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SUPERCAPACITORS FOR BATTERY CYCLE LIFE IMPROVEMENT AND RANGE EXTENSION VIA FAST CHARGE IN ELECTRIC VEHICLES

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Abstract. The use of supercapacitors in HEVs (hybrid vehicles in general, both charge sustaining hybrids and plug-in hybrids) has proved to improve battery cycle life and even to reduce the total volume and weight required for energy storage. However, their use in pure EVs (electric vehicles) does not seem to offer enough advantages: although battery cycle life is extended, there is an important drawback in terms of extra volume and weight. In our paper, we propose the use of supercapacitors in EVs with an additional objective: range extension via fast charge. The main idea is to share the total energy storage between a lithium-ion battery module and a supercapacitor module, which is in charge of reducing the battery stress during the operation of the vehicle and also offers a fast charge option for a limited extra mileage. In this sense, a new measure of performance is proposed: extra mileage per minute of charge, where supercapacitors clearly outperform batteries.

Introduction

Nowadays, electric vehicles are only limited by the energy storage problem: their performances in terms of top speed and acceleration are comparable to those of fuel-based vehicles, their cost per kilometer is considerably lower and their mechanical complexity is also low.

However, the energy storage problem has not yet been solved. Even the newest, state of the art batteries are not capable of storing enough energy per weight or volume unit. The result is the so-called range anxiety concern (first mentioned in [1]): a concern that the car would run out of power and will require several hours to recharge.

A common solution is the use of HEVs (hybrid electric vehicles) instead of EVs (electric vehicles). The main idea is to combine an electric motor and a combustion engine. When batteries are below a certain charge level, the fuel engine is started. There are two different options: charge sustaining hybrids, which generate electric power exclusively through the combustion engine; and plug-in hybrids, which can be plugged to charge the batteries. The former cannot be considered electric vehicles in a strict sense, as they necessarily rely on fuel consumption; the latter are usually known as extended-range electric vehicles. However, HEVs suffer from important drawbacks: first, mechanical complexity (which is extremely low in a battery powered EV) is much higher in HEVs, even higher than that of standard fuel-based vehicles. Second, volume and weight are increased, as the vehicles must have an electric motor, a combustion engine, a battery pack and a petrol tank. Third, electric range is usually low, as batteries are considerably smaller than those of EVs.

A second solution is fast battery charging [2]. State of the art charging stations can provide up to 62.5 kW (electric vehicle charging stations level 3), enough for an 80% charge of a standard EV battery in 30 minutes. However, fast charge also has important drawbacks, the main one being the reduction of battery life when used too often.

Another solution is the use of battery-replacement systems [3, 4]. The idea is to completely replace the battery instead of charging it. In a few minutes, the vehicle can have a fully charged battery. Such a solution is, however, difficult to implement: the robotic system needed to perform the battery swapping is expensive; standardization in battery size, shape, connections and technology is required; etc.

We propose to use supercapacitors to partially solve the problem. The idea is to offer the possibility of an extremely fast partial charge for a limited extra mileage. By combining supercapacitors and batteries, vehicles can be completely charged when there is enough time (since battery charging is a slow process) and partially charged in less than one minute when only a few extra miles are needed (as capacitors can be charged extremely fast). In next sections, we detail the combination of batteries and supercapacitors in electric vehicles; the performances of state of the art supercapacitors; the different requirements of EVs and HEVs; our proposal for range extension; and the results that can be obtained in different vehicles.

Combination of batteries and capacitors in electric vehicles

As well as batteries, capacitors can also store energy. The main advantages of capacitors are: first, they are not limited by the number of charge cycles (batteries are not guaranteed to perform properly after a certain number of charge cycles); and second, their charging processes are considerably faster than those of batteries. Among the drawbacks, capacitors are not capable of storing energy for very long (they have current losses); and energy density is lower in capacitors (even in supercapacitors) than in batteries.

EVs and HEVs can benefit from capacitors whenever fast charges are required: in regenerative braking, for example; or when a fast acceleration is needed (and thus, a high current is drawn by the electric motor). When capacitors and batteries are combined, batteries are not subject to fast charge/discharge cycles and their lifetime is increased.

Due to their limited energy density, capacitors cannot completely replace batteries in EVs: the volume and weight added to the vehicle would be excessive. Besides, current losses also limit the application of capacitors. A good example of ultracapacitor-based EV is the ultracap powered Sinautec bus [5], which can travel around 5 miles between charges. The buses connect to overhead power lines at every bus stop in order to charge their capacitor banks. However, the buses also use batteries for long-term energy storage. In fact, such approach is similar to the one proposed in this paper.

State of the art in supercapacitor performance

Ultracapacitors, or electrochemical capacitors, are an active field of research since the early 1990s. There are two main technologies: activated microporous carbon double layer devices (carbon-carbon) and hybrid carbon pseudo-capacitive devices. Table 1 compares both technologies with traditional lead-acid batteries and modern lithium-ion batteries, in terms of power density and energy density (standard values are given; some experimental prototypes may reach much higher values). More details about ultracapacitors and their use in electric vehicles can be found, for example, in [6].

Technology	Carbon-carbon	Hybrid carbon	Lead-acid	Lithium-ion
Power density	2000 W/kg	750 W/kg	200 W/kg	400 W/kg
Energy density	5 Wh/kg	12 Wh/kg	30 Wh/kg	160 Wh/kg

Table 1: Energy density and power density for ultracapacitors and batteries.

Concerning energy density, both types of ultracapacitors cannot offer nowadays the performances of batteries. Thus, storing energy for long ranges is still a problem if only capacitors are used. A combination of both devices is the most logical alternative.

On the other side, power density is much higher in ultracapacitors than in batteries, and this fact make such devices ideal for fast charge and discharge processes (as mentioned in a previous section, some examples are regenerative braking and fast accelerations). In our approach, we make use of this high power density in order to perform fast battery charges.

Supercapacitors for EVs and HEVs

The use of supercapacitors combined with batteries is common in HEVs (hybrid vehicles in general, both charge sustaining hybrids and plug-in hybrids). The main objective is the improvement in battery cycle life, by reducing battery stress during fast charge and discharge processes.

Apart from that, supercapacitors may help in reducing the total volume and weight required for energy storage in HEVs. This may seem contradictory, considering that energy density is much higher in batteries, but it must be taken into account that the total amount of energy that can be stored (and, thus, the electric range) is not an important restriction in HEVs (because there is a combustion engine that is always ready to extend the range). On the contrary, the most important restriction in HEVs is power density: batteries are smaller than those of EVs, due to space limitations, but almost the same power is required. Only ultracapacitors can offer power densities high enough as to cope with such requirements.

On the other side, ultracapacitors are not commonly used in EVs. Battery sizes are considerably higher than those of HEVs, in order to obtain high enough ranges and, with such battery sizes, power delivery is not a problem, even with low power densities. Combining ultracapacitors and batteries in an EV will necessarily increase the volume and weight required for energy storage.

Proposal of range extension via fast charge

As mentioned in the previous section, combining ultracapacitors and batteries in EVs increases volume and weight; however, we focus in its two main benefits: an improvement in battery cycle life and an alternative to fast battery charges in order to extend the range.

The benefits in terms of battery cycle life extension are well known, but the possibility of fast charges has not been considered previously. The scenario where such fast charges may be useful is that of an EV user who is running out of energy but is relatively close to his/her destination (we consider that such a scenario may be common for EV users). With a conventional, battery powered EV the only alternative is a fast charge, but there are two main drawbacks: it takes about 30 minutes and it reduces battery life. If a combination of batteries and ultracapacitors is used, the process will be much faster and will not harm the battery (nor the capacitor). The only limitation is the amount of range extension, which will be lower, but enough for the proposed scenario. A new measure of energy storage performance is proposed: extra mileage per minute of charge, where supercapacitors clearly outperform batteries. Figure 1 shows standard charging times for both devices; where we have considered a supercapacitor that takes less than 1 minute to be fully charged and is capable of store 300Wh; a lithium-ion battery that takes 8 hours for a full charge and is capable of storing 24kWh; and a standard EV with a consumption of 120Wh/km.

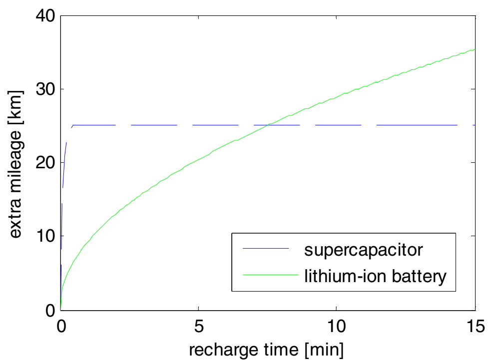

Figure 1: extra mileage vs. minutes of charge

It becomes clear that the fast charging system proposed in this paper saves time: the same range extension takes less than one minute via supercapacitor charge and about 8 minutes via standard battery charge.

Expected range extension per vehicle

Using the present technology, and considering a standard mid-size EV (120 Wh/km) and a commercial lithium-ion capacitor offering 15Wh/kg, the extra weight required for a range extension of 25km. would be 200kg; but further developments in supercapacitors may improve substantially such estimation (carbon aerogel capacitors have already achieved densities of 90Wh/kg, which will result in only 33 extra kg.). Table 2 shows the expected range extension in a quick charge like those proposed in this paper for different EVs, considering they are equipped with a 300Wh supercapacitor module (energy consumption is obtained from the official figures given by the manufacturers).

Manufacturer	Model	Energy consumption	Expected range extension
Smart	Fortwo EV	120 Wh/km	25 km
Mitsubishi	MiEV	125 Wh/km	24 km
Reva	Reva-i	133 Wh/km	22.5 km
Think	City	144 Wh/km	21 km
Nissan	Leaf	173 Wh/km	17.5 km
Tesla	Roadster	199 Wh/km	15 km

Table 2: Expected range extension via fast charge for different EVs.

Conclusions

A combination of supercapacitors and batteries can be used in EVs in order to allow for extremely fast charges that can extend the range up to 25 kilometers, without decreasing battery life.

Considering the present state of technology, the supercapacitor pack needed for a range extension of around 25 km will add an extra weight of 200 kg.

An energy storage system like the one proposed may offer multiple different charging strategies depending on the needs: 1) full -and slow- charge of both battery and capacitors when there is enough time; 2) fast charge of the capacitors for a limited extra range; or 3) fast charge of both capacitors and battery when the extra range required is higher (although using this option too often will obviously limit battery life).

References

[1] R. Acello: Getting into gear with the vehicle of the future, *San Diego Business Journal*, 1997.

[2] BTCpower: electric vehicle chargers level 3, http://www.btcpower.com/products-and-applications/electric-vehicle-chargers-level-3/

[3] Renault Quick-drop system, http://www.renault-ze.com

[4] Better Place, http://www.betterplace.com

[5] Sinautec ultracapacitor bus: http://www.sinautecus.com/products.html#hybrid.

[6] A. Burke, M. Miller: Electrochemical Capacitors as Energy Storage in Hybrid-Electric Vehicles: Present Status and Future Prospects, *EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium*, 2009.