WHITE PAPER

HIGH RELIABILITY POWER BACKUP WITH ADVANCED ENERGY STORAGE

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For mission-critical applications that require uninterrupted power, for example in industry or hospitals, it's essential that the right standby power generation equipment is in place. With power grids having more and more demands placed on them, the continuity of mains supply can never be guaranteed.

Designing or selecting an uninterruptible power supply (UPS) can be tricky. Companies need to balance how important it really is for the UPS system to do its job – is it absolutely mission-critical, for example for a large investment firm or a telecoms basestation? Or could the company cope with occasional short outages, and the role of the UPS is to improve uptime in a cost-effective way? For many organizations, the UPS's most important function is to protect equipment from damage in the event of a mains interruption, and to shut down in an orderly fashion

1 BRIDGE POWER

Standby power generation equipment, for example diesel generators or gas micro-turbines, takes a short but important period of time to come online and provide consistent power. This is typically in the region of 30-60 seconds, so a secondary power source is required to provide short-term "bridge" power until the main backup starts up.

In fact, the statistics for mains power failure show that almost all disturbances are short. 99% of all mains interruptions are shorter than 3 seconds, and more than 90% are less than one second. A graph of typical mains disturbances is shown in Figure 1.

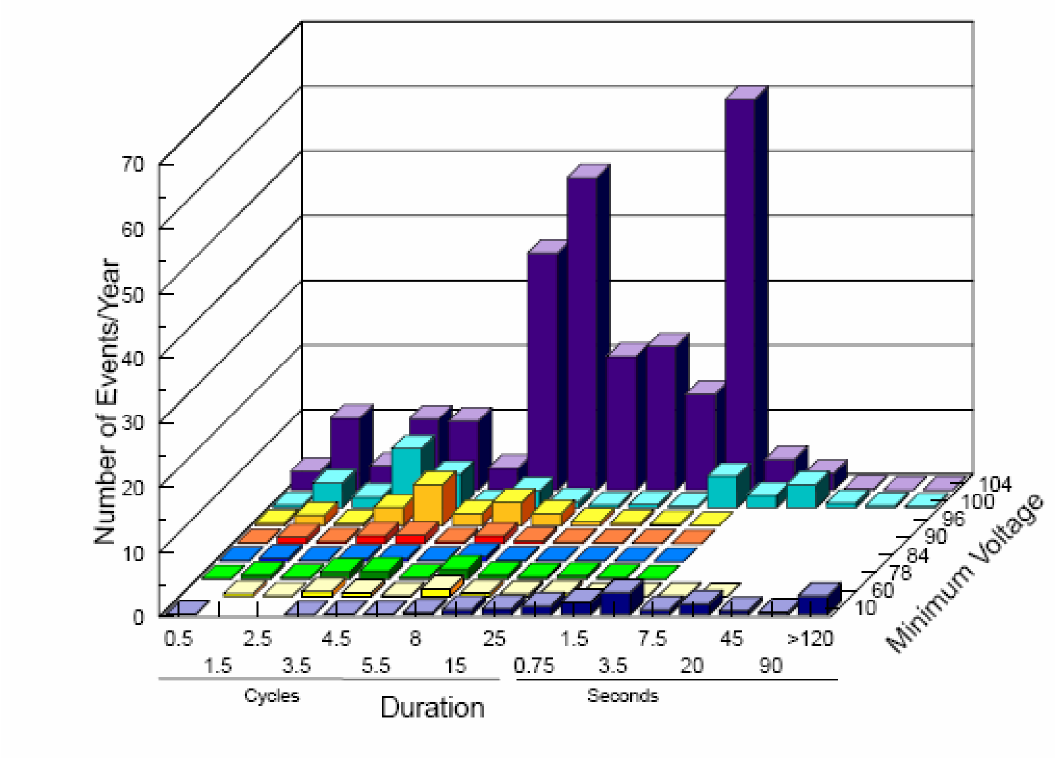

Figure 1: Power quality date: all sag/interruption events

2 BRIDGE POWER TECHNOLOGIES COMPARED

In the past, the chosen short-term backup power solution has usually been batteries. These have predominately been lead acid, but today engineers have more options, including advanced Li-ion and NiMH battery technologies. Another solution is to use flywheels, but these are bulky and expensive, and also have reliability problems.

While these new battery technologies have made great advances and have been designed in to many solutions, they still present the same basic problem as lead acid batteries. They are based on a chemical reaction, which means that they suffer from a limited life, and can only operate in a limited temperature range. High current demands will also

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restrict their operating lifetime. For long-lasting, reliable applications this means there is a higher maintenance cost, and concerns about reliability.

An alternative solution is the ultracapacitor, an energy storage device that is well-suited for short-term power delivery such as bridge power. Also known as supercapacitors or Electrochemical Double Layer Capacitors (ELDC), they are not a new component, but the technology has advanced dramatically in the last 10-15 years.

The beneficial characteristics of ultracapacitors are made possible by their composition and construction. Their activated carbon electrode has a specific surface area of 2000m^2/g with a charge separation of 10 Angstrom or less, giving them a very high capacitance and thus power density. The energy storage mechanism is highly reversible, with no chemical bonds being made or broken, leading to a cycle life of over 1 million cycles with minimal degradation. Wide operating temperatures between –40degC and +65degC, or even higher for short durations, are possible due to the high conductivity, low freezing point electrolyte.

With the maturation of the ultracapacitor industry, ultracapacitors are highly competitive with, and in many cases superior to, older bridge technologies. They offer the functionality, life cycle costs, and reliability necessary to make mission-critical power backup systems successful. Since the ultracapacitor is used strictly as a bridge, its high power density is well suited to supply high power for short periods of 30-100 seconds. A battery is more typically sized to deliver power over longer periods, making them larger than necessary. If a battery is sized for the actual duration required, it may have difficulty supplying the necessary power.

One key challenge with batteries is the difficulty in measuring their state of charge. The charge of an ultracapacitor, however, is measured solely by its voltage. Additionally, since ultracapacitors operate on a different principle than batteries, the ultracapacitor is capable of sitting on a charge voltage for extended periods without any loss of capacity, unlike a battery.

Furthermore, cycle depth isn't an issue, so ultracapacitors can be micro-cycled (cycled less than 5% of their total energy) or full-cycled (cycled greater than 80% of their total energy) with the same long life.

Ultracapacitors are inherently reliable because of their composition and construction. There are no mechanical moving parts as in a flywheel, eliminating all maintenance.

Combined with the wide temperature range, long life, and flexible voltage range, ultracapacitors provide an extremely reliable solution for bridge power.

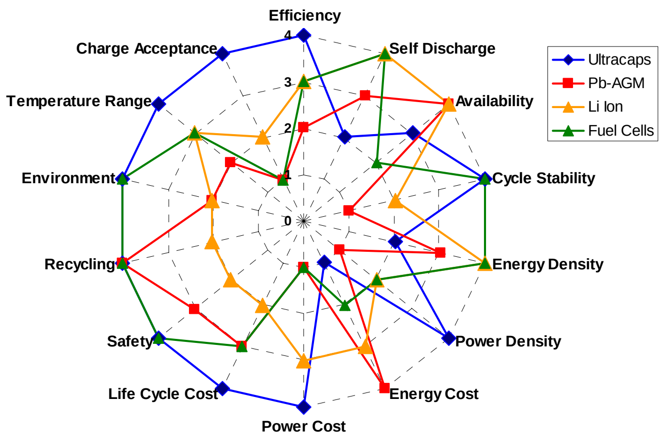
Figure 3 compares ultracapacitors with battery technologies and fuel cells for backup applications. It shows that each energy storage solution has advantages and disadvantages. No technology by itself can satisfy the entire spectrum; therefore, for applications that require broadly based demands we must look at the best possible combination.

As can be seen, a good match is to use ultracapacitors and fuel cells together. This combination results in an energy rich, reliable, maintenance free solution that is also very environmentally friendly. A typical fuel cell has a start up time of around 20 seconds, with some taking up to a minute to achieve full power. The ultracapacitor provides short-term power to “bridge” this gap and smoothly deliver power through transient interruptions.

Fuel cells have also provide reliable, with over 1 billion hours of operation over 10 years in back-up power applications such as hospitals. Based on a 10-15 year useful life and compared to a 5-year replacement cycle for batteries, a fuel cell based solution can be around 30% less expensive than a battery backup solution [1].

Ultracapacitors have another advantage over batteries that makes them suited to support fuel cells in backup applications. A fuel cell’s output varies with load (which is then regulated by power electronics). A battery’s output is fairly fixed, and will affect the fuel cell’s performance by loading the fuel cell’s output (unless it is employed on the output of the power electronics in a dc system, in which case the battery output is then unregulated). An ultracapacitor, however, has no fixed operating voltage, and therefore can operate directly across the output of the fuel cell, directly into the power electronics.

In fact, where the highest reliability is required, a “waterfall” architecture should be considered, using a cascading set of different technologies (e.g. engines, fuel cells, micro-turbines), bridging between each transition with short-term bridge power technologies (e.g. batteries, ultracapacitors, flywheels). For example, this has been used by telecoms companies, which require much more reliability than that of a traditional generator/battery combination.



2.1.a *Figure 2: Characteristics of energy storage solutions*

To provide a more quantified comparison between batteries and ultracapacitors, let's look at the table below. This compares a solution using 10 ultracapacitors each of 650F, with a lead-acid battery system. While they occupy the same volume, the battery solution does provide power for longer. However, this advantage is not of great significance in many applications, as the requirement for bridge power is only for a few seconds. The much longer lifetime of the ultracapacitor solution is much more important in practice.

230V, 50Hz DC link 24V	**Pb Battery**	**Ultracapacitor**
Technology	2*12V, 7Ah	10*650F
Volume (litres)	2	2
Weight (kg)	5	2
Backup time	6 minutes	10 seconds
Lifetime	2 years	10 years

Example of ultracapacitor-based bridge power system

Ultracapacitors are now proven components, with well-tested installations in the field. One example is the PureWave® Electronic Shock Absorber (ESA), an innovative grid stabilizing device for wind farms developed by S&C Electric Company (see Figure 3).

The first ESA system was installed by S&C Electric and Hawaiian Electric Company, Inc. (HECO) in January 2006, at Lalamilo Wind Farm on the Big Island of Hawaii, USA. The wind conditions at Lalamilo make it a suitable location to test the system.

Housed in a 30-foot trailer, the ESA system provides short-term electrical energy storage, using 640 ultracapacitors to store 3MJ of energy. This improves voltage support and overall stability of the transmission system.

The ultracapacitors' wide operating temperature range, zero maintenance and higher power output made them a good choice for this application.

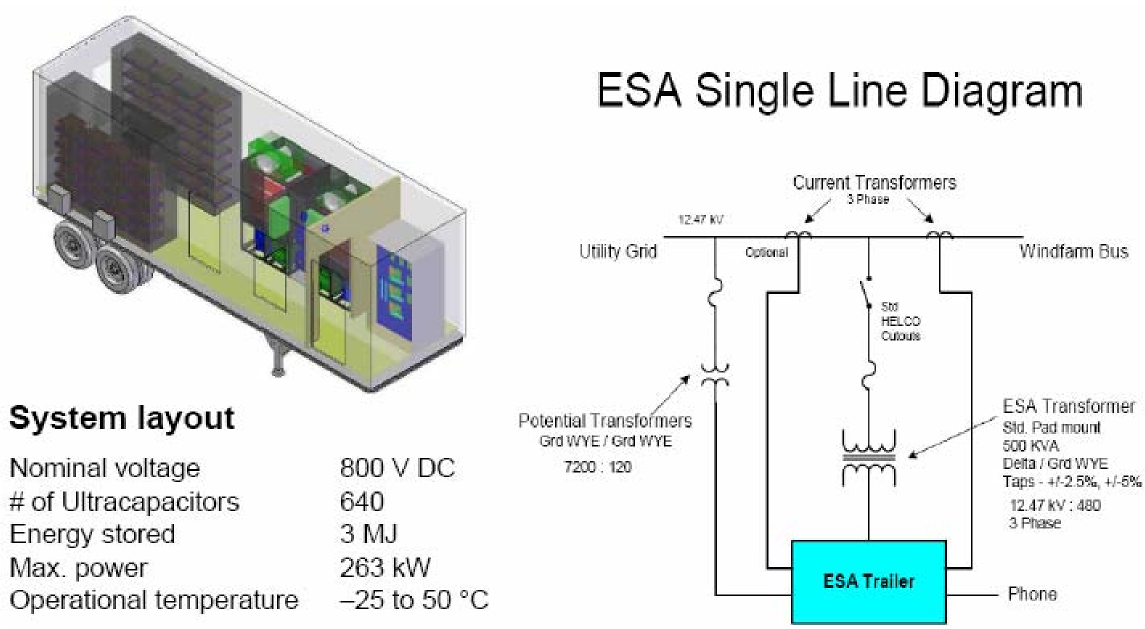


Figure 3: The Electronic Shock Absorber (ESA)

References:

[1] Citigroup Research report - "Switch Signals: Fuel Cells in Distributed Telecom Backup, August 2005, available at https://www.citigroupgeo.com/pdf/SZA34560.pdf