Ultracapacitors and their applications

Abstract

The need for lighter, compact wireless and portable devices with more ingenious features crammed into an ever-tighter space has led to a related quest for the next power supply innovation—a powerful, long-lasting and compact battery. Current battery technology often satisfies the desired space and weight specifications but compromises on peak power requirements. Batteries 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. Ultra capacitors, also known as supercapacitors, offer an alternative source that promises to circumvent the battery scramble and extract greater efficiency from existing power sources. They offer boundless growth potential because they respond to key market and societal needs: They are environmentally friendly, help conserve energy, and enhance the performance and portability of consumer devices. Ultracapacitors are also free from characteristic battery problems, such as limited cycle life, cold intolerance and critical charging rates. This makes them a very viable option for practical applications and will create a revolution in long lasting and powerful energy supplies.

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**Introduction:**

What is a supercapacitor? Like any capacitor, a supercapacitor is basically two parallel conducting plates separated by an insulating material known as a dielectric. The value of the capacitor is directly proportional to the area of the plates and inversely proportional to the thickness of the dielectric. Manufacturers building supercapacitors achieve higher levels of capacitance while minimizing size by using a porous carbon material for the plates to maximize the surface area and a molecularly thin electrolyte as the dielectric to minimize the distance between the plates. Using this approach they can manufacture capacitors with values from 16mF up to 2.3F. The construction of these devices results in a very low internal resistance allowing them to deliver high peak current pulses with minimal droop in the output voltage.

Available for decades, a conventional electrolytic capacitor is an energy-storage device that can be compared to a container that gradually fills with electrical energy and then delivers it when needed in a sudden burst. Offered just recently, an ultracapacitor is a high-energy version of a conventional capacitor, holding hundreds of times more energy per unit volume or mass than the latter. When fully charged, ultracapacitors deliver instant power in an affordable, compact package. Long considered an enigma because of price, the advent of inexpensive, compact ultracapacitors, characterized by an exceptionally high surface area, excellent conductivity, and superior chemical and physical stability, herald a new era of practical usage.

**Construction of an Ultracapacitor:**
An ultracapacitor can be viewed as two non reactive porous plates, or collectors, suspended within an electrolyte, with a voltage potential applied across the collectors. In an individual ultra-capacitor cell, the applied potential on the positive electrode attracts the negative ions in the electrolyte, while the potential on the negative electrode attracts the positive ions. A dielectric separator between the two electrodes prevents the charge from moving between the two electrodes.

**Comparison with ordinary Capacitors:**

In a typical capacitor, electrons are removed from one plate and deposited on the other. Polarized molecules in the dielectric concentrate the electric field. One major factor determining capacitance is the surface area of the plates.

However, an ultracapacitor can store more charge than a capacitor can, because the activated carbon has a pocked interior, much like a sponge. This means that ions in the electrolyte can cling to more surface area. The difference can clearly be understood with the help of the following diagrams:
The use of activated carbon effectively increases the surface area of the capacitor to many times that of the electrolytic capacitor. This results in a significant increase in capacitance and energy density according to,

$$C = \varepsilon \frac{A}{d}$$

By using activated carbon, which is a highly porous carbon material with a surface area up to 2000m$^2$/g as electrodes, commercial Ultracapacitors can achieve a energy density much greater than the energy density of a conventional capacitor.

However, recent research conducted by the MIT has suggested that by replacing the activated carbon with carbon nanotubes, greater energy storage is made possible due to the finer dimensions and more uniform distribution of the ions as shown below:
Ultracapacitor with nanotubes

From the Power vs. Energy characteristics, it is observed that ultracapacitors (6Wh kg\(^{-1}\)) have much higher energy densities when compared to a conventional capacitor. However, this figure is much lower than the energy density reached by Lithium-Ion batteries (120Wh kg\(^{-1}\)). This clearly proves that ultracapacitors by themselves cannot be a replacement for a conventional battery.

![Power vs. Energy characteristics of energy-storage devices](image)

**Applications:**

Ultracapacitors provide short term bursts of current and therefore are not a valid replacement for a battery. However they can be used to increase the lifetime of a battery by connecting them in parallel with the source. During high current requirements, the capacitor provides the current and hence reduces the load on the battery and thereby prolonging its life. Ultracapacitors find many applications in,

*Transportation engineering*

On a larger scale, ultracapacitors are well suited for many transportation applications. The endless cycles of acceleration and braking of vehicles and mass transit vehicles 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 an on-vehicle or a stationary system design. 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 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.

Driven by the goal to reduce fuel consumption, automotive manufacturers are developing product lines that incorporate advanced drivetrains. 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 upkeep costs. 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. Newer power systems which use ultracapacitors have allowed the HEV to recapture and reuse braking energy.

**Industrial engineering**

In industrial electronics, numerous firms are already well into the production cycle for ultracapacitor-based systems. Applications such as elevators and conveyor systems use ultracapacitors to reduce power peaks in the net and to achieve more energy savings.

As short deviations in power supply voltage can influence or interrupt the correct operation of electrical equipment, uninterrupted 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.

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.

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 short time period UPS applications.

**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. The battery, which is the main source of power in portable products, represents an ongoing challenge in finding one that is ideal in terms of size, weight, and performance. 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 an ultracapacitor hybrid is much more efficient.

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. Ultracapacitors are already being 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.

Ultracapacitors also benefit products designed for use with batteries capable of high-power discharges as in the case of a web-enabled Personal Digital Assistant (PDA) that uses a nickel cadmium battery to supply power when sending internet emails might be better served by an ultracapacitor. The battery alone 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.

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**Conclusion:**

Although ultracapacitors are not a viable replacement to batteries, they will play a vital role in providing a greener solution to energy conservation. 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. Although some ultracapacitor applications, such as memory backup, are already in widespread use, many of the applications just discussed are still in the initial phase of adoption. Higher-voltage ultracapacitor technology looms on the horizon, and the implications of such a development are enormously far reaching.

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