WHITE PAPER

ULTRACAPACITORS DRIVE NEW EFFICIENCIES FOR HYBRID SYSTEMS ARCHITECTURES

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Summary

Today the car manufacturers and the suppliers are aware of Ultracapacitors for use in automotive power-trains and subsystems. All advantages of the product is meeting their business and technical requirements.
Ultracapacitors are becoming a standard energy and power storage option!
The significant differences between batteries and Ultracapacitors require new system design approaches. This paper discusses the reason for the growing acceptance and presents the benefits of Ultracapacitor powered new vehicle designs.

Introduction

The development of electric and hybrid vehicles (EV/HEVs) is a response to the growing global pressure on improving the environment and the subsequent search for significantly cleaner and more efficient vehicles. The success of these new vehicle architectures depends on the development of advanced energy storage technologies, including batteries and Ultracapacitors. The majority of vehicle systems in development today rely on battery technology because of its relatively high energy density, its relative maturity, and its familiarity to designers. Many power train and subsystem architectures are specifically designed around the characteristics of available battery technology. Since Ultracapacitors and batteries have significantly different characteristics, few current designs can immediately replace the battery with an Ultracapacitor. The unique characteristics of the Ultracapacitor allow additional dimensions in design to be explored, and open up opportunities for the development of new powertrain and subsystem architectures which can improve on the goals of performance, efficiency, and cleanliness.

Driven by the goal to reduce considerably the amount of fuel consumption, automotive manufacturers are developing product lines that incorporate advanced drive trains. Perhaps the most promising near-term solution is the Hybrid Electric Vehicle (HEV) technology. HEV technology combines the best characteristics of fuel-driven engines, electric motor drives, and energy storage components. It is designed with a combustion engine in function of primary power source, and an electric power storage system as the secondary power source. The presence of the secondary power source allows designers to size the combustion engine for cruising power requirements. The secondary source handles peak power demands for acceleration. Additionally it is used for capturing regenerative breaking energy and applying this energy for further acceleration or for the basic energy needs of supplementary electrical systems. Through this basic design structure, HEVs promise to offer low maintenance, clean operation, and high fuel economy. Ultracapacitors significantly improve power management in hybrid electric vehicles. In addition, Ultracapacitors decrease emissions optimize fuel-efficiency and improve electrical drive capabilities. The new power system using Ultracapacitors allows the HEV to recapture and reuse braking energy. Compared to conventional diesel engines the reduction of fuel consumption is estimated higher than 50%; reduction in particulate emissions is 90% or even more; as well the reduction of nitrogen oxide emissions by 50%.

Figure 1: BMW X3, Hybrid concept car shown at IAA Auto show 2005

Subsystems with variable voltages will ultimately be a part of all vehicles, including traditional combustion engine vehicles. In these systems, Ultracapacitors can be used not only to provide power for acceleration purposes, but also to provide the possibility of capturing regenerative breaking energy.

Ultracapacitors fits in applications as in the propulsion system of conventional gasoline and diesel hybrid as well as in fuel cell hybrid vehicles. BMW's hybrid X5 and Volkswagen's fuel cell powered Bora for instance are prototype vehicles, whilst Honda's IMA, and Toyota's ES are production vehicles that incorporate Ultracapacitors as high power energy storage devices in the hybrid electric power trains. The reason for the acceptance of Ultracapacitors in vehicle propulsion systems is their high pulse power capability, fast transient response, and high efficiency during charge and re-charging plus full charge cycling in excess of 500k cycles.

Ultracapacitor technology advanced significant in the last few years, driven by the need to develop components for the new electric and hybrid vehicles. Development of Ultracapacitor technology has moved from the universities and national laboratories into the commercial realm. New materials and processes have improved the capabilities of this storage technology to new heights. Excellent life and temperature characteristics compared to other technologies have been demonstrated. The task is to place this new component into the hands of the designers and engineers and enable those realising new and innovative concepts.

Ultracapacitors in Hybrid Electric Vehicles (HEV)

HEV technology combines the best characteristics of fuel-driven engines, electric motor drive and energy storage components. Manufacturers of HEVs are looking at relieving battery's load during high power times, such as initial acceleration and braking or for the basic energy needs of supplementary electrical systems. Here the batteries see the highest current levels. By load levelling these spikes by a secondary power source the batteries will last longer and due to this saving the customer money. The presence of the secondary power source allows designers to size the combustion engine for cruising power requirements. Through this basic design structure, HEVs promise to offer low maintenance, clean operation, and high fuel economy.

The fuel reduction for hybrid vehicles bases on:

- Start-stop
- Braking energy recuperation and
- Down-sizing of engine.

Depending on the power demands of the electric machine as well as the function between the following hybrid classes can be shown:

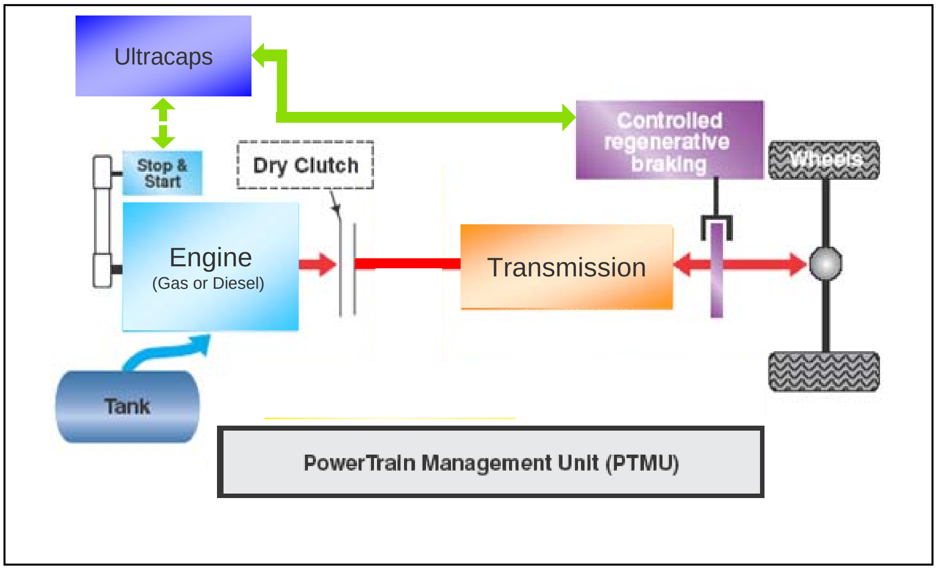

Figure 2: Micro Hybrid System Architecture

The systems differ by the power requirement for the energy storage system. The challenge for the HEV manufacturer is to reduce the peak power from the battery, which occurs during high power times such as during braking and acceleration as well as high power demands of additional electrical systems. Here the battery is exposed in general. If these peaks are covered by a secondary power source, the battery can be down-sized and its lifetime strongly be increased and saving therefore money.
Maxwell Technologies Ultracapacitors were designed to work with system batteries to improve power management and take away peak load stress from batteries. So Ultracapacitor technology protects the battery what means it allows the battery to handle the energy requirements while the capacitors handle the high power requirements.

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Figure 3: Maxwell Module solution for micro hybrid

Ultracapacitors in start-stop systems

Idle-start-stop power train functionality is clearly an easy way to increase fuel efficiency and reduce pollution reduction by stopping the engine during normal idling conditions and restarting at accelerator tip in. The use of a 15-V Ultracapacitor Module will support high pulse power loading imposed by high occurrence of engine warm restarts under idle-stop-start control. The use of engine start/stop and regenerative braking is expected to increase fuel efficiency by 7 to 15% whiles' reducing pollution by an even higher percentage.

Maxwell Technologies Ultracapacitors are designed to work in module configurations. Our new 15Volt building blocks can store approx. 45kJ to meet the idle-start-stop requirement as well as capturing braking energy. This allows a 5kw braking charge to be absorbed for several seconds and then reused for several seconds of engine starting power.

Distributed power modules

Due to increasing power demand as well as the requirement for redundancy in new vehicle functionalities such as electric assist steering, electromagnetic valve control, electric door opening and electric braking require, auto-motive engineers need to develop new electrical distribution system architectures.

Electrical system architecture with modular and distributed power modules is one method of addressing the need for power and redundancy required by the safety critical and security systems in automotive applications.

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Distributed Ultracapacitor modules alleviate electrical distribution system voltage sag and transients by supplying high peak power locally, while requiring only the average power from the vehicle's primary power supply. This essentially decouples the high transient power load from the vehicle's power supply system.

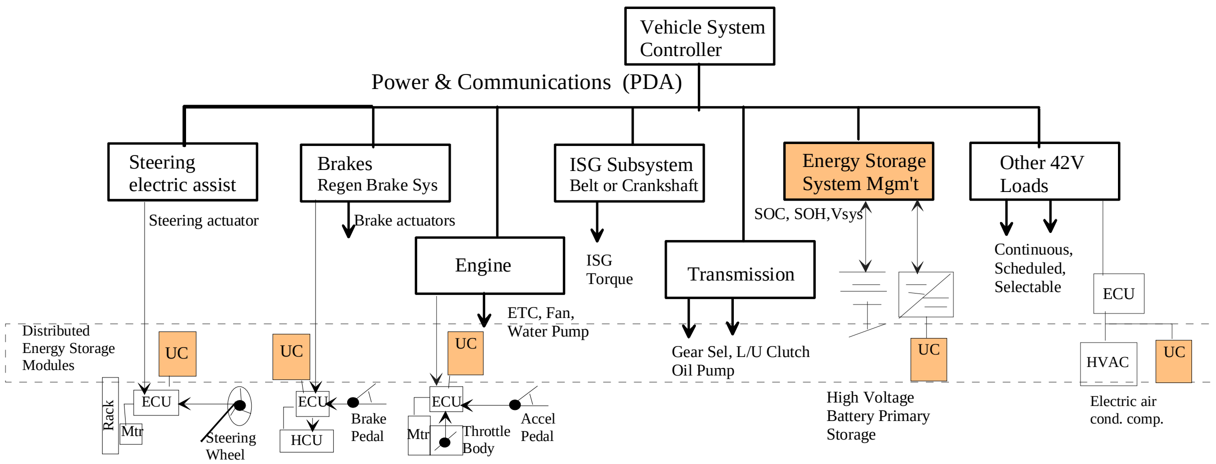

Figure 8: Distributed module architecture with Ultracapacitor modules (UC) for vehicle safety critical and hybrid functionality

A further requirement of safety critical applications is the necessity of redundant power supply in the event of loss of the main electrical distribution system branch circuit for x-by-wire functions. Distributed power modules located at critical loads such as near the electric power assist steering system, or near electro-hydraulic brake modules offer the vehicle designer additional redundancy for such safety critical applications.

Ultracapacitor characteristics

Ultracapacitors differ from batteries in a number of characteristics.

- A battery will store much more energy than the same size Ultracapacitor, however in applications where power determines the size of the energy storage device, an Ultracapacitor may be a better solution

- The Ultracapacitor is able to deliver frequent pulses of energy without any detrimental effects. Many batteries experience reduced life if exposed to frequent high power pulses.
- An Ultracapacitor can be charged extremely quickly. Fast charging damages many batteries.
- An Ultracapacitor can be cycled hundreds of thousands of times. Batteries are capable of only a few hundred to one or two thousand cycles.
- Based on the low internal resistance of Ultracapacitors they are more efficient than batteries; 84-95% compared to an average of below 70% for batteries in this application.
- An Ultracapacitor can be charged to any voltage within its voltage rating, and can be stored totally discharged. This allows more freedom for the design of bus voltage control algorithms. A battery can be permanently damaged if over-discharged.
- Calculating the state of charge of an Ultracapacitor is a function only of voltage and capacitance. The capacity of an Ultracapacitor can be calculated real-time by measuring current and voltage change over time. Accurately determining the state of charge of a battery involves multiple dynamic calculations, and the battery's capacity is often in question, and difficult to determine real-time.
- Ultracapacitors have a wide temperature range down to -40°C. Many batteries fail to perform as temperatures drop below –10°C.
- An Ultracapacitor operates by polarizing an electrolyte within a high surface area electrode. The characteristics of the electrolyte, electrode and separator materials determine the performance capabilities of the Ultracapacitor. High surface area electrodes and small ions provide high capacitance, while efficient electrolytes, separators and material and product designs provide low resistance. Because the energy stored in an Ultracapacitor is not bound in chemical bonds, it has a fundamentally different behaviour than a battery

These differences require new approaches to systems design with Ultracapacitors, whether complementing or replacing batteries. Battery system design seeks to optimize the utilization of the battery. System requirements define whether the battery is sized for energy (e.g. EV range), or sized for power (e.g. hybrid assist). In cases where the battery is sized for energy, the battery typically has adequate power capability. In those instances where system requirements indicate the need to optimize for power, the battery is often oversized with respect to energy. Substituting an Ultracapacitor, with lower energy but equal or greater power, allows another solution for the designer. In these cases, an Ultracapacitor would be sized for energy, and would have more than adequate power for the application.

One key difference between Ultracapacitors and batteries is in the ratios of energy density to power density. Ultracapacitors have higher power density and lower energy density than batteries. Therefore, in those solutions where the battery has been sized for power, the Ultracapacitor will likely be sized for energy and may have more than the required power capability. The ideal solution for any one specific driving cycle will perfectly match energy utilization and power utilization. However, there is no single optimization point for a real-world vehicle, which must operate on a variety of driving cycles over its life.

The optimization challenge is extended when one considers how to balance power between multiple simultaneously available power sources in a hybrid vehicle.

Conclusions

All kind of application in transportation requires storage systems which are durable, long operating life and wide temperature ranges. This all low cost! Batteries, even advanced technologies cannot meet this entire requirement. This is especially true in systems requiring high power and little energy.

Ultracapacitors offer long cycle life and excellent cold temperature performance, and the basic materials used in their construction pose no significant barriers to affordable cost in quantities typical of the automotive market. The introduction of Ultracapacitors into subsystems and “stepping-stone” power trains will accelerate the adoption of the technology into the automotive market, and will drive up the volumes, and therefore drive down the cost. This volume-driven cost reduction combined with the ongoing performance enhancements, the understanding of the complete technology of Ultracapcitors, driven by Maxwell Technologies will continue to make Maxwell’s

Ultracapacitor technology an excellent solution for current and future power trains, local power nodes and electrically driven subsystems.

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