Review of the Topology and Energy Management Hybrid Energy Storage on Electric Vehicle

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Abstract. There are several ways to improve the mileage of the electric vehicle (EV). High-efficiency drivetrain and high energy density are the main factors. Energy storage source for EV obtained from the battery, ultra-capacitor (UC) and fuel cells (FC). Each of that has own characteristics and capacity. The battery has a good energy density, UC and FC are superiors on power density. Combining some of the energy storage will improve performance and mileage. On this paper, the topology of combining energy storage are reviewed. In addition, also review the power management strategy of hybrid energy storage. By using a convenient strategy, hybrid energy storage becomes very worth.

1. Background
Energy storage in the electric vehicle must comply for power density and energy density. High power density energy storage such as battery consists of some types. The common use in this era is Lithium Ion (Li-Ion). Although there are some other types of the battery such as Lead–Acid, Nickel–Metal Hydride (NiMH), Nickel–Zinc (Ni–Zn) and Nickel–Cadmium (Ni–Cd) [1]. Lead-Acid is popular in automotive use, but not suitable for EV because of the low energy density and power density. NiMH has twice energy density than Lead-Acid and also can be recycled. But if repeatable use in high load power demands the cycle count will reduce 200-300 cycle. For applying on EV need advance power management because of dynamic power demands. Ni–Cd has economically priced and long lifetime. However if Ni–Cd if it is not fully charged it can cause problems with capacity because there is a memory effect [1][2]. The upcoming energy storage is Ultra-Capacitor (UC). UC basically have similar construction like existing capacitors. Using advanced materials can make UC with better performance than the capacitor by the same dimension. Appropriate to capacitors characteristics, UC can charge and discharge instantaneously.

Purpose of research on an electric vehicle is improving the mileage range. Using the best performance energy storage is the solution. But every energy storage has primacy and limitation. Combining energy storage can fulfil the limitation. This paper [1] explaining energy sources and hybrid energy storage. And also detailed comparison on the application and the price. In addition, to get a better result, some research did optimization. There are two way of optimization, standard clustering and using artificial intelligence. Paper [3] combining batteries, UC and fuel cells. Using the SOC parameter for clustering the
2. Review of Hybrid Topology

There are three basic topologies that use on hybrid energy storage. Series, parallel and series-parallel configurations [3]. These topologies developed on energy storage for electric vehicle based on the capacity of electric vehicle’s drive train. And also, all of the topologies can be connected as a passive or active configuration. Advantage of active configuration is can be a potentially smaller dimension that passive configuration as the same load.

2.1. Basic Passive Parallel

In a simple way, the passive configuration doesn’t need any kind of power electronics/converter on the hybrid system [5]. By that’s condition there is a major problem for utilized the hybrid energy storage.

![Figure 1. Basic passive parallel configuration](image1)

2.2. Ultracapacitor (UC)-Battery Configuration

This configuration is the most popular because of a simple system. Also, because using a bidirectional dc / dc converter makes this system applicable in many conditions. The development of hybrid energy storage systems starts with this system. So this system becomes the initial gate of research in terms of hybrid energy storage.

![Figure 2. Ultracapacitor (UC)-Battery Configuration](image2)

Figure 2 shows the diagram of UC - Battery configuration. The bi-directional DC/DC converter is located between UC and battery, so it needs larger size converter to handle the power of UC. Furthermore, the voltage of UC can be lower from converter specifications and the battery directly connected to the DC link that causes the DC link voltage cannot be changeable.
2.3. Battery-UC configuration

![Battery-UC configuration](image)

Another conjuration is changed the position between UC and battery. Battery located before the converter. By this condition, the battery can be hold onto lower or higher than the UC voltage [5]. Shows on figure 3, UC located after the converter and connected to DC link. UC also working as low pass filter because of this condition. The advantage of this configuration is the control of DC link voltage can be adjusted within a range so that the UC energy can be more effective.

2.4. Cascade Configuration

![Cascade configuration](image)

Diagram of the cascade configuration shows in figure 4. Using two converters, unidirectional/bidirectional converter located between battery and UC, other bidirectional converter located between UC and DC link [5]. The development of these configurations explained below.

2.5. Multiple converter configuration

From the cascade, the configuration can develop become parallel connection the inverter output that connected to the DC link. The diagram shows below in figure 5.

![Multiple configuration](image)
The advantage is output voltage from both converter can be hold onto lower than the dc-link voltage, so the voltage on DC link can be balanced [5]. In addition, the UC using can be maximized because of the wide range of voltage. But this configuration needs two powerful converters that will affect price and dimension.

2.6. **Multiple input converter configuration**

To reduce the problem on multiple converter configuration, the new configuration is researched [5]. Named multiple input converter configuration. The diagram shows in figure 6 below.

![Figure 6. Multiple input converter configuration](image)

The use of hybrid energy storage systems can use a DC / DC converter with less power as charging a UC bank. Even with a relatively constant load profile will make battery life longer because there is no need for a fluctuating load. So using this system has the potential for efficiency if sizing and adjusting is done accurately.

2.7. **Threeway Configurations**

Three way systems consist of battery units (BU), fuel cells (FC) and ultra capacitors (UC). This system is quite complicated to apply because each energy source has different characteristics. Sizing between components must be absolutely right because by using many different energy sources the risk of failure will also increase. In addition, high installation costs are still a challenge in this system.

A bidirectional step up/step-down dc/dc converter, as shown in Fig. 7, connects each power source to the dc link. From each source to be able to supply the load using a step-up dc / dc converter so that the resulting voltage will be stable. Conversely, when it functions to store energy regenerative braking, a step-down dc/dc converter is used to charge the battery and the UC. In this condition the system needs to be added to the safety system so that the current is flowed according to the current charging capacity of each source.

![Figure 7. Multiple input converter configuration](image)
3. Power Management
Supply energy to the loads needs to manage the power on each energy source, such as the battery, UC and RFC. Purposes of power management extend the range, improve vehicle performance and extend the battery life [6][1]. In general there are two power management strategies in HESS, the most widely used system today is the rule base method with certain restrictions. In addition, fuzzy methods based on artificial intelligence are widely studied. [4]. Another optimization is developed from those strategies. The main target of optimal sizing to get the best combination between each energy source which can minimize the weight and maximize the power output.[7].

![Figure 8. Fuzzy on power management system](image)

In the research [8], author focus research on power management using fuzzy logic based on the safe condition. The safe condition means that the electric vehicle is on the low power state, so every energy source needs to keep the performance and condition above minimal value and characteristic. On fig 8. Diagram of fuzzy for power management using three data input, there are SOC, velocity and acceleration. For energy storage that uses RFC, research [7] use clustering on frequency to get the best optimal sizing of RFC.

To determine the power consumption, research [5] separated as four driving modes. On each mode has own characteristics so need to define own management system. There are low constant speed mode, high constant speed mode, accelerations mode and decelerations mode. Low constant speed mode when power of dc-dc converter (Pconv) can handle the power demand (Pdmd). Otherwise, if Pdmd higher than Pconv it means on high constant speed mode. In low speed mode, the voltage of UC can be preserved higher than the battery current directly supply to the DC link and dc/dc converter not operated.

In acceleration mode, fig 9 shows first condition that UC voltage higher than the battery voltage. When Pconv < Pdmd, UC voltage will decrease. UC and the dc/dc converter are supplying power for the vehicle acceleration. After a while, fig 10 shows UC voltage will be the same as the battery voltage then dc/dc converter will energize the vehicle demand and UC.

![Figure 9. Acceleration mode 1](image) ![Figure 10. Acceleration mode 2](image)
There is two steps on deceleration mode. First, on fig 11 and 12 the regenerative power will energize UC. The dc/dc converter on boost operation or not depend on the UC voltage. Then on fig 11, when regenerative power is in continuously, dc/dc converter will act like a buck converter. So the battery will absorb the energy from the vehicle. This condition will save the UC from over voltage condition.

Figure 11. Deceleration mode 1 & 2

Another way to optimizing is by using multiobjective optimization algorithm [9]. By using wavelet-based algorithms, the battery state of health (SOH) is highly concerned with dimensions and battery life. The algorithm performs smart settings related to power delivery between the battery and the UC. UC handles very high transient power requirements. These conditions cannot be done with batteries. Conversely, for stable conditions, a battery source is used. Until now there has been no comparison between methods with fuzzy and rules in certain applications.

4. Conclusion
In this paper, topologies of hybrid energy storage for electric vehicle present on some type. Each topology has its own advantages. DC/DC converter has an important role because of every topologies strategy use its device as the load management. There are two power management strategies in HESS, the most widely used system today is the rule base method with certain restrictions. In addition, fuzzy methods based on artificial intelligence are widely studied. By using power management, application on hybrid energy vehicle can be optimized.
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