Designing auto power systems with ultracapacitors

Over the last decade, advances in materials and construction techniques have transformed ultracapacitors from 'minor' backup components to extremely powerful energy storage solutions. Though they store a fraction of the energy of batteries, they can charge and discharge much faster, delivering hundreds of thousands of high-power pulses over their lifetime and easily outlasting the product into which they are designed. Ultracapacitors can be recharged as fast as they can be discharged and they can be stored at any level of charge, even completely discharged, with little effect on component life. Indeed, ultracapacitors have become a viable component for production-intent designs in the power electronics world. Further, many companies, recognizing the technical advantages and high availability of ultracapacitors, are already producing ultracapacitor-based systems.

Engineers generally address peak power needs by designing the primary energy source, such as an engine or a battery system, to the size needed to satisfy peak demands, even if those demands occur for only a few seconds. Sizing an entire system for peak power needs, rather than for the average power requirement, is costly and inefficient. Such systems can be significantly improved by storing electrical energy from a primary energy source such as a battery in a secondary energy storage device, and then delivering that energy in controlled high power bursts when required. Such high power delivery provides electrical systems with dynamic power range to meet peak power demands for periods of time ranging from fractions of a second to several minutes. Batteries are not designed to provide bursts of power over many hundreds of thousands of cycles. Ultracapacitors perfectly meet this requirement.

Ultracapacitors, also known as electrochemical double-layer capacitors (EDLCs) or supercapacitors, have been around for decades and first appeared as low power, low energy (but long life) backup devices in VCRs and alarm clocks: but had few other applications. Until now.

Over the last decade, advances in materials and construction techniques have transformed ultracapacitors from 'minor' backup components to extremely versatile energy storage solutions. Indeed, ultracapacitors have become a viable component for production intent designs in the power electronics world. Further, many firms, recognizing the technical advantages and high availability of ultracapacitors, are already producing ultracapacitor based systems.

What is an ultracapacitor?

Capacitors generally fall into three categories. Depending on the medium that sustains an electric field between a pair of electrodes, a capacitor is either an electrostatic, an electrolytic or an electrochemical double layer. Of these three, electrochemical double layer capacitors (ultracapacitors) boast by the far the highest values (up to several thousands of Farads). This is because the electronic properties of an ultracapacitor are strongly dependent on the porosity of the activated carbon and on the molecular size of the electrolyte ions.

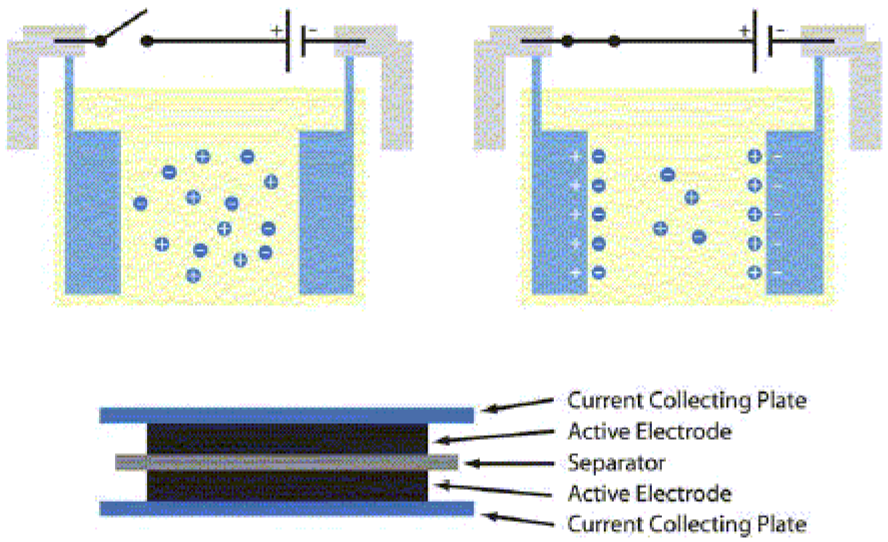


Figure 1: Ultracapacitor construction

Activated carbon electrodes used in ultracapacitors have specific surface areas of up to 2,000m^2/g and the charge separation distance is in the order of 10 Angstrom or less. Ultracapacitors with organic electrolytes have voltage ratings of <3.0V per cell.

Due to the impregnation with a high conductivity organic electrolyte, the excellent electrode electronic conductance and the high ionic cellulose based separator conductance, ultracapacitors exhibit very low series resistance. Today, commercial ultracapacitors have specific energy densities over 5 Wh/kg and specific power densities of up to 20 kW/kg.

Ultracapacitors rely on an electrostatic effect, which is purely physical and therefore highly reversible. Charge and discharge occurs upon the movement of ions within the electrolyte. This energy storage process is in contrast to all battery technologies, which are based on chemical reactions. With no chemical bonds being made or broken, cycle life of over 1 million cycles has been demonstrated with minimal degradation.

A good way of comparing the relative merits of ultracapacitor energy storage technology against batteries and others is to position them on a Ragone plot. They plot energy storage (Wh/kg) against power storage (in W/kg) and typically show how energy density diminishes for increasing (pulse) power density. They are good means of quantifying an energy storage system and to size the system for a variety of applications, ranging from traction drives to energy caches for electrified ancillaries.

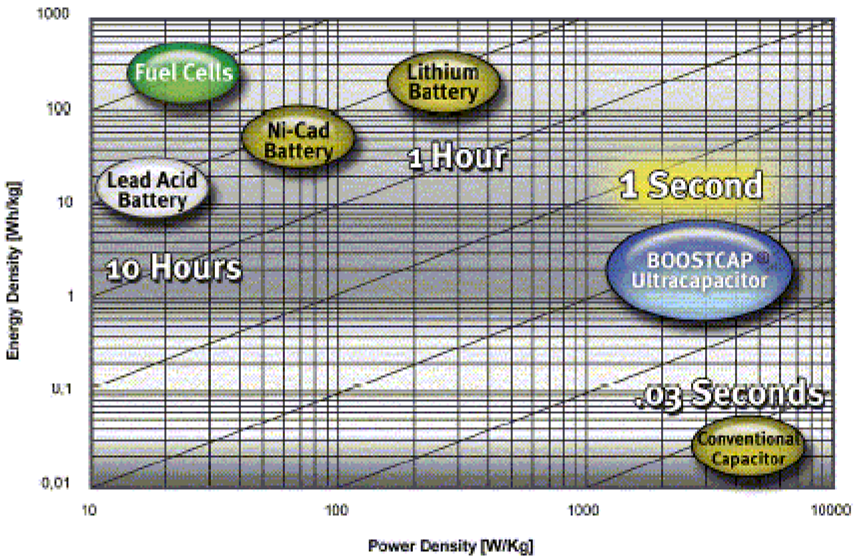


Figure 2: Ragone plot

Ultracapacitor characteristics

Ultracapacitors differ from batteries in a number of characteristics. The main differences are shown in the following list. * 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% as 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 operating 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 ultracapacitor's performance capabilities. 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 behavior than a battery.

Products

Today, ultracapacitors are available from major production firms in the United States, Europe, and Asia. They are available in a variety of sizes, and in a variety of configurations. Maxwell offers the proprietary BOOSTCAP' ultracapacitors in several form factors, ranging from 5-farad postage stamp size small cells to cylindrical 2,600-farad large cells. To facilitate adoption of ultracapacitors for applications which require integrated packs consisting of multiple ultracapacitor cells, Maxwell provides fully integrated power packs that satisfy the energy storage and power delivery demands of large systems. The module is a self-contained energy storage device, comprised of individual ultracapacitor cells, laser welded bus bar connections, and an integral active cell balancing circuitry. Units may be connected in series to obtain higher operating voltages, parallel to provide additional energy storage or a combination of series/parallel arrangements for higher voltages and energy. When connected in series, unit to unit voltage balancing is also available. The module packaging is a heavy-duty aluminum extruded enclosure and is a permanently sealed device requiring no maintenance. Low internal resistance of the energy storage modules enables low heat generation within the modules during use. As with any electronic components, the cooler the part operates the longer the service life. In most applications natural air convection should provide adequate cooling. In severe applications requiring maximum service life, forced airflow may be required.

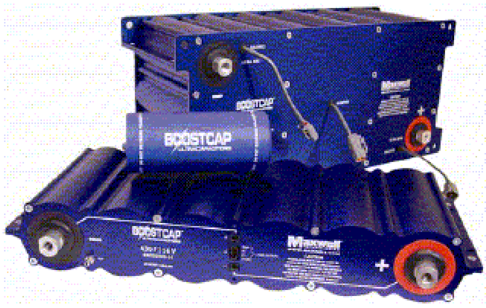


Figure 3: Maxwell large cell BOOSTCAP ultracapacitor family: Single cell with 2'600F, 2.7V, BMOD0430 with 430F and 16V and BMOD0140 with 140F and 48V

Markets and applications

When designing a system it may seem natural to size the system's primary energy source to cope with peak demands, even they only occur for a few seconds, as opposed to average or continuous demands. However, sizing a system for peak power needs is costly and inefficient. Systems can be significantly improved by storing electrical energy from a primary energy source and then delivering that energy in controlled high power bursts as and when the peak power is required.

In this role, ultracapacitors provide a simple, solid state, highly reliable solution to buffer short-term mismatches between power available and power required. This enables new functionality, reduces system size and cost and improves performance and reliability.

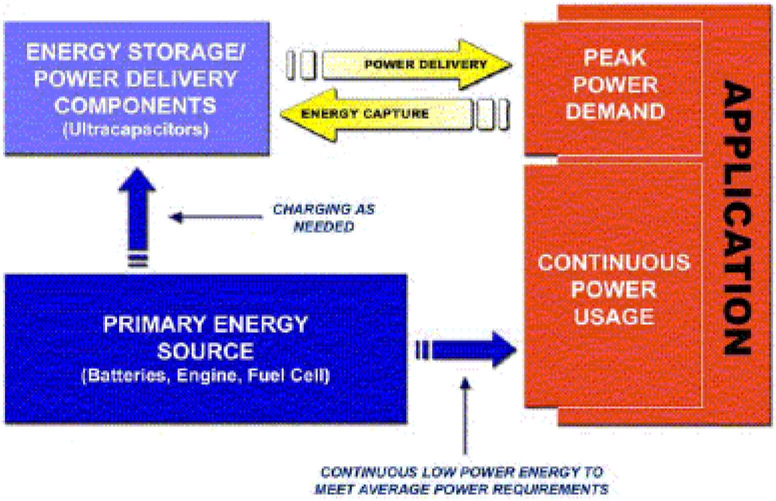


Figure 4: Application model

There are two primary uses for ultracapacitors. The first is for temporary backup power and additional short-term emergency power when a primary power source is insufficient. Here ultracapacitors have become an alternative to batteries in applications where 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 these applications, ultracapacitors are used either alone for systems that require peak power delivery or 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 and a reduction of overall battery size.

Although batteries currently are the most widely used component for both primary energy sourcing and energy storage/peak power delivery, ultracapacitors are increasingly being used for energy storage and peak power delivery.

Indeed, any application that requires the storage of electrical energy and the discharge of highly variable amounts of power is a potential market for ultracapacitors. The following list gives an overview of the available market domains and applications for ultracapacitors.

Market domain	Application
Automotive	Hybrid drives, board net stabilization, distributed power
Trains, trams	Regenerative braking, voltage stabilization
Buses	Regenerative braking
Aerospace	Electric actuators, or latches
Pitch systems	Emergency power for windmill blades
Robotics	Peak and back-up power
Telecom	Back-up power

Material handling	Peak power for fork lifts, cranes and straddle
Elevators	Peak and emergency power
UPS/power quality	Back-up power
AMR (Automated Meter Reading)	Power supply
Consumer electronics	Power supply, burst, peak and back-up power

Table 1: Market domains and applications

Uninterruptible power supply, back-up power

Back-up power systems are now an integral part of most, if not all, mission-critical installations. Services as varied as data centers, communications networks and plant operations all rely on the continuous availability of quality power. Small back-up systems traditionally rely on batteries for energy storage, while larger systems may use a generator set, or more exotic or complex systems such as flywheels, superconducting magnetic energy storage, or more recently, fuel cells. Each of these technologies has particular limitations; batteries are notoriously unreliable, flywheels have required more maintenance than originally thought, and generator sets and fuel cells have poor turn-on response. Ultracapacitors used alone, or with longer term energy sources such as gensets or fuel cells, are proving to be the next wave in high reliability backup power.

For installations that need up to about a minute’s worth of support, ultracapacitors really come into their own, whether that is to buffer poor power transients, allow equipment to perform an orderly shut down or to transfer to a secondary power source,. Further, when one considers that the majority of power outages are in the order of seconds, ultracapacitors can relieve the genset or fuel cell from having to come on at all – reducing overall system wear and tear and thus maintenance and costs.

As mentioned, ultracapacitors boast fast response times and can deliver hundreds of thousands of complete cycles with minimal degradation of performance. Furthermore, cycle depth is not an issue: so ultracapacitors can be micro-cycled (cycled by less than 5% of their total energy) or full-cycled (by more than 80% of their total energy) with the same long life.

Pitch systems of windmills

To enhance the level of safety, newer wind turbine technology uses the wind not only to produce wind energy but also for its own safety. The converters in the windmill’s rotors feature aerodynamic braking by individual pitch control. The rotor attains the full braking effect with a 90 degree off position of all three blades. To enhance the level of safety each of the autonomous pitch systems is equipped with an emergency power supply to immediately ensure the reliable functioning of the fast blade pitch system in the event of a total power failure or for maintenance purposes.

Today ultracapacitors are widely used for emergency power supply, due to their excellent performance, wide operating temperature range, long life, flexible management, reduced system size, and cost effectiveness. Each of the autonomous pitch systems in a windmill is equipped with an ultracapacitor emergency power pack. The ultracapacitor pack is always charged to its nominal voltage and has a high enough energy content to run the system for more than 30 seconds with nominal power. The ultracapacitor pack is directly connected to the DC link of the motor converter of the blade drive.

Door and slide management system

The Airbus A380 is the newest and largest passenger airliner in the world. Designing an aircraft of this size brings with it new technical challenges. One example is the 16 passenger doors on the A380: these are larger and heavier than typical airliner doors, and are therefore electrically operated. To meet the high safety and reliability standards required for commercial aircraft, it must be possible for the doors to be opened independently of the A380's main electrical system, for example after a break in the fuselage following a crash. As well as the doors themselves, the Door and Slide Management System (DSMS) actuators developed by Diehl Luftfahrt Elektronik GmbH also power emergency slides. The DSMS must be extremely reliable, requiring the minimum of maintenance and able to function in harsh environments, and must not place too high a burden on the A380's electrical system.

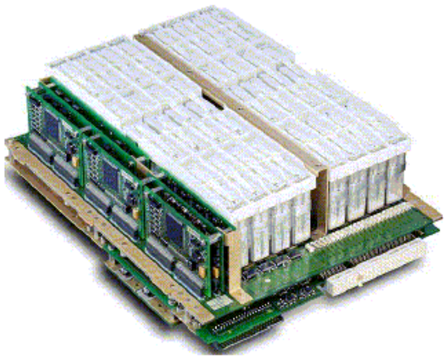


Figure 5: Door and slide management system

To provide the necessary emergency door opening, the DSMS in each door has an ultracapacitor energy storage system that provides the required momentum of 800-900 nanometers and takes no more than 130VA from the A380's main AC electrical system. The power system is maintenance-free and has extremely high availability, with all functions working normally even with single hardware failure. The DSMS is able to stay on standby for up to 8 hours. This is possible due to the low self-discharge rate of ultracapacitors The DSMS is required to operate in a temperature range of -40°C up to +70°C. Weight is also tightly constrained, the DSMS weights less than 4.2kg, including the local ultracapacitor system, and fits in a space around the size of a shoebox. Finally, the system has a 25 year lifetime.

Power robotic systems

Conventional mobile industrial robotic systems currently in use are powered with a combination of batteries and off-board power supplied through a tether, which limits the range of mobility of the system to the length of that tether. The off-board power is required because batteries alone would need to be prohibitively large in order to sustain the combination of continuous and peak power required for extended operation.

By integrating ultracapacitors in the application, the need for the tethered link to an offboard power source is eliminated, and the mobility of the system is upgraded. The ultracapacitor is sized to shave the damaging peak loads off from the battery or even a fuel cell. Using the ultracapacitor provides two benefits: The battery (or fuel cell) is sized for continuous power rather than peak power, and is therefore smaller, lighter, and less expensive; and the ultracapacitor provides the response time which cannot be practically achieved by the battery or fuel cell, regardless of size. The same design strategy can be used with any power source that has excellent energy capabilities but poor power performance, or poor response time, or both. The system can now operate with complete mobility, for longer periods, and requires less weight and volume than an equivalent battery pack.

Automatic meter readers (AMR)
Companies creating the latest wireless remote transmitting devices were facing challenges such as power supply size, life and cost. Lead acid batteries had been the original power source, but their life expectancy of only three to five years was undesirable, as were their relative heaviness and the costly battery replacement process. Leakage was also an issue in some instances. The power supply has to effectively run internal components at a generally constant rate, but also to handle the power peaks demanded by the unit's wireless connectivity – something that sharply reduces the life of most batteries. In addition the power source has to withstand operating temperatures ranging from -40°C to +70°C, extremes of which also reduce the operating performance and life of batteries, and can cause degradation in their packaging. By using ultracapacitors, instead of more traditional energy sources such as Lithium ion or Ni metal hydride batteries, the life expectancy of the power supply in remote transmitting devices is extended to over ten years – representing a one hundred to three hundred percent improvement over lead acid batteries. The required small cell ultracapacitors in each unit are also lighter and smaller, and facilitate a simpler design-in process. Ultracapacitors are slightly more expensive in initial cost, but because the life of ultracapacitors is much longer, an overall cost savings of over two hundred dollars per unit is realized. Additional per unit savings of between fifteen and twenty dollars are achieved through the smaller footprint of the new ultracapacitor-based power supplies.

Consumer electronics
Now more popular than ever, portable electronics are marvels of engineering, with more features and functions than we could have imagined even a few years ago. They allow us to put cameras, video, high fidelity audio, GPS navigation and wireless communications capabilities into our pockets. All of these features can be found today in commercially available products, which are no larger than a deck of cards. Despite all these capabilities, they often become mere toys because their batteries are not up to the task. The big power pulses required in moving camera motors, burning images into flashcards and sending bursts of information over wireless systems, all overstress existing battery technologies, severely limiting their practical life between charges. In addition, the need for smaller and more lightweight systems increases, and design engineers require innovative design approaches to reduce size and heaviness without sacrificing overall performance and reliability.

Today, ultracapacitors have become an alternative to batteries in applications where the ultracapacitor is charged from the primary power supply but functions as a backup power source when the primary source fails or peak power has to be provided. Not surprisingly therefore, ultracapacitors are making their way into many consumer products.

High pulse power applications

Digital cameras

Digital cameras have a variety of frequent pulse loads. The major high peak demands are observed during the microprocessor activity, writing to disk and LCD operation. Expensive rechargeable batteries (and the cost of the charging circuitry) are being replaced with embedded ultracapacitors and conventional, disposable alkaline batteries. Though alkaline batteries have a lot of energy, normally they can't deliver the power needed to operate these cameras.

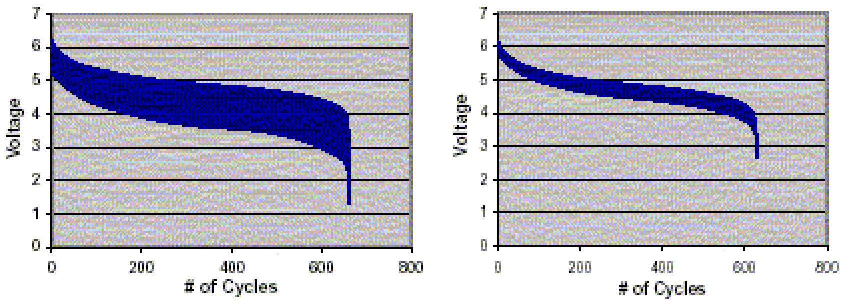


Figure 6: Voltage swing for rechargeable batteries and alkaline-ultracapacitor combination

By teaming the alkalines with an ultracapacitor, each does what they do best; the alkalines deliver continuous energy, and the ultracapacitor delivers pulses of power. Figure 6 shows the voltage swing for a defined cycle. As it can be seen the voltage swing is large with rechargeable batteries, but with the alkaline – ultracapacitor combination the voltage swing is reduced significantly. In conclusion the results show that by adding ultracapacitors to the product, it allows the end customer to use inexpensive alkaline batteries, which in the long run saves them money and allows ease of use. Figure 7 shows that the capacitor performance has not changed even after 16 sets of battery changes, which was equivalent to

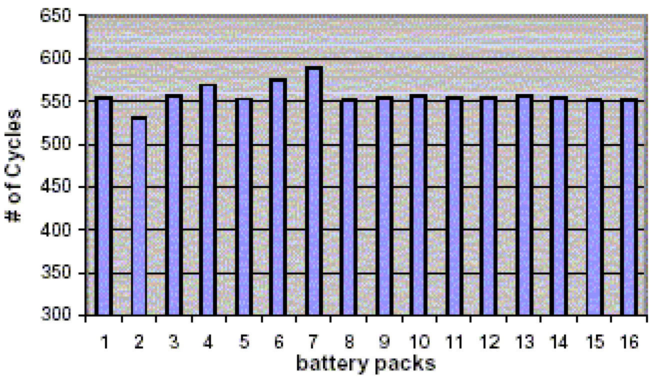


Figure 7: Number of cycles per alkaline battery pack using the same ultracapacitor pack

Wireless systems and burst-mode communications

Wireless systems that use burst-mode communications techniques benefit in the same way as digital cameras. Burst-mode communications are used in local areas such as stock and commodity exchange floors, warehouses and even in restaurants, where order takers and information processors use wireless terminals and modified PDAs to communicate real time information to a central data centre. Customers are integrating ultracapacitors with their battery packs, freeing commodity traders from having to change batteries during the day.

Fast charge applications

Toys

A number of companies are now using this "instant charge" design concept to make great toys. The most popular is a small race car with an ultracapacitor inside; you charge up the car in less than 10 seconds from a set of alkalines in a small charging pod. The play scheme fits the short attention span of children very well, and adds an exciting real-world "pit stop" element to racing.

Instant charge hand tools

How many times have you needed to drill just a couple of holes, only to find out your battery's dead and you have to wait for an hour recharge to do a 2-minute job? With the ultracapacitor, this is no longer a problem. The weekend handyman is freed to do those quick jobs with instant charge modules for cordless tools.

Long life storage applications

Personal emergency equipment

Since you can store an ultracapacitor completely discharged for an indefinite time, shelf life is not an issue. This is critical for personal emergency gear, such as wind-up radios and flashlights. You don't have worry when the power in the house goes out. Instead of wondering if the flashlight's batteries are good, simply wind up the flashlight and charge the ultracapacitor inside.

The future of power in consumer electronics

Multi-function pocket appliances

Integrated cell phone/camera/PDA/MP3 players and GPS/personal alarm/emergency beacons are now the cool gadgets at the global electronics shows. Stuffing all these features into a small package requires a lot of energy AND power. To get all the power out of the battery kills it, and to carry a huge battery defeats the whole pocket appliance concept. The greatest opportunities for ultracapacitors in consumer electronics are all those ideas that can only be accomplished by separately addressing power and energy needs. The right approach is to design intelligently and use two components to solve two different requirements, a battery for energy and an ultracapacitor for power.

Automotive

Hybrid drives

Ultracapacitors have proven to be an ideal augmentation to hybrid power trains as an electrical peaking unit. The reason for the acceptance of ultracapacitors in vehicle propulsion systems is their high pulse power capability, fast transient response, and high efficiency during discharge and recharge, plus full-charge cycling in excess of 1 million cycles. They will last the lifetime of a car with no maintenance, and offer better performance at extreme temperatures than batteries.

	System			
Function	**Full hybrid**	**Mild hybrid**	**Mini hybrid**	**Micro Hybrid**
Start-stop	√	√	√	√
Recuperation	√	√		√
Passive boosting	√	√		√
Active boosting	√	√		
Electrical driving	√			
Additional features	√			√

Table 2 : Different hybrid systems

Among the companies that have announced programs for using ultracapacitors in vehicle powertrains include such big names as BMW, VW, Audi, Honda, Nissan and Toyota, along with many others, some still at concept stage and others ready to go into production. Mild or full hybrid vehicle have a combustion engine that functions as the primary power source, and an electric motor with a power storage system that functions as the secondary power source. Designers are able to size the combustion engine for cruising power requirements thanks to the presence of the secondary power source that handles the peak power demands for acceleration. Additionally, regenerative braking energy is captured by the secondary power system and that energy is applied for further acceleration. Mild or full hybrid drive trains produce between 7 and 25% increased fuel efficiency while reducing pollution by an even greater percentage.

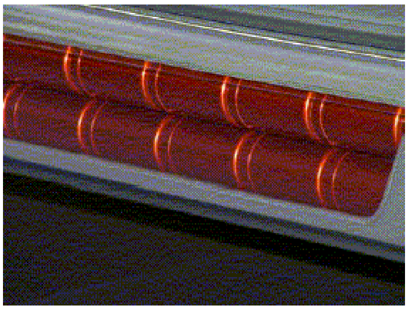


Figure 8: BMW X3 with 190kJ ultracapacitor tube modules in the door sills

Originally announced at the Frankfurt motor show in September 2005, BMW's X3 uses ultracapacitors with a quoted specific power density of around 15kW/kg, substantially more than the 1.3kW/kg available from a nickel/metal hydride battery. Given the same weight, voltage and power supply, the ultracapacitor offers an efficiency of 98%, compared to 84% from a NiMH battery, operates well at low temperature and is not subject to internal thermal run away (and risk of fire) like the NiMH batteries.

Figure 9: Maxwell 38.5V/46F ultracapacitor modules for a micro hybrid system

Mini hybrid vehicles use a power generator that delivers the power required to handle start/stop idling only. Finally, in the micro hybrid concept developed by Audi and presented in 2005, there is a power generator and power energy storage source to handle start/stop idling, fuel consumption reduction due to energy recuperation/acceleration assist, and to power some additional features like fast windshield heating.

Board net stabilization, distributed power modules

As well as power trains, the modern car has high demands for electrical power, particularly short peaks in demand for systems like powered braking and steering. These base level loads have dramatically increased from 1 or 2 kW in the 1980s to over 6 kW today and the dynamic loads have gone from 2kw to over 18kw in high end modern automobiles. In a 14-volt system, this requires currents from 500 to 1,500 amps for several seconds.

If a short-term demand causes a voltage drop on the board net (the power distribution supporting the logic boards), the control electronics may stop functioning due to low voltage cut-off. With 50 to 100 control modules competing with 50 to 100 electrical actuators and motors in a modern car, this is a major reliability and safety issue. Electronic fuel controls may stop, causing the engine to stall, and lights and sound systems may fluctuate. In the worst cases, the car will require towing to a service centre to be reset.

Board net stabilization is one of the best and easiest to implement applications for ultracapacitors. The short-term power demands that cause voltage dipping can be buffered with a 14V power module designed with enough energy storage to “ride through” or supplement peak power demands. This offer replaces the need for a second battery, takes less weight and space, is not a maintenance item, lasts the life of the car, and performs reliably at -40°C. The cost in high volume is about the same as a second battery and associated cabling, and the life cycle cost to the consumer is lower. Modules like the one shown in Figure 10 below are designed for board net stabilization and are currently being tested by many automotive manufactures as the solution for voltage dipping.

Figure 10: Ultracapacitor products for board net stabilization (58F, 15V)

Ultracapacitors can also be used to support higher demand intermittent power applications, such as electrical power steering and braking. These applications usually demand 1 to 2 kW for a second or two, then a smaller demand for several more seconds. To meet safety requirements, the ultracapacitor module has sufficient energy to perform this operation 5 to 10 times without recharging. Most of the time, power steering is quiescent, drawing little power for actual steering. When called upon, the power requirement is a brief, high power pulse of less than one to two seconds. The profile for a typical electrically powered steering event is a one- to three-second ramp to approximately 2000 watts for several hundred milliseconds, which quickly returns to quiescent. In centralized power architecture, the power required can be supplied by the central energy storage, but this would require a very heavy and costly power cable. The voltage drop due to the high current could require that either the cable or the energy storage system be oversized.

Figure 11 shows a typical power steering event. This system includes a 350W converter supplying 42V from the 12V bus, and an energy storage device (in this case, an ultracapacitor) load-leveling the power steering event. Without the use of energy storage, the converter would have to be sized to supply the 2000W peak, and be able to respond quickly to this transient demand.

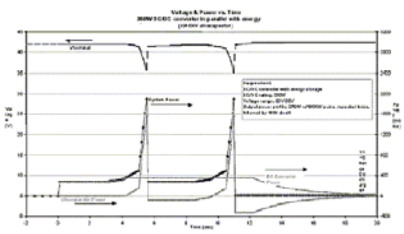


Figure 11: Power steering profile

Transportation

Hybrid electric buses

Hybrid electric buses combine the best characteristics of fuel-driven engines, electric motor drives and energy storage components. Initial solutions for hybrid drive trains utilized batteries providing the electrical power storage. However, system engineers faced several challenges with battery technology, such as sophisticated charge equalization management, performance limitation at extreme of temperatures, limited cycle life resulting in high replacement cost and increased life-cycle cost of the vehicle, and reduced efficiency of the hybrid electric drive system design. To address the limitations posed by battery systems, bus manufacturers today use ultracapacitors as the secondary power source.

As an example, ISE, a California-based hybrid bus manufacturer has incorporated ultracapacitors into its hybrid electric vehicles with extraordinary results. A 40-foot hybrid-electric transit bus with ultracapacitor energy storage has passed accelerated life testing at the Altoona Test Track in Pennsylvania. The system is already in use on more than 100 buses in California. The operation data indicate the average fuel efficiency of a bus with an ISE ultracapacitor-based hybrid-electric drive system is significantly better (around 70%) compared to a bus with competitive battery-based hybrid-electric drive system and the efficiency is improved from below 70% with batteries up to 95% with ultracapacitors.

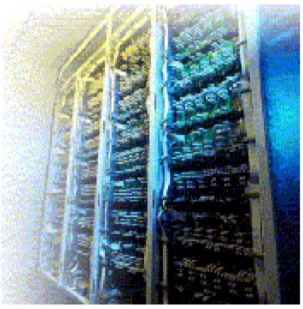
Trains and trams

On vehicle energy storage

Ultracapacitors have also been installed in light rail applications. In Germany, a prototype vehicle developed by Bombardier Transportation has been in passenger operation since 2003, and has demonstrated the potential for energy savings of up to 30% as compared to a modern regenerative light rail vehicle. Used to store energy from braking, the ultracapacitors go through somewhere between 100,000 and 300,000 load cycles per year in a typical light rail vehicle – which means that batteries would be unsuitable for this application. Ultracapacitors are also lighter than a comparable battery.

Stationary energy storage

To achieve important energy savings as well as overcome power outages the local transport authorities of cities in Europe, the US and China are now installing an innovative energy storage system called SITRAS SES, developed by the engineers of Siemens TS. One system, operational for around 22 hours per day, reduces the annual primary energy demand by as much as 500 MWh or 30 percent. SITRAS SES also makes a decisive contribution to stabilizing the network, which not only enhances the reliability of mass transit systems, but also improves the tempers of passengers.



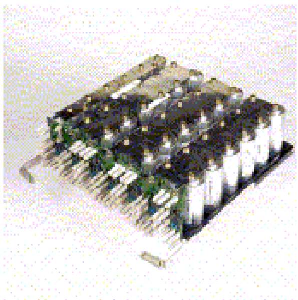


Figure 12: A glimpse at the SITRAS SES system: The 2600 F BOOSTCAPs

Before choosing ultracapacitors as energy storage source the engineers first decided to use flywheel storage systems. But already after the first extended service tests, it was clear that they were not suitable for long-term use, due to their complex maintenance. That’s why the engineers then concentrated on developing capacitor energy storage systems.

The system, which includes a connection unit, a voltage converter and control electronics in addition to the capacitors, is housed in two rows of cabinets, each of which is 3 meters long and 2.7 meters high. If one or more trains start at the same time, the SITRAS SES system releases the energy absorbed during braking, and the network voltage never drops below the critical level. The system thus not only saves energy, with its fast response time it also prevents a sudden loss of power for the trains and thus avoids leaving hundreds of frustrated passengers sitting stranded.

Conclusion

The challenge for power systems design engineers is to understand the technologies available, and make the most of them in an integrated system that manages energy storage and power delivery as two complementary requirements, recognizing the subtle yet critical difference between power and energy. When appropriately applied, ultracapacitors represent an outstanding design option for advanced power systems design. Ultracapacitors can provide long life, high power capability, durable design, wide temperature range, and low maintenance. They have proven to be ideally suited for applications that require highly efficient energy storage and repeated bursts of power for periods of time ranging from fractions of a second to several minutes.

In recent years, growing demand for ultracapacitors in the electronics and industrial markets has spurred materials and design advances leading to dramatic cost reduction. Global suppliers are also aggressively addressing the cost issue, making ultracapacitors affordable for a wide range of applications. Production centers now exist in Asia, Europe, and North America. They are available in various form factors, as single cells, modules or more specific customized solutions.

Ultracapacitors are now considered a peer to other options for production-intent designs in the power electronics world. 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.

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