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Extending Battery Life in Transportation and Mobile Applications with Supercapacitor Technology

With battery life rising in prominence as one of the most critical areas of system performance and reliability, the introduction of supercapacitors is helping to extend life of batteries in two major application areas. First, they can dramatically reduce battery replacement costs and improve reliability in vehicles such as trucks, cars, ships and motor generators. Second, they can extend the run time as much as 400 percent in mobile devices such as smartphones and tablets.

Supercapacitors, or supercaps, with their unlimited recharging capability and high energy density, provide automotive, heavy transportation, marine and traction applications with guaranteed engine starting over broad temperature range even when a battery fails.

In mobile electronic systems, supercaps provide the ability to regulate peak current over several different application usage scenarios. With better regulation of the discharge, the batteries are able to hold their peak capacity of energy longer and extend the run time of devices.

Examining the market needs of both application areas demonstrates that the benefits of adding super capacitors but in critically different ways.

Engine Starting

The most critical factor in the transportation sector is engine starting reliability. Every time a lead-acid battery is used to start an engine, it is one step closer to end-of-life. Using a bank of supercapacitors for ignition system relieves the battery from the harsh discharging of engine starts that typically diminish life span. A typical lead-acid battery can have its useful life extend by as much as 70 percent in certain applications through the use of supercaps. Additionally, starting an engine off a supercap enables greater reliability in colder temperatures.

In the case of the trucking industry, there are several factors where super capacitor usage could help improve daily operations. Typically, 18-wheel tractor trailer rigs and passenger buses carry three to four batteries. When one battery fails, and the vehicle requires a jump start, it can be relatively expensive at a cost of $600 per incident.

Additionally, battery replacement costs are about $200 each and because of this, market research shows that battery theft in both trucks and buses is a problem area. Furthermore, starting reliability for lead-acid cells drops precipitously in temperatures below -10° Fahrenheit. Supercaps, on the other hand can extend that range to -40°F, further improving engine start reliability where cold weather conditions prevail.

In the case of motor generators that are generally used at construction sites where grid power is unavailable, 60-to-80 percent of engine failure is due to bad batteries, according to market research conducted by Eaton. Battery theft is also a significant issue, research shows.

Locomotives must operate reliably and operate in all conditions to meet very demanding train schedules. Cold weather is one of the most prevalent operation conditions and super capacitors can enable engine starting at -40°, whereas lead-acid batteries aren't reliable below -10°F.

Engine starting for boats is critical because they operate in conditions where jump starts aren't readily available, and where environmental conditions such as storms or strong tides demand reliability. Additionally, other electrical systems on the boat for electronic equipment (fish finders and navigation) place a considerable load on lead-acid batteries when the engines aren't running.

In cars, emission regulations will drive automakers to install stop-start systems. It is forecasted that 40 to 70 percent of new vehicles by 2017 will have stop-start. Requiring a car's engine to automatically turn off after an idle period will require numerous more restarts that will strain lead-acid batteries and shorten their lifetime. Today, most vehicle manufacturers install a second battery to ensure reliability of stop-start systems.

Supercap Installation Methods

Super capacitors can provide benefits in all the situations above and they can be installed in one of three ways:

- Direct Parallel
- Supercap Starter
- Smart Start

The Direct Parallel approach installs a bank of super capacitors in between the battery and the engine's electrical system. It offers the simplest and least expensive way to have supercapacitors operate with existing batteries. A schematic diagram for this approach is offered below.

With the Direct Parallel approach above, the supercap extends battery life and it shares the high current loads of the system. But it offers no protection from house load drain, so a vehicle with the lights turned on after the engine is turned off may still fail to restart.

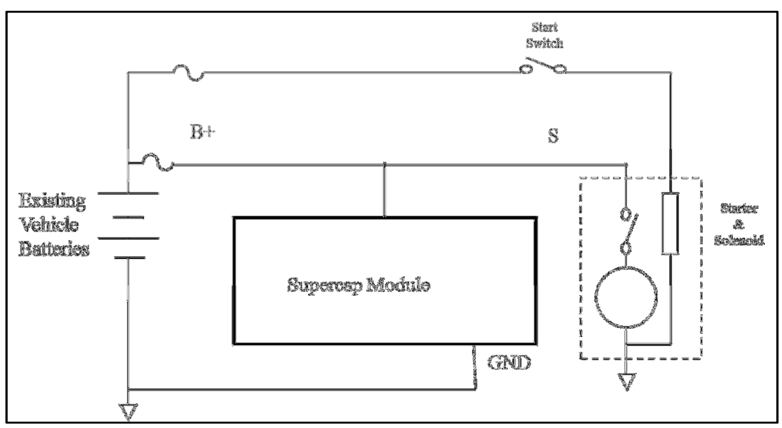

Figure 1. Schematic diagram shows the parallel installation of a bank of supercapacitors in a vehicle's electrical system.

Under a typical operating conditions, batteries have a lifespan of two to four years. Adding a super cap to the system extends the life of the battery significantly enough where it may seldom have to be replaced and engine-start reliability improves dramatically.

The Supercap Starter approach is designed to guarantee starting by making it less susceptible to house load drains. The supercaps are directly connected to the starter, and lead-acid batteries would only supply the other electricity needs in the car such as radios, lighting and air conditioning. The schematic in Figure 2 below provides a typical configuration for the Supercap Starter approach.

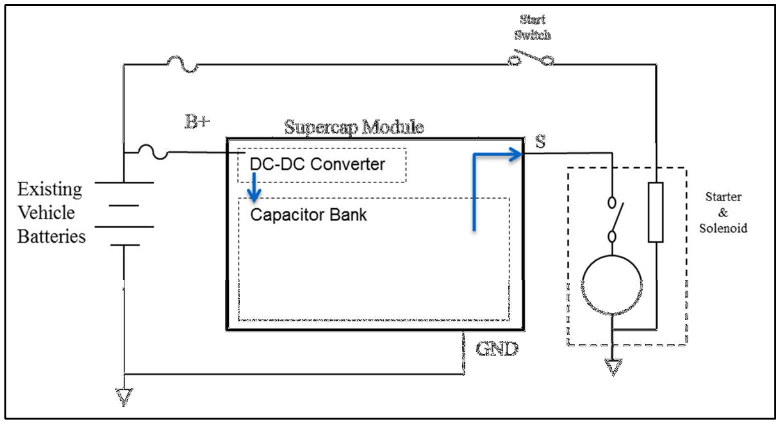

Figure 2: Schematic diagram shows supercapacitor installation in a vehicle's electrical system referred to as Smart Start. This method prevents the supercap from draining due to house loads and maintains engine-start reliability.

Heavy vehicles - such as busses, trucks, construction and mining equipment - can also take advantage of supercapacitor starting. These designs (Figure 3) utilize three terminals on the device, with one of the positive terminals connected only to the starter. The other positive terminal connects to the battery for recharging. This scenario offers to extend the longest battery life because it does not subject the lead-acid battery to the typical 1,000-2,000 amp discharges required for engine starts.

The Smart Start approach offers the flexibility to start an engine either off the battery or the supercap, or a combination of both. Because the starter receives a charge from the supercapacitor, it can operate at lower temperatures. Supercapacitors operate down to -40^{o}F. The Smart Start design is optimized for starting and system capability. A controller determines how much energy is pulled from the supercaps and it offers the longest battery life of the three installation schemes. Starting is also protected from house loads.

Figure 3. Heavy-duty supercapacitors feature two positive terminals, one for the engine starter and one for the battery. This prevents the battery from the constant wear and tear from typical engine start discharges.

Comparing Supercaps to Batteries

The chart (Table 1) compares supercapacitor specifications against battery specifications. Batteries in this chart represent a range of technologies, from the lowest performance lead-acid types to the higher performance Lithium-Ion.

Supercapacitors can dramatically extend the battery life for a range of vehicles and they operate over a broader temperature range. Vehicle electrical systems can be optimized for reliability, cost and flexibility to meet the most pressing needs of the application area, whether it's for 18-wheelers, boats, passenger vehicles or motor generators.

Table 1. A comparison of supercap technology versus battery technology demonstrates the differences between the two, especially in terms of cycle life and power density.

Key Characteristic	Units	Supercapacitor	Batteries
Voltage	V	2.5 – 5V	1.2 – 4.2
Cold Operating Temp	°C	**-40**	-20
Hot Temperature	°C	**+70 (85)**	-60
Cycle Life		**> 500,000**	300 – 10,000
Calendar Life	Years	**5-20**	0.5 – 5
Energy Density	Wh/L	1 – 10	**100 – 350**
Power Density	W/L	**1000 – 10,000**	100 – 3,000
Efficiency	%	**>98**	70 - 95
Charge Rate	C/x	**>1,500**	<40
Discharge Time		Sec / Minutes	**Hours**

Designers of these systems should choose supercapacitors that deliver a long life-span and high reliability. One key parameter to consider in supercapacitor design is ESR performance. For transportation needs, lower ESR and performance over time translates to greater reliability and lower cost in the long term. Also, carefully consider weight, cost and temperature performance.

Eaton offers a range of supercapacitor solutions for engine starting from the XB series and XV series cells to the XVM Module. They are designed to cover a range of applications in transportation applications and can be selected based on the electrical system requirements and battery types.

Supercaps Extend Run Time in Mobile Devices

In mobile devices, the issue of battery replacement is not as prominent as it is in transportation because users typically turn in their device every two years or so. What is important is the amount of time a battery can operate in between charges.

Without supercaps, cell phone and tablet batteries typically act like a shrinking tank of water. When these tanks are drained rapidly, they typically have less energy storage capacity. Over time, this diminishes the run time of the device.

Using a supercap in conjunction with a Lithium Ion battery in mobile applications provides better regulation of the peak current. In doing so, peak current drain is better controlled and the energy capacity of the battery is preserved over a longer period of time.

There basically three configurations for using supercaps in a mobile application:

- Parallel (similar to vehicle)
- Separated
- Smart

Connected in-line with the battery, the parallel setup features low-cost and simplicity. By separating the supercap from the battery, devices will have the longer battery life but it depends upon the application types. Each of the configurations deliver:

- Longer device run-time on one charge
- Smaller/thinner devices
- Lower cost energy storage
- Longer battery life
- Reduction of high repeated charge/discharge currents

Testing of typical use case on a mobile device-- consumed 6W 40 seconds 40W 10 second-cycle—reveals the advantage of combining supercaps with a battery. The battery was drained of its energy in 0.4 hours but when a supercap was added, the system run time was improved to 2.12 hours, marking a 400 percent increase by limiting the battery discharge to a 1C rate.

The bottom line is that supercapacitors provide improved battery performance in mobile devices in compelling ways:

- Effectiveness of adding supercapacitors to a Li-Ion battery has been shown for multiple power profiles.
- Duty cycle and peak-to-baseline power profile are critical to the value of adding supercapacitors.
- Supercapacitors offer a cost effective and volume effective way to significantly extend run time.
- Supercapacitors are a long life, high power device capable of repeated high current charge/discharge.

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