APPLICATIONS OF ULTRACAPACITORS IN ELECTRIC AND HYBRID VEHICLE

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ABSTRACT

In this paper short history, operating principle, and basic properties of the ultracapacitors are mentioned. Ultracapacitors are compared with other electrical energy accumulating devices, lead-acid batteries conventional electrolytic capacitors. Then the structures of electric vehicles (EVs) is described with respect to possibilities of ultracapacitor applications. In next chapter ultracapacitor control structure for single-track electric vehicle is introduced.

Keywords— Ultracapacitor, Electric vehicles

1.INTRODUCTION

Ultracapacitors are modern electric energy storage devices, designed similarly to conventional electrolytic capacitors. Their advantages are high specific energy and high specific power capability along with high cycle life, which makes them ideal for peak power applications. Ultracapacitors application in electric vehicles can improve their performance, making them more interesting for automotive market by operating range increase and operating costs cut. In the paper it is also described, how ultracapacitors can help to minimize hybrid electric vehicles emission by making unconventional engines application possible.

2.WHAT THE ULTRACAPACITORS ARE

First commercial development of the electrochemical double-layer capacitor originated in the Standard Oil of Ohio Research Center (SOHIO), in 1961. Early capacitors were designed for low voltages and delivered low power. First high-power capacitors were developed for military purposes in Pinnacle Research Institute in early 1980's. These devices had low resistance and high power capability (over 10kW/kg), but energy density was still low. Nevertheless, this reports started U.S. Department of Energy studies of the possibility of increasing the energy density to at least 5Wh/kg. The program was started in 1992 at Maxwell Laboratories, San Diego, California. Other programs, with similar goals, started also in Europe and Japan.

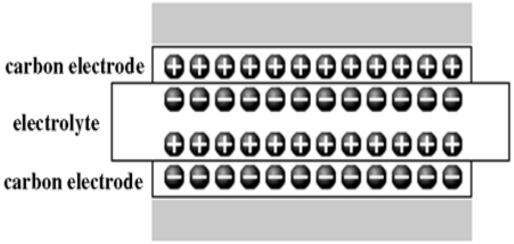

Fig. 1: Double-layer capacitor (charged state)

Ultracapacitors, as shown in Fig. 1, consist of two electrodes, separated by separator soaked in electrolyte. As a result we get two capacitors connected in series. Capacitance of each is proportional to the electrode area and inversely proportional to the distance between charges. The difference between conventional electrolytic capacitor and ultracapacitor is in electrode material. Ultracapacitors use activated carbon so achievable electrode area is approx. 2000m^2/g so far, allowing production of single cells with high capacitance, up to thousands of farads. This could make ultracapacitors similar to batteries, but the most important difference between batteries and ultracapacitors is that in ultracapacitors the ions form electrolyte approach electrode material, but do not react with it, so there is no electrode structural degradation. This highly improves cycle life of an ultracapacitor. Another concept is asymmetrical electrochemical capacitor, which uses two different electrochemical processes on different electrodes in one cell. Typical example is C – NiOOH system with KOH electrolyte. Advantage of such device is higher specific energy capability. Today's commercial symmetrical cells reach capacity up to 5kF, with rated voltage 2.5V and rated current up to 600A. The highest available capacity of asymmetrical cells is 80kF, with operating voltage window (0.8 – 1.7) V. For higher voltages there are modules with cells connected in series. Parameters of conventional capacitors, batteries and ultracapacitors are shown in Tab. 1.

Characteristic	Lead-acid Battery	Conven-tional Capacitor	Ultra capaci-tor
Charging Time	1-5 hrs	10^{-3}-10^{-6} sec	0.3-30 sec
Discharging Time	0.3-3 hrs	10^{-3}-10^{-6} sec	0.3-30 sec
Cycle Life	1000	›100000	›500000
Efficiency	70-85%	›95%	85-98%

3.ELECTRIC VEHICLES CONCEPTS

Pure electric vehicles (EVs, meaning onboard power sources) are generally simple. Electric energy is supplied by battery, mostly of lead-acid or nickel-cadmium type. The drive load is not continuous, with high current peaks when accelerating, causing decreases of battery cycle life and cycle efficiency. If regenerative braking is used, the short and high current input peaks will not effectively charge the battery, due to the long discharge/charge change time. Instead, the battery is more heated than charged, shortening cycle life again. Ultracapacitors can help to avoid these problems. They can deliver the peak power for acceleration and store part of vehicle's kinetic energy during deceleration. Ultracapacitors can also fully replace the batteries. Though such vehicle could run smaller distance in comparison with battery powered one, the main advantage is very short charging time. Esma-cap, Russia, developed two such experimental vehicles. Electric bus with 50 passengers capacity, maximum speed 20 km/h, energy stored 8.6 kWh, charging time 12-15 minutes, average-1 distance on one charge 9.2 km. Electric truck with payload limit 1,000 kg, maximum speed 70 km/h, average distance on one charge 33 km (at average speed 30-35 km/h). Assumed application of these vehicles is in Moscow city parks and in All-Russian Exhibition Center.

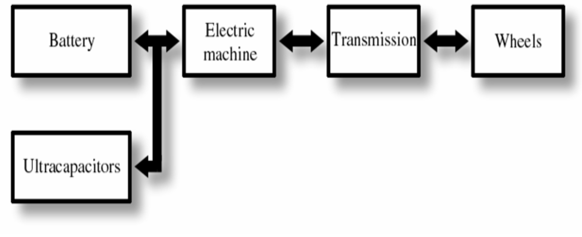

Fig. 2: Electric vehicle with ultracapacitors scheme

Hybrid electric vehicles (HEVs) provide efficiency of electric drive train without the need of large battery pack. Generally, the combustion engine (CE) used in HEV is designed for average power needs, unlike in conventional cars, where engine must deliver peak power when needed. Running under average conditions, they are relatively inefficient, which is most significant in city traffic.

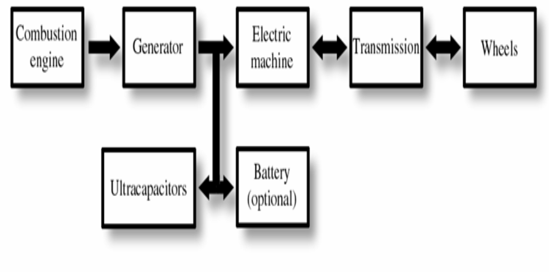

Fig. 3: Series hybrid electric vehicle with ultracapacitors

Fig. 3 shows the series concept of HEV. The main disadvantage could be the need for the generator. But the Generator – Combustion engine electromechanical system could be designed in very convenient way, for example, at constant power, speed increase leads to smaller dimensions and weight of the equipment. Generator speed is not dependent on actual vehicle's speed, so it could run on its optimal speed-torque operating point to reach high efficiency and low emissions. Combustion engine could be, among conventional internal combustion engine, also micro-turbine. General Motors develops engine based on Stirling cycle, improved to be suitable for hybrid electric vehicles. Because it uses external combustion, there is wide variety of fuels the engine can run on, with even lower emissions than ICE or turbine. Ultracapacitors here can help, like in EVs, with peak power delivery and braking energy storage. Their application almost essential when micro turbine or Stirling engine is used, because these engines change their output power less dynamically than the common internal combustion engines.

Fig. 4 shows parallel hybrid electric vehicle scheme. Even though there is no need for generator, the above-mentioned advantages of series concept cannot be utilized. Nevertheless, today's sold vehicles use this system with a common ICE (for example Honda and Toyota), which is for now probably the best way to cut the manufacturing costs and to use proven technology. Ultracapacitors here can improve vehicle's performance by braking energy storage. Generally, ultracapacitors can replace batteries in HEVs, because of their longer cycle life and shorter response time.

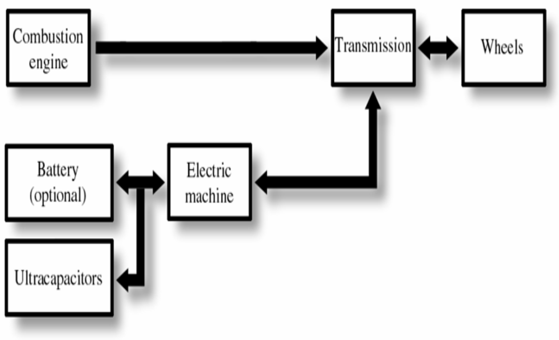

Fig. 4: Parallel hybrid electric vehicle with ultracapacitors

4.EXAMPLE OF ULTRACAPACITOR CONTROL STRUCTURE

Ultracapacitors behave like conventional electrolytic capacitors that means their voltage is approximately proportional to stored charge, so it is necessary to use buck-boost converter for ultracapacitor – electric machine system. In Fig. 5 there is the control structure for ultracapacitors applied in single-track electric vehicle. Symbols meaning are I_{BR} for the real battery current, v for speed, U_{CR} for real ultracapacitor voltage, U_{CW} for demanded ultracapacitor voltage, I_{CW} for demanded ultracapacitor current and I_{CR} for real ultracapacitor current. Main control aim is to avoid battery current peaks. That needs also voltage control, which could be described as when vehicle's speed is zero, we expect acceleration to follow, so the ultracapacitor is charged to maximum voltage (to store maximum energy). When the vehicle runs at top speed, we expect braking, so voltage level is minimal. One half of rated voltage has been chosen to be the lower limit, because the converter efficiency descends as it works with high input/output voltage difference.

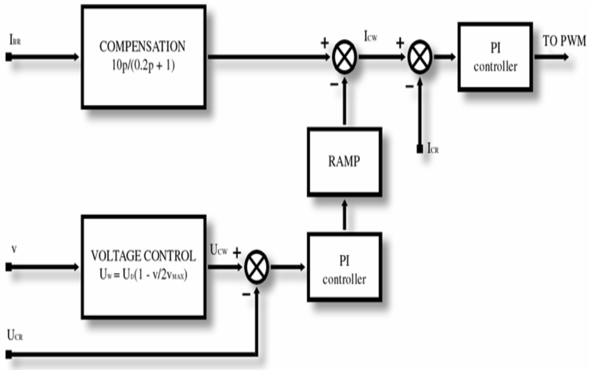

Fig. 5: Control structure scheme

5.CONCLUSION

Ultracapacitors can generally cover peak power demands and store energy released during regenerative braking. In EVs, ultracapacitor application can increase battery cycle life as well as battery cycle efficiency, prolonging vehicle's operating range. Ultracapacitors can even replace battery and become the only onboard power source. In HEVs they allow to apply unusual combustion engines as power source, for example micro-turbine. This can improve the vehicle's efficiency and its emissions.

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