WHITE PAPER

ULTRACAPACITOR APPLICATIONS IN THE POWER ELECTRONIC WORLD

Adrian Schneuwly, Gianni Sartorelli, Juergen Auer and Bobby Maher
Maxwell Technologies, Inc. ®

Maxwell Technologies, Inc.
Worldwide Headquarters
9244 Balboa Avenue
San Diego, CA 92123
USA
Phone: +1 858 503 3300
Fax: +1 858 503 3301

Maxwell Technologies SA
CH-1728 Rossens
Switzerland
Phone: +41 (0)26 411 85 00
Fax: +41 (0)26 411 85 05

Maxwell Technologies GmbH
Brucker Strasse 21
D-82205 Gilching
Germany
Phone: +49 (0)8105 24 16 10
Fax: +49 (0)8105 24 16 19

Maxwell Technologies, Inc. - Shanghai Representative Office
Rm.2104, Suncome Liauw's Plaza
738 Shang Cheng Road
Pudong New Area
Shanghai 200120, P.R. China
Phone: +86 21 5836 5733
Fax: +86 21 5836 5620

info@maxwell.com – www.maxwell.com

Introduction

There has been a lot of progress in control and motor design, due to the increasing power demand in electric applications, as well as ongoing pressures for more environmentally friendly and high efficiency solutions. However, designers and engineers have not been successful with regard to the electric power storage systems. This is due primarily to the fact that batteries are used to provide the power peaks in most of the currently developed solutions relying on a power storage system. The deficiencies of battery storage systems are many and they create a variety of design challenges for engineers. Batteries have a poor low-temperature performance, a very limited lifetime under extreme conditions - resulting in repeated replacement throughout the life of the system - and they are not designed to satisfy the most important requirements of power sources: To provide bursts of power in the seconds range over many hundreds of thousands of cycles [1].

Today, ultracapacitors are available from major production firms in the United States, Europe, and Asia, and are available in a variety of sizes and configurations.

Figure 1: Typical available ultracapacitors from Maxwell: PC10 with 10 F and BCAP0010 with 2600 F

Ultracapacitor prices are within the cost targets of many industrial systems, and will be approaching $0.01 per farad in production volumes of millions by 2004. When appropriately designed with a systems approach, they offer excellent performance, wide temperature range, long life, and flexible management. When used in combination with other energy storage solutions (e.g. lead-acid batteries, fuel engines, and fuel cells), the complete system can meet performance and cost goals unachievable with a single energy storage device. Ultracapacitors from Maxwell are available under the trade name of BOOSTCAP®.

Transportation engineering

On a larger scale, ultracapacitors are well suited for many transportation applications [2]. The endless cycles of acceleration and braking of vehicles, buses, mass transit trains, and metro systems are ideal for this technology. Here ultracapacitors are used for capturing regenerative breaking energy and re-applying that energy to acceleration or the basic energy needs of supplemental electrical systems. This can be done using either on-vehicle or stationary system designs. Stationary ultracapacitor energy storage systems have been developed recently that can be operated in two different ways. First, such installations are able to store the braking energy of light rail trains and release it during the concurrent or subsequent acceleration phase of a departing train. Thus, the energy storage system allows a significant energy cost reduction as the amount of primary energy is strongly reduced. Second, the installation can be used to stabilize the system voltage of typically 750 V. In this case the energy storage system is kept in a fully charged state and only discharged if the system voltage falls below a defined voltage level. The installation is then recharged by a braking vehicle or slowly through the DC net. Thus cost reductions are achieved due to the cancellation of subsystems.

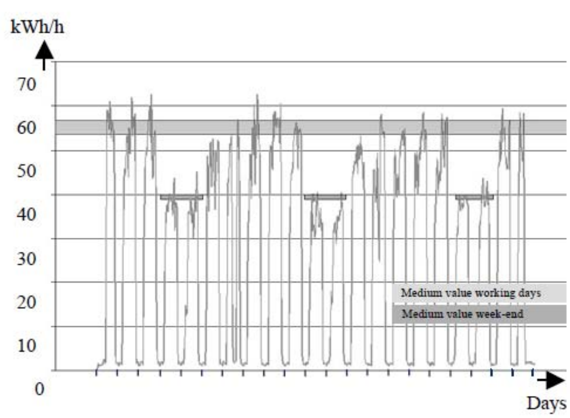

Figure 2: Results of energy saving per hour over 3 weeks

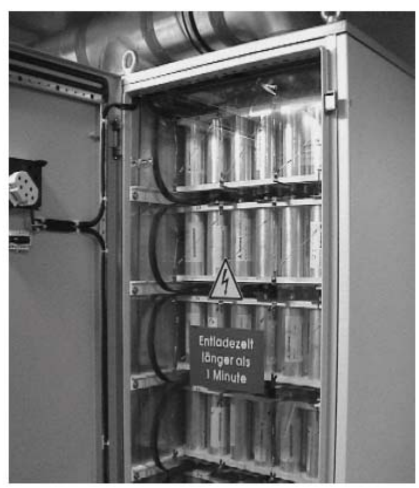

Figure 3: Energy storage system

Maxwell Technologies, Inc.
Worldwide Headquarters
9244 Balboa Avenue
San Diego, CA 92123
USA
Phone: +1 858 503 3300
Fax: +1 858 503 3301

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Switzerland
Phone: +41 (0)26 411 85 00
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Figure 2 shows the results in energy savings per hour obtained by an energy storage system over a time period of 3 weeks. The medium reduction of the operating power by 50 kW results in energy savings of up to 340 MWh per year. In addition, due to the protection of the braking resistors a reduction of the CO2 emissions of almost 370 t per year are achieved. In Figure 3, a storage box equipped with ultracapacitors is presented. To achieve the system voltage of 750 V as well as the required energy content necessary to store the braking energy of a light rail vehicle, several hundreds of ultracapacitor cells are connected in series and parallel. The typical performance of an ultracapacitor energy storage system is an energy content of more than 2 kWh and a maximal power of 1 MW. The efficiency of the whole ultracapacitor arrangement amounts to 0.95.

In the automotive domain, due to the increasing power demand in future vehicles for comfort improvement, as well as ongoing public and governmental pressures for more environmentally friendly and fuel efficient means of transportation, automotive manufacturers are developing new vehicle subsystems and components. A result is the substitution of mechanical by electrical systems such as electric power steering, electromagnetic valve control, electromechanical braking and electric door opening as well as the introduction of new drive-train functions like start-stop and recuperative braking. The storage of braking energy can also be usefully applied for vehicles with internal combustion engines, especially for the improved alternators used as braking generators - so-called integrated starter generators [3].

The electric power steering system shown in Figure 4 relies on a dual voltage network. The concept shows a 42 V power steering system that is fitted into a conventional 14 V vehicle. A DC/DC converter provides 42 V from the main 14 V bus. The ultracapacitor system load levels the DC/DC converter, with the ultracapacitors providing 80% of the required peak power of up to 1.5 kW. The fully integrated 42 V ultracapacitor module is built up with 3 times 18 PC100.

Driven by the goal to considerably reduce fuel consumption, automotive manufacturers are developing product lines that incorporate advanced drive-trains. Perhaps the most promising solution is the Hybrid Electric Vehicle (HEV) technology. Manufacturers of HEVs are looking at relieving the load on a battery during high power requirements, such as initial acceleration and braking. These are the instances when the batteries are subject to the highest current levels. By load leveling these spikes the batteries last longer, saving the customer money. Ultracapacitors significantly improve power management in the HEVs, and extend battery life. In addition, ultracapacitors allow for lower emissions, better fuel-efficiency and advanced electrical drive capabilities. The new power system using ultracapacitors allowed the HEV to recapture and reuse braking energy. Compared to conventional diesel engines the reduction of fuel consumption is estimated at greater than 50%; reduction in particulate emissions is greater than 90%; and reduction of nitrogen oxide emissions is 50%.

In conclusion, ultracapacitors play a large part in revolutionizing the entire transportation industry - an industry which increasingly requires power technologies that respond to changing consumer demands for environmentally sensitive, high-performance and low-cost products.

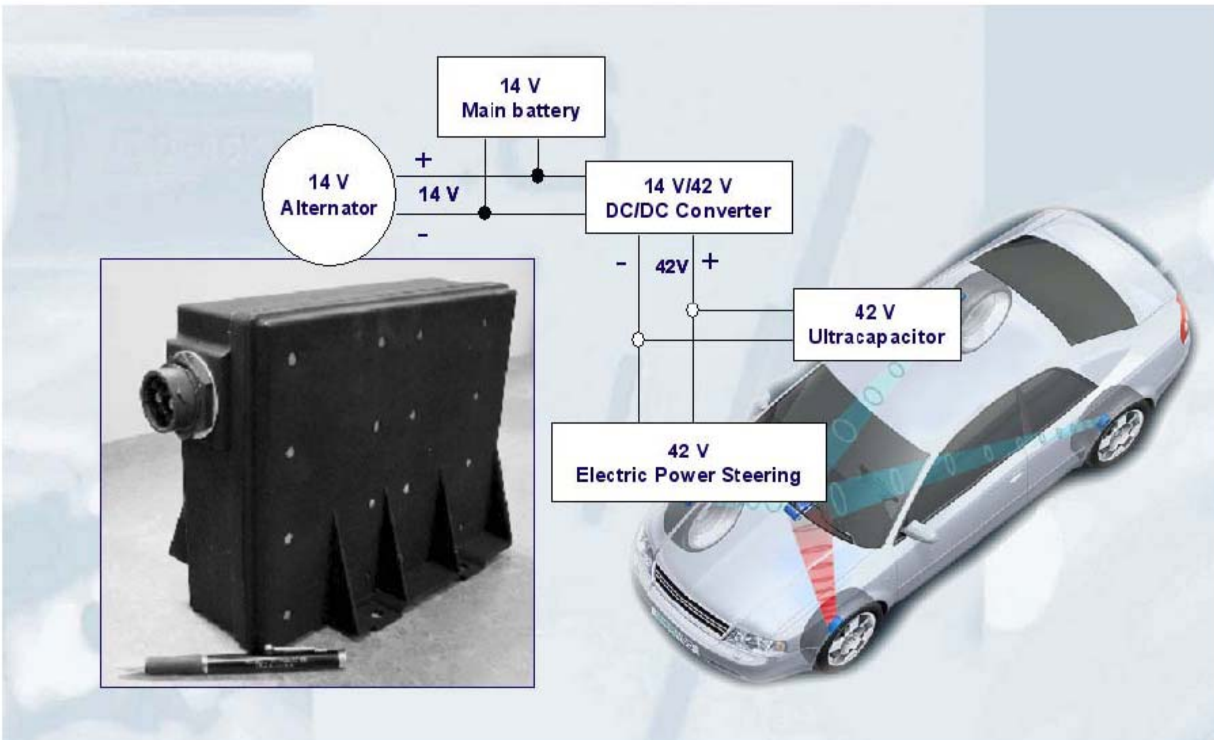

Figure 4: 42 V Electric power steering system

Industrial engineering

In industrial electronics, numerous firms are well into the production cycle for ultracapacitor-based systems - recognizing the advantages and availability of the ultracapacitor to meet their business and technical requirements. Applications such as people movers, elevators and conveyor systems use ultracapacitors to reduce power peaks in the net and to achieve important energy savings [4].

As short deviations in power supply voltage can influence or interrupt the correct operation of electrical equipment, uninterruptible power supplies (UPS) are used to improve power quality and guarantee the reliability of power back-ups. During voltage sags or complete interruptions of the power supply, local energy storage devices must supply the energy. The storage device is directly coupled to the DC link and works in stand-by mode. Over 98% of power outages in the low voltage mains last less than 10 s as shown in *Figure 5*.

Lead-acid batteries, the conventional energy storage choice for UPS, cannot be designed to bridge interruptions less than any minutes. In contrast to batteries, ultracapacitors are an ideal energy storage device in maintaining the voltage at the DC link for several seconds in case of a voltage sag or interruption. The excellent power delivery capability of a 400 V ultracapacitor UPS system at 50% load is shown in *Figure 6*.

Further advantages such as long life, no maintenance or costly test runs, the possibility of full discharge and the short charging times for frequent power failures make ultracapacitors superior storage devices for UPS applications.

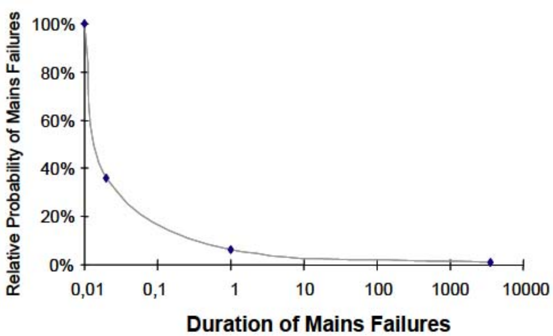

Figure 5: Relative probability of mains failures during discharge at 50% load

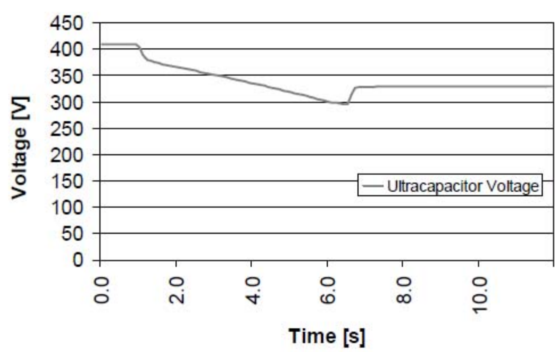

Figure 6: Ultracapacitor voltage

In wind power plant pitch systems ultracapacitors represent an optimum power supply system due to their high reliability, efficiency and operating lifetime.

Figure 7 shows the rotor head with the three pitch systems. The latest technology uses the wind not only to produce wind energy but also for its own safety. The converters feature aerodynamic braking via individual pitch control of each individual blade. Even if a blade pitch unit fails, the other two rotor blades safely complete the braking process. To enhance the level of safety, each of the three autonomous pitch systems is equipped with an ultracapacitor emergency power supply to immediately ensure the reliable functioning of the fast blade pitch system, as in the event of a total power failure. A pitch control unit equipped with BCAP0010 ultracapacitors is presented in *Figure 8*.

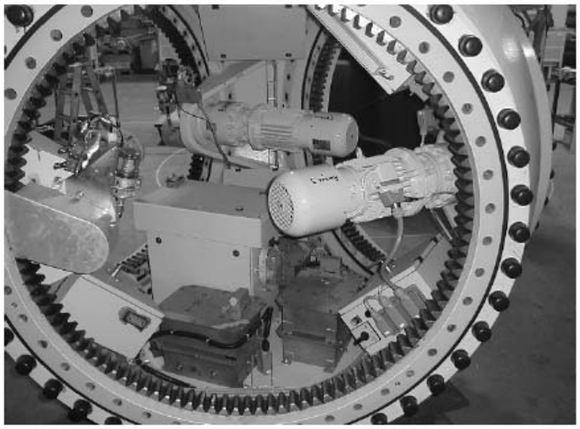

Figure 7: Wind turbine pitch systems

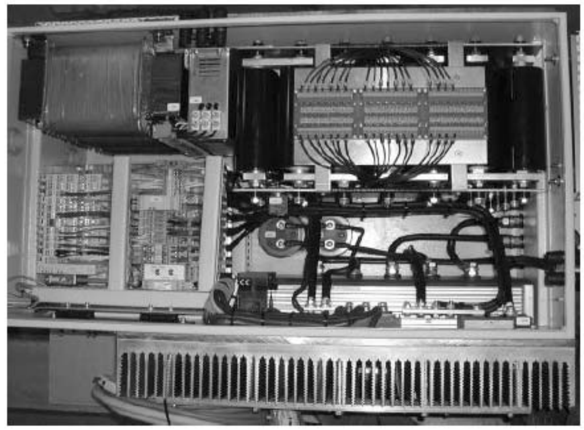

Figure 8: Ultracapacitors integrated in the pitch control unit

Electronic device engineering

As the need for smaller and more lightweight systems increases, design engineers require innovative design approaches to reduce size and heaviness without sacrificing overall performance and reliability, especially of portable products. Interestingly, the component that presents perhaps the keenest challenge in many portable designs is the same component that remains an inescapable necessity to those designs – the battery. As the main source of power in most portable products, finding an ideal battery in terms of size, weight, and performance represents an ongoing challenge for even the most resourceful and industrious engineer. In applications requiring only high amounts of energy and low amounts of power (such as calculator, clock/watch, and portable radio applications) a battery or set of batteries can be more than sufficient to supply a small amount of current over a reasonable amount of the product's lifetime. However, in applications with an additional demand for high power – i.e., a large amount of current over a short period of time – batteries have proven to be less than satisfactory.

There are two primary uses for ultracapacitors. The first is for temporary backup power in electronic devices for functions such as computer BIOS settings, telephone and camera configuration settings, and secondary short-term emergency power when a primary power source is insufficient. Here the ultracapacitor is charged from the primary power supply, but functions as a backup power source when the primary source fails. The second use for ultracapacitors is in supplying peak power in electronic devices. In these applications, ultracapacitors are used in tandem with batteries for systems that require both constant low power discharges for continual function and a pulse of power for peak loads. Here, ultracapacitors relieve batteries of peak power functions, resulting in an extension of battery life, reduction of overall battery size and thus an important reduction in product size. In fact, ultracapacitors have been used in a variety of applications, ranging from portable scanners for factory bar-code reading to digital cameras.

In a typical scanner application, ultracapacitors provide the pulsed power functions necessary for activating the system trigger-pulls and lasers that read bar code information while batteries provide low power for memory storage and basic functioning. As a result, the ultracapacitors level the load on the batteries, extending the overall life of the scanner. And because the batteries do not supply the energy for peak power functions, a smaller-sized battery can be used, reducing system size and making the scanner more easily portable.

This kind of design strategy is demonstrated more specifically in a two-dimensional scanner application that uses two PC10 ultracapacitors. By using the ultracapacitors, the manufacturer of the scanner was able to design the system for portable operation in an application that would normally require wall current or a large number of batteries that would be quickly depleted.

Similarly, in a digital camera application, representative of a typical ultracapacitor-enhanced design, two PC10 ultracapacitors work with a battery to provide overall system power management. The ultracapacitors drive the initial power-up of the camera, and drive functions involved in composing photographs, such as microprocessor, zoom, and flash functions. The major high peak demands were observed during the microprocessor activity, writing to disk and LCD operation. As with the scanner application, by providing peak power functions the ultracapacitors

level the load on the battery. It can be seen that by adding the ultracapacitors across the alkaline batteries, the cycle life is drastically increased (*Figure 9*). Important to note is that with the help of the Ultracapacitors the basic, inexpensive alkaline batteries achieve the same life cycle as expensive, new high-power batteries. By using the ultracapacitor in parallel with the alkaline batteries, the overall system impedance will drop, therefore allowing the battery to act as a pure energy source. Thus, replaceable, low-cost, off-the-shelf alkaline batteries can be used, making the camera smaller, lighter, and truly portable.

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9244 Balboa Avenue
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USA
Phone: +1 858 503 3300
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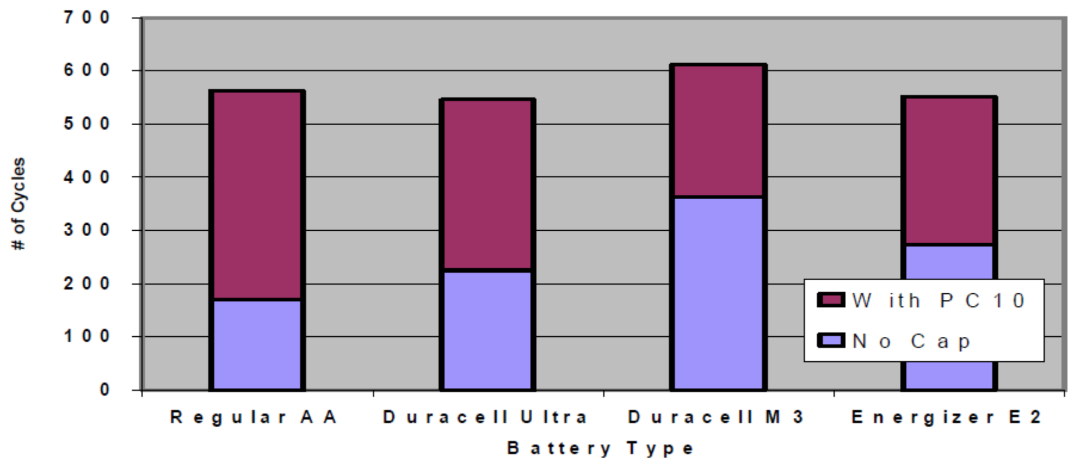
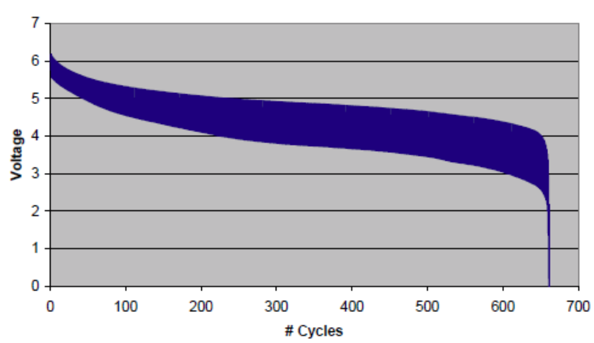


Figure 9: Cycle life of several different batteries, with and without ultracapacitors

The graphs in *Figure 10* and *Figure 11* show the voltage swing for typical digital camera cycles. As indicated, the voltage drop increases rapidly with batteries only, but when an ultracapacitor is placed in parallel in the system, the entire voltage drop is decreased and maintained.



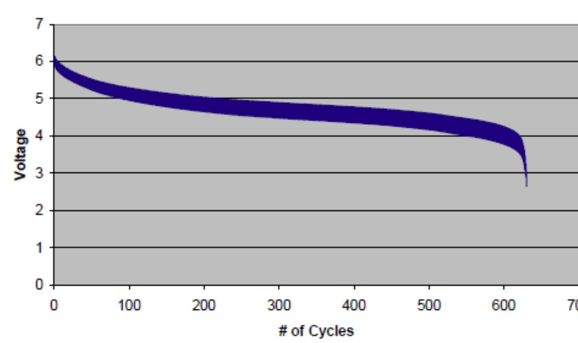


Figure 10: Voltage swings with batteries only

Figure 11: Voltage swings with batteries and ultracapacitors

Ultracapacitors can also benefit products designed for use with batteries capable of high-power discharges. For example, a web-enabled Personal Digital Assistant (PDA) that currently uses a nickel cadmium battery to supply power when sending internet emails might be better served by an ultracapacitor. To be sure, the battery is an adequate source of energy for transmitting information from the PDA, however, it has a finite life and would ultimately need to be replaced. By contrast, an ultracapacitor can cycle enough times to last the life of the product.

Other current and potential portable ultracapacitor applications include two-way pagers, GSM-protocol cell phones, hand-held GPS systems, and power tools, just to name a few. And as the demand for smaller portable devices increases, the flexibility, durability, and power of the ultracapacitor will help designers enhance product functionality while simultaneously decreasing size - proving the old adage that the best things come in small packages.

Toy engineering

Battery operated toys are another high potential application for ultracapacitors. In this industry the price is the key. Toy companies will explore every option to reduce expenses and increase their overall margins. After price, the toy manufacture business requirements include product availability and performance. Today, the toy market has embraced the use of ultracapacitor technology. Toy manufactures can benefit by placing a permanent ultracapacitor on board in place of a battery. A clear advantage is the ultracapacitor is much lighter, which awards performance advantages, and it can be re-charged hundreds of times by a battery pack. Small cells with a flat design, such as PC5 and PC10, are especially suitable in providing the designer with a new option for developing a toy application. The use of ultracapacitor technology also has more energy per gram than other solutions available on the market. This provides our toy designers with more run time.

Conclusions

Today ultracapacitors are available, cost-effective, and perform well in power electronic systems. They are considered a peer to other options for production energy storage system requirements.

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