battery, sodium ion battery, lithium-ion battery and liquid flow battery, etc. Power storage devices mainly include flywheel energy storage, super capacitor and lithium-ion capacitor.

At the same time, the hybrid energy storage system (HESS), which consists of energy storage technology and power storage technology, also shines brilliantly. Hybrid energy storage system is an efficient system for energy management and power management. It gives full play to the persistence of energy storage and the rapidity of power storage, which greatly improves the comprehensive performance and economy of energy storage system. And it provides an important solution for the application field with complex working conditions.

2. Electric car batteries

Classification of electric vehicle batteries:

2.1 Electric vehicle batteries are divided into these categories

- Alkaline batteries. That is, the battery whose electrolyte is alkaline water solution
- Acid batteries. That is, the battery whose electrolyte is an acidic aqueous solution
- Neutral battery. That is, the electrolyte is a neutral water solution of the battery
- Organic electrolyte solution battery. A battery in which the electrolyte is an organic electrolyte solution.

2.2 According to the existence of active substances, it can be divided into these categories

- The active substance is stored on the electrode. Can be divided into primary battery (non-regenerative, galvanic) and secondary battery (regenerative, battery);
- The active substance is continuously supplied to the electrode. It can be divided into non-renewable fuel cells and renewable fuel cells.

2.3 According to certain characteristics of the battery

- High capacity battery
- Maintenance-free battery
- Sealed battery
- Combustion-junction battery
- explosion-proof battery
- Button type battery, rectangular battery, cylindrical battery, etc.

3. Supercapacitors

With the technological progress and industrial development in the field of new energy, energy storage technology has attracted more and more attention from all parties and become a key link to solve the future development of new energy industry. At present, energy storage technology can be roughly divided into physical energy storage and electrochemical energy storage. Supercapacitor is a technical device with the most commercial prospect in physical energy storage, and it is a good complement to other electrochemical energy storage technologies.

Supercapacitors have the following main characteristics: high power density; Very long cycle life of charge and discharge; Very short charging time; The storage life is extremely long; High reliability, little maintenance work; Suitable for wide temperature range. Therefore, supercapacitors can be widely used in many fields, including new energy vehicles.

3.1 Advantages of application in new energy vehicles

Supercapacitors are widely used as auxiliary power for starting, braking and rolling of new energy vehicles. Frequent starting, climbing and braking of gas vehicles cause great changes in its power demand curve, especially in urban road conditions. This requires frequent switching between peak power and operating power. The ratio of peak power to average power of a high-performance electric vehicle can be up to 16:1, but the duration of these peaks is usually short and the energy required is not high. For pure electric, fuel cell, and series hybrid vehicles, this means either insufficient vehicle power or constant high peak currents on the voltage bus, which will undoubtedly greatly impair the life of the battery or other APUs. If a supercapacitor with a larger power is used, it can provide the peak power when the instantaneous power demand is greater. And it absorbs the peak power during braking feedback, then the pressure on the battery, fuel cell or other APUs can be reduced. It can

greatly increase the power output of the system during starting and accelerating, and the high-power braking energy can be efficiently recovered. Doing so can also increase the battery's service life and improve its discharge performance.

Due to the high power density of supercapacitors, the discharge current can reach hundreds of amps, which can better meet the power requirements in high-current applications, especially in high-energy pulse environments. At the same time, the supercapacitor has short charging and discharging time and high efficiency. It can complete a charging and discharging cycle in a very short time, which is much lower than that of rechargeable battery. It is especially suitable for short-distance vehicles, and its fast charging and fast discharging characteristics make it more suitable for providing the main power for buses. Supercapacitor buses not only have incomparable advantages over lithium battery buses in terms of power density and safety, but also their cost is much lower than battery-powered buses. Assuming that each bus consumes 150 kWh per day, supercapacitor cars can reduce the usage of supercapacitor by increasing the number of charging times.

3.2 Advantages and disadvantages of ultracapacitor batteries

1) Advantages:

a) It has the super-large electric capacity of farad class, which is much larger than the ordinary capacitance.

b) can instantly release power is nearly ten times higher than the ordinary battery, and will not be damaged.

c) The cycle life of charge and discharge is more than one hundred thousand times, which is one of the biggest advantages. The traditional battery can only be charged and discharged hundreds of times.

d) can be used normally in the ambient temperature of 40 degrees to 60 degrees, the efficiency of the traditional battery at low temperature will be greatly reduced.

e) It has the super ability to maintain the charge, and the leakage is very small. The traditional battery needs to be charged frequently to maintain the state.

f) charging quickly, its speed is dozens of times faster than the ordinary battery, a few minutes can be filled with a car to the power.

g) itself will not cause pollution to the environment, really free maintenance, and the traditional battery is still polluted.

2) Disadvantages:

a) large volume, its volume is relatively large, compared with the volume of the battery, its storage capacity is small.

b) low electricity, even if it reaches the farrah level of electricity, but compared with the traditional battery, it is still very little, according to the current technology, it still cannot be used as an important electric power storage appliance, because its electricity can only drive the vehicle for a few kilometers.

3.3 Working principle of ultracapacitor battery

The basic principle is the same as that of other kinds of double-layer capacitors, which use the double-layer structure composed of activated carbon porous electrode and electrolyte to obtain large capacity. The "double layer principle" is at the heart of the supercapacitor, which is determined by the double-layer structure of the device.

Supercapacitors are capacitors that use the double layer principle. When an applied voltage is applied to the two plates of an ordinary capacitor, the device stores charge in the same way, that is, the positive electrode corresponds to the positive charge and the negative electrode corresponds to the negative charge. In addition to these functions, if the supercapacitor is subjected to the electric

field, it will generate opposite charges between the electrolyte and the electrode. At this time, the positive charge and the negative charge are respectively in different contact surfaces, and the load distribution under this condition belongs to the "double electric layer". Due to the improvement of the capacitor structure combination, the supercapacitor has a great capacitor storage capacity. In addition, if the electric potential between the two plates of the supercapacitor is less than the standard potential of the electrolyte, the supercapacitor is in normal working state, and the opposite is not normal.

According to the principle of supercapacitor, there is no chemical reaction in the process of application, only the change of physical properties, so the stability of supercapacitor is more reliable

3.4 Application status

In terms of the industrialization of supercapacitors, well-known foreign manufacturers mainly include: Maxwell Company of the United States, Nesscap Company of Korea, Econd Company of Russia, Panasonic Company of Japan, etc. And countries are racing to Batter the batter for electric vehicles: the U.S. Department of Energy and USABC (USAdvanced Batter Consortium) organized the National Laboratory, Lawrence Livermore, Los Alamos, in 1992. Sandia), University (Auburn) and industry (Maxwell, Federal Fibers Fabrics (GE), launched a feasibility study plan for supercapacitors used in electric vehicles. The three American automobile giants set up the USABC institution to preside over the research and development of EDLC. In early 1996, the European Union began its supercapacitor research program, led by Saft. Its members are Alcatel As thom, Fiat, Magneti Maralli SEPA Division, Danioncs, University of Kaiserslautern and ECN

And it aims to meet the requirements of electrochemical cells and fuel cell electric vehicles in preparation for industrial development. The New Sun Shing Project elected by Japanese government departments has attracted many high-tech enterprises to participate in it. The research and development of supercapacitors is one of the important projects, and the "New Capacitor Research Institute" has been established. Russia focuses on capacitor vehicle technology and research on braking energy recovery of electric vehicles. The specific power of its starting supercapacitor has reached 3 000W/kg, and the cycle life is more than 100,000 times.

4. Hybrid energy storage system

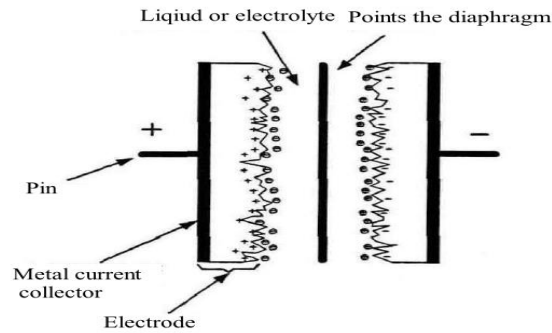
4.1 Overall integration of hybrid energy storage systems for electric vehicles

In electric vehicle supercapacitor HESS, the components that provide energy are lithium battery pack and SC module. The bidirectional DC/DC power converter controls the output power of the two energy storage components and the stability of the DC bus voltage, so as to achieve power distribution. The three-phase bridge converter realizes the conversion of direct flow AC, thus controlling the operation of the motor. At the same time, it also ensures that the energy generated during the feedback braking of the electric vehicle is fed back to the DC bus by the three-phase converter and stored in the SC.

1) Super capacitor module

As shown in Figure 1, SC consists of a metal collector plate and a liquid electrolyte separator. The internal resistance of SC is negligible, its energy input and output loss is small, and the State of Charge (SOC) is positively correlated with the voltage at both ends. The SC module in HESS is composed of a large number of single supercapacitors combined in series and parallel. In order to make DC voltage fluctuation small, it is necessary to use DC/DC circuit for voltage boost and voltage regulation, but the supercapacitor needs to absorb the electric energy returned during the braking process of electric vehicle, so the use of bidirectional DC/DC converter can ensure the voltage regulation and

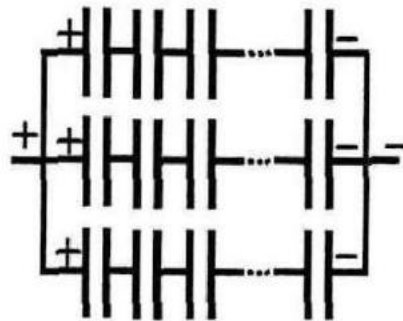
energy input and output at the same time.



SC Schematic diagram



SC Physical symbol



SC Structure of group

Figure 1: Schematic diagram of super capacitor structure

2) Lithium battery pack

Lithium battery is an energy storage component with many advantages at present, which is widely used in various occasions that need to store electric energy. In the hybrid energy storage system of electric vehicle, the lithium battery achieves the driving voltage requirement of electric vehicle through series and parallel. The bidirectional DC/DC conversion circuit increases the battery voltage to the DC bus voltage value. Lithium-ion battery packs for electric vehicles are made of many monomers in series and parallel. Due to the influence of hardware structure, each monomer of lithium battery packs has slightly different loss and charging and discharging status of monomers, and this difference becomes more and more obvious when the operating range of electric vehicles becomes longer

3) Two-way DC/DC converter

Figure 2 shows the most basic structure of the bidirectional DC/DC converter, which is actually

modified and designed on the basis of single-phase chopper to allow the energy to flow bidirectional. The bidirectional DC/DC converter uses the DC chopper circuit as the main component, and then the diode and the switch tube are connected in reverse parallel respectively to achieve the function of controlling the bidirectional energy flow. The bidirectional DC/DC converter is used to boost the DC voltage at both ends of the SC module or lithium battery pack into a higher level of DC voltage to be transmitted to the DC bus. At the same time, the two-way DCDC will reverse transfer the returned electric energy to the SC and the lithium battery during the braking of the electric vehicle. The bidirectional DCDC converter can accurately control the energy on-off and transmission direction through the controller, which is one of the most important modules for SC and lithium battery power distribution.

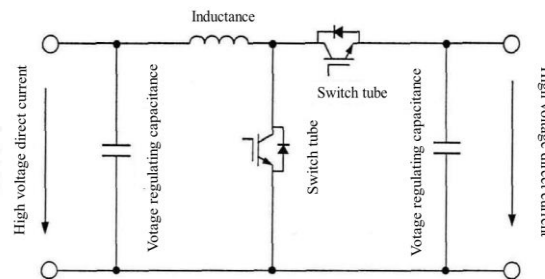


Figure 2: Schematic diagram of bilateral DC/DC structure

4.2 Structure of hybrid energy storage system:

1) Overview of hybrid energy storage system structure

HESS structure is mainly divided according to the basic structure of DCDC converter, which can be divided into passive, semi-active and active structures[1,2].

Figure 3 shows the passive configuration of the hybrid energy storage system. The main feature of this structure is that there is no DC/DC converter, so the SC and the lithium battery pack are directly connected in parallel. Because there is no converter, the efficiency is improved and the control is simple. However, the two energy storage components are directly connected, and when the voltage between the supercapacitor and the lithium battery pack does not match, a large circulation will be generated. Generally, a variable resistance is added between the supercapacitor and the lithium battery pack to inhibit the circulation, but this will cause unnecessary loss[3]. Due to the lack of bidirectional DC/DC converter to control the energy flow, the energy provided by SC and lithium battery pack is distributed according to the system state and demand according to the pure circuit physical model, which cannot play the full potential of HESS and greatly reduces the practicability[4].

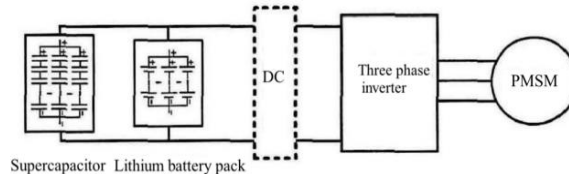


Figure 3: Hybrid energy storage system in passive configuration

As shown in Figure.4, the semi-active configuration only uses a bidirectional DC/DC converter to realize the output voltage and power output size distribution of energy storage components. For all kinds of power distribution algorithms, it has the basic conditions for implementation and can realize the control of energy flow[5].

Figure 4(a) The bidirectional DC/DC converter is connected to both ends of the SC and distributes its input and output power. This structure makes the terminal voltage matching of SC higher, and it

does not need to force the supercapacitor to fail to reach the number of series and parallel modules required for the optimal performance of hybrid energy storage, as the passive configuration does, so it improves the flexibility of capacity ratio and capacity utilization[6]. Voltage matching can be realized by controlling SC voltage matching to bus voltage by bidirectional DCDC converter. Lithium battery is directly connected to the DC bus, and the power fluctuation on the DC bus directly affects the charge and discharge of lithium battery. If the power fluctuation is too large, the capacity and service life of the battery will be reduced.

As shown in Figure 4(b), the structure in Figure 13(a) is just the opposite. The converter is connected to the lithium battery pack in series, and the SC is directly connected to the bus. This connection mode helps distribute low-frequency power fluctuations to the lithium battery, and then the SC takes over the rest of the demand. However, this situation makes the SC voltage change greatly, resulting in the mismatch, which restricts the SC capacity utilization rate 35.

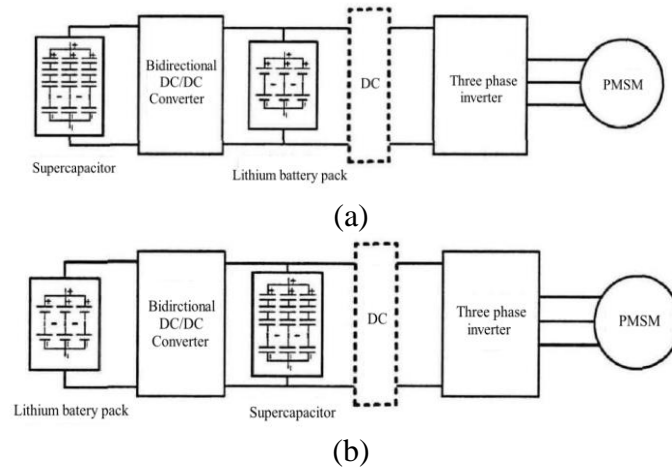


Figure 4: Semi-active dynamic configuration hybrid energy storage system

The active configuration is shown in Figure 5. Two bidirectional DC/DC converters are respectively connected to the energy storage element group. Two two-way DC/DC makes the voltage and two-way energy transmission of the two energy storage components controllable, which greatly improves the control freedom and reduces the difficulty of DC bus voltage matching. However, two converters increase the difficulty of algorithm design, and reduce the efficiency of power conversion and system reaction speed[7]. In addition, the active type requires two high-power bi-directional DCDC converters, which makes the manufacturing cost high, which is also one of the disadvantages of the active configuration. The two converters also cause the reduction of power transmission efficiency.

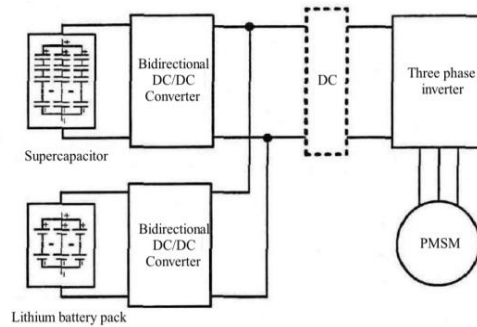


Figure 5: Active configuration hybrid energy storage system

4.3 Application of hybrid energy storage system

Hybrid energy storage system has advantages of both power density and energy density, and has strong adaptability to working conditions, so it is very suitable for application in the environment with complex working conditions. It can be applied in electric vehicles [8, 10-11], electric energy storage [9], rail transit and other fields. Generally, HESS is composed of devices with high power density and high energy density, so as to meet both energy and power requirements. The appropriate HESS depends on the variety of storage conditions, including storage mix purpose, storage cost, geographic location and storage space availability.

In order to save energy and reduce emissions, countries around the world are now starting to develop electric vehicles. The core technologies of electric vehicles are endurance, battery life and speed of acceleration. It is easy to damage the battery when the car accelerates suddenly or climbs a hill, which is very common in electric vehicles, because different factors, such as driving style and road, lead to the rapid change of power consumption and current level. When the electric car needs a large current in the acceleration process, the battery pack releases a large current output. Similarly, high rate current is generated into the battery in the process of vehicle braking, which will adversely affect the battery electrolyte and shorten the battery life in serious cases. At present, various types of batteries have been applied to electric vehicles. Figure 3 shows the schematic diagram of HESS applied to electric vehicles. Using HESS can reduce the negative effect of current fluctuations on batteries and extend their service life. Hybrid energy storage can also improve the efficiency of electric vehicles by absorbing the energy generated during braking [10].

When HESS is incorporated into the design of an electric car, the car's braking energy is stored in the battery, where the supercapacitor absorbs the main peak power, and the battery absorbs power after the supercapacitor. A well-designed hybrid energy storage electric vehicle with high energy density and long cycle life has much better performance than battery pack electric vehicles and can solve the drawbacks of batteries. Therefore, HESS can greatly improve the performance of the vehicle, which can have a positive impact on the overall performance of electric vehicles. First of all, HESS can make the vehicle cold start, and when the temperature is relatively low, it can be started by the supercapacitor. The second is that electric vehicles are provided with high rate current by super capacitors, which can avoid the input and output of large current of the battery, prolong the battery life and reduce the cost. The third is to use supercapacitors to absorb the feedback energy generated during braking to reduce energy loss. Finally, the supercapacitor assisted drive is faster when the car accelerates, more power to climb the hill, and the endurance is improved.

5. Simulation and Results

The electric vehicle is selected as the application object, and the simulation analysis of supercapacitor, lithium battery and hybrid energy storage is carried out. The hybrid energy storage is the combination of supercapacitor and lithium-ion battery.

It can be realized by modifying certain parameters in simulink software. In the same classic Chinese city driving conditions, we also check the SOC of supercapacitor and lithium battery as well as the voltage and current.

As shown in Figure 6, this is the simulation model, consisting of a lithium battery and a supercapacitor

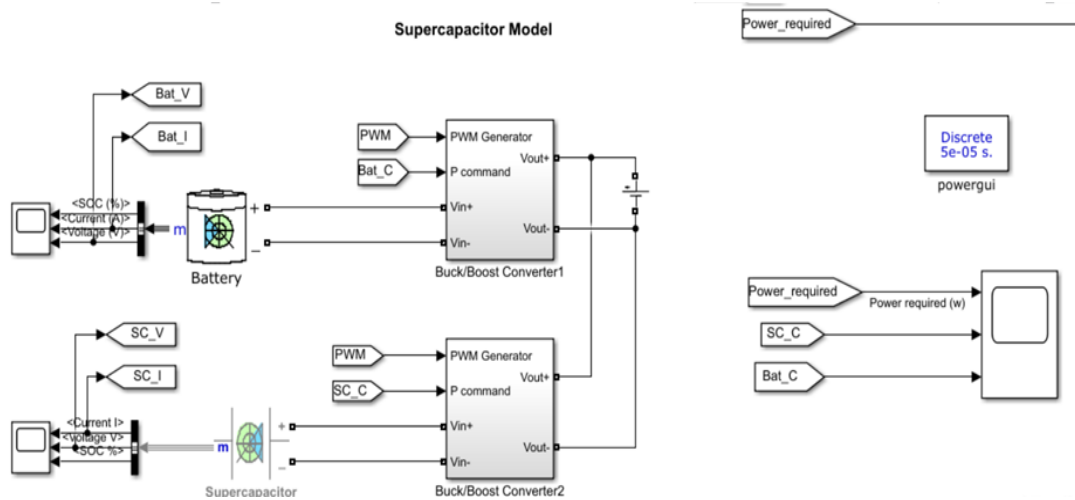


Figure 6: The simulation model

We first obtained the SOC, voltage and current parameters of the super capacitor and the super capacitor by observing the power of the supercapacitor and the lithium battery. And we can see the power of ultracapacitors and lithium batteries from Figure 7.

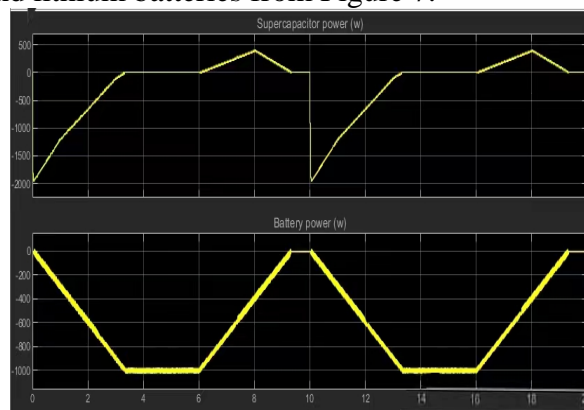


Figure 7: Power of ultracapacitors and lithium batteries

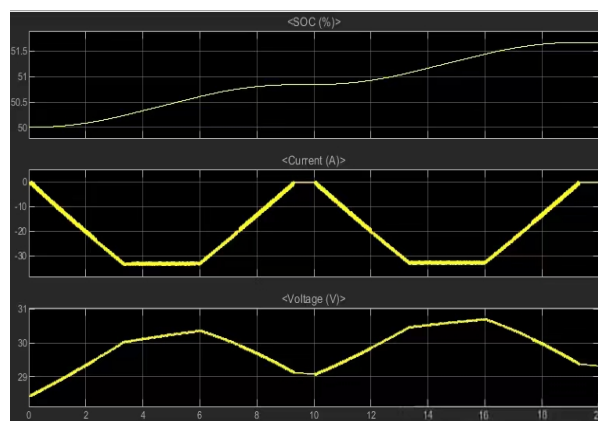


Figure 8: SOC, voltage and current parameters of lithium battery

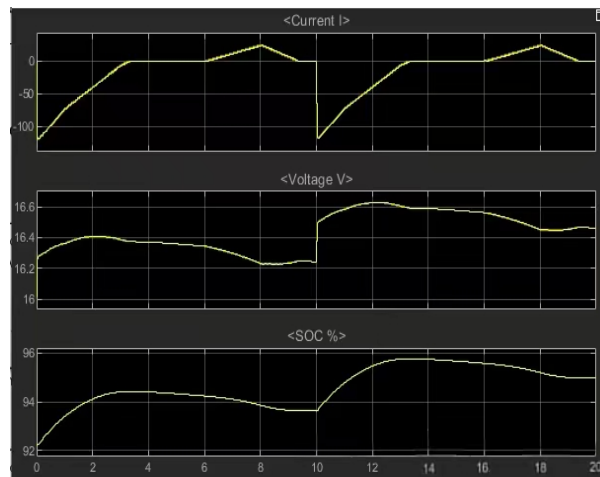


Figure 9: Supercapacitor SOC, voltage, current parameters,

It can be seen that the changes of SOC and current of supercapacitor are more stable than those of lithium battery, without big fluctuations. The SOC of supercapacitors declines more smoothly and has more storage compared Figure 8 with Figure 9.

Then I simulate the hybrid energy storage system.

Here, I have simulated two modes, one is the ordinary mode, which simulates the charge and discharge situation of the MOTOR in the simple fast and slow mode. The simulation results are shown in Figure 10.

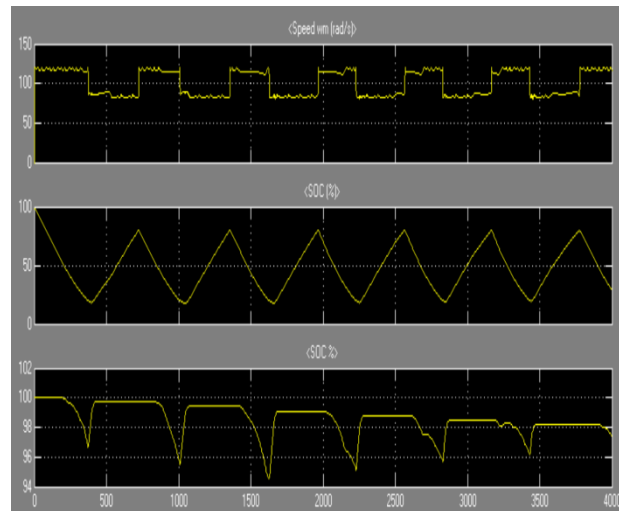


Figure 10: Simulation of Motor simple mode

As can be seen from the simulation results in the figure above, when the vehicle speed is fast, the battery is in discharge state, and when the battery is discharged to a certain extent, the capacitor also starts to discharge with the battery. After the car is slowed down, the battery and capacitor discharge, and absorb the kinetic energy of the reduced speed back and gradually charge.

Then, daily vehicle driving conditions are used for simulation, and the simulation results were shown in Figure 11.

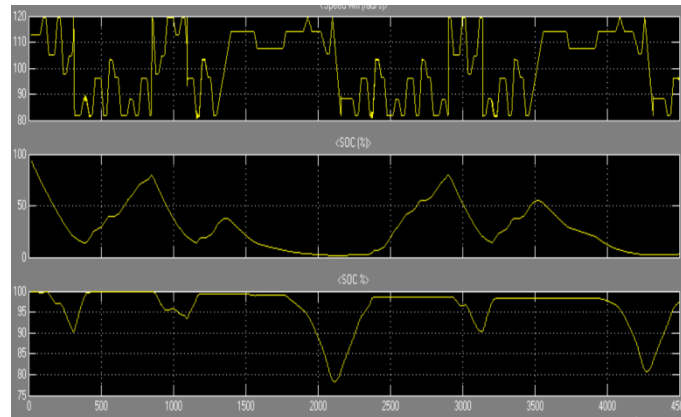


Figure 11: Results of daily vehicle movements

As can be seen from the simulation results, when the speed is low, SOC increases; when the speed gradually increases, SOC decreases, and the same result is obtained.

6. Conclusion

We focused on the discussion of supercapacitors, as well as the overall structure and composition, classification, and use and benefits of hybrid energy storage system. Later, we simulated the SOC and current voltage of lithium batteries and supercapacitors through simulink simulation, and found that supercapacitors from the current or from the SOC. Both are better than lithium batteries.

Then we carried out the system simulation of hybrid energy storage, respectively in different driving conditions, we can see that the effect of the super energy storage system is very good.

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