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Hybrid Energy Storage System: Plug-In Hybrid Electric Vehicle perspective

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ABSTRACT: In recent years, the hybrid electric vehicle (HEV) has come to the forefront as the leader for alternative fuel vehicles. With the increased demand for HEVs, more research has gone into the improvements of these vehicles. In order to achieve better performance the researchers have focused on many elements of the vehicle and how these elements affect the overall vehicle performance. And Storage system technology has been the discussion topic. There have been many developments on battery technology to increase cell life and performance. In order to achieve a better performing energy storage system, the concept of hybrid energy storage systems has been discussed. With the combination of different energy storage devices, the energy storage system can be improved to be for adept to accepting high regenerative braking current as well as endure high dynamics when it comes to driving performance.

Super-capacitors are the options with higher power densities in comparison with batteries. In this paper, I have discussed the State-of-the-art of energy storage system. This paper includes the supercapacitor mechanism of energy storage. This paper also presents the electric field of hybrid supercapacitors.

KEYWORDS: Hybrid Energy Storage System, Plug-In-Hybrid Vehicle, supercapacitors, hybrid electric vehicles, Battery, HEVs, PHEVs. Energy Management System, Ultracapacitors.

I.INTRODUCTION

Hybrid Electric Vehicles (HEV) are expected to be one of key technologies for future cleaner and fuel efficiency vehicles [7]. HEV is is an optimal combination of two power sources, A conventional internal combustion engine (IEC) and a rechargeable energy storage system. Increase in fuel cost and emission standard across the globe have popularized this alternative form of transportation. Recent surveys have shown a remarkable result that 36% of motorists worldwide wish to buy a car with hybrid drive system. While 46% showed interests in buying full electric cars. And it is expected that the numbers will increase over the time period.

Moreover, Hybrid Hydraulic Vehicles (HHV) have also been the subject of a revival interest with a series of works devoted to the design, the simulation and the optimization of hybrid hydraulic systems for trucks. The Success of HEV or HHV design requires optimal sizing of its key mechanical, electrical components. In addition, for more hybrid vehicle (HV) efficiency, an optimal management of energy flow (control strategy) is required. Therefore, in their design process, there is a large variety of design variable choices including HV configuration, key mechanical, electrical or hydraulic components sizes and control parameters. Moreover engineers are faced with several conflicting design constraints and objectives aiming at increasing performances and comfort while minimizing environmental impact [5]. In hybrid topology, Since the vehicle is no longer dependent on only one type of fuel, they have many benefits for the vehicle, From emission reduction to performance and efficiency improvements. The efficiency and all electrical range of hybrid electric vehicle dependent on their capability of their energy storage system(ESS),Which not only utilized to store large amount of energy but also should be able to release it quickly according to large land demands[1][8].

In this paper, The discussion over various configuration for a HESS and their advantages and disadvantages is also presented and the HESS presented in this paper is a combination of batteries and ultracapacitors.

II. STATE-OF-THE-ART: BATTERIS FOR HEVs AND PHEVs

With the recent trend for lighter and better performing batteries, much research has gone into developing batteries. These developments led to the arrival of chemistries such as lithium-ion, lithium polymer, and lithium- phosphate batteries among others. Also the concept for the ultracapacitor used as a viable energy source has become increasingly popular. The new technologies being developed and tested have shown increased performance over the widely used lead acid battery and below in Table I, one can see the aspects of various types of chemistries and how they compare to each other. The ultracapacitor, however, has different operating principles than a battery which results in characteristics that are quite different. Table II shows the same operating aspect as shown in table I but for UCs. As the tables show, batteries have a relatively high energy density which varies with chemistry and low power density[2].

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Chemistry	Nominal Voltage (Volt)	Energy Density (Wh/kg)	Power density (kW/Kg)	Life Cycle (Number)
Lead Acid	2	30-40	0.18	Up to 800
Ni-Mh	1.2	55-80	0.4-1.2	Up to 1000
Li-Ion	3.6	80-170	0.8-2	Up to 1200
Li-Polymer	3.7	130-200	1-2.8	Up to 1000
Li-Iron Phosphate	3.2-3.3	80-115	1.3-3.5	Up to 2000

Table 1: Characteristics of battery technology

Chemistry	Nominal Voltage (Volt)	Energy Density (Wh/Kg)	Power Density (kW/Kg)	Life Cycle (Numbers)
Li-Polymer	3.7	130-200	1-2.8	Up to 1000
Ultracapacitor	2.5-2.7	5-10	4-10	0ver 1000000

Table 2: Characteristics of Ultracapacitor.

On the other hand, The UC has a much lower energy density, Significantly higher power density and the cycle life of te UC is significantly higher than that of batteries. In the terms of a hybrid electric vehicle, One can easily see that the power density of a battery would yield a much better performance of the vehicle [2].

III.ULTRACAPACITORS/SUPERCAPACITORS: A LIGHT INTRODUCTION

The Supercapacitors usually have large capacitance, high energy density and a long life. It is a perfect choice as storage energy elements used in pulse power source and electric vehicles at present, however the working voltage of existing supercapacitor units is usually low, only a few volt. In order to raise the work voltage of super-capacitors, a new structure of hybrid supercapacitors is fabricated by combining the anodes of electrolytic capacitors with the cathodes of electrochemical capacitors [9] [10].

The hybrid supercapacitor has the high working voltage of electrolytic capacitors and the high storage energy density of electrochemical capacitors; therefore it can effectively exhibit its merits of large capacitance and high storage energy density, and will play an important role in pulse power systems.

The UC stores energy by separating positive and negative charges physically. Those charges are stored on two parallel plates diving by an insulator, Since there are no chemical variations on the electrode, The UC have a long life cycle but low energy density. Below the FIG.1 shows the structure of an individual UC cells[1]. Potential on the negative electrode attracts the positive ions while negative ions get attracted with the positive electrode.

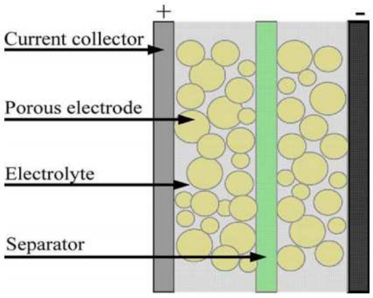


Fig1: Individual UC cells [1]

The ultracapacitors can be used as assistant energy storage device for the HEVs. In Urban driving, There are many stop and go driving conditions, and the total power requirement is relatively lower. The UC are capable of capturing electricity from regenerative braking and can quickly deliver the power due to their fast charging cyles.

Currently, Five UC technologies are in development: Carbon/Metal fiber composite, foamed carbon, A carbon particular with a binder, Doped conducting polymer films on a carbon cloths and mixed metal oxide coating on a metal foil. Higher energy density can be achieved with a carbon composite electrode using an organic electrolyte rather than a carbon/Metal fiber composite electrode with an aqueous electrolyte [1].

IV. HYBRID ENERGY STORAGE SYSTEM

The combination of batteries and ultracapacitors has the potential to dramatically increase the performance of a hybrid electric vehicle by combining the energy density of the battery with the power density of the ultracapacitor. But There are many factors that must be considered when combining the two energy sources including voltage strategy, protection of over current, power electronic size and cost, and reliability just to name a few. To discuss the idea of Hybrid energy storage system this section will discuss the combinations in types of active and passive.

1) Parallel Methods.

a) Passive parallel: Passive paralleling is the simplest method of combining battery and UC bank together because the two energy sources are hybridized without the use of any power electronic converters or inverters. Fig.2 shows the basic topology of basic passive parallel method.

b) Passive parallel with bi-direction DC/DC converter: One can also use a DC/DC converter after the passive parallel connection to control the overall output. This type of combination is still considered a passive connection because the converter is placed after the combination. Fig. 2 shows this type of configuration. One should note that the use of power electronics in this type of configuration still does not allow for the full use of voltage range of the ultracapacitor [2].

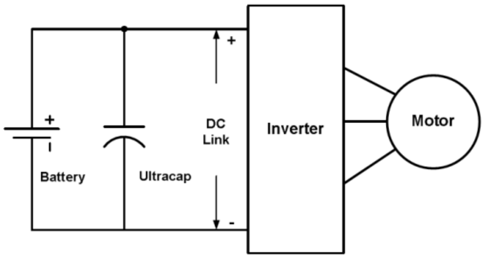


Fig.2: Passive parallel configuration[2]

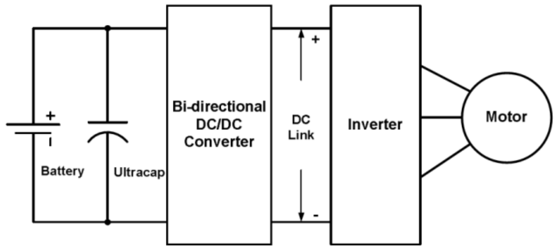


Fig.3: Passive parallel with bidirection DC/DC converter[2]

2) Active methods.

There are three major active methods of HESS combination available and in order to classify these methods, they are named for the power electronic converters used in the hybridization.

I. Ultracapacitor/Battery configuration: In this configuration, the UC is connected to the DC link via a bi-directional converter as shown in Fig. 4. Voltage of the ultracapacitor is maintained lower than the DC link voltage because a lower storage device voltage is preferred. The Ultra-Capacitor/Battery based HESS has been one of the most active areas of research. This type of configuration provides three major advantages- (i) Ultra-Capacitor can be used in a wide range by controlling the bi-directional DC/DC converter; (ii) the nominal voltage of the UC bank can be lower; and (iii) the battery is connected directly to the DC link which yields a rather constant DC link voltage. The disadvantage of this system is that the energy provided by regenerative braking cannot be controlled effectively to provide majority to ultracapacitor which is inherently better for accepting these large short term current spikes [2].

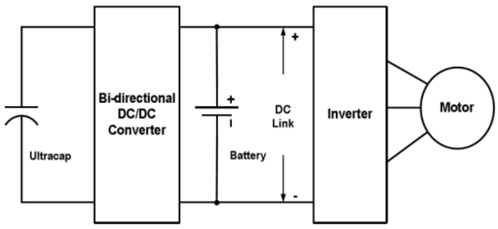


Fig. 4: Ultracapacitor/Battery active configuration[2]

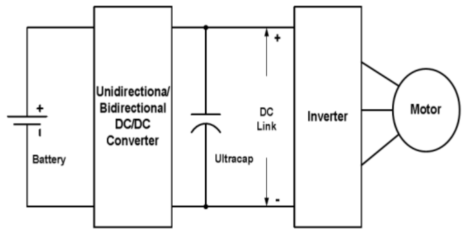


Fig. 5: Battery / ultracapacitor active configuration[2]

II. Battery/Ultracapacitor Configuration: As one can easily guess, one can switch the location of the energy sources to achieve a Battery/UC configuration. This type of configuration is shown in Fig. 5 By connecting the battery to the DC link via a DC/DC converter, the voltage of the battery can be maintained lower which can lead to a lighter overall energy storage system among other things. This configuration also allows for the ultracapacitor to naturally accept and provide the current spikes which are experienced during operation. Finally, with the ultracapacitor in this placement it also allows for regenerative braking current to be fully utilized[2].

III. Multiple Converter Configurations: This type of configuration, shown in Fig. 6 utilizes the two sources with two separate converters. This allows the two source voltages to be lower than the overall DC bus voltage. This is advantageous when considering the complications of a higher voltage source, particularly when considering the battery source because of issues such as cell balancing that lead to poor and sometimes destructive operation.

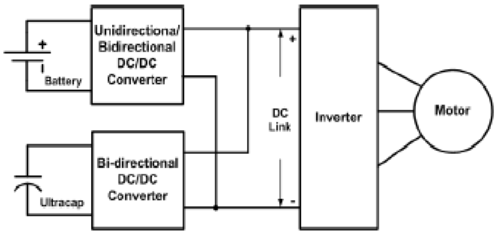
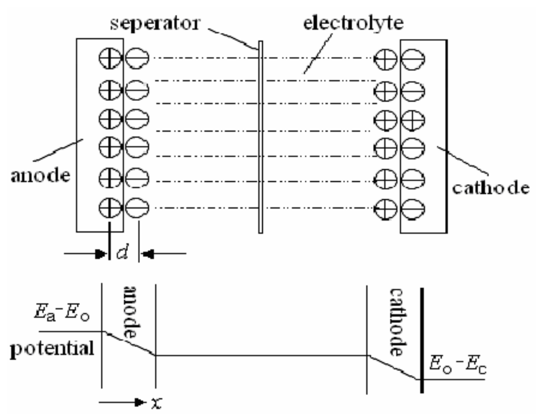


Fig. 6: Multiple converter active configuration[2]

This type of configuration, shown in Fig. 5 utilizes the two sources with two separate converters. This allows the two source voltages to be lower than the overall DC bus voltage. This is advantageous when considering the complications of a higher voltage source, particularly when considering the battery source because of issues such as cell balancing that lead to poor and sometimes destructive operation.

V. THE SUPERCAPACITOR MECHANISM OF ENERGY STORAGE

According to the mechanism of energy storage, super-capacitor can be subdivided into two kinds: double-layer capacitors and faradic pseudocapacitors [11]. Double-layer capacitor form double electric layers (Helmholtz Layer) to store the electric energy. Positive and negative ionic charges within the electrolyte accumulate at the surface of the solid electrode and compensate for the electronic charge at the electrode surface, as seen in Fig.7. The electrode materials of double-layer capacitor always have high electrode surface area created by a large number of pores, e.g. the active carbon (> 1000m2/g). When the electrolyte enters the pores of electrode, an increased amount of charge and ion can be stored in the double layer on the highly extended electrode surface area as seen in Fig.8. Faradic pseudocapacitor is worked by fast faradic reaction from active material of electrodes, occurring not only on the surface of the electrode but also the inside of the whole electrode, as a result to obtain higher specific capacitance and energy density than double-layer capacitor [6].



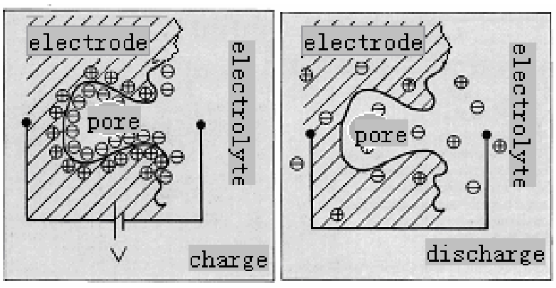


Fig 7: Schematic of super capacitors and potential Distribution throughout electrochemical capacitor During charge

Fig 8: The structure of double layer charge during charge and discharge

VI. SUPERCAPACITORS ELECTRIC FIELD

The anode of the hybrid super-capacitors in the study[6] adopted the anode of tantalum electrolytic capacitors. It was made from high-purity pores tantalum powders, pressed into the modeling, sintered at high temperature, and then formed a layer of tantalum pentoxide dielectric on the surface of the tantalum anode by electrochemical method. The cathode adopted the electrode of electrochemical super-capacitors, which was made of the composite electrode materials of hydrous ruthenium oxide and active carbon powders at certain mass ratio, prepared them to membranes with the thickness of 0.2mm according to the membrane preparation technology, and then pressed them on the current collectors to make up of the cathodes of the hybrid super-capacitors. The two electrodes were separated by the fiberglass cloth and composed of the hybrid super-capacitor unit. The electrolyte is 38wt% vitriol solution. The working voltage of the sample hybrid super-capacitor prepared in this study is 40V with the dimensions of the anode being 15mm diameter by 3.5mm high.[6]

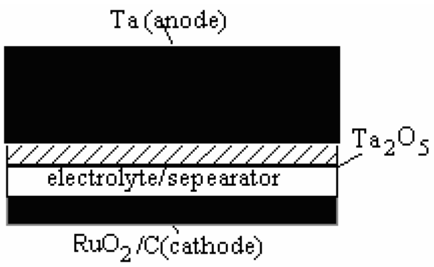


Fig. 9: the structure of hybrid capacitor[6]

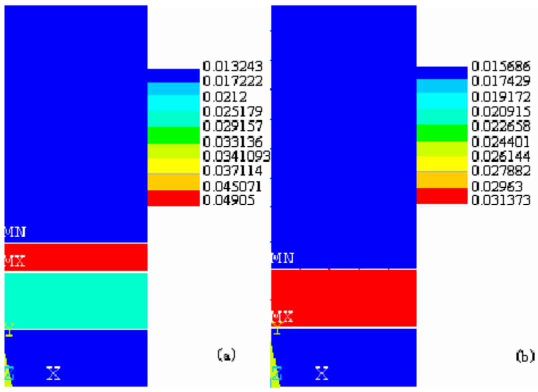


Fig. 10: The electrostatic field of hybrid capacitor: (a) It has Ta2O5 membrane (b) with no Ta2O5 membrane [6]

Fig.9 is the structure of the hybrid capacitor. Fig.10 is the electrostatic field of hybrid capacitor by ANSYS. Because its structure can be seen as the plain capacitor and the assumed inner parts of each material is uniform, the electrostatic field of layer is 1nm, the inner parts is uniform. The relative permittivity up to down is 100, 27, 50, and 80. In Fig.10, the maximum value of *E* which has Ta2O5 membrane is in Ta2O5 membrane, but in the electrolyte which has no Ta2O5 membrane. The value of *E* in the elctrolyte which has Ta2O5 membrane is lower than the one which has no Ta2O5 membrane. It may reach the breakdown electric field intensity of electrolyte if the hybrid capacitor has no Ta2O5 membrane. Ta2O5 dielectric has the impotant effect to improve the distributing of electric field for the hybrid capacitor. The working voltage of common supercapacitor is low for the electrolyte as the dielectric cant accept the voltage exceeded its breakdown voltage. But the working voltage of the hybrid super-capacitors is determined by the breakdown voltage of tantalum pentoxide dielectric on the surface of anodes, the voltage can reach 300V now. Therefore, it can improve the working voltage of the hybrid supercapacitors by increasing the thickness of the anode dielectric layer, but the capacitance will decrease with it. [6]

VII. CONCLUSION

The paper presents State of the art of HESS technology with the light emphasis on supercapacitors and the energy management. HEVs and PHEVs have proven to be effective solution for current energy and environment concerns.

With revolutionary contributions of power electronics the HESS technology in PHEVs and HEVs perspective will further grow better and bigger in coming years of research. Low-cost high efficiency hybrid ESS would make this hybrid vehicle technology more feasible to compete with conventional vehicles in the near future. The discussion in electric field of super capacitor is also shown in this paper with the help of reference [6]. The physical and electric parameters may influence the performance of supercapacitors and can improve the energy and power density.

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BIOGRAPHY

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