# WHITE PAPER

## FUEL CELLS AND ULTRACAPACITORS – A PROVEN VALUE PROPOSITION VERSUS INCUMBENT TECHNOLOGIES


**John Dispennette**
**Application Engineer**



**Maxwell Technologies, Inc.**
**Worldwide Headquarters**
9244 Balboa Avenue
San Diego, CA 92123
USA
Phone: +1 858 503 3300
Fax: +1 858 503 3301

**Maxwell Technologies SA**
CH-1728 Rossens
Switzerland
Phone: +41 (0)26 411 85 00
Fax: +41 (0)26 411 85 05

**Maxwell Technologies GmbH**
Brucker Strasse 21
D-82205 Gilching
Germany
Phone: +49 (0)8105 24 16 10
Fax: +49 (0)8105 24 16 19

**Maxwell Technologies, Inc. - Shanghai Representative Office**
Rm.2104, Suncome Liauw's Plaza
738 Shang Cheng Road
Pudong New Area
Shanghai 200120, P.R. China
Phone: +86 21 5836 5733
Fax: +86 21 5836 5620

**info@maxwell.com – www.maxwell.com**

Maxwell Technologies demonstrates the viability of fuel cells and ultracapacitors for extended run back-up power systems. Making leading edge contributions to commercializing economical and efficient products, new products are being developed providing increased availability and backup power runtime addressing the demanding standards and requirements of the telecommunications industry.
Based on Proton Exchange Membrane (PEM) technology the voltage conditioned fuel cells and ultracapacitor solutions utilize hydrogen for energy storage and have demonstrated their flexibility to meet real telecom load backup power needs. These rack-mountable and space efficient backup generators utilize hydrogen to offer high quality extended run backup power, zero emissions and are turnkey solutions capable of replacing incumbent technology.

Many fuel cell based stationary UPS systems have been introduced to the market. Examples include Altergy, Hydrogenics, Idatech, Plug Power, Relion, and UTC Power to name a few. These systems provide backup power ranging from 500 W to 10 kW with products sized to target different market segments. A primary focus for these systems are remote telecom sites where high reliability is necessary. Reliable communication is paramount in preventing lost business revenue and in times of natural disaster.

Fuel cell installations have been demonstrated to be reliable and an attractive complement for redundant reliability. Different aspects of the technology have been marketed as advantageous against the incumbent technologies. These include elimination of noise and pollution compared to diesel generators and maintenance and disposal costs of batteries. Typical battery selections for telecom sites have historically been based on lead acid technologies, either flooded or valve regulated (VRLA). Both types have undesirable attributes which the end user must deal with. Flooded lead acid require provisions for spill containment and cooling, along with regular maintenance. VRLA major issue has been life. VRLA batteries have not exhibited the life promised, with typical battery life being much shorter than the advertised 10 year [1]. Manufacturers of VRLA batteries say the reason for such short life is the way batteries are being used. At temperatures greater than 25°C battery life degrades, and with the increased number of telecom sites having unregulated environments, VRLA users are experiencing battery life times of three to eight years [1].

Telecom companies and others requiring a high reliability back up solution are left with some major decisions. Do they continue to use lead acid batteries with all their disadvantages or look to new technologies? On the surface lead acid batteries offer the most cost effective solution. For initial cost, it is very hard to beat the price of flooded or even VRLA batteries. This cost advantage is deceiving over the true life of the application.

**Maxwell Technologies, Inc.**
**Worldwide Headquarters**
9244 Balboa Avenue
San Diego, CA 92123
USA
Phone: +1 858 503 3300
Fax: +1 858 503 3301

**Maxwell Technologies SA**
CH-1728 Rossens
Switzerland
Phone: +41 (0)26 411 85 00
Fax: +41 (0)26 411 85 05

**Maxwell Technologies GmbH**
Brucker Strasse 21
D-82205 Gilching
Germany
Phone: +49 (0)8105 24 16 10
Fax: +49 (0)8105 24 16 19

**Maxwell Technologies, Inc. - Shanghai Representative Office**
Rm.2104, Suncome Liauw's Plaza
738 Shang Cheng Road
Pudong New Area
Shanghai 200120, P.R. China
Phone: +86 21 5836 5733
Fax: +86 21 5836 5620

**info@maxwell.com – www.maxwell.com**

As mentioned before most of these batteries have life times between three to eight years. With the continuous demand on the batteries this lifetime is reduced. Therefore, during the life of a telecom site there could be several battery replacements. Each of these replacements not only includes the cost of the batteries but also the handling and disposal of the old units. Not to mention the unfriendly environmental concerns.

Let's assume the choice has been made to utilize fuel cell based UPS over lead acid based UPS systems. A limitation for the fuel cell technology is that the PEM based systems require some start up time. Fuel cell technology has made advancements over the years but appraisal of the current available products still seems to require about 20 seconds startup. So how do they bridge this startup time requirement with the power demands of the application? Believe it or not, the initial choice has been with batteries. This has still been determined to be a more reliable solution as the number of batteries required for 20 seconds backup is considerable less than several hours of backup plus all of the diagnostics can be controlled internal to the fuel cell system.

Ultracapacitors can easily bridge the 20 seconds backup time and is well within the sweet spot of energy/power demands for the products. So why are ultracapacitors not provided exclusively as the bridge power component within fuel cell based UPS systems? Initially, the ultracapacitors were considered an immature technology and it was felt the risks associated with ultracapacitors and fuel cells were too high. Almost all of the fuel cell based UPS providers do now offer ultracapacitors in lieu of batteries and have independently validated the performance and reliability of the systems.

Ultracapacitors have been utilized in many applications with new applications developing constantly. The key benefits ultracapacitors offer in comparison to batteries are:

- Indefinite shelf life
- Greater than 10 years operational life
- Reduced maintenance requirements
- Reduced disposal concerns
- Improved low temperature performance

Today's hurdles or limitations to full adoption of the technology have been limited to initial cost. Ultracapacitors have significantly reduced in cost over the years and further cost reductions will be realized in the coming years as volumes continue to steadily increase. In order to address the current state of implementation of ultracapacitors vs. batteries for bridge power within a fuel cell UPS system a life cycle cost analysis is performed.

It must be noted the life cycle cost analysis is only looking at a return on investment (ROI) comparison of ultracapacitors vs. batteries for the internal bridge power requirement of the fuel cell based UPS system. This is not intended to be a ROI comparing the fuel cell based UPS vs. traditional battery based UPS systems. Figure 1 outlines the assumptions and inputs for the life time cost of the two technologies. It is based on a simulation of a 5 kW power requirement for 20 seconds although it has been shown to be consistent with 0.5 to 10 kW systems. The calculation is based on the added cost of an ultracapacitor based system so the initial battery cost and subsequent battery hardware replacement price is assumed to be $0. The ultracapacitor price utilized assumes a medium volume (approximately 25 UPS systems) and the replacement price is the same as current price. The first simulation assumes the best case battery conditions are maintained and a 10 year battery life is achieved. The only variable difference in the comparison is the assumption of the frequency of maintenance. It is assumed that battery maintenance is required every year whereas ultracapacitors only require maintenance every six years.

| | | | | | |
|---|---|---|---|---|---|
| **Capital Expenditure: Ultracapacitor vs. Batteries for UPS** | | | | | |
| **System Inputs** | | | | | |
| UPS Size | 5 | kW | Energy Storage Power Control Information | | |
| Startup time | 20 | sec | | **60** | V max |
| | | | | **54** | V nominal |
| | | | | **32** | V minimum |
| Energy required | 100 | kJ | | | |
| | | | Product | ***BMOD0430-E016*** | |
| **Cost & Maintenance Assumption Inputs** | | | | | |
| | | | **Total UPS Service Life =** | **30** | **years** |
| ***Ultracapacitor Information*** | | | ***Battery Information*** | | |
| Ultracapacitors | 8 | | Batteries | 5 | |
| $/ultracapacitor | **$345** | | $/battery | **$0** | |
| Initial ultracapacitor cost | $2,760 | | Initial battery cost | $0 | |
| Maintenance period | **6** | years | Maintenance period | **1** | years |
| Maintenance cost | **$500** | | Maintenance cost | **$500** | |
| Replacement period | **10** | years | Replacement period | **10** | years |
| Replacement cost (labor) | **$1,000** | | Replacement cost (labor) | **$1,000** | |
| Relative hardware price | **100%** | | Relative hardware price | **100%** | |
| Handling & disposal | **$96** | | Battery handling & recycling | **$400** | |
| Total life cost | $12,472 | | Total life cost | $17,300 | |
| ***Projected savings*** | ***$4,828*** | | | | |

Figure 1: Best case battery life vs. expected ultracapacitor life

Figure 2 is a plot of the cumulated costs for the first simulation over a 30 year period. Whether the UPS itself would last 30 years is debatable but plotting the accumulated cost over time indicates the service life time one technology may be favorable over another. With the assumptions the UPS system would need to be in service for approximately 12 years before the ultracapacitor based bridge power solution would become more favored. Over a 30 year period the total savings would amount to approximately $5,000.

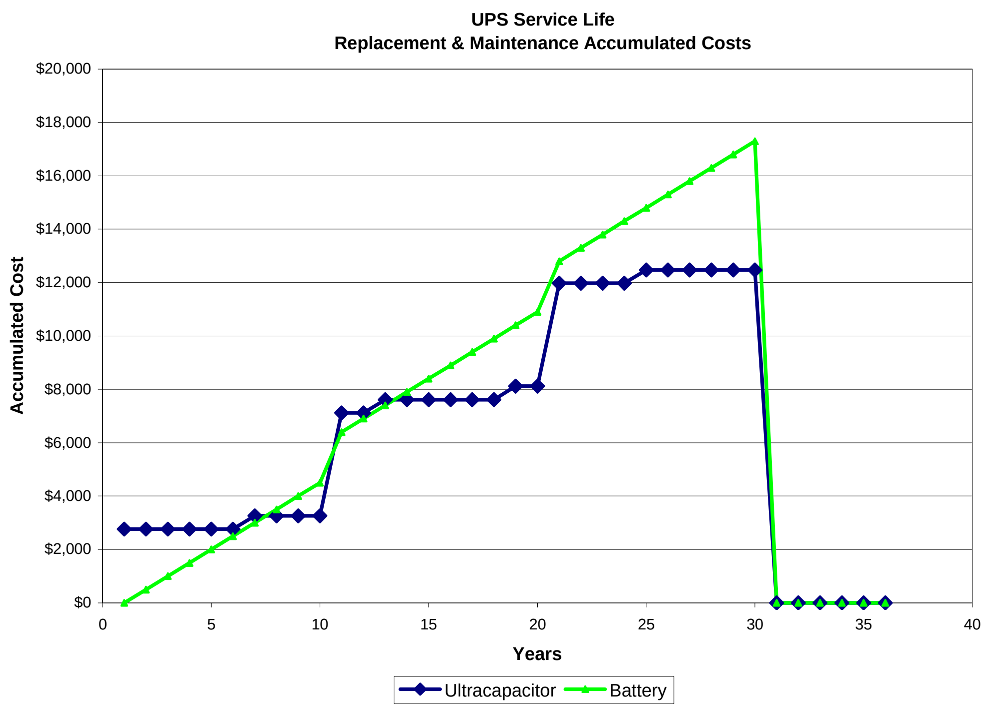


Figure 2: Accumulated cost of best case battery life vs. expected ultracapacitor life

A second simulation is performed with the assumption of a 3 year battery replacement requirement. Additionally, it is assumed the price for the ultracapacitors will be reduced by one half by the next required replacement period (approximately 10 years). The assumptions for the simulation are provided in Figure 3. From the plot of the simulation depicted in Figure 4 it is seen the breakeven point for the two technologies occurs at 4 years with ultracapacitors providing a cost benefit every year thereafter. Under the

Maxwell Technologies, Inc.
Worldwide Headquarters
9244 Balboa Avenue
San Diego, CA 92123
USA
Phone: +1 858 503 3300
Fax: +1 858 503 3301

Maxwell Technologies SA
CH-1728 Rossens
Switzerland
Phone: +41 (0)26 411 85 00
Fax: +41 (0)26 411 85 05

Maxwell Technologies GmbH
Brucker Strasse 21
D-82205 Gilching
Germany
Phone: +49 (0)8105 24 16 10
Fax: +49 (0)8105 24 16 19

Maxwell Technologies, Inc. -
Shanghai Representative Office
Rm.2104, Suncome Liauw's Plaza
738 Shang Cheng Road
Pudong New Area
Shanghai 200120, P.R. China
Phone: +86 21 5836 5733
Fax: +86 21 5836 5620

info@maxwell.com – www.maxwell.com

assumptions provided it is anticipated that over a 30 year period the total cost savings of an ultracapacitor based bridge power solution is approximately $18,000.

These two simulations are based on some very basic assumptions, but what is readily seen by looking at the best case/worst case battery life that the maintenance costs are a significant portion of the total life cycle costs, not the initial hardware costs. The assumption of a $500 maintenance cost is considered conservative when factoring in the total elements of the maintenance call (scheduling, logistics, labor, transportation, etc.) especially in remote locations. The most significant cost of the total life cycle costs based on a 3 year battery replacement schedule is the cost of the battery replacement. Again, the $1000 incurred replacement cost is considered to be conservative as it includes all the elements of a maintenance call plus the labor, handling and testing of the replacement batteries.

| Capital Expenditure: Ultracapacitor vs. Batteries for UPS | | | | | |
|---|---|---|---|---|---|
| **System Inputs** | | | | | |
| UPS Size | 5 | kW | Energy Storage Power Control Information | | |
| Startup time | 20 | sec | | **60** | V max |
| | | | | **54** | V nominal |
| | | | | **32** | V minimum |
| Energy required | 100 | kJ | | | |
| | | | Product | ***BMOD0430-E016*** | |
| **Cost & Maintenance Assumption Inputs** | | | | | |
| | | | **Total UPS Service Life =** | **30** | **years** |
| ***Ultracapacitor Information*** | | | ***Battery Information*** | | |
| Ultracapacitors | 8 | | Batteries | 5 | |
| $/ultracapacitor | **$345** | | $/battery | **$0** | |
| Initial ultracapacitor cost | $2,760 | | Initial battery cost | $0 | |
| Maintenance period | **6** | years | Maintenance period | **1** | years |
| Maintenance cost | **$500** | | Maintenance cost | **$500** | |
| Replacement period | **10** | years | Replacement period | **3** | years |
| Replacement cost (labor) | **$1,000** | | Replacement cost (labor) | **$1,000** | |
| Relative hardware price | **50%** | | Relative hardware price | **100%** | |
| Handling & disposal | **$96** | | Battery handling & recycling | **$400** | |
| Total life cost | $9,712 | | Total life cost | $27,100 | |
| ***Projected savings*** | ***$17,388*** | | | | |

Figure 3: Worst case battery life vs. expected ultracapacitor life

**Maxwell Technologies, Inc. Worldwide Headquarters**
9244 Balboa Avenue
San Diego, CA 92123
USA
Phone: +1 858 503 3300
Fax: +1 858 503 3301

**Maxwell Technologies SA**
CH-1728 Rossens
Switzerland
Phone: +41 (0)26 411 85 00
Fax: +41 (0)26 411 85 05

**Maxwell Technologies GmbH**
Brucker Strasse 21
D-82205 Gilching
Germany
Phone: +49 (0)8105 24 16 10
Fax: +49 (0)8105 24 16 19

**Maxwell Technologies, Inc. - Shanghai Representative Office**
Rm.2104, Suncome Liauw's Plaza
738 Shang Cheng Road
Pudong New Area
Shanghai 200120, P.R. China
Phone: +86 21 5836 5733
Fax: +86 21 5836 5620

info@maxwell.com – www.maxwell.com

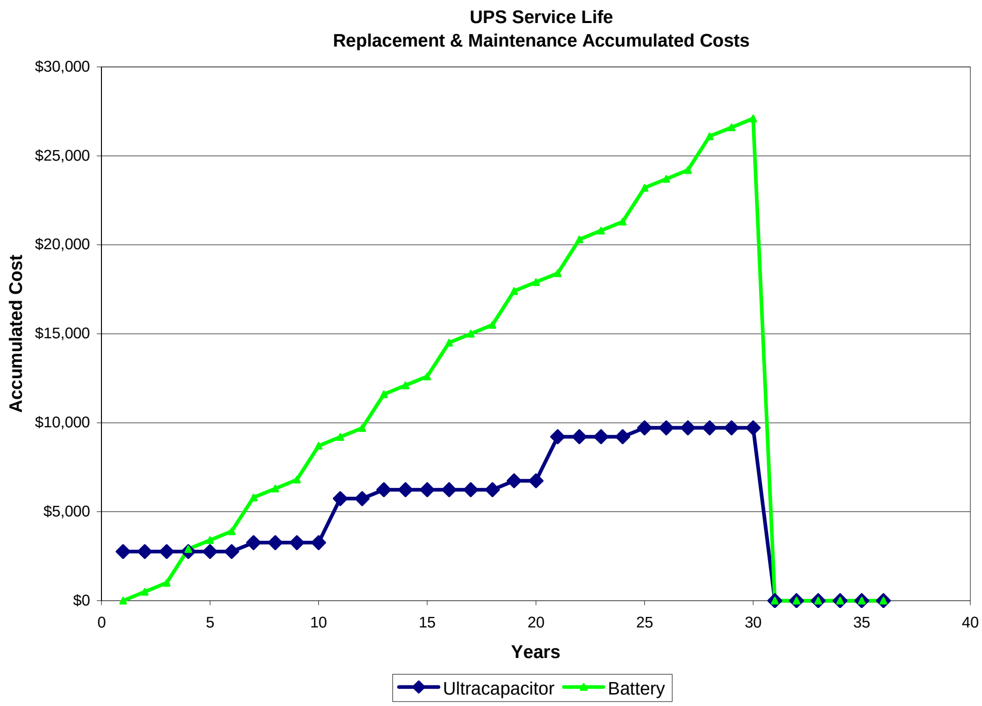


Figure 4: Accumulated cost of worst case battery life vs. expected ultracapacitor life

Based on the best case/worst case battery life assumptions it is seen that an ultracapacitor based bridge power solution can easily have a ROI within a 4/12 year period. For remote locations this projection could easily be improved.

1. M. Corcoran, "Battery Battle", Wireless Review (2004).