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Energy Storage, Fuel Cell and Electric Vehicle Technology

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Abstract – The energy storage components include the Li-ion battery and super-capacitors are the common energy storage for electric vehicles. Fuel cells are emerging technology for electric vehicles that has promising high traveling distance per charge. Also, other new electric vehicle parts and components such as in-wheel motor, active suspension, and braking are emerging recently to upgrade the vehicles' performance. In this tutorial, the above topics are discussed and an outlook on future vehicles is highlighted. The tutorial paper is suitable for researchers or engineers with a deep knowledge of electric vehicles and is also suitable for someone new to the field.

Keywords: Energy storage, Electric Vehicles, Redox flow battery, super-capacitor, fuel cell, active suspension, in-wheel motor, configurable EV, ABS.

I. INTRODUCTION

The critical components of an Electric Vehicle are the battery and the motor drive. Energy storages such as batteries and super-capacitors are now the major energy storage units. The energy sources like fuel cells and flow batteries are also getting popular and are promising energy storage for future devices. Thanks to the hydrogen economy, the coming new fuel with zero carbon will be a trend. Energy cell packaging is now in a new direction. The use of energy cells to integrate with the vehicle body has been reported and suggests good potential for energy management. The energy management and balancing technique is now a necessary component to manage the energy cells. Besides the energy storage and the traction motor and drives, there are numerous motors and actuators used in modern electric vehicles. They are located in various positions of a vehicle to replace the conventional mechanical and hydraulic system. They may include an active suspension system to replace the conventional hydraulic system. The In-wheel motor is based on integrating the motor and wheel into a single unit that increases the power density and presents a real 4-wheel drive. The skid steering can, therefore, be realized. Also, the E-anti-lock braking (ABS) is an all-electric braking system and replaces the conventional hydraulic system in ABS. In this paper, the energy and fuel technology are reviewed and the new electric vehicle technology is examined and highlight future vehicle development.

II. BATTERY TECHNOLOGY

A. Common battery

In general, energy storage for all feasible energy storage for an electric vehicle could be electrochemical, electrostatic, and chemical types. Fig 1 shows an illustration. Basically, the energy storage or fuel can be classified into Electrochemical – conversion between electricity and chemical energy, electrostatic – conversion between electricity and static electric/magnetic field, mechanical – conversion between mechanical energy and electric energy, chemical – conversion from thermal chemical to electricity.

In the past, using hydrogen Internal combustion enginer (ICE) has been developed because of its zero emission, but it is gradually replaced by hydrogen fuel cell .

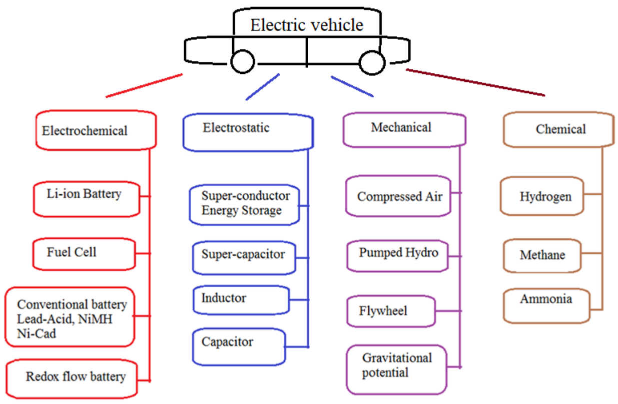


Fig 1: Fuel and energy storage for electric vehicles.

The battery is now using Li-ion as the common energy storage because its technology is ready and quite mature. Table 1 shows the typical energy storage for common cells:

Table 1: Common Lithium ion battery characteristics

	$LiCoO_2$	$LiMn_2O_4$	$LiNi_{⅓}Mn_{⅓}Co_{⅓}O_2$	$LiFePO_4$	$Li_4Ti_5O_{12}$	$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$
Specific Energy (Wh/kg)	180	100	180	140	100	160
Number of Cycles (life time)	1000	1000	1000	2000	10000	1000
Cell voltage (V)	3.7	3.8	3.8	3.2	2.2	3.7

Besides the above common batteries, other higher performance battery such as Lithium-Sulphur [1] or Li-Oxygen battery [2] has promising performance and may be an option for a future vehicle. Fig 2 shows an illustration of different energy storages. The fuel cell has a good potential for the future long-range vehicle, and super-capacitor is suitable for high power short-range vehicle.

B. Redox flow battery

Reduction-oxidation (Redox) flow battery is another possible battery for electric vehicles because its energy storage is based on the electrolyte [3]. Therefore the charging is similar to adding liquid fuel which is the electrolyte to a vehicle's tank. Fig 3 shows the configuration. The disarm shows a popular diagram for vanadium Redox flow battery, but other flow battery suing other technology such as Zinc-bromide is also common.

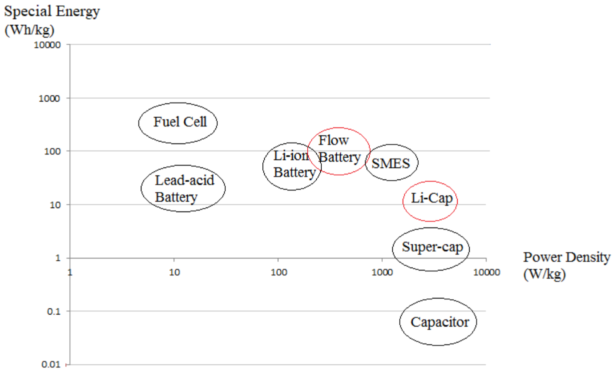


Fig 2: Special energy of various energy storage or fuel

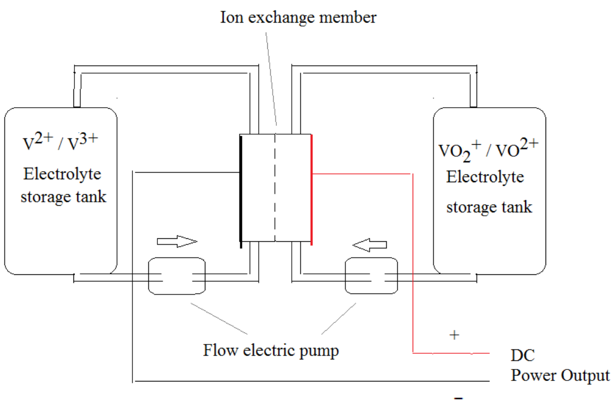


Fig 3: A schematic of redox flow battery (with vanadium)

III. BATTERY MANAGEMENT SYSTEM

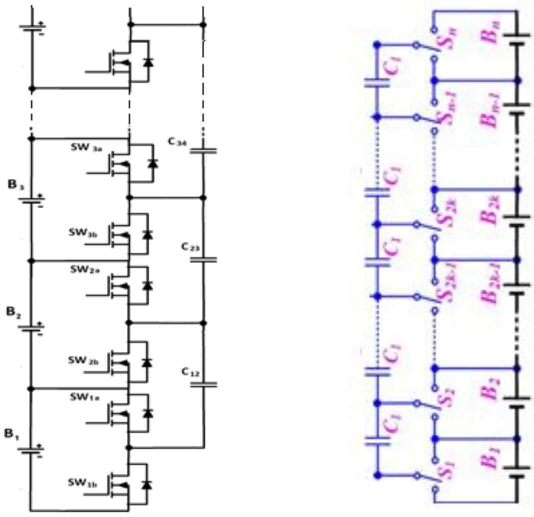
Battery management system (BMS) is the basic protection and monitoring devices for all battery vehicles. It allows the estimation or the measurement of the State of Charge (SoC), State of Health (SoH), cell equalization, and communication and control, with other vehicle parts and vehicle control unit (VCU). SoC varies with the current, temperature, and cell voltage, therefore the estimation of SoC cannot be done by Coulomb-counting, but predictive modeling is needed.

A. Passive Cell Equalization

The common cell balancing is using passive balancing in which the over-charge cell is discharged by a resistor and hence the balancing is not adaptive and it is more like overvoltage protection [4].

B. Active Cell Equalization

The active version is using inductors or capacitors to temporary to store the energy and use it to transfer energy from over-voltage cell to under-voltage cell. Fig 4 shows the two typical methods:



a) Inductive Balancing b) Capacitive balancing

Fig 3: Typical Cell Equalization scheme

IV. BODY INTEGRATED SUPER-CAPACITOR FOR VEHICLES

A. Body integration concept

The new concept of energy storage is not to place all the energy storage in a single compartment of location, such as in the back, of the bottom of a vehicle, but to distribute the energy storage over different vehicle parts. The door, wing, boot, or chassis can be part of the body integrated energy storage location. The idea is to integrate the package of the super-capacitor and the body part to reduce the unnecessary package or enclosure. Of course, the location is special and it must be selected so that it does not affect the vehicle operation and even under accident, it is safe proof. This concept is called distributed energy storage for vehicles. The design allows energy storage can power electronics units locally and reduce power distribution and loss. It also allows the future design of configurable vehicles. Fig 5 shows the concept:

Fig 5: Distributed energy storage concept for vehicles.

B. Super-capacitor and battery management system, The management for both supercapacitor and battery is shown in Fig 6. It consists of the battery management unit (BMU) and the Super-capacitor management unit (SMU) to measure the information from each battery and supercapacitor module respectively. Their information is communicated to the master control unit through the CAN bus.

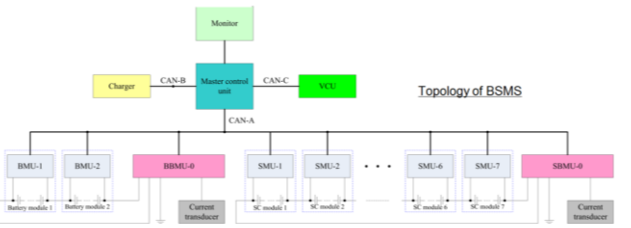


Fig. 6: Super-capacitor and battery management system

IV. Fuel Cell Vehicle

A. World metal resources

Vehicles using Lithium-ion battery has a potential problem. The world production of Lithium is very low as compared with other metals. The first is iron and the second is aluminium. The production quantity of lithium is close to silver or gold. That means it is precious and the source is limited. Fig 7 shows the chart of the metal world production. Therefore using Lithium as energy storage will impose a major issue in coming years.

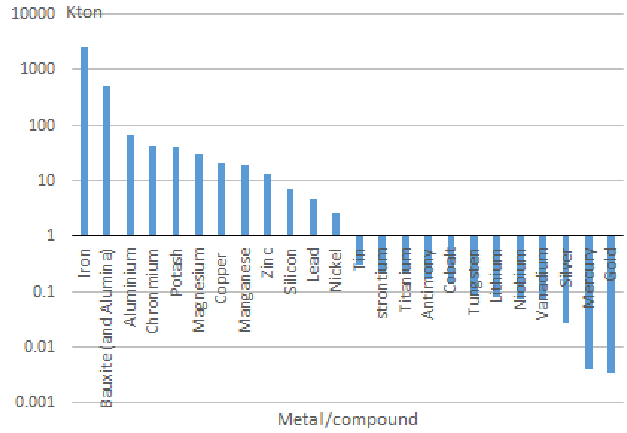


Fig 7: World production of major metals per year.

The Aluminium and zinc's prices in the last 5 years are very stable and therefore using Aluminium and zinc as the fuel such as Aluminium and zinc fuel cell, the potential benefit is much better than Lithium or Cobalt. The price of Aluminium in the last 5 years varies between USD 360 to 510 / ton and Zinc's price varies between USD310 to 750 / ton [5]. The variation is 1.7 times and 2.4 times for Aluminium and Zinc between the highest and lowest price.

B. Effect to battery materials

However, for Cobalt and Lithium which are the major metal components for Li-ion batteries, the price varies significantly in the last 5 years. Cobalt's price varies from USD 4500 to 20000 / ton whereas Lithium's price varies between USD 5000 to 22000 per ton [6]. They represent the variation of 4.4 times between the highest and lowest price.

C. Fuel cell vehicle

The design of any fuel cell vehicle needs energy storage such as battery and supercapacitor in order to ensure the dynamic energy during braking and declaration can be stored because fuel cell cannot convert electrical current to fuel. Fig 8 shows the typical design of a fuel cell vehicle. The fuel shown can be any hydrogen carrier fuel that may be cracker or purifier. However, if it is metal fuel, then it is directly inserted into the Fuel cell reactor.

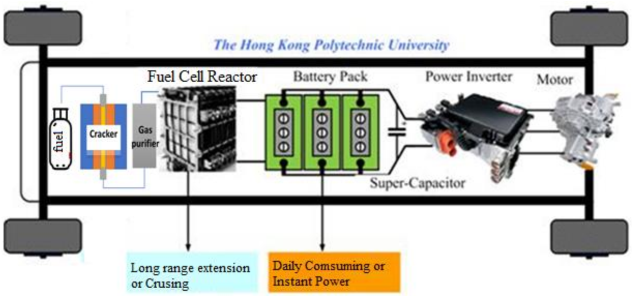


Fig 8. Fuel cell vehicle configuration.

V. In Wheel Motor

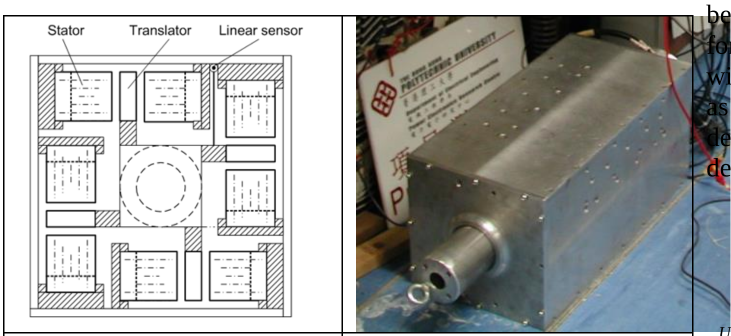
The integration of the motor to the wheel is so-called the in-wheel motor. The design criteria are that the motor must have high power density so that it can be included in the wheel and it is, therefore, direct-drive and there is no mechanical linkage such as transmission, gearbox, crutch, and shaft and thus the efficiency is high. The wheel speed is designed to be low and the torque must be large. The motor should have vibration tolerance as well. Fig 9 shows the development of an in-wheel motor using switched reluctance motor technology so that the permanent magnet can be eliminated [7]

Fig 9: In-wheel motor with the cover open.

VI. Active Suspension

Instead of using hydraulic suspension which is slow and not adaptive, using a linear motor to replace the conventional suspension is a future design for vehicles [8]. It provides high dynamic performance and its response is much faster. Fig 10a shows the design of an active suspension which forms or a linear actuator or motor. . It consists of a translator which is the moving part to control the sprung mass of the vehicle to move and the stators consist of a number of phases that is fixed on the four wheels. The active suspension is controlled to reduce heave and vibration.

Fig 10b shows the sample of the active suspension which its shape is square. Another shape is available with different designs of the translator and stators. Another advantage of the active suspension is that its vibration energy that is wasted in the conventional hydraulic suspension is wasted, whereas the present system can recover the energy and return to the battery.



(a) Configuration (b) Image

Fig 10: The Active suspension using switched-reluctance Technology

VII. All Electric Anti-Lock Braking System

The mechanical disk braking basically relies on a hydraulic or pneumatic system which is not reliable and needs maintenance. The recent research using force motor to replace the mechanical system is a preferred design. It has high dynamic performance [9] and can control the optimized slip as shown in Fig 11. Fig 12 shows how the force motor connected to the wheel.

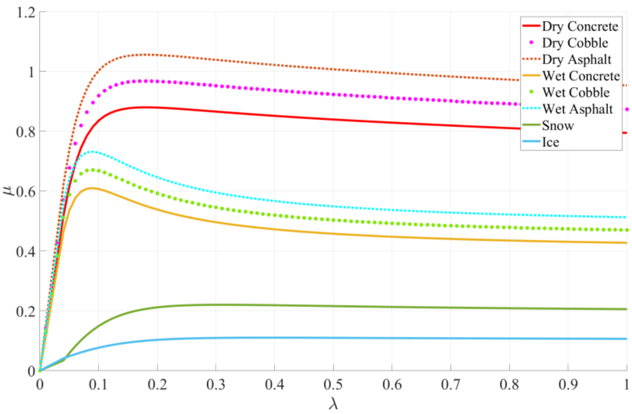


Fig 11: Relationship between Road friction coefficient and slip

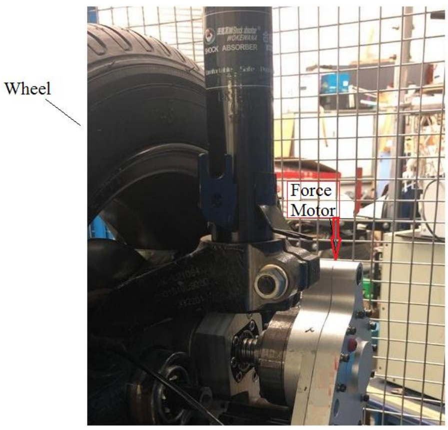


Fig 12: E-ABS testing in the laboratory

VIII. Wireless Power Transfer for Vehicles

The conductive charging has a few issues that are not welcome by users. For example, the cable connection is bulky, worry of electrical shock, concerned humid of raining season, connection aging, compatibility of socket and plug and standardization. The wireless power transfer is usually applied to a charger which can be briefly divided into stationary and move–and–charge. The coils between the primary and second are coupled inductors that form the air-gapped transformer. The converter associated with the coupled inductor is the bridge resonant converter as shown in Fig 13. Fig 14 shows the coils and converter development which is technology for move-and-charge design [10].

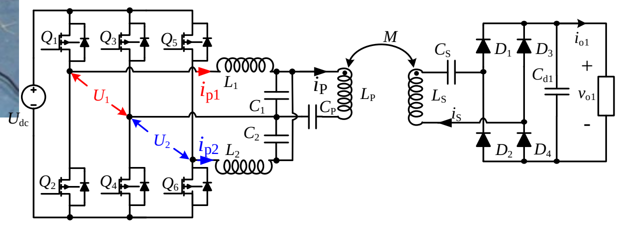


Fig 13: Coupled inductor used in resonant power converter.

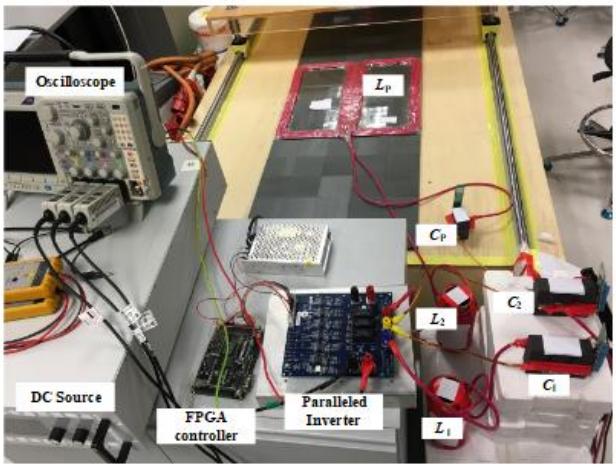


Fig 14: Implementation of the move and charge for vehicles.

IX. Future Vehicles and Conclusion

Future vehicle design should meet the requirement of long traveling distance per charge. The maintenance is expected to be low and also the control is simple and has good and smart sensing and monitoring, as well as fault tolerance. Therefore autonomous driving is one of the present and future features of the electric vehicles. All the conventional mechanical and hydraulic systems will be replaced by electric motors or actuators so that diagnosis is all computerized and traceable. Therefore the dynamics response of the vehicle is fast.

The technologies of power electronics, magnetics, motors, smart sensors, and smart control are the tools for electric vehicle development. Other special applications of vehicles will also be in demand such as configurable vehicles so that a vehicle can change its shape or function when needed.

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