Redflow

Understanding the RedFlow Battery

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advanced energy storage

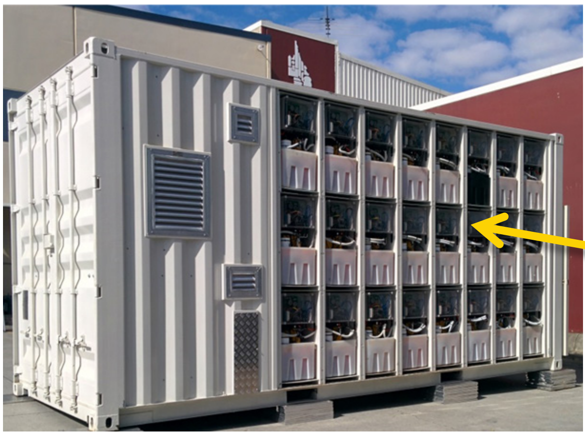

Figure 1.The Redflow large scale battery system **(LSB)**

Figure 2.The Redflow zinc bromide module **(ZBM)**

Introduction

Flow batteries are a well understood class of energy storage device. To date, production flow batteries been relatively large in terms of both physical size and storage capacity. Redflow has successfully designed and commercialised a small, modular, flow battery based on Zinc-Bromine reactants and referred as ZBM (Zinc Bromine Module). The ZBM has proven to be very versatile and is being successfully used for a variety of energy storage applications.

In this white paper the Redflow battery technology is described with the intent of focussing on the flow battery advantages, resilience and robustness. After introducing the battery, its underlying composition is discussed. Key advantages of this technology are listed, along with the design choices that made the ZBM the reliable and robust battery that is today. Finally, it will be will broadly addressed the topic of ZBM integration and installation, while noting that specific application notes and design guidelines can be found on the Redflow website.

The Redflow ZBM at a glance

From a strictly electrical point of view, the ZBM battery presents very good characteristics. In its base configuration, addressed as ZBM, it is a 210Ah, 48V nominal battery (a nominal energy storage and delivery capacity of 8kWh at a typical roundtrip efficiency of 80%), with voltage range between 36V and 57V. Without any ageing effect, it can be charged and discharged completely at rates up to 3kW and operated in a wide range of ambient temperatures as long as the electrolyte is kept between 10 °C and 50 °C (beyond these limits the ZBM automatically suspends operation to protect itself). The roundtrip efficiency of the battery is above 80% and the life is warranted for a minimum of 1000 cycles at 100% depth of discharge (DoD) for a total of approximately 8MWh of energy throughput.

Since the ZBM is a flow battery, it features approximately 100 litres of water based solution of Zinc-Bromide salt flowing around in two separate hydraulic circuits. During the charge phase, the Zinc is extracted from the liquid phase and plated onto carbon based electrodes. During a discharge phase, the Zinc is de-plated and restored inside the solution.

The ZBM is entirely managed by an on-board Module Management System (MMS). The MMS controls battery operation and protects the battery against misuse. The MMS also

provides access to the battery status, real-time data, event log, alarms, warnings, etc.
A picture of the ZBM battery is shown in Figure 1. The L-shaped tanks filled with the electrolyte are visible at the base. At the top, the electrode stack and the MMS box are visible.

Flow battery characteristics

In its general definition, a flow battery features an electrolyte flowing, continuously or not, between a storage compartment (i.e. one or more tanks) and a reaction chamber where the electrodes are placed.
A battery of this kind is mechanically more complex than standard batteries like Lead Acid or Nickel Cadmium where there are no moving and no minimum electrolyte flow rate that must be maintained during battery operation.
A flow battery is composed by larger number of parts and it is characterised by an added design complexity featuring moving parts and sophisticated chemical containment. These batteries are normally deployed in stationary applications as the electrolyte flow (and therefore the electrical performance) can be **negatively affected by the system vertical alignment, or by changes in momentum or inertia**
The ZBM on-board module management system (MMS) that controls and safeguards the battery adds an active element to each battery that is not present in standard batteries. While this makes the battery more overtly complex, the MMS provides key functions to allow the ZBM to be self managing and to protect itself against potential environmental or operational damage risks.
Active interfacing to the MMS in a deployment design is optional; If a ZBM is used to replace a conventional battery in a system design, a charge cycle is commenced by simply presenting an appropriate charging voltage and current to the ZBM. The MMS responds to this voltage by commencing a charge cycle. Likewise, a discharge cycle is commenced by simply drawing power from the battery, with the MMS managing the underlying active components to deliver the energy to the external load as required.
A common characteristic of flow batteries (including the ZBM) is the complete discharge that the battery can encounter during normal operation. Unlike a conventional battery, a complete discharge is harmless to a ZBM.
However, this 100% discharge capability results in the battery output voltage falling to zero volt and the on-board MMS halting operation.
This is a circumstance that a conventional battery management system may report as an alarm or may respond to in turn by halting system operations.
Once fully discharged, ZBM operation is re-commenced by simply applying an appropriate charge voltage to the system. In response, the MMS re-starts and commences a ZBM charging cycle.
As a consequence, the design of a system incorporating ZBM modules needs to be structured accommodate this 100% discharge and re-start scenario as a normal part of ZBM operations.

ZBM Self Maintenance Cycles

Periodically the ZBM *must* be completely discharged (in the manner previously noted) as a self-maintenance requirement in order to maximise the surface area of the battery electrode surfaces.
This 'electrode scrubbing' operation is engaged automatically by the ZBM through the MMS on a periodic basis if the battery has not been recently discharged to zero during normal operations.

This operation is a typical flow battery characteristic that needs to be accommodated in system designs using the ZBM.

For single battery system designs, the design must therefore accommodate short periods where the ZBM is effectively 'off' at the end of a scrubbing cycle.

For multiple battery designs, ZBM batteries can communicate with each other and pass a 'token' using their MMS controllers and a simple interconnection cable. The automated communication ensures that a maximum of one battery will be undertaking a scrubbing operation at any given time, so that there are always energised batteries available to the system overall.

For the Redflow LBS (a grid-scale energy storage system using up to 60 ZBM batteries in a 20 foot shipping container form-factor), ZBM scrubbing is transparently managed within the included LBS control system.

In the LBS, only a few batteries out of 60 will ever be scrubbing at a given time, resulting in only a trivial reduction in energy storage and output for the LBS overall when this automatic cycle is being undertaken.

The flow battery advantages

The various flow battery characteristics discussed to this point can be leveraged to create unique advantages in a system design built around the ZBM.

As for most of the flow batteries, the Redflow ZBM features the separation of the energy part (the tanks filled with the electrolyte) and the power part (the stack composed by electrodes). This separation enables uncommon advantages for flow batteries, such as recycling, refurbishing and repair of the battery parts.

In particular, the Redflow electrode stack can be replaced when it reaches end-of-life, while preserving other elements of the ZBM.

As the electrode represents less than 50% of the total cost of the battery, this provides for a very cost effective second 'lifetime' for a given ZBM by performing a 'stack swap'.

This is a cost-effective path to doubling the overall lifetime of the ZBM for a swap cost of around half of the original battery cost. Accordingly, the effective cost per kilowatt-hour for operating a ZBM installation in the long term reduces markedly during this second 'lifetime' of a given ZBM.

When factored into the total cost of ownership, the ZBM becomes an extremely cost effective and long-lifetime choice for a variety of energy storage and delivery applications.

Where a conventional battery would have had to be completely replaced regularly in most systems, the ZBM enjoys a cost-effective 'second life' in this situation.

For these reasons, the Redflow ZBM is one of the most sustainable (and cost effective) batteries available today.

Another advantage of the 'unconventional' ZBM battery compared to conventional storage batteries (such as lead-acid) is the reduced attractiveness of the ZBM to incidences of theft in the field.

Conventional battery banks composed of several 2V, 6V or 12V batteries are considered attractive targets for theft, as the single elements can be sold or reused.

Because of its weight of approximately 250kg, the ZBM is not subject to the routine incidences of opportunistic theft that conventional batteries often suffer in remote field applications.

In addition, the specific characteristics of the ZBM, as already discussed, mean that the battery will be of little use to a potential thief outside of the application for which it has been designed.

The separation of power and energy components in the ZBM also allows for an almost immediate shutdown in just a few seconds, by interrupting power supply to the flow pumps. Since no reactants are supplied to the electrodes when the pumps are shut down, electrical energy cannot be transferred and the system is total quiescent.

This in turn allows for the very safe transport of ZBM's in this fully shutdown state.

In addition, a ZBM suffering mechanical damage will not be at risk of explosion,

dangerous high current output from short-circuit, or of thermal runaway.
This characteristic (together with the water based electrolyte) makes the flow batteries inherently safe and reduces to a minimum the risks of fire and thermal runaway in small, medium or large energy storage systems. Additionally, the electrolyte flow favours even heat distribution across the battery which contributes to an easier thermal management of the battery and more effective cooling capabilities.
Regarding the MMS, it can be observed that in general terms, a battery equipped with the manufacturer Battery Management System (BMS) and data communication can offer a multitude of advantages.
Firstly, the battery can be accessed at any time and can provide information about status, real time data, diagnostic and event history. All these features contribute to improve the control of the system (local or remote) and its performance. Moreover, reliability and fault tolerance also benefit from the employment of a 'smart battery'. Additionally, the MMS provides active protection for the battery and the system against misuse, damage or extreme operating conditions (e.g. voltage, temperature). This improves safety and longevity of both the system and the battery, minimising also failures and early replacements. The MMS can also be extended in its functions, giving the battery a central role in the system for example in applications where no other intelligent device is available. Common desirable extended functions of the MMS are: data logging and extraction, fault signalling (email, sms, etc.), auxiliary software controlled I/Os, etc.
Finally, the 100% depth of discharge of the flow battery can be very advantageous in many applications were other batteries struggle. As the battery can stay partially or fully discharged for an indefinite time (with no degradation) it becomes the best choice for applications in which the usage of stored energy can be scheduled and periods of idle are common. For example in solar applications, the battery can be started at 0% state of charge every morning and used to store the excess energy supplied by the Sun during the day. The entire capacity (100%) of the battery is available for Sun generated energy. At any time during the day or the night, the battery can be discharged partially or back down to 0% state of charge and can be safely left in this condition overnight. If the next day no Sun energy can be supplied to the battery, no ageing of the flow battery will happen.
In comparison, other batteries must start the day at a higher state of charge (for example 50%) to avoid deep discharge states that could age the battery faster. This limits their practical daily energy storage capacity. When the stored energy is needed, the batteries can be discharged back to 50% but no further discharge is allowed. The circumstance is further complicated if the next day no energy can be supplied by the Sun as the battery life and capacity is negatively affected by deep discharge conditions (leading to sulfation).
The capability for safe and complete discharge of the ZBM battery can also be used to advantage in diesel backup generator minimisation applications.
Hence a key difference with ZBM compared to other battery technologies in this case is the better sizing of the energy storage system that can be achieved using the 100% capacity of the flow battery.
It is *very* important to factor this large difference in useable capacity for a ZBM into comparisons of battery system capacity.
A conventional battery requires the reservation of a large proportion of the theoretical battery capacity in order to protect the battery from damage or reduction in useful life that would be caused by 100% depth-of-discharge conditions.
A conventional battery can also take a long time to fully charge, with charge-rate falling as the battery approaches the completely full state.

Accordingly, even more theoretical battery capacity is usually reserved away from the application in practice, in order to accommodate this battery characteristic.
By contrast, a ZBM can be operated routinely from 0% to 100% state-of-charge and back to 0%, for every operational cycle, without loss of performance and without risk of battery damage.
In addition, charge and discharge cycles for a ZBM operate at a near linear voltage and current levels across the entire range of charge states.
This allows a ZBM to be charged on a near-linear basis. It also allows the entire ZBM capacity to be usefully delivered to the required system load, output current and voltage also remaining consistent and stable across the entire discharge phase.
In cases of extremely remote applications where site access is not easy (e.g. seasonal impediment, transport difficulties, etc.) ZBM flow batteries can be preferred for their tolerance to long power outages.
Some other advantages are directly generated by the ZBM physical and mechanical characteristics. For example, the standard ZBM battery produced features 30 cells in series directly interconnected to reach 48V nominal voltage. This is the battery that is tested and characterised in terms of lifetime performance and reliability. Other technologies run the tests for the single cell, for example the 2V cell (for Lead Acid chemistry) and no information is provided on the performance of the 24 interconnected cells needed to reach the 48V.
Another advantage is related to the ZBM sealed assembly and the corrosion resistant materials used. These features make the battery ideally suited for extreme condition environments. A summary of the Redflow battery complications and advantages is reported in the following Table 1.

ZBM Feature	ZBM Disadvantage	ZBM Advantage
Higher parts count	More complex physical system	Recycle, Repair, Refurbish
Stationary, 250kg weight	Unsuitable for some physically mobile applications	Very small potential for theft
Separation of power and energy components of battery	Electrolyte in motion during battery, necessary battery control and management components.	Immediate shutdown possible, easy thermal management, intrinsically safe after physical damage, very safe for transport/delivery, stack can be replaced to extend battery life, extremely long storage life in quiescent state.
On-board MMS	System integration effort	Smart battery
Supports 100% Depth of Discharge	System integration effort	100% of energy storage and delivery cycle available
Sealed and corrosion resistant	-	Suited for extreme environments

Table 1

The ZBM design

Although flow batteries proved to be a good choice for a large number of applications, most of the installations worldwide fall in the class of large scale systems where the battery is custom made for the specific purpose.

Redflow's approach to commercialise a modular, small scale battery enables the flow battery to be employed in additional applications previously considered too small for flow battery deployment such as residential, industrial and telecommunications.
The Redflow LBS combines up to 60 ZBM modules into a shipping-container form factor to deliver large scale modular energy storage capacity suitable for renewables integration, and Uninterruptable Power Supply systems applications.
In addition the LBS is itself modular, allowing multiple LBS units to be deployed for grid-scale energy storage and load-levelling applications.
In order to use one battery for all purposes some key design choices had to be made to match all the possible employment scenarios of the battery. In this section, some the crucial design choices are discussed.

Mechanical design

The mechanical assembly of the battery features an easy-to-remove stack placed at the top of the battery. This allows for stack replacement and battery refurbishment as discussed earlier. Two tanks, with one-inside-the-other, provide interstitial space to catch potential electrolyte spill and improve the simplicity of the assembly. Additionally, the MMS sealed box has been frontally collocated to avoid direct exposure of the battery terminals and to facilitate the cabling access.

DC pumps

Redflow has co-developed a role-specific advanced DC pump for the ZBM. This pump delivers a multitude of advantages. Firstly the power for the pumps can be supplied directly by the battery itself without AC components being required. The DC pumps employed by Redflow feature brushless motors that offer superior performance in terms of life, noise, torque, reliability and robustness. An important feature is also the capability to dynamically adjust the pump speed (and hence the flow speed) according to the charge or discharge rate required. This offers an improvement in overall battery efficiency and extends the life of the pumps. Pump flow rate is monitored by the MMS and this also allows pump failure to be detected and reported.

Cooling apparatus

The ZBM is equipped with an internal cooling apparatus which has been designed to extend the operating temperature range of the battery allowing operations up to 50 °C for the electrolyte temperature without any negative effect on the battery life.

Advanced MMS

Since a battery for storage application is conceived as a plug-and-play device, Redflow developed a smart battery which can appear like a standard battery but that can also work independently from the surrounding system. This has been achieved by using an advanced MMS which can perform independent operations and take action when needed. Some operations can also be started with external commands so the system integrator can adjust or drive the response of the ZBM through the system controller in order to have the battery work appropriately with an existing system.
For the majority of the applications though, the overall system's control unit will not need to access the ZBM's MMS. Some examples are provided in the following section.

Operational features

The ZBM design has been optimised for telecommunication applications therefore the following features are available: Voltage range adjusted for standard Lead Acid systems with a maximum charging voltage up to 57V and a low voltage disconnect at 42V, extended high-end temperature range, no ageing due to deep discharge and long discharged periods, low maintenance.

Additional features have been added for integration with renewables and interfacing with advanced monitoring. For example, an electronic protection for overcharge (not affecting the instantaneous discharge) has been introduced for direct connection to solar panels and renewables.

Moreover, several ZBMs can be connected in parallel without adverse inter-battery current flows due to differences in charge/discharge state. No protection devices are required in this configuration, and no unwanted flow of power can be observed among multiple ZBM modules connected to the same DC bus.

For residential/industrial applications the ZBM can be used with commercially available inverters to provide backup or renewables shifting. ZBM monitoring can be easily integrated in more complex supervisory systems.

For large energy storage applications with the LBS product, ZBM modules are connected in series to reach higher voltages. The de-facto standard is the 600-800V range. For this application Redflow designed a variation of the MMS module that allows for series connection without affecting the ZBM protection and access to the battery information.

ZBM control using the MMS

In order to communicate with the MMS, Redflow developed a short and simple data protocol. It follows the MODBUS RS485 standard and it is based on registers that can be accessed for reading alarms and warnings as well as data points like for example voltage, current and the battery state of charge. A protocol specification can be found on the Redflow web site

Redflow also developed the ClusterMonitor program that can be downloaded from the Redflow website. The program allows the user to monitor and log the data of up to 6 ZBM batteries connected in parallel. If combined with a rugged industrial PC, the ClusterMonitor already proved to be a robust and reliable RTU for remote energy storage applications. More details on the ClusterMonitor can be found on the Redflow web site.

ZBM as a pre-charged generator

One of the most exciting operational modes of the ZBM is the storage mode in which the battery act as a pre-charged electrical generator. The ZBM can be charged and left unattended for months, with no self-discharge taking place and therefore no need of trickle charge, equalisation or conditioning. During this period the voltage on the battery terminal can decay down to zero Volts even if the battery can retain up to 80% of its original state of charge. In case of need, the battery can be restarted with a voltage of 36V and a power of 100W supplied for 20 seconds. After this time the battery can self-sustain and supply the entire energy stored (up to 8kWh for one ZBM). If more ZBMs are connected in parallel, once restarted the first battery can power up all the others and restart them in a few seconds.

The ZBM in storage mode can be used in conjunction with other batteries for UPS applications.

Today expensive Lead Acid battery banks are used with significant costs related to ageing, power consumption, weight and maintenance. It is estimated that the average size of the Lead Acid battery bank can be reduced by 90% by adding needed backup capacity with ZBM batteries. The capital and the operational costs will be considerably reduced. On a similar note, areas experiencing frequent blackouts can rely on ZBM working in storage mode. Without requiring any maintenance charge, the ZBM can be started in case of outage and can be used to power emergency lights and appliances. With a complete discharge every week for example, the battery can be expected to last more than 20 years, with no maintenance cost over the entire period.

ZBM Product portfolio

The Redflow ZBM is available in three different variations: ZBM, ZBM2 and ZBM3. The three types are characterised by the same mechanical dimensions and weight.

The first two types are characterised by the one-to-one compatibility with the standard voltage range of a nominal 48V battery bank. ZBM can supply up to 8kWh in output and is warranted for 10MWh of energy throughput. Conversely, ZBM2 can output up to 10kWh with a warranted energy throughput of 20MWh.

The ZBM3 is the advanced product designed with a large energy storage capacity specifically for residential and large scale applications. The voltage range upper limit is extended to 63V and up to 11kWh can be discharged from the battery. The ZBM3 is warranted up to 22MWh of energy throughput.

Future Developments

Redflow is actively working on further improving the ZBM technology. The self-maintenance ‘scrubbing’ cycle frequency and duration can be reduced through ongoing MMS design enhancements and via continuing electrode surface advances over time.

As for all batteries, further reducing self-discharge characteristics and extending the ZBM operating temperature range are continuing objectives.

Redflow also has ongoing work streams focussed upon lowering future component costs of the battery and toward ongoing simplifications in the production and manufacturing processes used to make the ZBM.

Conclusion

This article focussed on explaining the Redflow battery technology and its characteristics. Listing the ZBM flow battery features and advantages show why this type of battery is receiving far increased interest for energy storage applications.

The Redflow ZBM extends the range of applications for flow batteries into far smaller installations than previously though possible for this type of battery.

At the other end of the scale, very cost-effective grid-scale storage and grid-levelling is now available through flow battery technology by using the Redflow LBS.

This containerised product combines many ZBM modules to offer reliable and scalable energy storage into the Megawatt-Hour range.

New ZBM operational modes, only available with this technology, hold the promise to revolutionize UPS and emergency applications, along with other applications requiring extremely long battery ‘standby’ capabilities.

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Off-Grid Remote Power and Telcos

Renewable Energy Integration

Transmission and Distribution Deferral

Smart Grid