Everything You Wanted To Know About Energy Storage But Were Afraid To Ask

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ABSTRACT

With today's environmental thinking Transit industry needs to step up and begin to save energy. Using energy storage technology is one way to advance this idea. There are some opinions that up to 50% of the energy presently consumed by electric traction systems can be recovered. There are several options for energy storage available. This paper will explore the myths and realities behind the different technologies. We'll investigate the cost and function, operational histories, and successes and failures. We will pose the questions that are being asked and then attempt to answer them. We will explore the various systems available and present a menu of what there is, how they work, what they cost, who is making them and where they could be most effective.

WHAT ARE THE CHOICES?

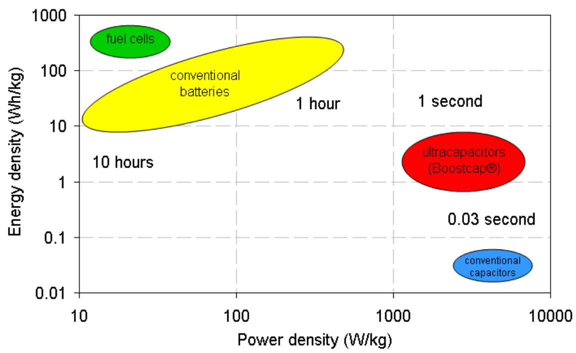
Energy storage devices are presently available in three different classifications, Chemical (battery), Static (capacitor) and Kinetic (flywheel). The chemical or battery type is further segregated by type. The more commonly known types are Lead Acid, NiCad (Nickel Cadmium), NiMH (Nickel Metal Hydride), NiZN (Nickel Zinc) and Li-ion (Lithium Ion). The Static is a capacitor called Electric double-layer capacitors and are also known as supercapacitors, pseudocapacitors, electrochemical double layer capacitors (EDLCs) or ultracapacitors. Conventional capacitors are not feasible as they are typically in the order of a thousandth the capacity of these super capacitors. Rotational devices are basically high energy flywheels that rotate at extremely high angular velocity (revolutions per minute).

HOW DO THEY WORK?

Batteries are chemical devices that use electrochemical reactions. The types being considered are electrically reversible and rechargeable for a limited number of times and for a limited number of years. The various types also have varying charging and discharging rates. Overall capacity can be created by using several cells in a series and parallel configuration to create the required voltage and the current capacity. Capacitors are static charge devices made up of metallic plates with a dielectric material between them. They store charge on the plates. The total energy stored is proportional to both the amount of charge stored and the potential (voltage) between the plates. The amount of charge stored is a function of the size and the material used for the plates. The materials used for the dielectric can be varied to develop the needed voltage storage. Capacitors can be charged rapidly and will also discharge rapidly. Flywheels store kinetic energy. While charging they operate as motors that speed up to thousands of RPM. They typically have very low friction bearings and composite rotors that operate in a vacuum so that they can maintain their speed for long periods without additional energy. They convert to generators when the discharge their energy. The time interval between the charging and the discharging is crucial to their efficiency.

IS ONE BETTER THAN ANOTHER?

The Ragone chart is a bubble chart used to compare energy storage devices through representation of energy density and power density characteristics. Values of energy density are plotted versus power density. Both axes are logarithmic to accommodate the large performance variation between device types. Conceptually, the vertical axis indicates available energy and the horizontal axis indicates how long the energy will last. Energy density is measured in Watt-hours or kilojoules per kilogram. Power density is measured in Watts per kilogram. A high performance device that can store lots of energy while charging and discharging rapidly would be the optimal device appearing in the upper right corner of a Ragone chart.



Ragone chart showing energy density vs. power density for various energy-storing devices. (Source Maxwell Technologies)

Batteries provide very large storage capacity that can provide energy for a longer time than either capacitors or flywheels. They have very high energy density but not a very high power density. The physical size of the various batteries varies from very large and heavy for the lead acid and much more compact for the Li-ion. The other battery types typically fall in between. Batteries should be able to also provide some degree of backup power in the event of a power failure. Batteries take a longer time to recharge but on the other hand they can be discharged over about the same time if the current draw is not excessive. However they cannot survive long and age rapidly if discharged to zero. Batteries must use a limited maximum charging current to extend their lifetime. They are very temperature sensitive as heat has an adverse effect on their lifetime. As they are basically a chemical reaction cold temperatures may cause them to limit their ability to discharge their stored energy.

Electro-chemical Capacitors with trade names such as super-capacitors or ultra-capacitors would probably require more physical space as energy density equivalent batteries because of their lower energy density that is about 1/10th of a battery. However their power density can be as much as 10 times that of a battery. Energy density has an effect on physical size and for the amount of kilowatts that may be required for wayside storage size will be an issue. Capacitors have a virtually unlimited life cycle as they can be cycled millions of times. They can be discharged completely with no loss of life.

Flywheel systems have a design life of 20 plus years which is substantially longer than either batteries or capacitors. Their charge and discharge rates are similar to capacitors. They require standby power to keep the flywheel rotating. Since the energy is stored in a high speed device, it must be anchored well. The bearing is kept in a vacuum atmosphere to eliminate windage, while magnetic or fluids are used to suspend the rotating mass. Flywheels systems require less floor space than an equivalent capacity battery or capacitor system by about 4 to 1. They also require a solid base to be anchored to because of the gyroscopic effect of the thousands of RPM, especially during discharge, that tend to drift it across the floor.

WHAT ARE THE PROS AND CONS OF EACH?

Batteries

PROs: Given the high energy density and a properly rated device can provide power for hours, at low cost (lead acid).

CONs: Charging can take hours, heavy, temperature sensitive, limited lifetime (4-7 years); power discharge must be controlled to maintain life

Capacitors

PROs: Long Life (10-12 years), high charge and discharge rates, low internal resistance, and no corrosive electrolyte, can charge is seconds.

CONS: Low energy density, complex controller to maintain effective storage and recovery of energy, overcharging can overheat and damage cells; cells are low in voltage requiring serial connections for traction power system voltages, moderate self discharge.

Flywheel

PROs: Not temperature sensitive, good energy density, good power density, small foot print, longest life (over 20 years), millions of full discharge cycles, fast charge (full charge in seconds).

CONs: Needs special mounting, requires a constant power source (UPS) to keep spinning (similar to battery trickle charge), “flywheel separation” is possible if the tensile strength of the wheel is exceeded and it may shatter or in some assemblies that use composite material become unwound fibers, requiring anchoring for safety containment, requires a vacuum to be maintained for frictionless environment (Could operate with magnetic bearings but would still have drag from air).

CAN THEY WORK TOGETHER?

Batteries could be a good companion to either the flywheel or the super capacitor. They could be connected in parallel to take over after the short time flywheel or capacitors have been drained. Batteries could be a good companion to either the flywheel or the super capacitor. They could be connected in parallel to take over after the short time flywheel or capacitors have been drained. The Pairing of a flywheel with a capacitor does not appear to provide any service enhancement since they have similar operating parameters.

WHO IS USING ANY OF THEM NOW?

There is a wayside energy storage substation in operation in Sacramento, CA by Sacramento Regional Transit District in operation since 2009 that uses batteries and will soon include capacitors to address voltage sag problems.

There is a 2.5 MW flywheel substation under construction for the Long Island Railroad at its Deer Park substation to address voltage sag, another unit for long-term energy storage using a battery to optimize rate charging, and New York City Transit is experimenting with battery system to capture regenerative braking Super capacitors are in service in Europe and China. LA Metro has plans to install a Flywheel system on their subway within a year and is also considering Super Capacitors for the Goldline. WMATA in Washington, DC are studying variations of energy storage technologies.

WHERE DO WE GO FROM HERE?

Collect data from the presently planned installations and those that are operating successfully and those that may need some updating. The IEEE has two working groups that are presently preparing energy storage standards. The IEEE has a standards working group WG_P1809/1809 developing a “Guide for Electric-Sourced Transportation Infrastructure.”

Also IEEE WG 1679 is working on a recommended practice “WG_1679 Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications.” The APTA Chief Engineer, Martin P. Schroeder, P.E., has established a research committee that will lead the effort to progress the development of economical and efficient energy storage concepts and standards.

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