Integrating Renewables into the Grid: Applying UltraBattery® Technology in MW Scale Energy Storage Solutions for Continuous Variability Management

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***Abstract* -- Electricity providers are increasingly faced with the challenge to integrate variable renewable generation with their existing portfolios and into the electricity grid. UltraBattery® technology represents an entirely new class of advanced lead-acid batteries invented by Australia's national science agency (CSIRO). UltraBattery® technology allows the continuous management of variability and shifting of energy, crucial for the large scale integration of renewables. The UltraBattery® has already been successfully implemented globally in several MW scale energy storage projects to demonstrate:**

- **The endurance and longevity of UltraBattery® technology to manage the ramp rate of renewable energy and to shift renewables output;**
- **The superior performance of UltraBattery® cells in the provision of regulation services over incumbent gas peakers often used for regulation services; and**
- **The potential to reduce the cost of each MWh of storage used to control renewable energy variability.**

Existing projects have proven the ability of UltraBattery® technology to combine renewable energy sources with a storage system, providing multiple improvements to the reliability and grid dispatchability of renewable resources.

***Index Terms* – Advanced VRLA Batteries, Bulk Storage, Energy Storage, Power Smoothing, Energy Shifting, MW Scale, Intermittency Management**

I. Introduction

The rapid growth of renewable energy generation and their large-scale integration pose opportunities and challenges alike. Electricity providers are increasingly faced with the challenge of integrating variable renewable generation with existing portfolios and with the wider electricity grid. In order to operate reliably and stably, grids need to continuously balance supply and demand – a task complicated by the intermittency of renewable energy. The variability and uncertainty of renewable output is a major hurdle to large-scale integration of renewables and thus to transitioning from a fossil fuel to a renewables-based economy.

Energy storage is now the key to a quick adoption of renewable energy and its use has begun to be mandated in large US and European grids. Energy storage has the ability to control ramp rates of renewables output before presenting it to the grid and to store energy to cover periods of unfavorable weather conditions or to meet peak demand times, making renewables more reliable and dispatchable.

For energy storage to make its full impact, cost-effective, practical, safe and environmentally sound energy storage systems are needed that are simple to deploy, maintain and recycle – an 'ordinary' part of the grid design.

II. UltraBattery® Technology

Invented by the Commonwealth Scientific and Industrial Research Organization (CSIRO), the breakthrough advanced VRLA UltraBattery® is a completely new class of lead-acid technology: a hybrid, long-life lead-acid energy storage device that operates highly efficiently in continuous 'Partial State of Charge' (PSoC) use without frequent overcharge maintenance cycles (as indicated in Figure 1).

Ecoult would like to acknowledge the support of the Australian Department of Environment and Climate Change NSW; the Australian Department of Resources, Energy and Tourism under the AEST Grant; as well as the U.S. Department of Energy under the Smart Grid Storage Demonstration Program.

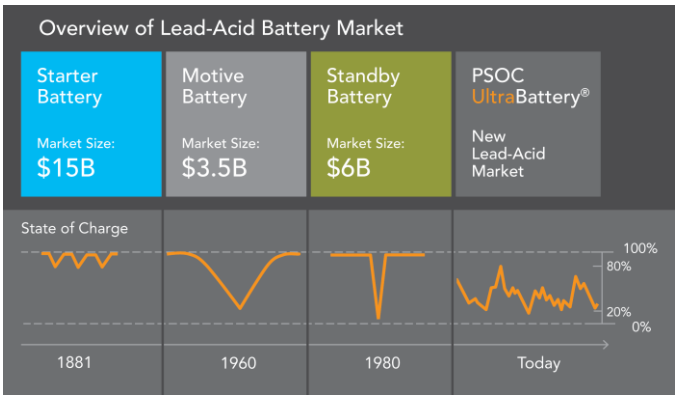

Fig. 1. Overview lead-acid battery market over time. Only UltraBattery® can function for long periods in the demanding PSoC range

UltraBattery® technology can be utilized to continually manage energy intermittencies, smooth power and shift energy, using a band of charge that is neither totally full nor totally empty when in use. It combines the advantages of the most proven and dependable advanced lead-acid battery technology with the advantages of an asymmetric supercapacitor (Figure 2) – enabling an optimal balance of an energy storing lead-acid battery with the quick charge acceptance, power discharge, and longevity of a supercapacitor.

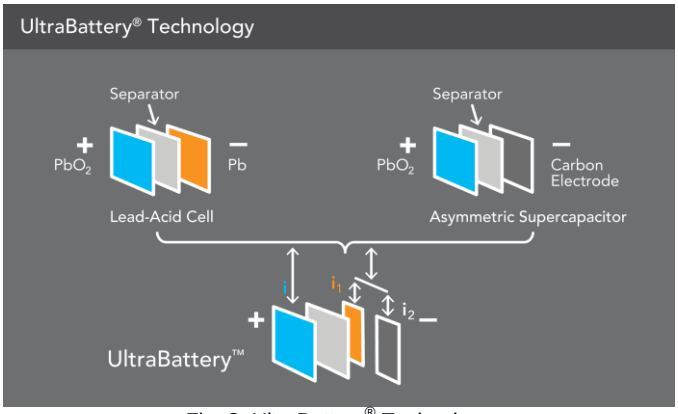

Fig. 2. UltraBattery® Technology

Standard valve regulated lead-acid (VRLA) batteries form 'hard' lead sulfate deposits inside the negative plate when operated continuously in a PSoC regime, unless given frequent refresh overcharge cycles. The capacitor integrated in the UltraBattery® chemistry however modifies the process associated with the formation and dissolving of sulfate crystals in the negative plate when charging and discharging. This enables the UltraBattery® to operate with high efficiency in PSoC use and, combined with the cycling endurance of the technology, results in an ability to process a much greater amount of energy in the device's useable lifetime – a significant multiple over standard lead-acid technology (as shown in Figure 3). This capability is fundamental to the typical grid and renewables requirements for smoothing the variability and shifting of energy.

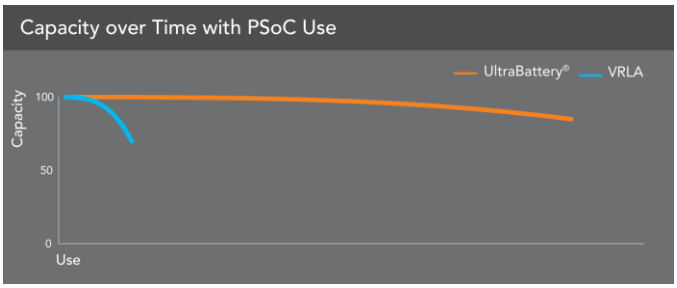

Fig. 3. Capacity over Time with Partial State of Charge (PSoC) Use

With its high cycling life, high conversion efficiency and low operating costs, UltraBattery® offers an economical $/kWh solution for whole of life for intermittency control and energy shifting and firming. It is safe, recyclable and (with virtually zero emissions) the economic and environmentally sound alternative to conventional generation assets. The outperformance of UltraBattery® compared with competing battery chemistries across a range of key performance parameters has been proven in multiple tests by the Advanced Lead Acid Battery Consortium (ALABC), CSIRO, Furukawa Battery, East Penn Manufacturing, Ecoult and Sandia National Laboratory [1].

The UltraBattery® will extend the dominance of the lead-acid chemical storage method to continuous variability management and shifting of renewable energy, while at the same time capitalizing on the complete ecosystem of safety, large-scale manufacturing, deployment and recycling of traditional lead-acid technologies.

III. Megawatt Scale Energy Storage Demonstration Projects

UltraBattery® technology has already been successfully implemented in several MW-scale energy storage projects globally, delivering ancillary services, wind and solar smoothing and energy shifting. Initial test results and system outputs show the ability of UltraBattery® technology to deliver ancillary services more efficiently than incumbent gas peakers, to successfully manage the ramp rate of renewable energy and seamlessly combine renewable energy sources with a storage system, hence supporting renewable resources to become increasingly reliable and dispatchable.

A. Wind Smoothing – Hampton Wind Farm (NSW, Australia)

Wind energy is clean and has the potential to supply many times the total current global energy consumption. Although wind energy is reasonably predictable, it is significantly variable. Fast ramp rates are often a feature of wind power generation (as the wind dies suddenly and the energy source disappears from the grid). This can create integration challenges for utilities and also limits progress by wind farm developers.

Wind power cannot be controlled. Wind farms exhibit greater uncertainty and variability in their output compared to fossil fuel generation. In power systems, which already manage a large degree of uncertainty due to the need of generation and loads to be equal, demand is constantly matched with generation to maintain system frequency. The variability and uncertainty of wind power further increases uncertainty in the system, disturbing its physical operation.

Further challenges with supporting increased penetration of intermittent resources are related to congestion issues in the transmission and distribution system as well as the mismatch between wind availability and prevailing demand. Oftentimes, local networks are constrained at times when the wind resource is good, forcing available renewable energy to be curtailed.

An immediate solution to wind integration challenges is to limit the ramp rate of wind output. The Hampton Wind Farm project objective was to demonstrate and optimize methods of applying UltraBattery® storage to constrain the 5 minute ramp rate of renewable output from the Hampton Wind Farm before presenting it to the grid. The impact objective was to demonstrate that higher penetration of wind and renewable energy were possible within electricity grid systems.

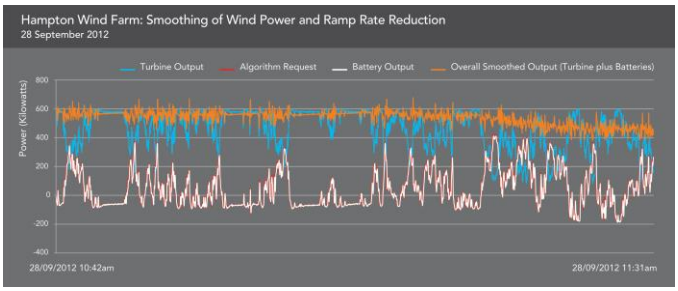

Fig. 4. Hampton Wind Farm: Smoothing of Wind Power and Ramp Rate Reduction

Ecoult provided and integrated a MW-scale smoothing system using UltraBattery® technology at the Hampton Wind Farm. Ecoult has been able to demonstrate the ability to limit the 5 minute ramp rate to 1/10 of the raw output while applying storage with a usable capacity (in kWh) 1/10 the rated output of the farm (in kW). So, for instance, a 1 MW wind turbine would use 0.1 MWh of storage. Figure 5 shows that the 5-minute power variability could be reduced by more than an order of magnitude.

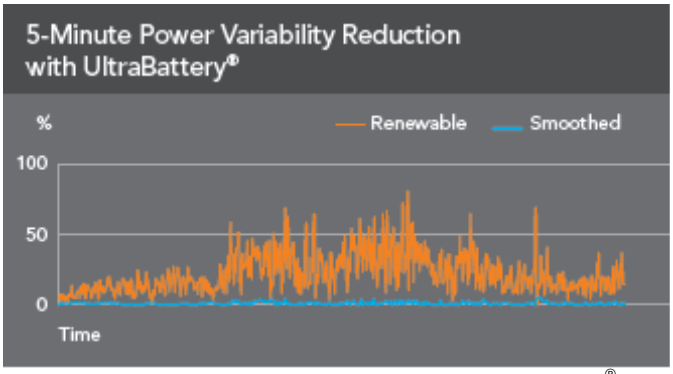

Fig. 5. 5-Minute Power Variability Reduction with UltraBattery®

The storage solution at the Hampton Wind Farm uses highly task optimized algorithms that have been developed by mathematicians at CSIRO. The overall storage architecture provides a robust and operationally reliable environment for the application layer to then further enhance use of the storage asset.

There is a considerable amount of effort being put into developing more intelligent ways of operating the storage systems. Algorithms are being developed which are adaptive to the prevailing inputs (e.g. service demands or renewable energy inputs) while minimizing degradation of the storage asset, thus maximizing economic returns from the use of storage.

While the Hampton system smoothes the energy produced “at the source” on the wind farm (as shown in figure 5), it is an objective of the work that the system and learnings are transferable wherever the benefit of reducing renewable energy variability exists, for example at grid nodes (or substations) or via the provision of ancillary services generally.

B. Solar Smoothing and Shifting – PNM, Public Service Company of New Mexico (NM, USA)

PNM, the leading electric utility company in New Mexico, USA, has integrated an Ecoult Energy Storage System based on UltraBattery® technology with a photovoltaic solar energy plant to demonstrate smoothing and shifting of volatile solar power and the ability to use the combination as a dispatchable renewable resource. The PNM Prosperity Energy Storage Project is the first solar storage facility in the USA that is fully integrated into a utility’s power grid. It features one of the largest combinations of battery storage and photovoltaic energy in the US.

Increasing levels of renewable energy penetration poses integration challenges for grids. In the case of New Mexico, there were two particular challenges:

- Better manage the misalignment between PV output and utility distribution grid and system peaks
- Better manage intermittency and the volatile ramp rates of renewable energy sources that cause voltage fluctuations

PNM working with Sandia National Laboratories, the University of New Mexico and a number of other contractors is applying the energy storage system provided by Ecoult to achieve several objectives including:

- Peak shaving and elimination of 15% of the feeder peak – benefit defined by avoided industry standard costs of substation and feeder expansion.
- Smoothing of PV ramp rates and minimizing voltage fluctuations – benefit defined by avoided cost of system upgrades that would be installed with high penetration PV.
- Demonstration of dispatchable renewable resource – benefit defined by contrasting the cost of an equivalently dispatched combustion turbine, allocating fuel, Operation and Maintenance and capital to a LCOE (levelized cost of energy) comparison and noting an allowance for CO_2 emission avoidance.

The PNM project has shown how significant energy shifting and smoothing can be on the grid, particularly in altering the profile of grid-scale renewables. Tests had revealed that the 500 kW New Mexico solar PV array experienced ramp rates of 136 kW per second as solar energy was lost to cloud cover. Such large fluctuations in energy output can become unsustainable if renewable penetration increases. UltraBattery® technology has successfully controlled and smoothed this PV output and is demonstrating the viability of combining PV with a battery-based energy storage system.

Ecoult's Energy Storage system is currently providing PNM 500 KW of energy smoothing capability and 250 kW/1 MWh of energy shifting capability. Results indicate that targeted objectives are easily being met, as shown in figures 6 and 7.

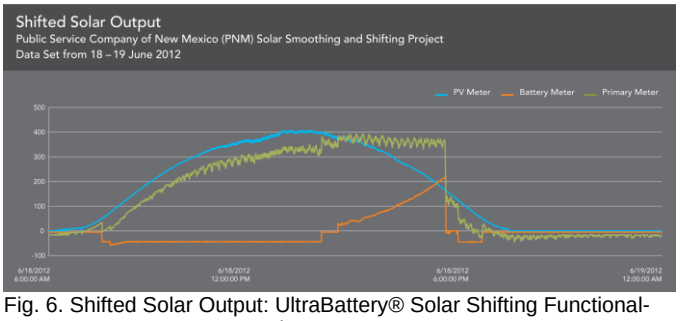

Fig. 6. Shifted Solar Output: UltraBattery® Solar Shifting Functionality Proven

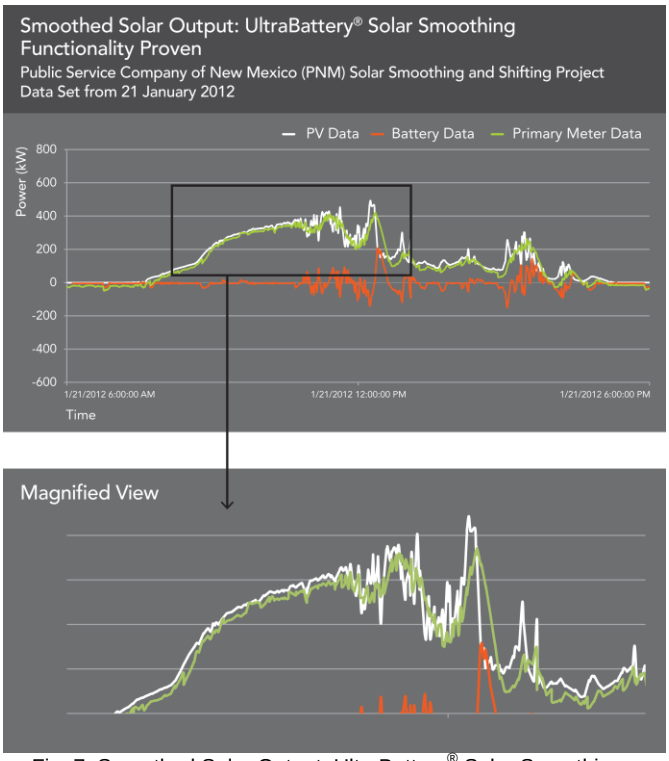

Fig. 7. Smoothed Solar Output: UltraBattery® Solar Smoothing Functionality Proven

C. Regulation Services – PJM Interconnection (PA, USA)

Ecoult implemented an energy storage system which provides 3 MW of regulation services on the grid of PJM Interconnection, the largest of ten Regional Transmission Organizations (RTOs) / Independent System Operators (ISOs) in the USA. The system is also used for peak demand management.

With renewable portfolio standards coming into effect, the large scale integration of intermittent wind and solar generation will affect the physical operation of the modern grid, resulting in an increasing need for regulation services.

Regulation Services are necessary to provide fine tuning in real time for the network to match supply and demand and, by virtue of this balance, keep a constant frequency. The energy store responds to a signal provided from the market operator, PJM.

The objective of the project is to demonstrate the outperformance of UltraBattery®-based storage solutions in the provision of regulation services compared with more traditional methods where Regulation Services are provided by fossil-fuel generators.

Fast responding UltraBattery® technology can manage regulation services more efficiently: it is faster, more accurate, cheaper and cleaner than the incumbent gas peaker often used for regulation services. UltraBattery® technology is therefore able to displace fossil fuel generation methods in the provision of regulation services and

to complement fossil fuel generation in the provision of other ancillary services.

The Ecoult 3 MW storage solution is implemented both in a building and a containerized format to demonstrate flexibility in approach for prospective adopters. It uses four strings of UltraBattery® cells and connects to the grid from inside the East Penn Manufacturing site in Lyon Station Pennsylvania.

The system provides continuous frequency regulation services bidding into the open market on PJM, responding to PJM's fast response signal. Figure 8 shows the signal received from PJM and how accurately the system responds to the PJM signal. In comparison, gas peakers with their slow response times only generate about 30% correction for each MW of regulation service they provide.

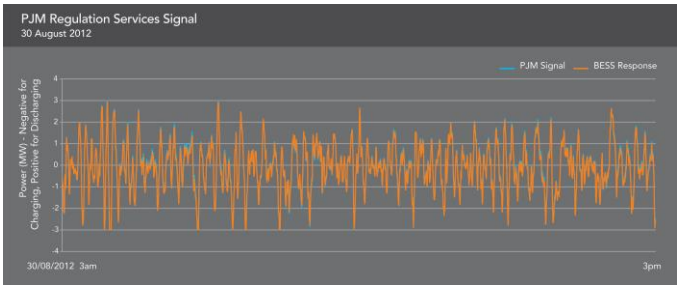

Fig. 8. Frequency Regulation: PJM Regulation Services Signal and Response of UltraBattery® Energy Storage System

In providing frequency regulation services, the batteries roam in approximately a 10-15% Partial State of Charge band. Ecoult has implemented an application that follows the PJM signal and maintains the State of Charge. Figure 9 shows the four strings being maintained in very tight alignment.

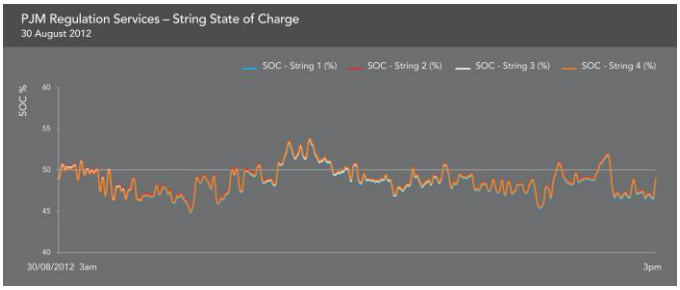

Fig. 9. Frequency Regulation: String State of Charge

Further, the system tracks the string voltage and the individual voltage of the cells. These are maintained in conservative bands, but to extend longevity Ecoult is currently implementing additional optimizations to achieve even tighter ranges. Figure 10 shows the fours strings, again in very close alignment.

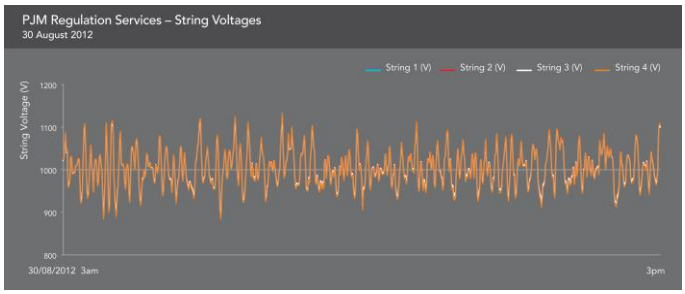

Fig 10. Frequency Regulation: String Voltage

IV. Conclusion

UltraBattery® has proven to have an extraordinary endurance and longevity performance when used for applications where power is cycled in a Partial State of Charge band. The objective is to deliver maximum impact on signal quality for minimum cost by combining the UltraBattery® cycle longevity, which reduces the cost of each MWh of storage used, with intelligent algorithms, which reduce the ratio of storage MWh required for the impact.

Current research is focused on reducing the cost of each MWh of storage (through endurance and longevity of the UltraBattery®) and extended use of each MWh installed (through intelligent algorithms). This is seen as the path to unlocking business case models with positive returns that will deliver growth in the storage industry. This in turn will lead to higher possible penetrations of renewables on the electricity grid.

Economic implementation also requires that platforms be safe, economical, environmentally sound and standardized while delivering flexibility to developers who implement storage to deliver specific business objectives. Ecoult's energy storage solution incorporating the UltraBattery® has been developed to provide such a platform.

Finally, to make its full impact, storage needs to become commonplace, and simple to deploy, maintain, and recycle – an 'ordinary' part of grid design. Lead-acid batteries are the dominant chemical storage method for large scale storage (primarily used for standby applications) and have a complete ecosystem of safety, manufacture, deployment and recycling in place today.

UltraBattery® extends lead-acid chemistry beyond standby applications to wherever power variability needs to be controlled. Adding High Rate Partial State of Charge cycling endurance and longevity to a safe, stable, fully recyclable platform, UltraBattery® offers a cost effective and low risk path for energy storage applications.

UltraBattery® technology has benefitted from great support from the Australian, US and Japanese Governments, and leading researchers in other countries. Ecoult's strong commercial and research partnerships will allow the company to continue its exploration into large-scale energy storage as well as commercial and smaller systems based on the UltraBattery® and other

technology breakthroughs currently in the mature R&D phase. These future systems will allow businesses and individuals to integrate renewables into the grid, making it a truly omnipresent technology, allowing the transition to a renewables-based economy.

V. References

[1] T. Hund et al., “Ultrabattery Test Results for Utility Cycling Applications”, Power Source Component Development Department, Sandia National Laboratories, Albuquerque, NM 87185-0614

VI. Speaker Information John Wood

John Wood is the Chief Executive Officer of Ecoult. He joined the energy storage community in 2008 having previously launched technologies globally in Security, Identity, Payment Technology, and Telecommunications.

As a technology CEO for more than 20 years, John has had the good fortune to have worked with excellent individuals and led excellent teams that have created businesses and numerous successful products and solutions from the ground up that are used and trusted by many of the world’s largest enterprises and governments, either directly or under license by many of the largest global technology enterprises.

John is now leading the Ecoult effort to commercialize the UltraBattery® storage solutions.