

Supercapacitor as SuperCharger in Electric Vehicle :Future Perspective

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Abstract

In order to provide the accurate SOC values of super capacitor for the vehicle control strategy of hybrid electric vehicle which is using the super capacitor, this paper completes the hardware and software design of super capacitor monitoring and control system, gives out the block diagram of the system, the hardware block diagram and the software flow diagram, achieved the measurement of the voltage, current and temperature; analysis the linear relationship between the open circuit voltage and the discharge depth of super capacitor, optimize the SOC estimation method of used the capacitor voltage state. The experimental results show that the voltage detection and the SOC estimated accuracy of the monitoring system better meet the testing requirements.

Introduction

One of the major reasons behind emergence of hybrid and electric vehicles as viable transportation options is the advancements in battery technology and power electronics. The current lot of electric vehicles rely on batteries to store energy. However, there are still a lot of challenges associated with electric vehicles. Many of the major constraints associated with electric vehicles – range limitation, performance limitation, charge acceptance, and safety, among other things, relate directly to the battery technology. A better energy storage system for electric vehicle demands for much improved battery technology. The question is: is there any other rechargeable energy storage technology that can replace batteries in future? Super-capacitor is one such technology that can potentially play this role. They can offer electric vehicles fast charging and a longer life. But traditionally Super- capacitors have been considered for high power applications, and not an option for energy storage system due to its comparatively low specific energy. Typical specific energy of Super-capacitors has been limited to 5 Wh/ kg. With such low specific energy, the achievable range for any type of vehicle is insignificant. However, super-capacitors have higher power density and quicker charging time. That is why even with available specific energy, Super- capacitors have been successfully used for regenerative braking applications in trains and trams, which use grid supply instead of on-board battery pack. The design of energy storage system with combination of Super-capacitor and battery has remained a challenge. However, there are some recent developments that indicate that in future .

SUPER-CAPACITOR TECHNOLOGY

Super-capacitors have several alternative names – super-capacitors, pseudo-capacitors, electrochemical double-layer capacitors (EDLCs).

Unlike batteries in which electrochemical reactions are responsible for charging and discharging, a capacitor stores energy by means of a static charge. In conventional dielectric capacitors, two electrodes are separated by a (dry) dielectric substance. Such capacitors have a very low capacitance (ranging from picofarads to microfarads), and are used to filter signals and tune radio frequencies. The second type is electrolytic capacitor that uses a moist separator. These capacitors are rated in microfarads (uF), and are used for power filtering, buffering and coupling. The third type, Supercapacitors use two layers of the same substrate with a nanoscale separation

between layers. The very small distance between layers and the presence of an electrochemical double-layer allows the electrodes to have a much larger area, resulting in large capacities. There exists some ambiguity in the classification of Super- capacitors. For simplification, they may be considered in three broad categories – Symmetric, Asymmetric and Hybrid. Symmetric Supercapacitors include Electric Double Layer Capacitors (EDLC), in which electrical charge is only physically stored in double layer; and pseudo-capacitors, in which a greater amount of charge transfer is due to faradaic mechanisms like electrosorption, redox reactions and intercalation, modified symmetric super-capacitors, with changes in the electrolyte compositions, mass loading and geometry of the electrodes. A Hybrid Super- capacitor uses two electrodes made of different materials and, eventually, using different operating processes (faradaic and non-faradaic). In several aspects, Super- capacitors are better than batteries. The main advantage is their long life. Super-capacitors can go through more than one million charging and discharging cycles. The rate of charge/ discharge is very high. Thus Supercapacitors are suitable for handling high power requirements. Other advantages include good reversibility, very low internal resistance, high efficiency, high power output, safety, maintenance-free operation, and simple loading methods.

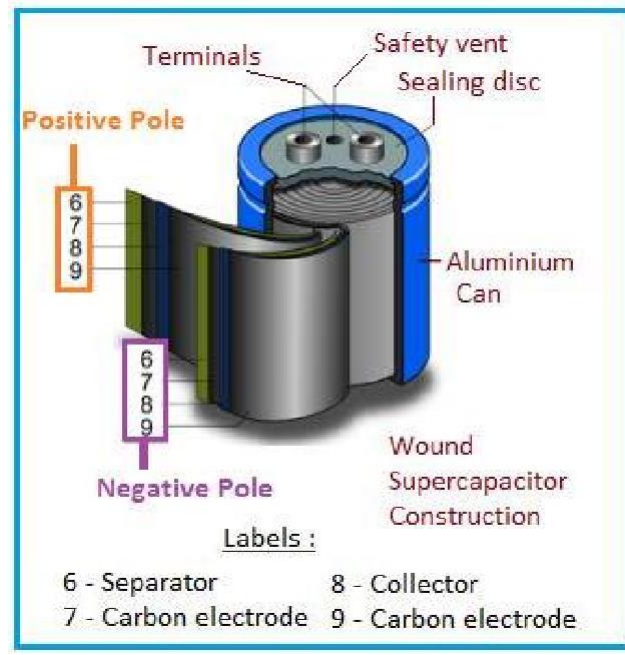


Fig: Supercapacitor Construction

The design of the super capacitor monitoring and control system

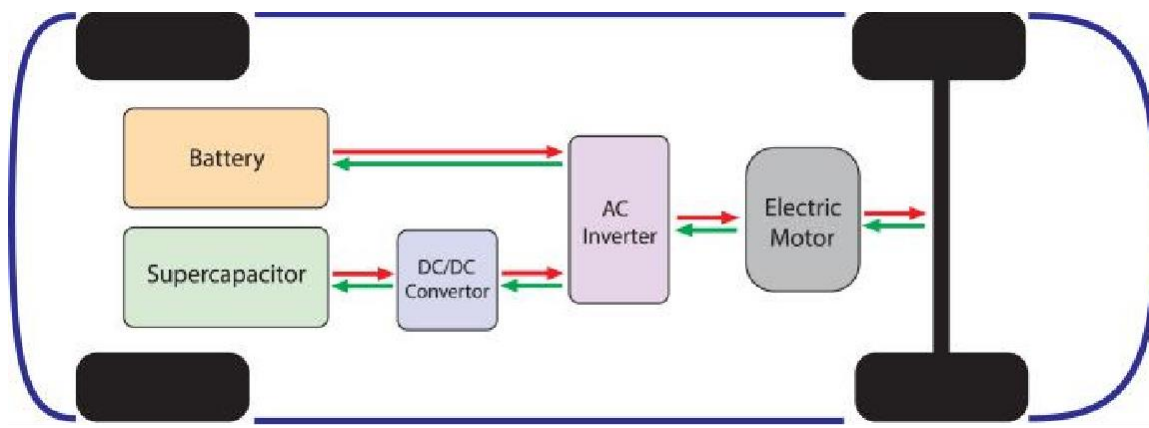
The core of the super capacitor monitoring and control system is the voltage collecting of the super capacitor and the estimating of surplus charge. Because there are some approximately linear relationship between the voltage of super capacitor and the SOC estimated value of super capacitor, therefore, the detection accuracy of the super capacitor voltage level will be directly determined the accuracy information of the super capacitor state. In the power capacitors of hybrid electric vehicles are formed by the serial number of super capacitors, and are arranged in distributed. Taking into account a large number of power devices, high-voltage and high-current power lines inside the vehicle, the electromagnetic environment is complex. The program mainly consists of two parts; there are the integrated management unit and capacitance monitoring and control unit. Integrated management unit is responsible for:

- 1) The signal acquisition and processing of supercapacitor level, such as the total voltage of

- the capacitance, the charge and discharge current, and the ambient temperature information etc.
- 2) The algorithms and data retention of the super capacitor monitoring and control system.
 - 3) The power devices and the man-machine interface circuit control.
 - 4) To exchange the information in the various control devices as a node of the vehicle communication network.
 - 5) To send commands to the monitoring unit of the capacitor within the system bus as the primary node, and receive the data upload.

Each monitoring unit of the super capacitor is responsible for:

- 1) The signal acquisition and processing of the single super capacitor, they are mainly responsible for the single-voltage collection of the super capacitor, and the temperature information collection etc, usually a super capacitor unit can be responsible for data collection of a few super capacitor module monome
- 2) To receive the integrated management unit command within the system bus as the from node, and send the related data. In this program can make the signal acquisition of the need for super-capacitor voltage and temperature place in the capacitor working environment by each single capacitor monitoring unit to completed closed, and upload the dealt data to the integrated management unit, estimate the remaining capacity of the capacitor by the integrated management, and send the relevant control command. The integrated management unit and monitoring unit of the super capacitor have a clear division of tasks, and arrange the sequence in time by the bus communication, ensured the synchronization of the signal acquisition, improved the reliability and real-time of the system.



ULTRA-CAPACITOR APPLICATION: PRESENT STATUS

The first commercial ultra-capacitor was introduced by Nippon Electric Company of Japan in 1978. Since then, the use of ultra- capacitors has diversified into many areas due to high reliability and long life. This is in spite of the cost being very high. The range of applications includes consumer electronics CMOS circuits, wind turbine blade control, automotive electrons, etc. The ultra-capacitor market is divided into two areas: small, effective super-capacitors for portable electronic applications, and larger ones for energy storage applications. High energy ultracapacitors are required for applications like hybrid and electric vehicles. In the automotive domain, the supercapacitors are used for onboard electrical systems like electromagnetic valve

control, catalyst preheating, brake actuators and steering. However, these are low power applications. Ultra-capacitor applications in hybrid and electric vehicle drivetrain include integrated starter generator, regenerative braking, and energy storage for the traction assistance. Even among these applications, there is a variation of power and energy requirements from the ultra-capacitors. Whereas engine start application involves very low energy content for very high power services, hybrid vehicle applications are comparatively more energy intensive. Demand for specific energy is even higher for fuel cell vehicles, and obviously for electric vehicles. Use of ultra-capacitor for cranking of IC engine, especially diesel engine at cold temperatures, has been offered by aftermarket vendors, and OEMs are also considering it. In case of micro-hybrids as well, the main feature is the start-stop technology, which turns off engines at traffic stops, and uses stored energy in battery to start the engine. Some start-stop solutions employ a combination of batteries with ultra-capacitors. A start-stop idle elimination system developed by Continental AG with Maxwell ultra-capacitors for micro hybrid diesel automobiles is used in PSA Peugeot Citroen. Start-stop system with ultracapacitors has also been adopted by Mazda and Volkswagen, among others. Ultra-capacitors can also play a significant role in Regenerative Braking Systems. During the time a vehicle is braking, part of the braking energy can be recovered by running the traction motor as generator and charging the ultra-capacitor. Since the braking happens within a very short time, the charging current is too high for regular batteries. Ultra-capacitors can accept charging faster. The electrical energy stored this way in ultra-capacitors is then available to assist in acceleration, to reduce fuel consumption. Auxiliary power requirements like for air conditioner, power steering and other electrical functions may also be supplied by the ultra-capacitor. Such a system helps the battery to be within a desirable SOC window, preventing battery drain. Regenerative braking also takes most of the load off mechanical brakes, reducing brake maintenance and replacement expenses. Ultra-capacitor application for regenerative braking is commercially available both in railway and hybrid vehicle applications. Bombardier Transportation is using large banks of them in the Energystore to recapture the braking energy of Bombardier trains. Bombardier Transportation has selected Maxwell ultra-capacitors as the energy storage element. Each Energystore unit incorporates an ultracapacitor array that is capable of storing up to two kilowatt hours of electrical energy generated by a rail vehicle's braking energy recuperation system. Reduction in grid power consumption by 20 % to 30 % is claimed to have resulted from this system. Stadtbahn trams in Mannheim, Germany have been using ultracapacitors since 2003. Super-capacitors are applied in Spanish and French trains and buses too. Maxwell ultra-capacitors are powering more than 4,500 hybrid transit buses currently in service worldwide. These include MAN, Gillig, New Flyer, and BAE Bus. MAN urban hybrid bus and the Sinautec pure electric bus use ultra-capacitor banks on the roof and dispense with lithium-ion batteries altogether. Sinautec's 41-seat Ultracap buses have been serving the Greater Shanghai area since 2006 [2]. When the bus stops at passenger stops, the overhead charger quickly recharges the ultra-capacitor onboard to allow the bus to go to its next destination. This bus uses 400 ultracapacitor cells (UCE15V80000A) manufactured by Aowei. The ultra-capacitor bank, which weighs 1,450 kg and has a volume of 1.5 m³, has energy storage capacity of 6 kWh. Mazda is the first vehicle manufacturer to introduce automotive 12 V regenerative braking system using ultra-capacitor in the new Mazda 6, set for production in May 2013. The system, called i-ELOOP has shown to improve fuel economy by 10 % in stop-and-go operation as per inhouse tests. It adds just 9.3 kg to a 12V car, out of which the ultra-capacitor bank weighs 6 kg. The Riversimple technology demonstrator fuel cell vehicle uses just 21 kg of super-capacitors, capable of absorbing over 30 kW of power from regenerative braking, and of delivering 15 kW for bursts of acceleration of up to ten seconds. Since 2001, MAN has been developing hybrid super-capacitor buses called the Lion's City Hybrid. The current commercial model, available since 2010, cuts diesel consumption by up to 30 %, and is now being used on a small scale in Paris and some other European cities. Mannheim trams use the Mitrac super-capacitor system produced by the Berlin-based company Bombardier Transportation. In 2011,

German transport operator RNV, which serves the Rhein-Neckar region and includes Mannheim, Heidelberg, and Ludwigshafen, ordered 11 more Bombardier trams for its 200-km network. However, for ultra-capacitor-only vehicles to have practical range there needs to be significant improvement in the specific energy and energy density of ultra-capacitors.

EMERGING TRENDS

EDLCs primarily use high surface area carbon materials. Pseudo-capacitor research has largely been dominated by oxides such as those of ruthenium and manganese. Carbon materials have the advantage owing to their abundance, stability and relative environmental-friendliness. The performance of the ultra-capacitors depends to a large extent on the specific surface structure of the electrodes. To achieve higher capacitance, the aim is to maximise the specific active surface area. The most commonly used material is activated carbon. Nanotechnology has been used to find solutions to increase the specific surface area. This involves carbon structuring at nanoscale, use of carbon nanotubes, graphene structures or nanowires. Electrodeposited metal oxide thin film based electrodes also display high energy and power performances.

Conclusion

The super capacitor monitoring and control system of the hybrid electric vehicles designed in the paper realized many functions such as the voltage acquisition of the super capacitor, the current acquisition, the temperature measurement, the driving of the cooling fan, etc. Based on the linear relationship between the open circuit voltage of the super capacitor and its depth discharge, optimized the method which is used the capacitance state of voltage (SOV) to estimate the state of charge (SOC). The experimental results show that the whole 21-10-2022 system better meet the requirements of the super capacitor voltage detection, the SOV estimation method meet the estimated requirements.

There has been significant improvement in specific energy of ultra-capacitors with specific energy being comparable to lead acid batteries, and further research efforts targeting to reach or surpass those values for commercial lithium-ion battery. However, there have been improvements in lithium-ion battery also, and research efforts provide perspective of specific energy, which is about 400 Wh/kg for lithium-ion batteries. Although theoretical specific energy for ultra-capacitors is much more, plenty of technological challenges will have to be overcome. But even with the present research level specific energy, ultra-capacitors may compete with batteries. However, the price of ultra-capacitors remains as a major barrier for its application in electric vehicles, in spite of the fact that in the past decade, it has fallen by 99 %. The cost of a 3,000 Farad ultra-capacitor 10 years ago was \$5,000, but today, the component sells for \$ 50. During the same period of time, battery price reduction measured only 30 to 40 % [5]. During the last couple of years, some manufacturers have become capable of large-scale production and have brought production costs down. As the number of suppliers increase, customers' dependence on any single supplier will be reduced, and porous carbon-based materials will be commodity. Due to the long life, ultra-capacitors may offer less lifetime cost as compared to regular batteries in many applications.

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