Energy storage for short shots

Ultracapacitors can take up less space and are more efficient than conventional batteries in applications demanding brief periods of power.

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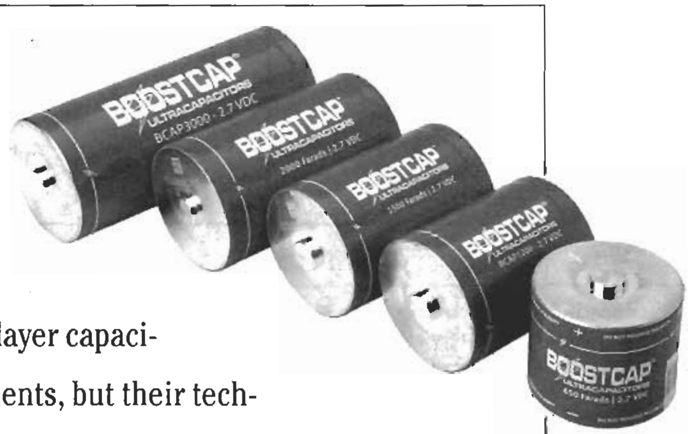


Boostcap ultracapacitors from Maxwell Technologies come in sizes ranging from prismatic 5, 10 and 100-farad cells to cylindrical 2,600-farad large cells. They are also available as fully integrated power packs that satisfy the energy storage and power delivery requirements of fast blade pitch systems.

Consider the ultracapacitor. It is an energy storage device well-suited for short-term power delivery. Also known as supercapacitors or electrochemical double layer capacitors (ELDC), ultracaps are not new components, but their technology has advanced dramatically in the last decade.

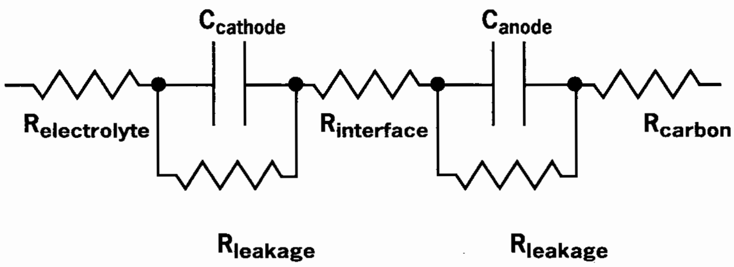
The beneficial qualities of ultracapacitors come from their composition and construction. Unlike many batteries, the anode and cathode of an ultracapacitor are comprised of the same material. For manufacturing and consistency purposes the terminals are marked with polarity. (A recommended practice is to maintain the polarity, although the ultracap won't fail if it is reverse charged for some reason. If the ultracap has been conditioned for charge in a certain direction and then is changed, the conditioning can reduce its life somewhat.)

Ultracap electrodes consist of activated-carbon, having a specific surface area of 2,000 m^2/gm with a charge separation of 10 Å or less. This large surface area gives them their high capacitance and power density. The energy storage mechanism is highly reversible, with no chemical bonds being made or broken, leading to a cycle life of over 1 million cycles with minimal degradation. Wide-ranging operating temperatures between –40 and 65°C, or even higher for short durations, are possible thanks to the use of electrolyte with a high conductivity and low freezing-point.

The high power density made possible by a large electrode surface area means that ultracapacitors are well suited to supply high power for short bursts of 30 to 100 seconds. Batteries, by contrast, typically are sized to deliver power over longer periods. In situations characterized by such short periods of demand, batteries will typically be far larger than an ultracap able to supply short-duration power. Conversely, a battery sized to handle short bursts may not charge up quickly enough to supply the necessary juice.

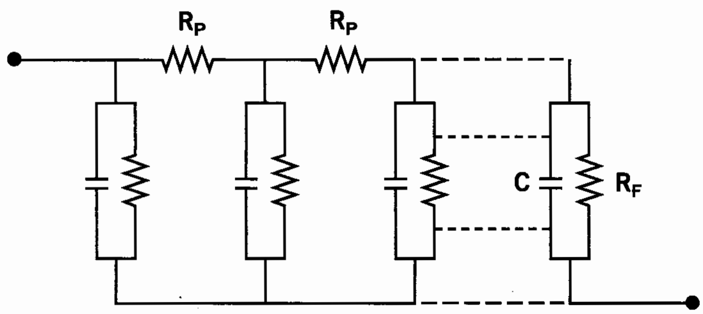
Because the energy storage mechanism of the ultracapacitor is not a chemical reaction, its charging/discharging can take place at identical rates. Thus the rated current for an ultracapacitor applies for both charge and discharge, and the efficiency of charge and discharge are in practical terms the

SIMPLIFIED EQUIVALENT CIRCUIT, ELECTROCHEMICAL CAPACITOR



In the simplified electrical model of an electrochemical or ultracapacitor, a separate capacitance represents each electrode. Charge transfers through resistances representing the carbon electrodes, the electrolyte, and the interface between the two. A resistance in parallel with the electrode capacitances represents leakage paths. A more detailed electrical model recognizes the high porosity of the electrodes through use of a transmission line network with pore resistance elements (RP) as well as distributed capacitance and leakage resistance RF.

TRANSMISSION-LINE MODEL ACCOUNTING FOR POROUS CARBON ELECTRODES



Ultracapacitors make it possible to use battery capacity that would otherwise be unavailable once battery-cell voltage drops below a certain level. The ultracapacitor is typically wired in parallel with the battery. When the load demands a sudden current peak, it sees a low resistance in the capacitor and a much higher resistance in the battery. Consequently, the capacitor supplies the current peak. The battery restores charge to the ultracapacitor when the load demands a lower current. An example of where ultracapacitors come in handy is in GSM cell phones. The GSM signal requires a current pulse of as much as 2 A for 500 µsec at a 4-msec repetition rate.

same. This lets ultracapacitors be recharged quickly without current limiting as long as the current stays within the ultracap's rated current.

The only efficiency losses associated with ultracapacitors come from their internal resistance, which causes an *IR* drop during cycling. For most uses ultracapacitor efficiency exceeds 98%. It is somewhat less for high current or power pulsing. Nevertheless, typical efficiency while supplying high-current pulses still exceeds 90%.

Ultracapacitors have a typical time constant of about one second. The time constant reflects the time needed to charge a capacitor to 63.2% of full charge or to discharge to 36.8% of full charge. The time constant of an ultracapacitor is much higher than that of an electrolytic capacitor. Therefore, ultracapacitors may overheat if exposed to a continuous ripple current.

One challenge with batteries is the difficulty in measuring their state of charge. The charge of an ultracapacitor, however, can be gauged solely by its voltage. Additionally, because ultracapacitors operate on a different principle than batteries, the ultracapacitor can sit on a charge voltage for extended periods without losing any capacity, unlike a battery. Furthermore, cycle depth isn't an issue, so ultracapacitors can be micro-cycled (cycled less than 5% of their total energy) or full-cycled (cycled greater than 80% of their total energy) with the same long life.

Ultracapacitors are capable of operating between their rated voltages and zero volts. Occasional spikes above the rated voltage will not immediately affect the capacitor. But their life can be reduced by voltage spikes, depending on their frequency and duration.

Alternative energy

Ultracapacitors are also beginning to play a role in alternative energy circuitry. A prime example is on the blade pitch-controllers for today's advanced megawatt-scale wind turbines. The largest turbines in production today generate up to 5 MW with rotor diameters of up to 110 m (360 ft). Here integrated packs of large ultracapacitors can provide emergency back-up power. Such wind turbines typically use a standard nominal voltage of 300 Vdc which can be handled by four 75-V ultracapacitor sub-modules connected in series.

In these large wind turbines, three independent electromechanical propulsion units typically manage blade pitch. Here, an electronic controller checks the power output of the turbine several times per second. It tells the blade pitch mechanism to turn the rotor blades slightly out of the wind when the power output becomes too high. Conversely, the blades turn back into the wind whenever the wind dies down.

Newer turbines also use the wind to aerodynamically brake the rotor through individual pitch control if safety demands it. The rotor goes into full braking by putting all three blades into a 90° off position. Even if a blade pitch unit fails, the other two rotor blades finish the braking process safely. Furthermore, each of the autonomous pitch systems has its own emergency power supply in the event of a total power failure or for maintenance.

Currently, most emergency power supplies of this sort are comprised of batteries. The batteries are sized to provide the peak power needed to adjust the rotor blades even if those power levels last only a few seconds. Indeed, battery storage systems have deficiencies that emerge during times of high power demand. They create many design challenges for pitch system engineers. Perhaps most important, batteries don't perform well in providing bursts of power for a few seconds at a time to handle rotor blade adjustments over many hundreds of thousands of cycles. This kind of action tends to diminish their capacity over time and reduces their operating life. Nor do commercial batteries work well at low temperatures, and extreme environmental conditions diminish their useful life. Typical battery lifetime is much less than the 20-year time horizon normally assumed for turbine installations, so these batteries must get replaced repeatedly.

Ultracapacitors overcome many of these problems. They excel at buffering short-term mismatches between the power available and the power needed. When appropriately designed with a systems approach, they perform well, work over a wide operating temperature range, take up less space than the equivalent batteries, and are economical.

Pitch systems sit in the rotating rotor hub of the wind turbine. The power supply and control signals for the pitch systems transfer by a slip ring from the non-rotating part of the nacelle. The slip ring connects to a unit which includes clamps for distributing power and control signals for the three individual blade drive units. Each of them consists of a switched-mode power supply, a field bus, the motor converter, an emergency system, and the battery or ultracapacitor bank. When the power supply switches on, the ultracapacitor module charges to its nominal voltage. Typical charging time is about one minute. The capacitor module typically contains enough energy to run the system for more than 30 seconds with nominal power.

The ultracapacitor module connects directly to the dc link of the motor converter. The converter then drives a 3-phase, 4-pole asynchronous motor that mounts directly to the gearbox of the blade drive. The motor is designed to give maximum torque at low rotational speed. Each blade has sensors that control its position.

More info

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Finally, ultracapacitors are especially well suited for offshore and remote wind power applications, partly because they need no ongoing evaluation of their state-of-health and state-of-charge, as is the case with batteries. Offshore installations, of course, are situated several kilometers off the coast, and daily inspections are impractical. Inclement weather may extend inspections to several months apart. This may have an impact on other aspects of the turbine operations, but not on the ultracapacitors. ■