High Power Storage Technologies for Distributed Generation

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Introduction

Industry experts are predicting large-scale implementation of distributed generation (DG) in coming years, in a trend that has been likened to the move from centralized mainframes to personal computers. This trend will be facilitated by a parallel implementation of distributed intelligence and distributed storage. This paper discusses the multiple roles that electricity storage can play in supporting DG and covers some of the most promising technologies.

Whether supporting residential fuel cell generators or microturbines, electricity storage devices are expected to exhibit certain common characteristics. They will be relatively small, highly modular, and will be capable of discharging or charging a large percentage of their stored energy in just seconds or a few minutes. Such high power capabilities involve serious compromises in today's batteries, so the best solutions to these requirements are likely to come from technologies that are still under development. These technologies include supercapacitors and high power lithium ion batteries.

As developed by Saft, these devices share certain design elements and are assembled on the same production lines. Their characteristics for DG applications are explained, along with the fundamental differences in their operating principles.

Battery Technologies

Most battery technologies can be designed for high power discharges. However, this generally involves compromises in terms of operating life, cost or some other factor. The following table shows the advantages and disadvantages of the main battery types that are considered for electricity storage applications.

Table 1: Battery comparison for high power requirements

Technology	Advantages	Disadvantages
Lead-acid	Low initial cost High power capability	Large and heavy High power versions have shorter lives
Nickel-cadmium	Long life, regardless of power capability	Relatively large High initial cost
Nickel-metal hydride	Better energy and power density	High power versions have shorter lives Initial cost?
Lithium ion	Very high energy density High power versions with same life	Initial cost?
Flow batteries	Long life and high cycling capability	Not optimized for high power
High-temperature batteries	Economical? High energy density	Not optimized for high power

The newer technologies listed above are not yet in high volume production. As with most products, their pricing is expected to be quite volume-sensitive and it will be some years before their true cost is fully realized.

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Lithium Ion

Lithium ion electrochemistry is unlike any of the conventional battery chemistries with which users are familiar.

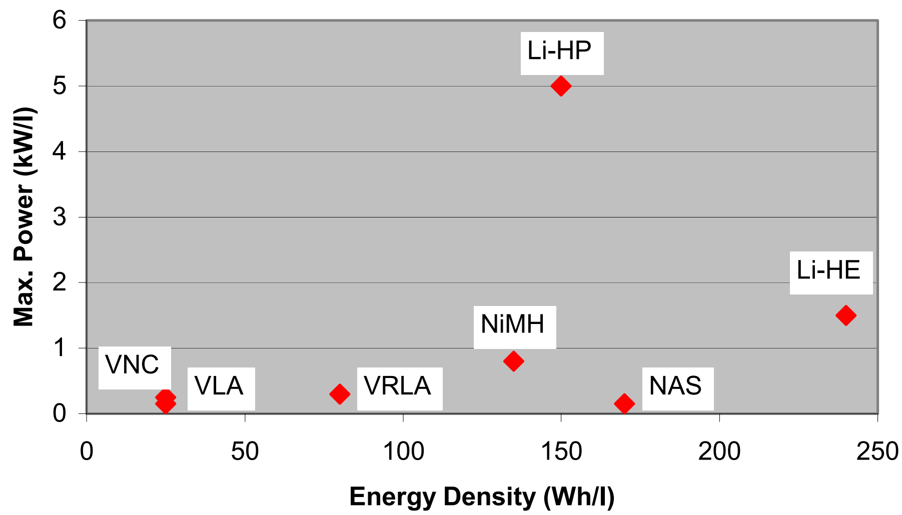

Figure 1 - Energy density vs. power density

Most batteries, such as lead-acid, nickel-cadmium, nickel-metal hydride and also the new flow battery technologies are based on water, using aqueous solutions for their electrolytes. Water is cheap, abundant and provides a conductive medium for ionic flows. Unfortunately, water also limits the voltage for electrochemical systems, since it will break down into hydrogen and oxygen above about 2 volts. The same dissociation is a side reaction that limits the energy efficiency of aqueous batteries, leads to heating effects in recombinant systems and allows grid corrosion in lead-acid batteries.

Using organic electrolytes, lithium ion cells can achieve voltages as high as 4 volts, with resulting high energy and power density, and better than 95% energy efficiency. Coupled with very high charge-discharge cycling capability and projected long lives in electricity storage applications, lithium ion batteries will be a major player in the stationary battery market.

Figure 1 shows a chart of typical energy density vs. power density for various battery types, clearly demonstrating the superior attributes of lithium ion in this regard. In the chart, VLA refers to vented lead-acid; VNC is vented nickel-cadmium; VRLA is valve-regulated lead-acid; NiMH is nickel-metal hydride; NAS is sodium sulfur (a high temperature battery); and Li-HE and Li-HP are the high-energy and high-power versions of lithium ion, respectively. Where applicable, longer-life versions of each technology have been used for the comparison.

Supercapacitors – Moving from Electrochemical to Electrostatic

The term 'supercapacitor' (synonymous with 'ultracapacitor') covers a wide variety of technologies. There are aqueous and non-aqueous systems, with symmetrical and asymmetrical electrode arrangements. Symmetrical technologies typically use high surface area carbon materials for both electrodes, while asymmetrical systems often incorporate a transition metal oxide electrode.

Supercapacitors are a cross between batteries and capacitors. While they have much in common with accumulators in their construction, true supercapacitors are like capacitors in that their operation is based on electrostatic interactions, rather than electrochemical. These interactions are highly reversible, so supercapacitors can accept charge as fast as they can be discharged and can be cycled millions of times. The symmetrical devices typically have very high power density (5 kW/kg is not uncommon), but very low energy density. Some asymmetrical supercapacitors introduce a measure of electrochemical activity as a means for increasing the stored energy, but the resulting energy density does not approach that of batteries.

Considering the technical maturity, the manufacturing processes, the expected performance and costs, activated carbon based supercapacitors are the most interesting and promising devices for industrial applications. This is the approach taken in the design of Saft's own range of supercapacitors, manufactured in a new facility in Bordeaux, France (see table 2 for typical specification).

Table 2 Supercapacitor Specification

Rated Capacitance	3500 F
Nominal voltage Maximum voltage Minimum voltage	2.5 Volts 2.7 Volts 0 Volts (1.0 Volts for practical purposes)
Resistance HFR ESR	< 0.5 mΩ (1 kHz or 2s pulse) < 1 mΩ (0.01 Hz)
Dimensions (diameter * height)	55 * 220 mm
Volume	0.5 l
Weight	0.65 kg
Maximum Current	1000 A (750 A repetitive)
Maximum specific power	3225 W/kg at 500 A
Operating temperature range	-40 °C to +60 °C
Transport and storage temperature	-40 °C to +70 °C

There is considerable synergy between this type of supercapacitor and lithium ion batteries. Manufacture of the Saft supercapacitors draws upon many of the production techniques already developed for lithium ion, including the use of electrodes manufactured using carbon powder and a classical ink coating process in a spiral wound configuration and housed in an aluminum container.

One of the interesting properties of electrostatic interactions is that they are largely independent of temperature. Using a highly conductive organic electrolyte, the performance of this design remains completely unaffected over a very wide range of temperatures from +70°C down to –20°C. Below this temperature the conductivity of the organic electrolyte will start to limit the performance of the supercapacitor, but even at –40°C half the power is still available. This is shown in figure 2.

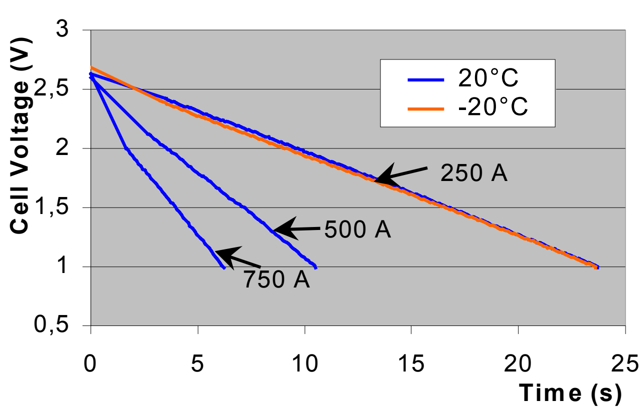

Figure 2 - Supercapacitor performance curves

Choosing a Technology

The final choice for a storage technology to support a particular DG application will frequently depend on the specific requirements for power and energy. Where storage is required simply as a buffer to compensate for the response time of the generator, or to supply load spikes that are above the generator's capability, the main requirement is for high power and low energy. Supercapacitors are likely to be a logical choice in this case.

Where there exists a need to provide additional blocks of energy, perhaps for black starting, for longer peak loads, or for bridging power while the generator is started, the application will still require high power but with more energy than a supercapacitor can provide. In this case there are two solutions from among the technologies described here. The first is a combination of supercapacitors to provide the power requirement with a conventional battery for the energy needs. The second is a battery-only solution.

If initial cost is the single most important factor, automotive lead-acid batteries are the obvious choice. But if long life and reliability are important selection factors, lithium ion is clearly the most promising technical option. Although its long-term cost will not rank it among the lowest-priced technologies in energy terms, the high power versions of lithium ion look set to be able to provide very competitive costs per kW in terms of life cycle cost. This has led to the choice of high-power lithium ion technology for a demonstration system that is soon to be placed in the field.

Demonstration System

Under a US Department of Energy contract administered by Sandia National Laboratories, Saft is producing a demonstration system, to be installed in the second or third quarter of 2002. This system comprises a high power lithium ion battery with a 100kW SatCon power conditioning system (PCS). Although the system can function as a standalone UPS device, it has also been designed to operate in conjunction with a 60kW microturbine. The microturbine is configured for current source grid-connected operation. The PCS will enable a seamless transition to 'island' operation by isolating the load from the line and providing voltage source standalone operation. The system will also support connected loads for sufficient time to allow for turbine startup or, if the turbine is already in operation, absorb excess power from the turbine until its output ramps down to the current set point determined by the PCS for load power management.

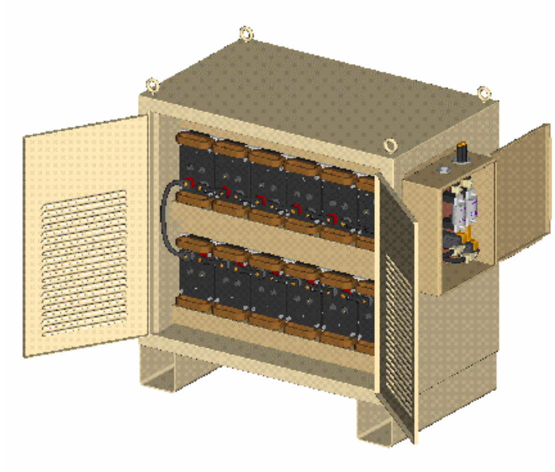

Figure 3 - Battery assembly

Figure 3 shows the modular design of the battery, with 11 battery modules and one (1) Battery Management System (BMS) module. Each module contains 12 series-connected Li-Ion HP30 cells plus module-level control electronics. Figure 4 shows a one-line diagram of the overall system.

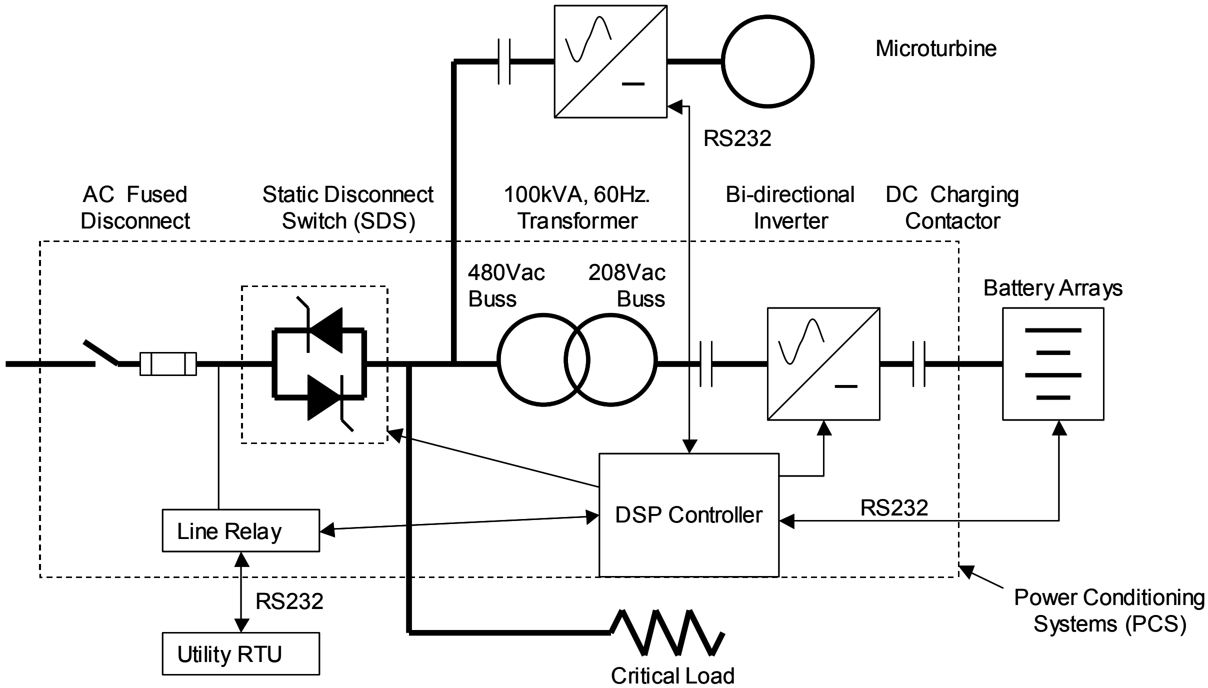

Figure 4 - One-line diagram of 100 kW system

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