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전기자동차 배터리의 에너지 저장장치로의 재사용에 관한 연구

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Research on the Re-Use of Electric Vehicle Battery for Energy Storage Systems

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ABSTRACT

The grid-connected energy storage systems, which could increase the reliability, efficiency, and cleanliness of the grid is presently restricted by the high cost of batteries. This problems could be solved by batteries retired from automotive services. These batteriescan provide a low-cost system for energy storage and other applicationssuch as residential applications and renewable energy integration. This paper gives an overview of technical requirements for the re-use of the electric vehicle batteries in energy storage systems.Firstly, the motivation of research is introduced. Secondly, the technologies needed for the re-use of the battery are introduced such asidentification of the battery characteristics, grading of the aged batteries, identification of the state-of-charge and state-of-health of the battery and suitable power electronic converter topologies. In addition the control strategy to maximize the battery lifespan and bypass the faulty batteries is presented and one-stop solution to implement the above mentioned technologies are also given.

Index Terms –Second life battery, energy storage system, grading of the battery, state estimation and one-stop solution.

1. Introduction

Despite the efforts to reduce the cost of the Lithium Batteries over the past few years, the li-ion battery ownership is still high in cost and at least 50% further cost reduction is required to be cost-competitive [1]. Research, development, and manufacturing ramp-up efforts are underway to reduce the cost of the battery by lowering material costs, enhancing process efficiencies, and increasing production volumes. It is also advisable to pursue increasing the total value of services provided by a battery over its lifetime. As EV batteries may have substantial performance capability left at the end of their automotive service life, additional value could be extracted by committing them to grid-connected services. By extracting additional services and revenue from the battery in a post-vehicle application, the total lifetime value of the battery is increased, and the cost of the battery can be shared between the primary and secondary users.

Many factors will determine the viability and economics of second lifebattery from the costs of repurposing processes to the evolution of competing for battery technologies. One of the most important factors in this equation is battery degradation in both the first (automotive) and second (ESS) service lives. The paper in [1] has presented anevaluation about the capacity fade based on the effects of the calendar, cycling, and average battery temperature. In [2], an estimation of the time to cell failure of the batteries within their second life application is given.

Second life battery should be available at lower cost than new batteries but reliability becomes an important issue as individual batteries may suffer from degraded performance or failure. Therefore, converter topology needs to be designed to guarantee the overall system reliability. The paper in [3] shows that the second life battery as the least reliable part of the system and minimizing the number of cells connected in series is a key part of increasing system reliability of a single unit. In [4], a work on battery failure rate is undertaken to suggest suitable topologies for use in high reliability.As shown in the Table I, it is important to decide a suitably rated power for each converter module in the second life battery application since they show some variation in the specification.

Table 1. The specification of current EV batteries

Manufacturer	Enerdel	Panasonic	Mitsubishi	Panasonic
Type of battery	Li-ion	Li-ion	Li-ion	Li-ion
Nominal voltage	144V	302.4V	330V	345V
Voltage range	120-168V	210-352V	250-360V	240-400V
Battery Energy	24.5 kWh	60 kWh	16 kWh	85 kWh
Vehicles	HPEVS 144V	Tesla model S	I MIEV	Tesla model X
Manufacturer	Samsung SDI	LG Chem	AESC	A123 System
Type of battery	Li-ion	Li-ion	Li-ion	Li-ion
Nominal voltage	355V	360V	360V	393V
Voltage range	260-393V	288-400V	240-403V	282-393V
Battery Energy	18.8 kWh	27 kWh	24 kWh	23 kWh
Vehicles	BMW i3 EV	IONIQ Kia EV	Nissan leaf	Chevrolet spark EV

The paper in [5] has presented a new adaptive state-of-charge control strategy for hybrid battery integrations to maximize the battery lifespan. For the optimal use of each module, a modular power management system using a separate power converter for each module is suggested.

2. Technologies needed for re-use of the battery

One of the most important data for reuse of electric vehicle battery is the battery degradation in the first automotive service. In [1], if the second life battery is usedfor daily peak shaving, they can last ten years or more in second life service when managed properly. However,the open circuit voltage of each string of the batter after the first EV use may be quite different as shown in Fig. 1. Therefore, the each battery string needs to be carefully examined and be graded when it is re-combined with others in order to recompose the module for second life use. In this process both Electrochemical Impedance Spectroscopy technique to grade the batteries and state estimation techniques for the state-of-charge and state-of-health estimation are essential. The other important technology is the selection of the suitable power electronic topologies which will be discussed in the following section.

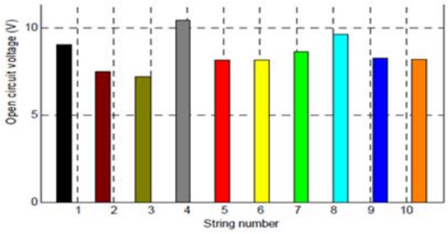


Fig. 1 The usable capacity of battery

3. Suitable Power Electronic Topologies

A. Parallel-connected converter

$Fig.2(a)$shows a parallel-connected converter where a high number of battery cells are connected in series in order to create a sufficient voltage for the dc-link of the inverterconnected to the grid.

B. Parallel-connected converter with integrated dc-dc converter

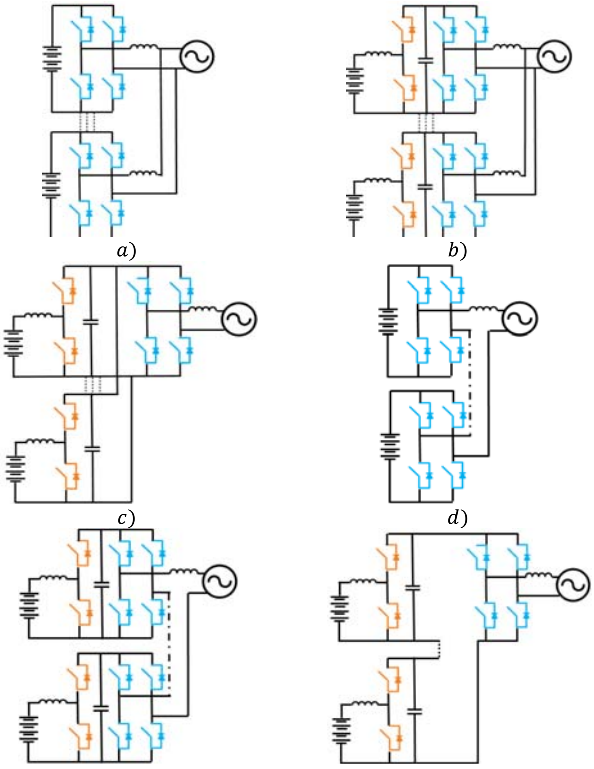
$Fig.2(b)$ and $Fig.2(c)$are parallel topologies. It has a dc-dc converter in each module which provides the capability to charge each module with different battery currents.

C. Series-connected converter

$Fig.2(d)$shows the series topology. The main advantage of this structure is its capability to implement a high voltage dc-link using a number of battery modules. However, it may be disadvantageous in terms of system reliability.

D. Series-connected converter with integrated dc-dc converter

This topology is shown in $Fig.2(e)$ and $Fig.2(f)$ .The advantages of this converter include avoiding a high number of series batteries and the opportunity charging each module at different currents.

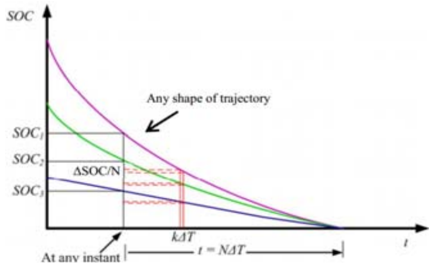

a) b) c) d) e) f)

$Fig.2$possible multi-modular topologies for second-life battery

4. Control strategy

A. Charge control based on the SOC information

The ESS system with second life batteries may consist of batteries with different charge/discharge rates and nominal voltages. Control of the batteries in different states in a system may be more challenging compared to the conventional battery management systems which mainly deal with the homogeneous batteries. The paper in [5] suggested a method to control the state-of-charge trajectory of the batteries which have different capacities. The method uses an instantaneous current sharingmethod to distribute the power among the batteries such that their discharge or charge trajectory finishes at the same time. It makes sure that the energy delivered/absorbed from each cell in a uniform manner to maximize the lifespan of the battery. The SOC control strategy for three different battery module is shown in $Fig.3$.

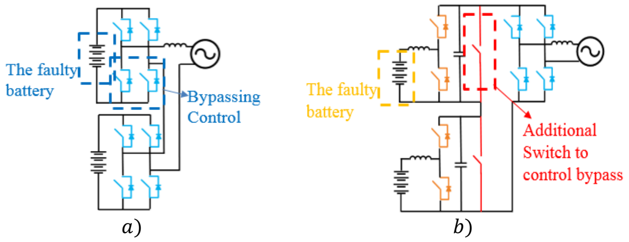


$Fig.3$SOC control strategy for the multi-modular topologies [5]

B. Bypassing control for the ride-through operation

Bypassing control could be an important functionality in second life battery applications because of its inherent poor battery reliability.For the parallel-connected converter, each module is connected to the grid independently. When a battery module is failed, it can be simply overridden from the system by the turning off of its inverter.

For the series-connected converter, the battery failure is critical for the continuous operation and ride-through capability which can be achieved by bypassing the faulty battery from the system is essential. In addition the rest of theconverters have to operate at a higher dc gain to compensate for the voltage of the faulty battery.The converter shown in $Fig.2(d)$ can perform the bypassing function by the turning on the two low side switches or two high side switchesas shown in $Fig.4(a)$. However, the converter shown in $Fig.4(b)$ has to useadditional switches to implement the bypassing function.



a) b)

$Fig.4$Bypassing control for different topologies

5. Conclusion

A short review of technical requirements for using the second life batteries has been presented. Three important factors such as battery grading, topologies and control strategy are reviewed to provide an efficient solution for reuse of electric vehicle battery.

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