Storage – the necessity for a Smart-Grid

Craig Froome[1], Paul Meredith[1], Adrian Mengede[1], Geoffrey Walker[2], Jared Lillywhite
Mike Giulianini[3]
[1]The University of Queensland, Brisbane 4072
[2]Aurecon Australia, Locked Bag 331, Brisbane 4001
[3]RedFlow Pty Ltd, 1/27 Counihan Road, Seventeen Mile Rocks, 4073
Corresponding Author: c.froome@uq.edu.au

ABSTRACT

Energy policy is driving renewable energy deployment with most of the developed countries having some form of renewable energy portfolio standard and emissions reduction target. To deliver upon these ambitious targets, those renewable energy technologies that are commercially available, such as wind and solar, are being deployed, but inherently have issues with intermittency of supply.

To overcome these issues, storage options will need to be introduced into the distribution network with benefits for both demand management and power systems quality. How this can be utilised most effectively within the distribution network will allow for an even greater proportion of our energy demand to be met through renewable resources and meet the aspirational targets set.

The distribution network will become a network of smart-grids, but to work efficiently and effectively, power quality issues surrounding intermittency must be overcome, with storage being a major factor in this solution.

Keywords* : *battery storage, PV array, renewable energy

INTRODUCTION

The energy sector has forecasted significant increases in demand over the next decade along with rapid growth in renewable energy deployment within the grid. Most of this growth will be within distribution rather than transmission networks and as a result we will see network providers review their current grid operations and upgrade to provide for greater two-way energy flows. As most commercially available renewable technologies are intermittent by nature, additional demand management controls and battery storage options will be an emerging component of the roll-out of new ‘smart grids’.

In managing peak energy flows, demand management options can only be considered part of the solution, completed when coupled with storage and distributed generation with appropriate control systems. Depending on the needs of the grid, storage can be used to shape demand or improve power system quality – key issues created through the deployment of intermittent technologies.

The University of Queensland (UQ) as part of the 1.22MW solar array, has deployed a 400kWh RedFlow zinc bromine flow battery connected to a 390kWp sub array to model the effect that storage will have on the distribution grid. UQ provides an ideal test site, with peak demand exceeding 20MW and the photovoltaic (PV) array being able to deliver ~ 5% of this demand, using solar resources.

This paper discusses the preliminary results of storage testing undertaken and the impacts that will flow through to future distribution grid design, with a particular emphasis on peak load shaving.

Initially we need to consider why storage is needed with the introduction of a greater amount of renewable energy generation into the current mix.

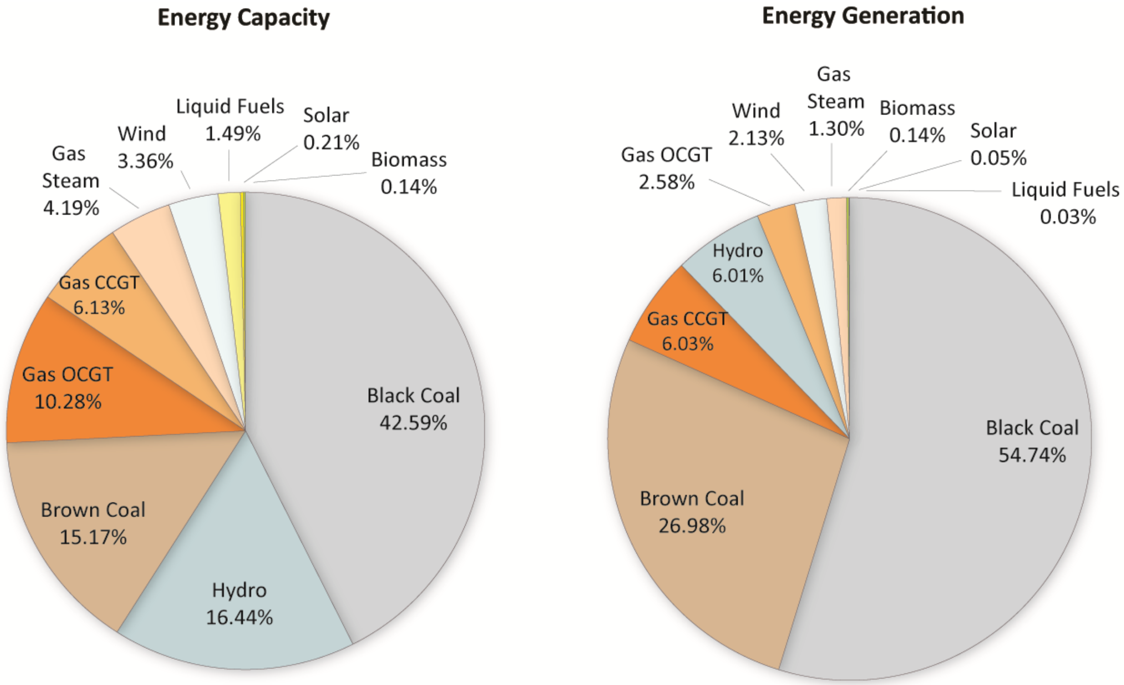


Figure 1 - NEM Capacity and Generation by Fuel Source 2009/2010
Source: (AEMO 2010)

Figure 1 sets out both the capacity and generation by fuel type currently within the National Electricity Market (NEM), which indicates that whilst coal only represents 57.76% of our energy capacity, it results in 81.72% of generation. This is further highlighted with the renewable resources representing 20.15% of capacity and 8.3% generation and gas providing 20.60% of capacity and 9.91% of generation. This highlights the intermittency of renewable generation and the extent of the stand-by gas plant.

Australia has a portfolio standard that requires 20% of generation be sourced from renewable resources by 2020 (although this has been set at 45,000 GWh, with 41,000 GWh attributed to large-scale generation) and without commenting on the likelihood of achieving this target, the above indicates that we will have considerable additional capacity compared to generation.

BATTERY STORAGE SYSTEM

The battery system is connected into the mains switch board for the PV array in the second of two identical carparks having identical number of panels and layout (providing a ‘business as usual’ case). This way the point of connection between the energy systems in the carpark and the University power grid is a composite of electricity generated from the PV and Storage. To facilitate this, the Switch Board and Sub Mains had to be upsized to cater for the possible case of simultaneous generation of

PV and final battery power configeration; in this case 339kW of PV and 120kW/360kWh of battery storage. High resolution energy and power quality metering has been installed on the carpark PV array and battery supplies at the carpark mains switch board. Another high resolution energy and power quality meter is installed at the UQ grid connection point at the relevant UQ substation. At the substation equivalent meters are installed to monitor the grid connection point of the carpark PV (also 339 kW) and the two distribution transformers (11kv/415V) which couple the PV output to the UQ high voltage network. At the local supply authority's connection point a further meter is installed on the particular UQ high voltage feeder feeding the substation.

The metering and system topology will allow for detailed monitoring of the relative effects of PV with storage and PV without storage under any number of trial scenarios.

Discussions with the local supply authority with respect to demand side management have indicated they require guaranteed dispatch of power and time shifting of power demand. As has been well documented, PV by itself is unsuitable to meet these demands (Hadjipaschalis, Poullikkas et al. 2009; Toledo, Oliveira Filho et al. 2010). The promise of storage is the ability to smooth the power generation (ride through or moderate short term power reductions due to passing clouds) and or move the power generation to coincide with network peak demand (generally 5 pm to 7 pm).

With regards approval for network connection the supply authority required compliance with a rigorous set of protection requirements including an extended delay before re-energisation after a power outage. In accordance with the operation of generating systems, the battery system was required to monitor mains and auto isolate in the event of loss of mains. Once mains power was restored the battery system is required to delay for a period of five minutes before any power flow to mains can occur.

The storage system being used (RedFlow ZBM) was designed for day-in day-out deep cycling – that is, storing electricity and then releasing it. It has a three to eight hour charge and discharge time, well matched to a daily charge and discharge cycle. This characteristic means it is ideally suited for use in large scale electricity storage, as so much of our daily generation and use of electricity also has a predictable daily rhythm:

- Daily peak usage of electricity in evening hours followed by minimal consumption in the early hours of the morning when consumers are asleep and factories and offices are closed; and
- A daily rhythm of the sun rising and setting, which means solar PV generation is also cyclical.

Zinc-bromine batteries are secondary flow batteries in which at the negative electrode Zinc is plated/dissolved according to the following reaction:

$$Zn_{(s)} \leftrightarrow Zn^{2+}_{(aq)} + 2e^{-}$$

Conversely, at the positive electrode bromine is reversibly reduced to bromide, following the reaction:

$$Br_{2\,(aq)} + 2e^{-} \leftrightarrow 2Br^{-}_{(aq)}$$

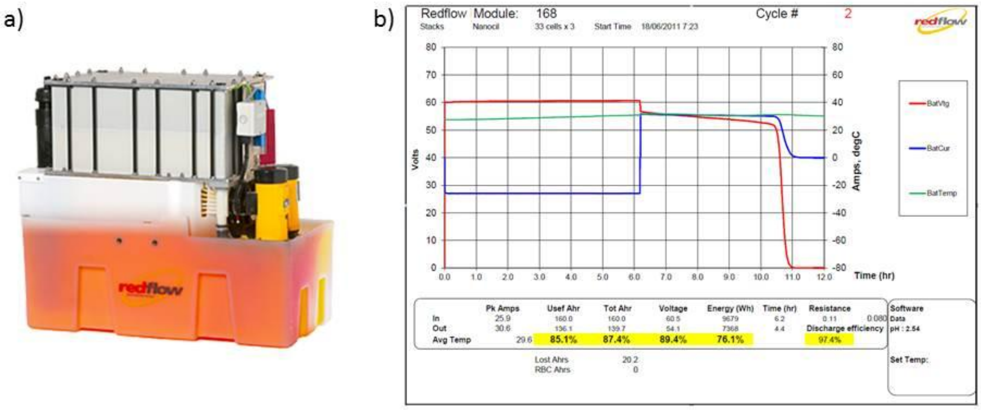
The overall cell reaction is therefore:

$$Zn_{(s)} + Br_{2\,(aq)} \leftrightarrow 2Br^{-}_{(aq)} + Zn^{2+}_{(aq)}$$

The measured potential difference is around 1.67 V per cell, with the advanced battery design features carbon nanotube enhanced conductive plastic electrodes and complexing agent improved electrolyte.

INITIAL TESTING RESULTS

In establishing the system, a RedFlow Generation 2.0 ZBM, pictured in Figure 2(a) has been installed which is rated at 5kW and 10kWh. It typically has a design Coulombic charge/discharge cycle efficiency of more than 85% and an overall energy efficiency of 76%, as depicted in Figure 2(b).



	Pk Amps	Usef Ahr	Tot Ahr	Voltage	Energy (Wh)	Time (hr)	Resistance	
In	25.9	160.0	160.0	60.5	9679	6.2	0.11	0.080
Out	30.6	136.1	139.7	54.1	7368	4.4	Discharge efficiency	
Avg Temp	29.6	85.1%	87.4%	89.4%	76.1%		97.4%	

Lost Ahrs 20.2
RBC Ahrs 0

Software
Data
pH : 2.54
Set Temp:

Figure 2 - RedFlow M15

The M15 unit installed at UQ features six ZBMs interfaced to the grid through SMA, Enatel and Outback power electronics. During the day, part of the energy provided by the sun is stored in the M15 system, with the initial testing set at the M15 charging phase selected between 8:00 AM to 5:00 PM when the photovoltaic power is generated. At 5:00 PM, the ZBMs are fully charged while the power contribution from the solar array to the grid is slowly decreasing.

The system then starts the discharge phase in which a controlled power of 15 kW is fed into the grid reducing the net power consumption of the UQ facilities. Figure 3 shows the power flow from two weeks of the M15 cycling at UQ.

The average length of the charge phase is 10 hours correspondent to the sunlight hours in an average day. This choice consents to select a conservative charging rate extending the battery life. Conversely, the discharge phase is carried out at higher power, on average 2.5kW per ZBM for the first 2 hours (15kW) and a slowly reducing power for the next 4 hours.

During the period 14 to 16 of August 2011, the overall delivered power is reduced to 12.5kW. This is due to the scheduled servicing of one ZBM during normal operation. As can be observed, the system continued to work demonstrating the redundancy and robustness of the architecture based on multiple 5 kW Zinc-Bromine modules.

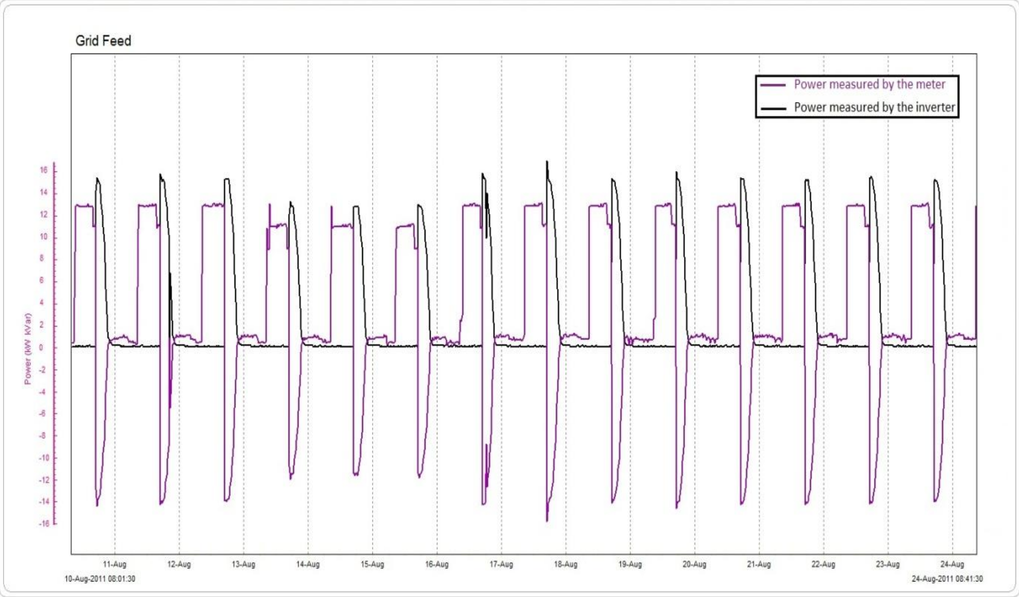


Figure 3 - Power flow during charge and discharge for the M15. The violet line is the power measured by the meter and it is positive during charge and negative during discharge. Conversely, the black line is the power measured by the inverter (used only in discharge) and it is positive during discharge.

Figure 4 provides more detail, with voltage and the current curves during the charge and discharge phase for two ZBMs in the M15. As can be observed, the ZBM voltage is 62-64 V during the charge at 30 A and 56 to 50 V during the discharge. At the end of the discharge, the ZBM is completely emptied (stripped) by performing a full discharge down to 0 V. This process removes any residual zinc deposited on the electrodes ensuring the restoration of the long-time operating conditions and extending the battery life.

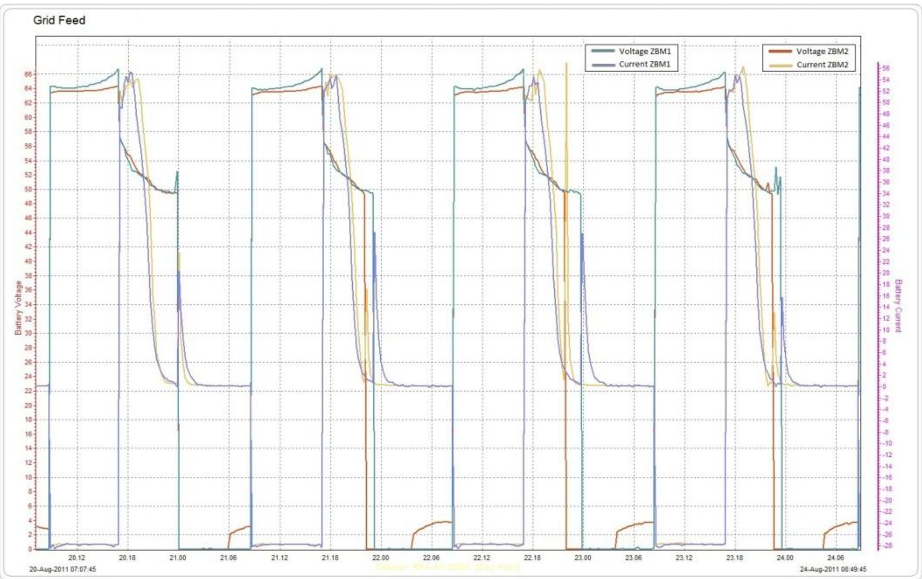


Figure 4 – Voltages and currents during charge and discharge of Zinc-Bromine batteries 1 and 2 in M15.

During the strip the battery is isolated from the circuit and fully discharged therefore high currents, up to 60 A as reported in the graph can be observed.

The system is completely automated, with performance and diagnostic real-time parameters logged continuously on the RedFlow server. The system health and performance are continuously evaluated allowing the detection of failures in the early stages and therefore avoiding breakdowns and loss of power.

This has allowed the battery storage designers to scope the design for the M120, an improved version of the M15. The fundamental changes regarding the system architecture and the power electronic firmware (designed for RedFlow by SMA) assure superior performance and extended features which include: -

- 120kW / 360 kWh;
- Full four quadrant operation;
- Phase balancing (Tri-Phase connected system); and
- Run mode (Solar power instantaneous backup to reduce renewables well-known intermittency).

Figure 5 shows the system architecture designed in order to fit in a 20-foot Hi-Cube shipping container. Side doors allow lateral access for the battery loading. The system features 24 SMA Sunny Backups and 36 ZBMs. The new firmware reduces the power electronics and simplifies the hardware.

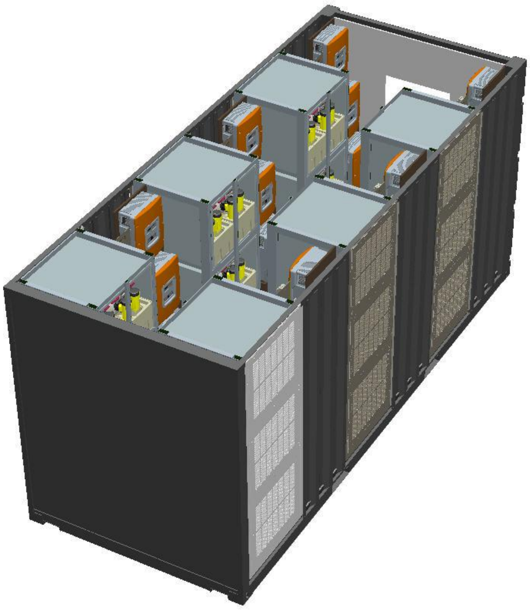


Figure 5 – RedFlow M120 3D view. Six racks of batteries each containing six ZBMs are interfaced to a Tri-Phase grid through SMA power electronics.

FURTHER RESEARCH

The battery storage system currently in place has performed in accordance with expectations whilst also ensuring that any potential grid integration problems have been resolved prior to the installation of the larger M120 unit.

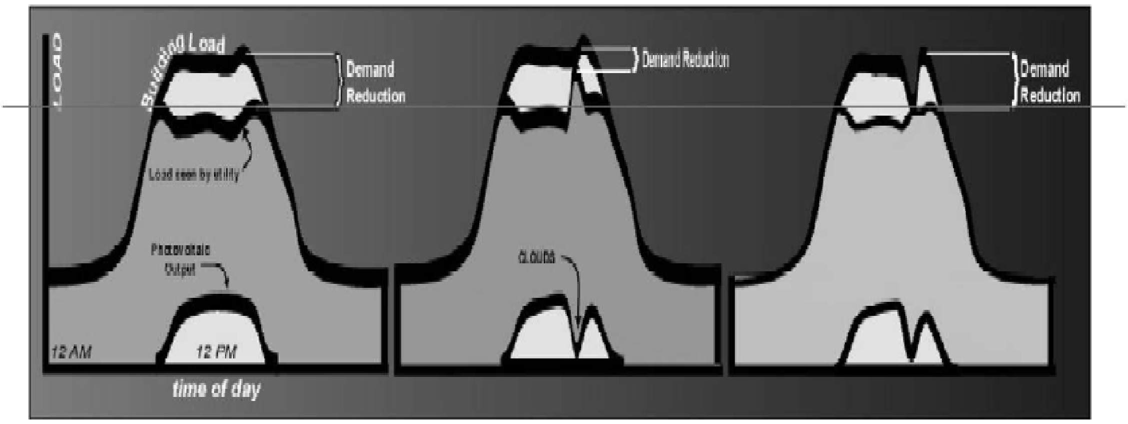


Figure 6 – Effects of Storage
Source: (Perez, Hoff et al. 2003)

Once the new unit is installed, it will be used primarily for research purposes, with the timing of the periods of charge and discharge varied to determine the optimum use of storage with potential options shown in Figure 6. The battery maybe charged overnight when grid demand is at its lowest (from 12:00 AM) and discharged mid-morning (noting that UQ peak demand is at mid-day) and recharged during the day for discharge during the grid peak in early evening.

Apart from looking at peak load shifting, further research will be undertaken to look at power systems quality issues. Looking at UQ's solar array generation, the intermittency issues due to clouding are evident (refer to www.uq.edu.au/solarenergy).

By undertaking a number of research projects covering both peak load shifting and power quality issues, the optimal use of battery storage for both the user and the supply authority can be determined.

CONCLUSION

For large scale deployment of intermittent renewable energy technologies, such as solar and wind, storage is a necessity. There will also be significant benefits for wave and ocean technologies currently being developed that also have significant power quality issues). As the above technologies continue to be commercially developed and deployed on a larger scale, grid integration, primarily through supply authority requirements, will be limited if storage is not included as part of the initial connection proposal.

We have already seen in the United States that as a result of high levels of solar and wind deployment and low levels of grid inter-connectors between the states (particularly in the south-west), electric companies are requiring integrated storage solutions as part of any proposed large-scale renewable energy projects prior to negotiating an off-take agreement.

Whilst there are benefits in storage for both the owners of the generating plant and the supply authority, this research will quantify those benefits and determine how storage can be optimally integrated into grid connected renewable energy systems.

For renewable energy to reach portfolio standards set and allow us to move towards establishing localized smart-grids, not only in Australia but also internationally, storage will not be an optional extra, but a necessity.

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