WHITE PAPER

ULTRACAPACITOR APPLICATIONS FOR UNINTERRUPTIBLE POWER SUPPLIES (UPS)

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Ultracapacitors have been used as backup power for several years in wind turbine generators, mobile communications base stations, and a variety of electronic devices and industrial machinery. Until recently they have not been considered for large scale uninterruptible power supplies (UPSs). Energy storage for UPSs has been dominated by lead acid batteries. As ultracapacitors have matured, costs have come in line for consideration in large scale UPSs as bridge power for datacenters, hospitals and high technology manufacturing. Typical system sizes will start at 20KW and can easily expand with modular solutions to MW-sized systems.

Each of these applications requires short term power to transition to a more permanent backup energy source such as a generator or fuel cell. Typical transition times are 15 to 30 seconds. While lead acid batteries have been the predominant energy storage, they suffer from short lifetimes (1-5 years), unexpected failures and difficult handling and toxic components. More recently, flywheels have also been used for transition power. They offer a long lifetime capability but at high maintenance and standby power costs.

Ultracapacitor Background

Ultracapacitors are high energy capacitors which hold hundreds of times the energy of a traditional capacitor due to very high surface area in activated carbon and nano-scale electrode spacing. This makes them well-suited for high power and energy requirements beyond electrical noise filtering applications. While batteries can still hold up to 20 times the energy, the electrostatic storage in ultracapacitors provide very fast charge/discharge characteristics with power up to 20 times that of a battery. Since no chemical reactions are required, ultracapacitors can run over 3,000 times the number of charge/discharge cycles as a lead-acid battery and 3 to 14 times the calendar life.

Ultracapacitors provide a long-life (8 to 15 years) green solution. State of health monitoring is not required but, if desired, it is straightforward to monitor. An overvoltage monitor is built into each module to signal if the module has experienced a severe overcharge. The capacitance can be monitored over time by measuring the voltage after a known load is applied for a brief time. This is in contrast to batteries which require sophisticated monitoring which can cost up to $20,000 per system.

Modules are easy to handle with one person able to carry a 10KW/56V module which weighs less than 40 lbs. Table 1 provides a high level comparison between the primary energy storage technologies against some key factors.

Table 1. Technology comparison between lead-acid batteries and ultracapacitors.

	Lead-acid Batteries	Flywheels	Ultracapacitors
Lifetime	1-5 years	20 years ✓	8-14 years ✓
Toxicity	Lead, Strong Acid	Hydraulic fluids	Non-toxic ✓
Monitoring	Sophisticated	Included	Not required, simple voltage, current measurement ✓
Modular	Multiple capacities ✓	50 kW min.	Standard, rackmount ✓
Handling	Very heavy		Lightweight easy handling ✓
Failure	Unpredictable	Unpredictable	Predictable wearout ✓
Initial Cost	Low ✓	High	Moderate
Life Cost	High	Moderate	Low ✓
Maintenance	Regular conditioning	Regular Maintenance	Maintenance free ✓
Power Density	Low	Medium	High ✓

Energy Density	High ✓	Medium		Low

Total Cost of Ownership (TCO)

These performance characteristics result in significant savings over the life of a UPS. Depending upon the replacement frequency of batteries, the savings can range from 30%-75% of total lifetime costs. For example, a 200kW UPS with annual replacement of batteries can save ~75% over a 15 year life. In a typical case of battery replacement every 3 years, the following TCO can be used as an example:

Table 2. Total Cost of Ownership example.

	Batteries	Flywheel	Ultracapacitors
User Requirements			
Lifetime	15 years	15 years	15 years
Power	200 kW	200 kW	200 kW
Bridge Time	15 seconds		15 seconds
Inputs			
Useful Life (typical)	2 years	15 years	15 years
Float voltage	560V	560V	560V
Minimum voltage	440V	440V	280V
Discharge Time	30 seconds	30 seconds	30 seconds
Initial cost	$17,000*	$48,000	$60,000
Annual cost**	$4,450	$2,140	$550
Total Lifetime Cost	$83,785	$80,150	$68,290
Savings			**$15,495 (18%)**

*includes $10,000 for monitoring system
**includes floorspace, electrical cost, maintenance and replacement

As designers look to reap the benefits of ultracapacitors, they can easily be used as a drop-in replacement for batteries. However, new UPS designs should be considered with inverters optimized for the use of ultracapacitors. A typical battery inverter will stop functioning at ~80% of the float voltage, as shown in the example above where the minimum voltage is 440V. When directly replacing batteries with ultracapacitors, this will limit the energy utilization from ultracapacitors to 36% of the total available. If the operating voltage can be reduced to 50% of the float voltage (280V), 75% of the energy is utilized. Ultracapacitors do not suffer shortened lifetimes when deep discharged as batteries do and could reasonably discharge to 30% of float voltage (170V) to utilize 90% of the energy. The minimum operating voltage is a tradeoff of maximizing the stored energy in

Figure 1. 56V Module which can work in series connection up to 750V. Each module can nominally support 10kW for 15 seconds.

the ultracapacitors versus balance of system costs to support higher current in constant power discharges.

It is clear that the payback analysis moves further in favor of ultracapacitors the more critical the application as batteries are replaced more frequently.

Additional Capabilities and Benefits

Ultracapacitors provide benefits in addition to basic lifetime and reliability concerns. Due to their high cycle capability, the ultracapacitors used in on-line UPS systems can be used for power quality improvement. In large installations (1MW and greater), energy storage may be used in multiple applications. New grid regulations are being added to provide significant payback for energy storage used as an on demand resource. While this must be balanced against its primary use as a UPS, it can be a source of more value.

Figure 2. Ultracapacitor modules easily fit into standard UPS battery racks.

Summary

Ultracapacitors have been used in the most demanding backup applications for many years. Their use in mainstream UPSs for improved reliability, system availability and total cost of ownership is clear. The operational benefits and total cost reduction far outweigh the initial cost advantage of lead-acid batteries.

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