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Ultracapacitors Provide Cost and Energy Savings for Public Transportation Applications

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Mass transit systems are facing increasing demands to provide efficient, cost-effective public transportation, due in part to a steadily increasing population. For buses, there are also issues of energy efficiency, and demands to improve fuel economy and reduce harmful emissions

As energy costs represent the most important part of the operating budget for many public transportations systems, typically amounting to $30,000 to $200,000 per year depending on the vehicle type, there is a constant pressure to save cost by improving the energy efficiency of the systems. There is also a need for energy resources to be used optimally for environmental protection and conservation.

This article looks at how the ultracapacitor, an advanced energy storage component, can help to achieve energy savings of up to 30 percent in public transportation. We will illustrate the benefits using two main examples, the SITRAS SES system from Siemens Transportation Systems for public transportation and hybrid buses from ISE Corp.

What is an Ultracapacitor?

Electrochemical double layer capacitors (EDLCs) are also known as supercapacitors or ultracapacitors. An ultracapacitor stores energy electrostatically by polarizing an electrolytic solution. Though it is an electrochemical device there are no chemical reactions involved in its energy storage mechanism. This mechanism is highly reversible, allowing the ultracapacitor to be charged and discharged up to a million times or more.

An ultracapacitor can be viewed as two non-reactive porous plates suspended within an electrolyte with an applied voltage across the plates. The applied potential on the positive plate attracts the negative ions in the electrolyte, while the potential on the negative plate attracts the positive ions. This effectively creates two layers of capacitive storage, one where the charges are separated at the positive plate, and another at the negative plate.

The capacitance depends directly on the size of the plates, and in conventional capacitors it normally lies in the range of several microfarads. Ultracapacitors, by contrast, can achieve capacitances of several thousand farads. Ultracapacitors are also able to deliver high power over short periods, which is another attractive feature for transportation applications.

An ultracapacitor derives its area from a porous carbon-based electrode material. The porous structure of this material allows its surface area to approach 2,000 square meters per gram, much greater than conventional capacitors. An ultracapacitor's charge separation distance is determined by the size of the ions in the electrolyte, which are attracted to the charged electrode. This charge separation (less than 10 angstroms) is much smaller than can be accomplished using conventional dielectric materials.

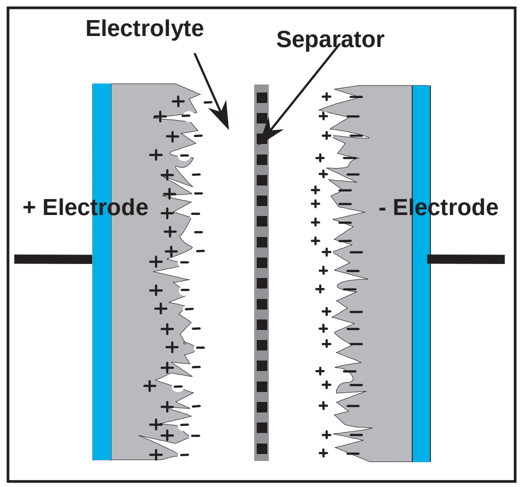

Figure 1. Ultracapacitor Charge Separation

The combination of enormous surface area and extremely small charge separation gives the ultracapacitor its outstanding capacitance relative to conventional capacitors.

Ultracapacitor Energy Storage in Practice - The SITRAS SES System

The local transport authorities of several cities such as Cologne and Madrid are now using an innovative energy storage system that is also designed to recover braking energy. This system is called SITRAS SES, and it was developed by the engineers of Siemens Transportation Systems. It allows system operators to achieve energy savings of up to thirty percent. SITRAS SES also makes a decisive contribution to stabilizing the voltage on the network, which enhances the reliability of mass transit systems by avoiding sudden power outages when several trains or trams draw power at the same instant and drag the voltage down. Another example that has shown similar benefits using Maxwell's ultracapacitors is the MITRAC system from Bombardier Transportation.

Underground trains that feed braking energy back into the electricity supply system first entered regular service around twenty years ago. When such a train brakes, its electric motor acts as a generator and feeds the regenerated energy back into the supply lines. However, this excess energy can only be used if there is an increased energy demand at the same time somewhere else in the network, which can for instance arise from a train just starting off. However, this is relatively rare. Otherwise, only approximately sixty percent of the regenerated energy can be used in normal operation. The remainder is dissipated as heat in the braking resistors of the vehicles, without being put to good use.

Around six years ago, the engineers at Siemens started thinking about an energy storage system that could absorb braking energy and release it later on to trains that are starting to move. Simulations and practical tests in various cities showed that using a suitable energy storage system operationally for around 22 hours per day could reduce the annual primary energy demand by as much as 500,000 kilowatt-hours. That corresponds to a reduction of CO2 emission of 300 tons.

Besides batteries, flywheels and capacitors, the types of devices that could be used for energy storage include exotic solutions such as superconductive motors. However, such motors are presently still too expensive for practical use. First the engineers decided to use flywheel storage systems. However, after the first extended service tests, it was clear that they were not suitable for long-term use, due to their complex maintenance. Batteries are also less suitable due to their low peak power capacity, and their limited lifetime. The engineers, therefore, then concentrated on developing capacitor energy storage systems.

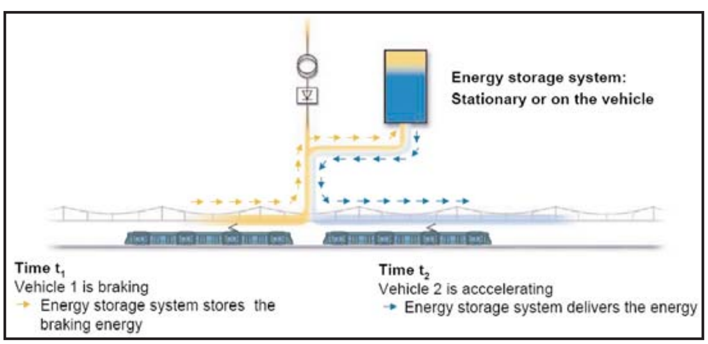

Figure 2. Energy Saving Operation

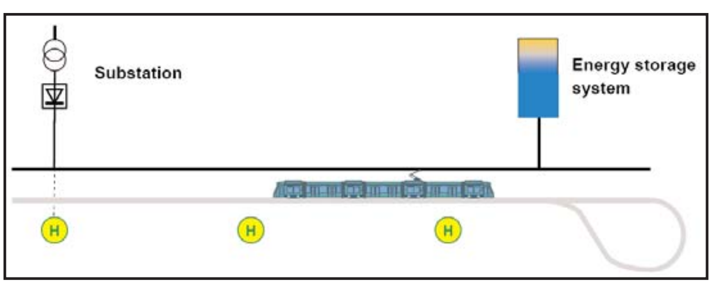

Figure 3. Voltage Stabilization Operation

Large Surface Area in an Extremely Confined Space

The 1344 Maxwell ultracapacitors used in the SITRAS SES system are operated at a voltage of 2.3 volts. Each of the BOOSTCAP capacitors has a capacitance of 2,600 farads with a size of a small soda can. The system provides a peak power capacity of one megawatt, and operates at an efficiency of 95 percent.

For practical use in an energy storage system, the ultracapacitors must be charged and discharged extremely uniformly in order to maintain their rated voltage as exactly as possible. Consequently, all of the capacitors are symmetrically charged during the nightly operational break, which means they are all brought to a well-defined, uniform charge level.

The system, which includes a connection unit, a voltage converter and control electronics in addition to the capacitors, is housed in two rows of cabinets, each of which is 3 meters long and 2.7 meters high. While ultracapacitors located on a vehicle could also be used to recapture braking energy, Siemens' engineers decided to utilize stationary, trackside storage systems.

The ultracapacitors can be recharged rapidly by braking vehicles or slowly through the DC network. A SITRAS SES unit can absorb the braking energy released by all stopping trains within a radius of up to three kilometers.

If one or more trains start at the same time, the SITRAS SES system rapidly releases energy, and thus ensures that the network voltage never drops below the critical level.

Results and Applications of the SITRAS SES System

Several operators of local transport networks have already recognized the benefits of the SITRAS SES system. Siemens delivered the first energy storage system using ultracapacitors to the Kölner Verkehrsbetriebe AG in Cologne in February 2001, and in 2003 the first regular production model of the SITRAS SES system also went to Cologne. In the meantime several installations are in operation, for example two systems have been installed in Madrid and in full-time service since July 2003.

Besides Europe, several cities in the US have expressed interest in the system. A demonstration system in the US located in Portland, Oregon, has been successfully operating since 2002.

The results have been excellent. For a typical installation, each SITRAS SES system can achieve savings of 320 MWh per year. Based on an approximate energy cost of $100 per MWh, this means cost savings of $32,000 per station. On a network with 400 stations, this would work out as 128,000 MWh saved per year, or a cost saving of $12.8 million annually.

Looking at voltage stabilization, the system has also been successful. In one implementation, it has meant that the network voltage has never dropped below the critical level of 490 V, while between 490 and 520 V the SITRAS system stabilizes the voltage (see Figure 4).

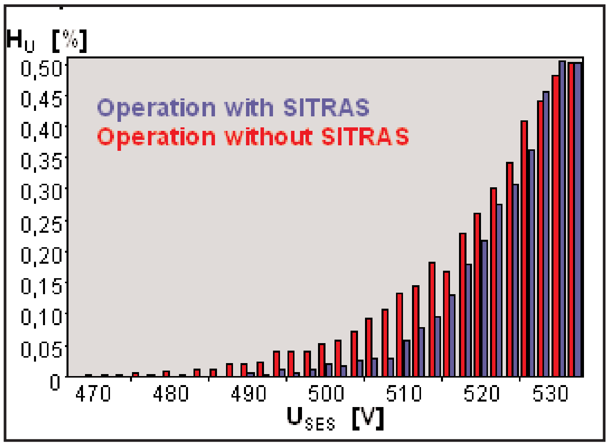

Figure 4. Improvement in Voltage Stabilization Due to SITRAS System

Ultracapacitors for Regenerative Braking in Buses

As well as rail transportation, ultracapacitors are finding applications in hybrid buses, where they improve fuel economy and reduce harmful emissions. One company that is developing such buses is ISE Corp. in the USA.

ISE specializes in production of "series" hybrid-electric drive systems, where the engine is not coupled to the driveline and is used only to generate electrical power. This type of hybrid architecture is especially attractive for large vehicles in stop-and-go driving, such as urban transit buses and delivery trucks. Conventional buses and trucks of this type use huge amounts of fuel and produce high levels of toxic emissions because they have large (typically diesel) engines that are constantly ramping up and down, the least efficient way to operate a power source.

In the ISE series hybrid system, engine efficiency is increased with the use of a smaller engine mated to a generator and operated at constant, efficient rpms and power output levels. When vehicle power requirements temporarily increase, such as during acceleration or hill climbing, additional power is drawn from an onboard energy storage system comprised of batteries and/or ultracapacitors. During deceleration, regenerative braking recaptures energy while slowing down the vehicle and recharging the energy storage system. At other times when vehicle power requirements are low, the generator can recharge the energy storage system.

In hybrid applications, batteries create many design challenges for automotive engineers. Firstly, batteries need a temperature management system to function well in extreme hot and cold weather. Secondly, batteries require charge equalization management to prevent premature cell failure. Thirdly, batteries have limited cycle life under deep discharge conditions, which can result in high-cost replacement throughout the life of the vehicle.

Perhaps most importantly, batteries are inefficient in quickly capturing energy, and providing bursts of high power during short duration events, such as acceleration and braking. This high power limitation reduces the efficiency of the hybrid electric drive system design. Because city buses spend much of the time either braking or accelerating, the ability to capture and regenerate braking energy is vital.

ISE turned to Maxwell Technologies to assist in the development of ultracapacitor solutions, which are used in ISE's Thunderpack II ultracapacitor packs.

Ultracapacitors have a number of advantages over batteries in this application:

• They perform well in cold weather, down to -40°C
• They are safe, as a pack is easily discharged overnight or for immediate maintenance.
• They have a long life cycle, which saves cost.
• They are 85 to 95 percent efficient, compared to 70 percent or lower for batteries in similar applications (as measured by ISE).
• They are environmentally friendly, as they are 70 percent recyclable and do not include heavy metals.

Since successful testing in 2003, ISE has incorporated ultracapacitors into its gasoline, diesel and fuel-cell hybrid electric vehicles with extraordinary results. The clean running, quiet, low maintenance vehicles are operating in a number of US urban areas including Long Beach, Palm Springs, Oakland, Gardena, Elk Grove, San Bernardino, Montebello, and New Jersey. There are over 100 buses in revenue service with an expected demand to double that number during the next year. As of early 2006, ISE estimates that the ultracapacitor powered bus fleets have put in over 1.5 million miles of clean, reliable service.

Other Public Transport Applications For Ultracapacitors

As well as the regenerative braking applications described above, ultracapacitors have other applications in public transport, including:

• **Diesel Engine Starting** - Ultracap modules are used to start huge diesel engines of locomotives and diesel electric trains. The modules are able to supply the needed power in a volume and weight strongly reduced compared to battery systems. Further advantages are the robust construction, the wide temperature range, the high reliability and no maintenance. This has been proven with systems from Stadler in Switzerland and Nedtrain in the Netherlands.
• **Door Actuator** - Medium size ultracapacitors are used to ensure a reliable functioning of electrical doors.
• **Tilting Trains** - Ultracapacitors are ideally suited to furnish the power needed to activate the tilting system of advanced tilting trains.

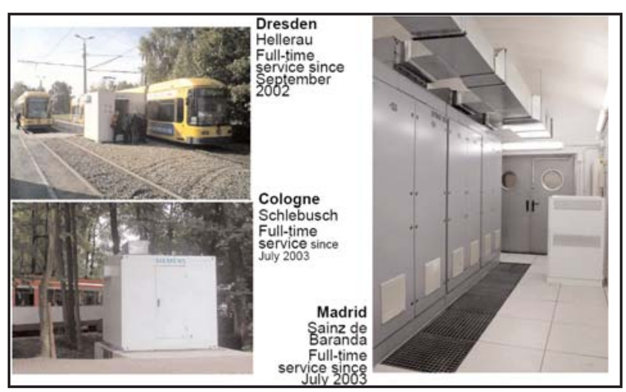

Figure 5. SITRAS SES Installation Examples

• **Support of Switch Drives** - Ultracapacitors cover the peak power demands and support of switch drives in case of a power outage in the seconds range.
• **Security Applications** - On-vehicle and stationary applications that require power bursts for several seconds. On-vehicle applications are GPS systems, signal horns etc. Stationary applications are automatic acoustic and optical warning units.

Conclusion

With up to 95 percent efficiency, an ultracapacitor-based energy storage system can effectively capture and release the braking energy in a transportation network and in hybrid buses. The concept has been reliably proved in several implementations over a period of years, with the maintenance-free ultracapacitors giving a 10-year lifetime.

The SITRAS SES system has delivered energy savings of up to 30 percent and reduced the peak power required from the network by 50 percent, leading to typical cost savings estimated in millions of Euros, while improving network stability. Similarly, ISE's hybrid buses are delivering large savings in energy and cost.

Mr. Maher heads up all sales & marketing activities and initiatives, as well as application engineering, for the Boostcap product for the entire North American market. He has been with Maxwell for over eight years, beginning his career with the company in the Product Development division working on developing advanced ultracapacitors systems and modules. Mr. Maher has an MBA, and also holds a Bachelor of Science in Electrical Engineering from University of California, San Diego.

For more information please visit www.maxwell.com.