# PRIMENA SUPERKONDENZATORA U ELEKTRIČNIM VOZILIMA

## APPLICATION OF SUPERCAPACITORS IN ELECTRIC VEHICLES

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*U radu su dati pregled stanja i pravci daljeg razvoja sistema za skladištenje električne energije na bazi superkondenzatora. Kritičnu komponentu svakog hibridnog ili čisto električnog vozila predstavlja skladište električne energije. Superkondenzatori su danas jedina dostupna tehnologija koja može obezbediti veliku specifičnu snagu i veliki broj ciklusa po povoljnoj ceni. Superkondenzatori imaju i druge karakteristike koje ih čine atraktivnim u električnim vozilima, kao što su mogućnost potpune upotrebe energije (tzv. regenerativno kočenje) za povećanje energetske efikasnosti, bez dodatnog održavanja, malo toksičnosti i lako odlaganje nakon upotrebe.*

***Ključnereči:*** *Superkondenzatori, EV, Skladištenje energije*

*The paper gives an overview of the state and directions of further development of the Electricity Storage Systems based on supercapacitors. Critical component at each hybrid or pure electrical vehicle presents electrical storage. Supercapacitors are nowadays the only available technology, which can provide great specific power and great number of cycles at reasonable price and save and reliable work. Supercapacitors have other characteristics that make them attractive in hybrid vehicles such as possibility of complete energy using (so called regenerative breaking) for increasing energy efficiency, with no additional maintenance, great recovery of electrical energy, little toxicity and easy disposal after usage.*

***Key words:*** *Supercapacitors, EV, Energy storage*

## 1 Introduction

Electric drive vehicles present one of the most important technological advances having in mind spread of this kind of nature pollution. Lately there is increased world interest for so called hybrid vehicles that have reduced fuel consumption and much less pollutants emission than regular vehicles. Hybrid vehicles can in broadest sense be described as vehicles utilizing combination of production and storage of energy. Good properties of conventional vehicles are combined (long range and acceleration, very good supply network) and electrical vehicles (zero emission, quiet operation, regenerative use of braking energy) [1,2].

Two kinds of these vehicles are in consideration - so called parallel and series hybrids. In parallel hybrids there is a connection between power generator and driving wheels, while in series that relation is not present. Series hybrids have substantial advantages compared to parallels due to their mechanical simplicity, flexibility in terms of design and ability of simple new technologies incorporation [2,3]. Supercapacitors are increasingly used in the power supply of electric motor drives, as well as electronic circuits in EVs.

## 2 Supercapacitors vs. accumulator batteries and fuel cells

Supercapacitors are relatively new type of capacitors distinguished by phenomenon of electrochemical double-layer, diffusion and large effective area, which leads to extremely large capacitance per unit of geometrical area (in order of multiple times compared to conventional capacitors). They

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are taking place in the area in-between lead batteries and conventional capacitors. In terms of specific energy (accumulated energy per mass unity or volume) and in terms of specific power (power per mass unity or volume) they take place in the area that covers the order of several magnitudes. Supercapacitors fulfill a very wide area between accumulator batteries and conventional capacitors taking into account specific energy and specific power [1,2]. Batteries and fuel cells are typical devices of small specific power, while conventional capacitors can have high specific power, but at a very low specific energy. Electrochemical capacitors improve batteries characteristics considering specific power or improve capacitors characteristics considering specific energy in combination with them. In relation to other capacitor types, supercapacitors offer much higher capacitance and specific energies, as illustrated in Figure 1 [2].

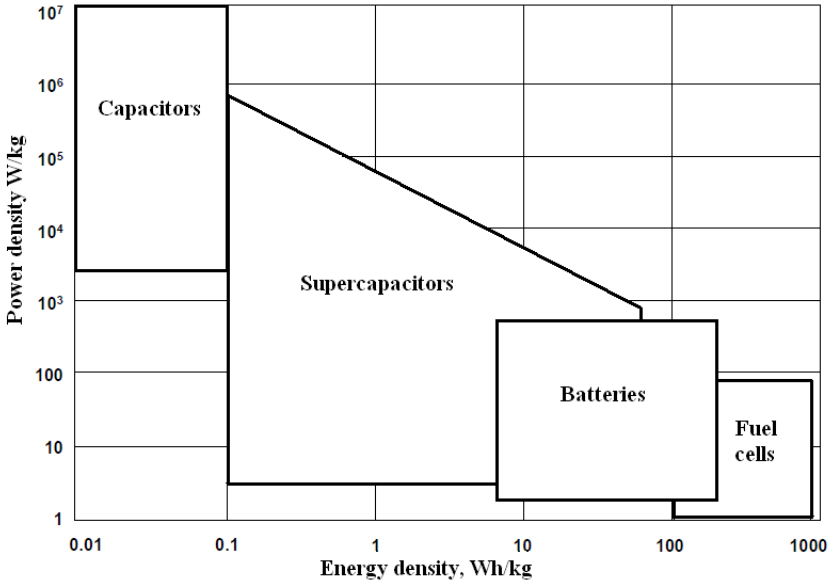


*Fig. 1 Area diagram for various energy storage systems [2]*

Accumulator batteries and low temperature fuel cells are typical devices with low specific power, where conventional capacitors may have specific power over 1MW/dm$^3$, but at very low specific energy. Electrochemical capacitor can improve characteristics of batteries in terms of specific power and improve properties of capacitors in terms of specific energy when they are combined with them [4].

Supercapacitors store charge in a similar way to conventional capacitors, but the charge does not accumulate in two conductors, but in the interface between the surface of a conductor and an electrolytic solution. Devices consist of two electrodes which allow a potential to be applied across the cell, therefore they present two double-layers, one at each electrode/electrolyte interface [5]. An ion-permeable separator is placed between the electrodes in order to prevent electrical contact, but still allows ions from the electrolyte to pass through. The electrodes are made with high effective surface materials, such as porous carbon or carbon aerogel [6]. Two principal technologies are used [7]: aqueous (maximum voltage of 1.2 V and work voltage of 0.9 V) and organic (voltage near 3 V but with a much higher series resistance).

The principal supercapacitor characteristic that makes it suitable for using in energy storage systems (ESS), is the possibility of fast charge and discharge without lost of efficiency, for thousands of cycles. This is because they store electrical energy directly. Supercapacitors can recharge in a very short time having a great facility to supply high and frequent power demand peaks [8].

Data given in Table 1 clearly show supercapacitor characteristics that make those devices adequate for purposes requiring great specific energy and great specific power combination or long lifetime denoted by charging and discharging number of cycles. In other words, capacitors have retained classical capacitors positive property to achieve almost unlimited charging and discharging number of cycles [2].

*Table 1 Capacitor, supercapacitor and accumulator basic characteristics*

| Characteristic | Classical capacitor | Supercapacitor | Accumulator |
|---|---|---|---|
| Discharging time | μs – ms | ms – weeks | min - months |
| Charging time | μs – ms | ms – minutes | hours |
| Specific energy | < 0,01 Wh/dm$^3$ | 0,5 – 5 Wh/dm$^3$ | < 500 Wh/dm$^3$ |
| Specific power | > $10^4$ W/dm$^3$ | (1-3) $10^3$ W/dm$^3$ | < 500 W/dm$^3$ |
| Cycles number | $10^6$ - $10^8$ (unlimited) | $10^6$ - $10^8$ | 200 - 1000 |

## 3 Supercapacitor applications in EV

Considering applying, there are four groups of supercapacitors. Depending on applying place, different characteristics of supercapacitors can be more or less taken into account. Some of them are of crucial importance for capacitor choice, and some of them can be of no importance at all [2].

Most strict requirements are related to capacitors of fourth group applying in electric haulage, i.e. for vehicles of the future. Nowadays, batteries of several hundreds farad capacitance are with working voltage of several hundred volts have been produced. Beside great capacitance and relatively high working voltage, these capacitors must have great specific energy and power (because of limited space in vehicle). Considering their specific power, they have great advantage in relation to accumulator batteries, but, on the other side, they are incomparably weaker considering specific energy. Hence, ideal combination is parallel connection of accumulator and condenser batteries. In an established regime (normal drawing) vehicle engine is supplied from accu-battery, and in the case of rapidly speeding, from supercapacitor. Very important is the fact that in the case of abrupt breaking, complete mechanical energy could be taken back to system by converting into electrical energy only in presence of supercapacitor with great specific power. Because of mentioned reasons, inner resistance of these supercapacitors has to be extremely small. Leakage current is not of essential importance. Vehicles with such drive are not still in wide use, and the reasons for that are for sure economic [2].

In Figure 2 the scheme of an electrical drive vehicle in which supercapacitor is used for energy storage and so-called regenerative breaking is presented.

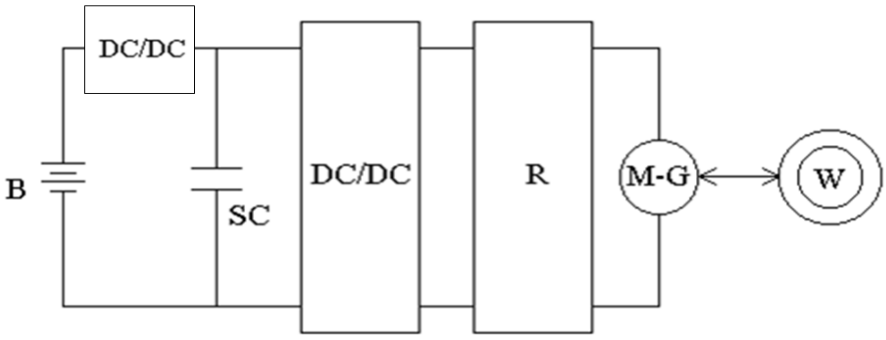


*Fig. 2 Scheme of electrical drive vehicle with supercapacitor with possibitlity for using breaking energy; B – one-way voltage source, SC – supercapacitor; DC/DC – direct voltage converter; R – regulator; M-G – engine – generator (depending on working regime; W – drive wheels [2]*

## 4 Conclusion

Critical component in every hybrid or purely electrical vehicle is energy storing. Possible solutions are accumulators, supercapacitors, flying wheels, hydraulic devices and new special materials for hydrogen storing. Supercapacitors are only available technology today that can provide high power and great cycle numbers at acceptable price. Supercapacitors have other properties that makes them interesting in hybrid vehicles, and it's ability of complete regeneration of energy of braking (so

called regenerative braking), which increases energy efficiency, no special maintenance needed, great utilization of electric energy, small toxicity and easy storage after use.

Batteries with large capacitance of several hundred Farads and few hundred volts of working voltages are already produced. Apart from large capacitance and relatively high working voltage those capacitors also must have high specific energy and power (for reason of limited vehicle space). They have huge advantage in terms of specific power compared to accumulator batteries, but they are incomparably worse in terms of specific energy. That's why the ideal combination becomes parallel connection of accumulator and capacitor batteries. In steady state (normal drive) vehicle motor is supplied from accu-battery and at sudden accelerating it is fed from supercapacitor. Very important fact is that at sudden breaking all mechanical energy can be returned to a system by transforming to electric energy only with presence of supercapacitors with high specific power.

## 5 Acknowledgement

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