ULTRABATTERY STORAGE TECHNOLOGY
AND ADVANCED ALGORITHMS AT THE MW-SCALE

Dr Peter Coppin[1] and John Wood[2]

[1]Dr Peter Coppin, Storage for Renewables, CSIRO Energy Transformed Flagship, Canberra (ACT), Australia, Ph +61 417415302 peter.coppin@csiro.au

[2]Mr John Wood, CEO Ecoult, Sydney (NSW), Australia, Ph +61488260443 john.wood@ecoult.com

Abstract

The Hampton project utilizes storage to smooth the 5 minute ramp rate of a wind farm. It is part of a systematic effort to reduce the cost of each MWh of storage used to control renewable energy variability. The Hampton Project set out to achieve two things:

1. demonstration of the endurance and longevity of the UltraBattery for wind ramp control; and
2. increase the value derived from each MWh used through the implementation of CSIRO's intelligent algorithms.

We believe effective battery storage coupled with effective algorithms to be essential enablers to generating generic business case models with positive returns.

Widespread implementation also requires sound, standardised platforms which have sufficient flexibility to deliver specific business objectives. The Ecoult Energy Storage Solution developed at Hampton using the UltraBattery has been developed to provide such a platform.

To make its full impact energy storage, needs to become 'ordinary' - simple to deploy, maintain and recycle.

Lead Acid Batteries are the dominant chemical storage method for large scale storage (primarily standby) and have a complete ecosystem of safety, manufacture, deployment and recycling. The UltraBattery hybrid lead acid chemistry Battery/UltraCapacitor energy storage device will extend this dominance to variability management. Through the Hampton Project, Ecoult has now taken energy storage for renewable variability management significantly closer to ordinary, simple to deploy, maintain and recycle.

Keywords: UltraBattery, storage algorithms, energy smoothing, ramp rate, regulation services

INTRODUCTION: ULTRABATTERY TECHNOLOGY

UltraBattery® technology, a combination of conventional VRLA and super-capacitor technology (Figure 1), has reached system implementation at the MW scale.

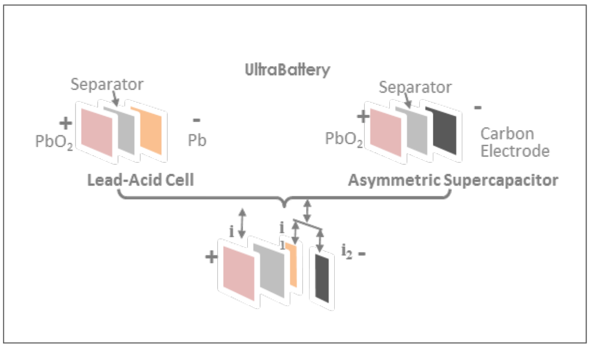

Figure 1 – UltraBattery Technology

East Penn Manufacturing Co. has implemented UltraBattery into its stationary battery production capability supporting high volume manufacturing capability. This has enabled the design and implementation of systems at the MW/MWhr scale for a variety of applications. Systems have or are being installed for wind and solar energy production smoothing, renewable energy peak shaving and regulation services.

Ecoult working with CSIRO in Australia have progressed technology characterization and application together through laboratory qualification and simulations through to MW scale at the Hampton Wind Farm. As the work has progressed there has been significant understandings developed.

THE ECOULT ULTRABATTERY ENERGY STORAGE SOLUTION

The objective of the energy storage solution implemented at Hampton is to smooth the ramp rate of the wind farm before presenting it to the grid. In turn the impact objective is to achieve higher penetration of wind and renewable energy in grid systems. While the Hampton system smooths the energy produced "at the source" on the wind farm, it is an objective of the work that the system and learning's 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. An adaptation of the same basic storage solution is being applied to deliver smoothing and shifting of solar energy alongside PNM at a US DOE demonstration project in Albuquerque along with a system that is currently being commissioned to deliver 3MW of regulation services to the PJM grid in Pennsylvania.

Hampton Wind Smoothing — *PNM Solar Smoothing* — *PJM Regulation Services*

Figure 2 – Ecoult Demonstration Projects

In all three cases (Figure 2) the UltraBatteries see a pattern of continuous charging and discharging commands at a reasonably high rate.

Figure 3 shows how the variable renewable power is converted to a smoothed output by the energy store acting somewhat like a set of noise cancelling headphones cancelling sound. A power conversion system integrated into the storage solution with the UltraBattery cells act to generate a signal which is delivered to the grid in parallel with the output of the wind turbine and delivers a combined result in accordance with the defined target objectives.

In the case of figure 3 the objective is 5 minute ramp rate control and so the resultant output is still quite variable when viewed over the course of a day but when considered in the context of 5 minute power variability (shown in the diagram at the top right corner of figure 3) it can be seen that the variability has been reduced by more than an order of magnitude (bottom right corner of figure 3).

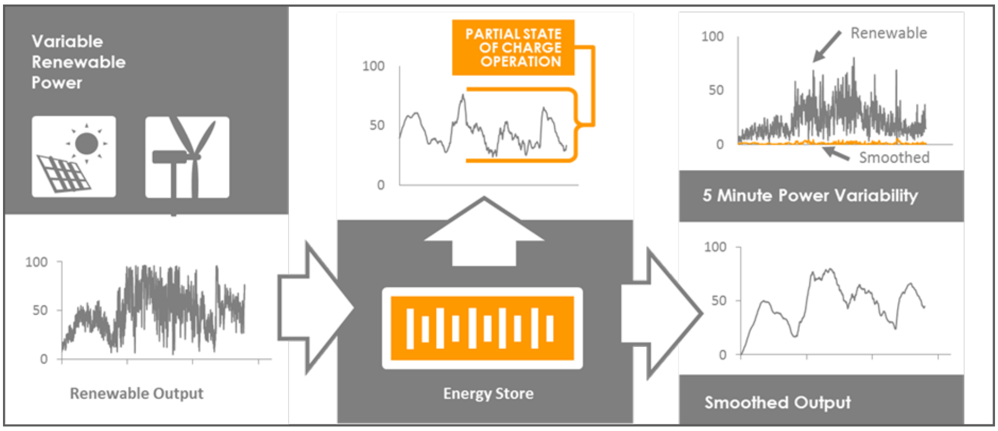

Figure 3 – Smoothed Renewable Power Output

The grid is adaptable and renewable variability at multiple sources can contribute to smooth each other out statistically. This however relies on the presumption that the transmission and distribution network is fully capable of tolerating the local noise levels generated at each farm, and collectively, to enable such cancellation. Oftentimes, the reality is that local networks are constrained with clean renewable energy being forced to be curtailed. An immediate solution to such curtailment may be to require limited ramp rate control such that the energy network can then carry more renewable energy overall from each of the farms by managing the short term variability.

Managing short term variability utilises a high power to energy ratio and this is an area that UltraBattery excels in terms of longevity. Algorithms in the energy store deliver the smoothing objective while maintaining the battery in a continually variable state of charge. The store is managed so as to use neither the very top area of the battery (completely full), nor the very bottom area of the battery (completely empty) but rather to keep the state of charge somewhere in between.

In terms of operation of battery technology this is described as a High Rate Partial State of Charge use “HRPSoC”.

UltraBattery was invented by Dr Lan Lam of CSIRO in Australia and was supported in development by funding from the Australian Federal government and the NSW state government. As CSIRO and Dr Lan developed the technology a technology alliance was formed with Furukawa Battery in Japan who contributed along with CSIRO to development of the solution. As the UltraBattery effort progressed it was also included in projects that received funding assistance from the Japanese government through NEDO. In 2007 the technology alliance was extended to East Penn Manufacturing who obtained a global head license for the manufacturing and commercialization of the technology for stationary energy storage applications (outside of Japan and Thailand where Furukawa Battery is the head license holder). Following the acquisition East Penn has been the beneficiary directly and indirectly of funding from the US DOE toward advancing implementation of UltraBattery technology toward grid scale storage use and so the overall UltraBattery campaign has had a global heritage.

UltraBattery has demonstrated in testing by multiple organizations including the Advanced Lead Acid Battery Consortium (ALABC), Sandia, CSIRO, Furukawa, East Penn Manufacturing, and Ecoult to have extraordinary longevity when used for HRPSoC applications (Figure 4).

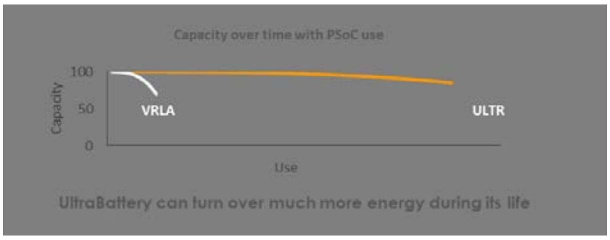

Figure 4 – Capacity Over Time With PSoC Use

This longevity translates into the total amount of energy that can be processed by the battery before replacement and in turn this translates to a much lower cost in terms of degradation (or depreciation) of the storage “capital asset” when used for these purposes. The commercial importance of this feature was demonstrated in an automotive context by the Advanced Lead Acid Battery Consortium ALABC when UltraBattery was tested and proven to exceed the benchmark goals set for HEV1 hybrid automotive use. In an overlapping period testing by Tom Hund of Sandia [1] against a profile provided by Charles Koontz of Integrys Energy which was created to be representative of providing regulation services on the PJM grid showed the outperformance of UltraBattery for managing grid variability.

Recognising that UltraBattery provided a path to grid scale energy storage solutions with breakthrough cost models CSIRO formed a subsidiary (Ecoult) to address the market. In May 2010 Ecoult was acquired from CSIRO by East Penn Manufacturing.

East Penn through its subsidiary Ecoult is bringing UltraBattery to market as complete Energy Storage Solutions and Modules ready for custom integration and this is the approach that has been applied in the Hampton system.

The Hampton project applies a generic Ecoult UltraBattery Energy Storage solution that is then customised at the application layer. The application uses highly task optimised algorithms which have been developed by CSIRO advanced mathematicians. The overall storage architecture provides a robust and operationally reliable environment for the application layer to then further enhance use of the storage asset.

Ecoult is following an approach of preparing the storage solution technology for application flexibly both in a system design sense and in an operational sense. This approach has now resulted in a strong storage solution platform approach.

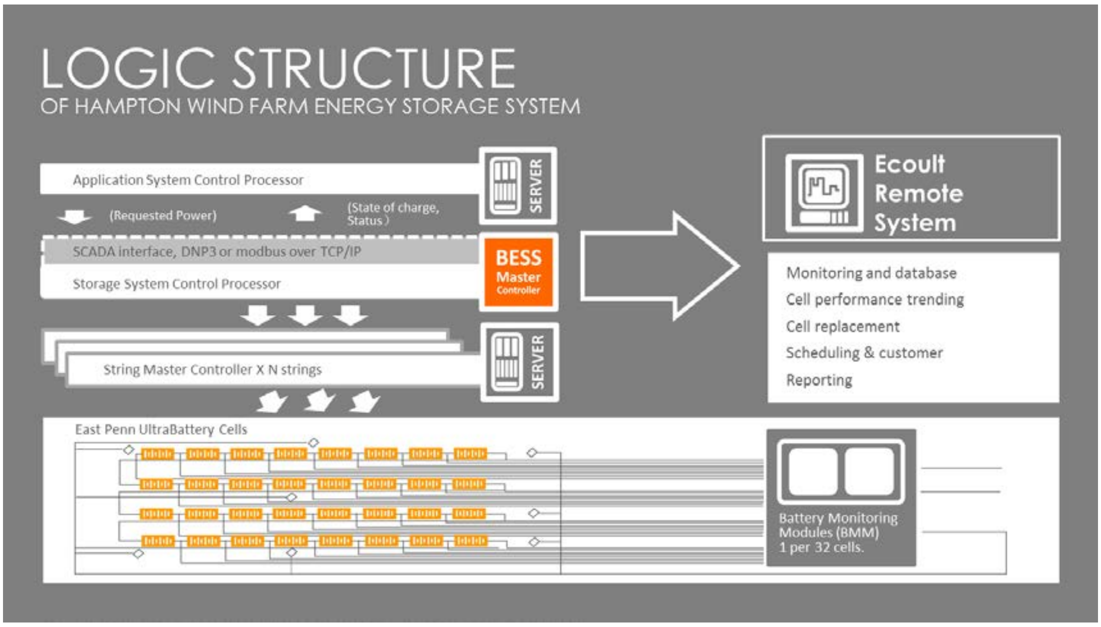

Figure 6 – Ecoult Energy Storage Solution Logic Structure

The logic architecture that underpins the Ecoult storage platform allows for the hardware configuration to use standard storage modules which can then be freely customizable in terms of MW and MWh capabilities (Figure 5).

When implementing our storage solution Ecoult ensured an open architecture approach for the Energy Storage Solution so that in consultation with a customer we could implement the power conversion system that was most suitable. Selection of, and integration to a suitable power conversion system is of course an essential part of implementing the energy storage solution. Ecoult has integrated its MW scale solutions with two different Power Conversion System (PCS) manufacturers and the solution can be ported to others. Figure 6 below shows the single line for the Hampton Wind Farm Project. In this case the solution uses a Purewave™ PCS that was purchased from S&C Electric Company to provide power conversion and grid integration. It is controlled by control signals generated within Ecoult's Battery Energy Storage System (BESS) Master Controller which are generated at the Application Level utilizing the advanced CSIRO algorithms as a function of the energy smoothing and shifting objectives, the state of the storage, and power quality demands. Ecoult offers turnkey accountability for the full Energy Storage Solution where Ecoult procures the Power Conversion System as part of an overall Ecoult system.

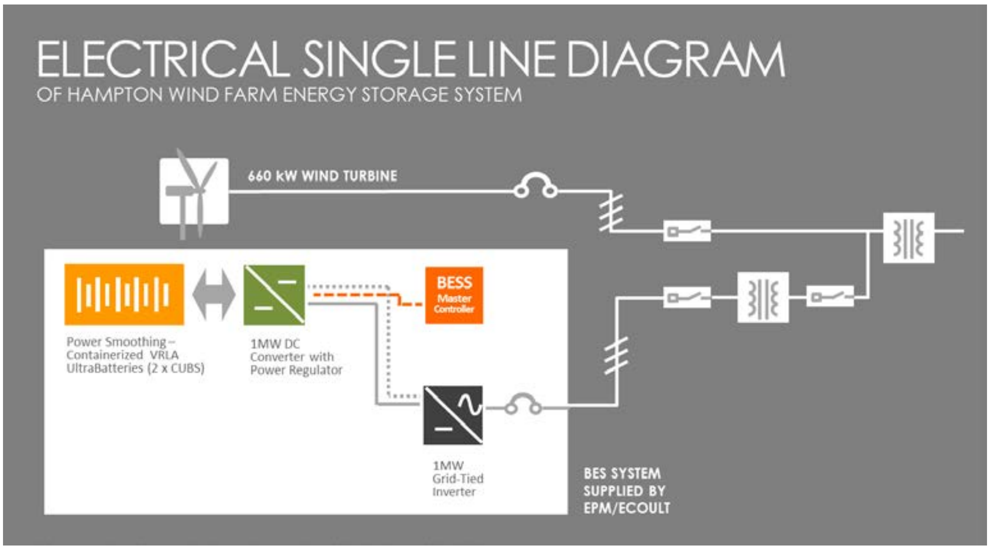

Figure 6 – Electrical Single Line Diagram of Hampton Wind Farm Energy Storage System

HAMPTON WIND SMOOTHING AND DEVELOPMENT OF THE SMART ALGORITHMS

Separating the storage and its battery management system from the application layer supports greater flexibility and innovation in use of the energy storage asset.

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

CSIRO's Storage for Renewables team led by Dr Peter Coppin has been utilizing the skill of mathematicians to progress the development and testing of intelligent algorithms to run as the application layer of the Ecoult Energy Storage Solution at the Hampton Wind Farm.

The project to implement a wind smoothing system at Hampton wind farm in NSW, Australia, followed a path of progression from laboratory trials, through a 100kW trial to a full MW-scale commercial system. Initial results from the first stage of the system show that with a simple proportional-integral, fixed parameter algorithm, significant reductions in rates of change of power output (ramp rates) can be achieved. Figure 7 shows results from one day with a variety of wind conditions. The lower traces show the raw turbine input and the smoothed output when combined with the storage system. The upper traces show the reduction in 5-minute ramp rate which averages a factor of 7. The 1-minute ramp rate reduction achieved by the system is a factor of 10.

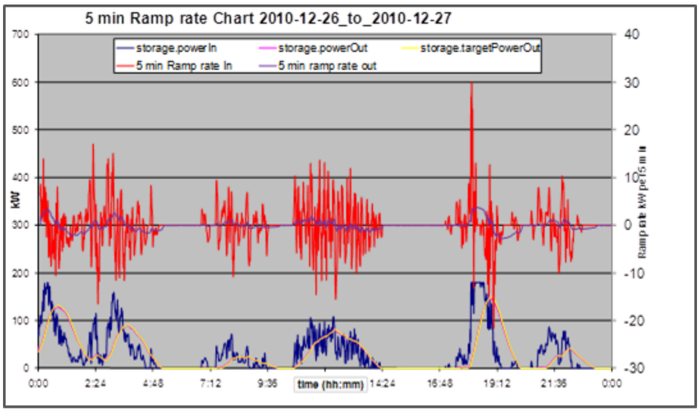

Figure 7 – Smoothing of Wind Output and Ramp Rate Reduction With Fixed-Parameter Controller Algorithm

A more advanced algorithm system is now being developed. The system, shown in Figure 8, works as an adaptive scheme which allows the smoothing parameters to be continuously changed. An offline optimising scheme is used to design the functions used in real-time. The optimisation takes into account a number of objectives (goals) and costs while being aware of system electrical and physical constraints. The system can be re-optimised for each installation.

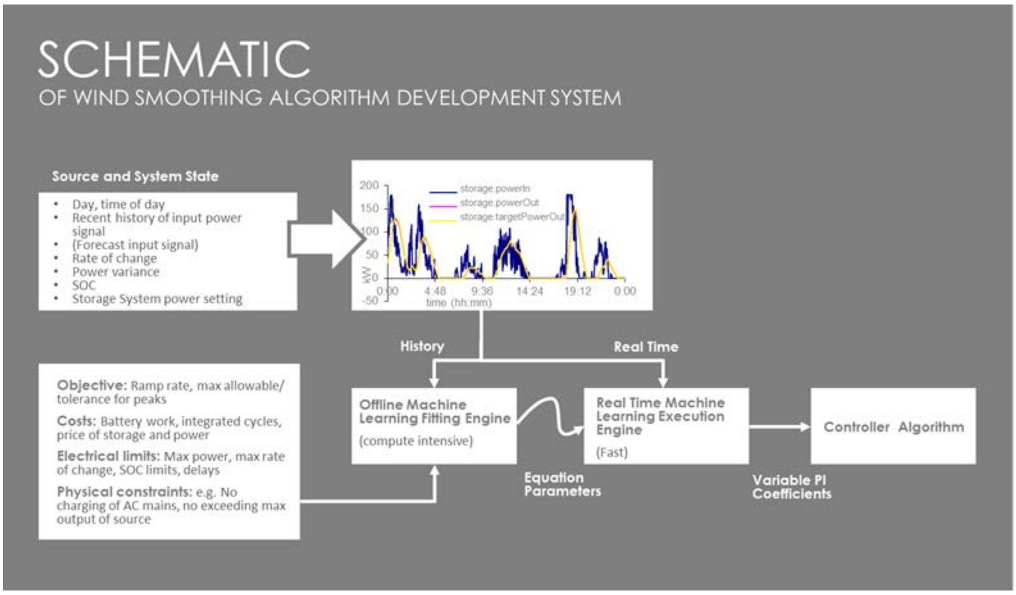

Figure 8 – Schematic of Wind Smoothing Algorithm Development System

The offline learning mechanism uses a quantum particle swarm optimisation algorithm. This is a meta-heuristic search method that copes well with highly non-linear objective functions and lends itself to parallelisation. This allows the optimiser to use of all 32 cores on a CSIRO multicore computing server. A 21 day training data set composed of a combination of challenging periods is used to evaluate the quality of adaptive parameter settings.

The learning engine is used to create functions for the execution engine. This engine generates PI variables in real time based on current conditions and derived from the learning that are in turn provided to the storage controller and used to generate charge and discharge commands to the batteries.

Initial trials show a significant improvement is possible using this approach.

Figure 9 shows the result of a simulated comparison where the Standard fixed parameter PI algorithm is run against the same wind data sample as the new Adaptive algorithm.

In this case the adaptive mechanism has achieved a result where it has achieved a superior reduction in the 5 minute ramp rate over the standard fixed parameter algorithm and significantly reduced the high frequency noise in the signal. As a result of the training the adaptive system recognised that wind conditions had been comparatively low for a period and anticipated the storm front that moved through by moving the state of charge of the energy store lower to where it had head room to react more efficiently.

The architecture approach with the adaptive mechanism allows for many variables to be considered during the learning and for performance to be optimised against a number of targets. For example minimisation of battery use has now been combined into the parameters optimised by the Hampton algorithm and CSIRO testing has shown that using the methodology the amount of energy passed through the energy store to achieve the ramp rate objectives can be significantly reduced while maintaining system performance.

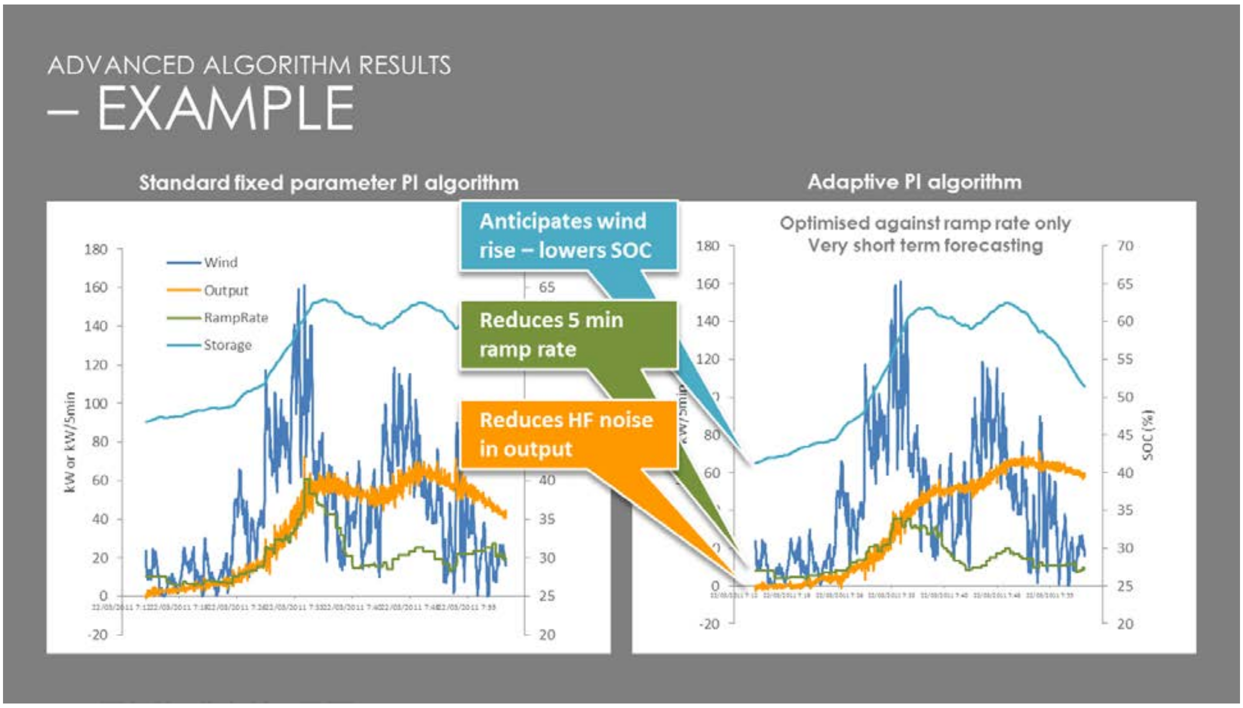

Figure 9 – Comparison of Standard Fixed Parameter PI Algorithm and Adaptive PI Algorithm

Summary

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 UltraBatteries used at Hampton (manufactured by East Penn Manufacturing in the USA) have exhibited this outperformance where the state of charge range is wide (40-60% +). 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.

We consider that systematic focus on reduction of the cost of each MWh of storage through endurance and longevity of the UltraBattery and use of the value derived from each MWh used through the intelligent algorithms, is the path to unlocking business case models with positive returns that will deliver growth in the storage industry and support energy storage contributing the impact it is capable of, and promises, in supporting higher penetration of renewables.

Economic implementation also requires that platforms be sound and standardised while delivering flexibility to developers who implement storage to deliver specific business objectives. The Ecoult Energy Storage Solution incorporating the UltraBattery has been developed to provide such a platform.

Finally, to make its full impact storage needs to become ordinary and simple to deploy, maintain, and recycle. 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 HRPSoC 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 is manufactured in the USA and available from Ecoult as a complete energy storage solution or storage modules. Manufactured by East Penn Manufacturing in Pennsylvania UltraBattery, it is supported cradle to grave.

The application and algorithm layer on Ecoult Energy Storage Solutions can be developed by customers, or by consultants, or channel partners, or by Ecoult. Ecoult can provide access to the CSIRO advanced algorithm engine and arrange access to consulting in this area on reasonable commercial terms.

Ecoult and CSIRO will be continuing to develop the Hampton solution and trial the effect of enhanced algorithms and will produce a final public report at the end of the project.

Ecoult would like to acknowledge the support of the Australian Government's Advanced Electricity Storage Technologies Program and the NSW Government's Climate Change Funding Program for the Hampton Project. The process of bringing UltraBattery to market has also been supported by the Australian Government via a "Climate Ready" and a "Start" grant and by the USA Department of Energy via a grant from the United States Department of Energy to East Penn Manufacturing to expand production capabilities for the manufacture of advanced lead-acid batteries including UltraBattery.

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