ORIGINAL INSTRUCTIONS V1

CE

ZBM3 Installation and Operation Manual

MNL-ZBM-003.1

redflow.com

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1 Introduction

1.1 Purpose

This manual is for Redflow's DC flowing electrolyte battery product, the Zinc-Bromine Module (ZBM). It provides information on the battery's installation, operation, and maintenance for nominal 48 Vdc systems. Installation of the ZBM must only be performed by trained installers.

1.2 About the ZBM

The ZBM is a DC flow battery with in-built electronic management. The ZBM is ideally suited to daily cycling of its full capacity and offers long cycle life energy storage in such applications. With appropriate ancillary circuitry, multiple ZBMs can be connected in parallel for increased capacity.

Figure 1: The ZBM

Note: When supplied, the ZBM is fitted with a bund but it is not shown in all images.

The ZBM's main components are:

- Electrode Stack
- Battery Control Module (BCM)
- Electrolyte and Tanks
- Analog Loom
- Pumps
- Cooling Fan
- Cooling Tubes
- Pressure Relief Valve
- Catch Can

Battery operation is controlled by the BCM. Operation of ZBMs must be kept within the boundaries of the operating envelope set out in Table 1 to ensure correct operation and to comply with warranty conditions; failure to keep within the boundaries will void the warranty. In applications where one ZBM would not be able to remain within the operating envelope, adding another ZBM may bring the performance of each ZBM back within the envelope.

Table 1: ZBM Electrical Operating Envelope

Power Rating *	Continuous charge power: 2.5kW Continuous discharge Power: 3kW Peak discharge Power: 5kW *Note: Refer to Section 10.4.3 for more information about peak power.*
Usable Capacity/Energy *	200Ah / 10kWh
Minimum Ah Output (end of life)	200Ah (standard cycle) Note: Standard test cycle is defined in Appendix C and is used for warranty claims.
DC Voltage Operating Range	40 to 58V DC
Absolute Voltage Range	0 to 70V DC *Note: ZBM have a terminal voltage = 0V on initial start-up and after maintenance cycles*
Auxiliary Power	180W maximum @ 40V DC minimum
Circuit Protection Maximum Rating	125A Note: Each ZBM must have a fuse or circuit breaker between the ZBM and the Power Control System DC bus.
Short Circuit Fault Current Rating	600A
Battery Operating Temperature Range **0-1000m above sea level****	**Charging:** 10 to 50 °C (50 to 122 °F) **Discharging:** 15 to 50 °C (59 to 122 °F) The battery temperature is the electrolyte temperature.
Allowable Ambient Temperature Range	Operation: 5 to 45 °C (41 to 113 °F) Storage and Transportation: -5 to 45°C (14 to 113 °F) Contact Redflow for advice if outside this range.
Self-Maintenance Cycle Frequency	Optimally every full discharge. A minimum of once every 72 hours of zinc pump operation. For warranty to be valid and battery performance to be maintained users must not override ZBM internal automatic self-maintenance procedures.
Stack Energy Efficiency*	80% DC-DC maximum
EMC Compliance	*Emissions:* EN61000-6-3:2007; *Immunity:* EN61000-4-2, 3, 4, 5, 6:2007
Approvals	CE RCM

* At beginning of life

** For altitudes between 1000m and 2000m upper temperature limit is 45.5°C (113.9 °F)

For altitudes between 2000m and 3000m upper temperature limit is 42°C (107.6 °F)

Contact Redflow to adjust the ZBM temperature limit to the correct setting if above 1000m

Any voltage exceeding the absolute maximum voltage specified in Table 1 will damage the electronics in the BCM if connected to the ZBM. Devices connected to the battery that produce voltages outside the allowable range and damage the ZBM will void battery warranty e.g. voltage spikes. For connected component compatibility contact Redflow.

The physical and communications characteristics of the ZBM can be found in Table 2.

Table 2: ZBM Physical and Communications Characteristics

Dimensions (ZBM)	LxWxH: 861 x 400 x 747 mm (34 x 16 x 30 in)
Mass (ZBM)	With electrolyte: 237 kg (523 lb) Without electrolyte: 80 kg (177 lb)
Dimensions (crated)	LxWxH: 1030 x 570 x 940 mm (40.6 x 22.5 x 37 in)
Mass (crated)	With electrolyte: 278 kg (613 lb) Without electrolyte: 121 kg (267 lb)
Orientation	The ZBM must be kept in an upright position (orientation shown in Figure 3) at all times of operation, storage, handling, and transportation. This is a warranty condition.
Electrolyte Volume	100 L (26 US Gal)
Module Geometry	One stack of 30 cells
Dangerous Goods Class	DG Class 8 for electrolyte or ZBMs containing any trace of electrolyte
Weather Protection	The ZBM must be installed indoors (out of weather) or in a weather-proof enclosure. This is a warranty condition.
Installation Requirements	ZBMs must be installed for stationary applications only on flat, level and fully-supported base surfaces. This is a warranty condition.
Transportation Requirements	ZBM must be transported in an original supplied crate/enclosure. This is a warranty condition.
Ventilation	During operation the ZBM must be adequately ventilated with minimum airflow of 50l/s (180 m^3/h) per ZBM not opposing the direction of ZBM cooling fan airflow. This is a warranty condition. During storage the storage area must be dry and appropriately ventilated. This is a warranty condition.
Humidity Conditions	5%-95% humidity, non-condensing. This is a warranty condition.
Explosive Environments	The ZBM is not intended for use in explosive environments. This is a warranty condition.
ZBM Bus Terminal Connection	Positive: 8mm (approx. 5/16 inch) eyelet Negative: 8mm (approx. 5/16 inch) eyelet
ZBM Bus Terminal Torque	10 Nm (7.4 lb-ft) (applies to bolts fitting cables to BCM)
Communications	RS-485 MODBUS RTU

1.3 Abbreviations and Definitions

The following acronyms, abbreviations and terms are defined here within the context of this manual.

Term	Definition
BCM	Battery Control Module
BMS	Battery Management System
ELV	Extra-Low Voltage
ESS	Energy Storage System
PPE	Personal Protective Equipment
SDS	Safety Data Sheet
SOC	State of Charge
ZBM	Zinc-Bromine Module

2 ZBM Safety

All low voltage (LV) wiring must be performed by licensed electrical personnel who are responsible for ensuring that all local and government regulations and applicable standards are complied with. This is a warranty condition and failure to comply will void the warranty.

The following safety rules apply for any operation of the ZBM batteries.

- Use tools with suitably rated insulated handles to make connections.
- No smoking near ZBMs.
- Check that cable connections between the ZBM and the rest of the Energy Storage System are tightened to the recommended torque value in Table 2 (10Nm), and torqued nuts and BCM are marked.
- Check DC cabling polarity to the ZBM is correct prior to powering the system up. Defects caused by reversed polarity void the warranty.
- Even when disconnected, a ZBM battery can remain charged and have voltage on any battery terminals (refer to Figure 4). Always check voltage before proceeding.

There are also four main areas of safety specifically relevant to the ZBM battery.

- Electrolyte characteristics
- ZBM battery voltage
- ZBM fire safety characteristics
- ZBM safety labelling

These are explained in detail in the following sections.

2.1 Electrolyte Characteristics

Ensure local government regulations and applicable standards are complied with when working with ZBM electrolyte.

The ZBM is a flowing electrolyte battery containing approximately 100 litres (26.5 US gal) of a water-based zinc-bromide electrolyte that includes additional supporting salts and complexing agents.

The electrochemical process of charging a ZBM battery alters the electrolyte. Zinc ions are plated out as metallic zinc, and bromide ions become linked with the complexing agents in the electrolyte to form a separate dense Bromine Complex phase.

2.1.1 Gas Emissions

Low levels of gas may be generated during operation of the ZBM. The gas is managed by the pressure relief valve. If the pressure exceeds the relief valve’s limit, gas is directed into the Catch Can, which uses activated carbon to capture gases thus reducing the concentration of any emissions that exit the ZBM. Regardless, energy storage systems containing ZBMs must be located in areas designed to ensure adequate ventilation. Refer to Section 10.2.3 for more information about ventilation requirements. Standards such as AS4086.2 (Section 2.7) also provide guidelines about battery room ventilation. Failure to provide adequate ventilation during both operation and storage will void the warranty.

2.1.2 Electrolyte Leaks

The presence of liquid electrolyte in the ZBM means that there is potential for a spill to occur. Any electrolyte leak or spill must be cleaned up in accordance with Appendix A.

STOP

Spills and leaks of ZBM electrolyte must be cleaned up as soon as possible by trained personnel. Until trained personnel are present, the area around the spill or leak should be quarantined.

The ZBM is packaged in a bund to contain a minor leak. To prevent electrolyte spillage during major leaks, secondary containment should be used.

2.1.3 Personal Protective Equipment (PPE)

The following, or equivalent, PPE must be worn when handling electrolyte or cleaning up an electrolyte leak.

Respirator: Moldex half-face pre-assembled respirator with multi-gas/vapour cartridges (available from Protector Alsafe (www.protectoralsafe.com.au), product code 8602A, part number 0109 0268)

Goggles: Bollé Blast Duo goggles (available from Protector Alsafe, product code 1669211, part number 0708 2904)

Gloves: Prosafe Premium 806 Blue PVC Gauntlets (available from Protector Alsafe, part number 0784 1563)

Spill kits should be kept on hand at all times, e.g. 62 litre Hazchem spill kits can be sourced from Global Spill Control at: http://www.globalspill.com.au/?gclid=CMTvvobp-64CFYJLpgodSBzjwQ.

There is approximately 100L (26.5 US Gal) of electrolyte in each ZBM, and while any leak would be unlikely to result in more than a few millilitres of electrolyte escaping, there is potential for a leak of up to 100L to occur.

Redflow's contracted global emergency contact can also provide additional details on how to clean up an electrolyte leak. Contact details are provided in the Safety Data Sheet (SDS).

2.2 ZBM Battery Voltage Hazard

A single ZBM can have between 0V and 58V DC on any battery terminals during operation. See Figure 5 to identify the battery terminals. While the ZBM should be fully discharged (terminal voltage at 0V) during transportation or storage, care must be taken in case the terminals are live.

2.3 ZBM Fire Safety Characteristics

The ZBM is an inherently low fire risk battery as its electrolyte is non-flammable and has many characteristics of a fire retardant (see Section 5 of the SDS).

As a failsafe measure, the ZBM's BCM automatically turns off the electrolyte pumps if it detects a leak. This prevents further electrolyte from being introduced into the battery's stack so the battery cannot self-sustain an energy discharge. While there will be a slight increase in temperature, these measures help prevent stack overheating.

2.4 Safety Labels

The ZBM label is located on top of the electrode stack and on the tank below the BCM. Figure 2 shows an example of the ZBM label and the information it conveys.

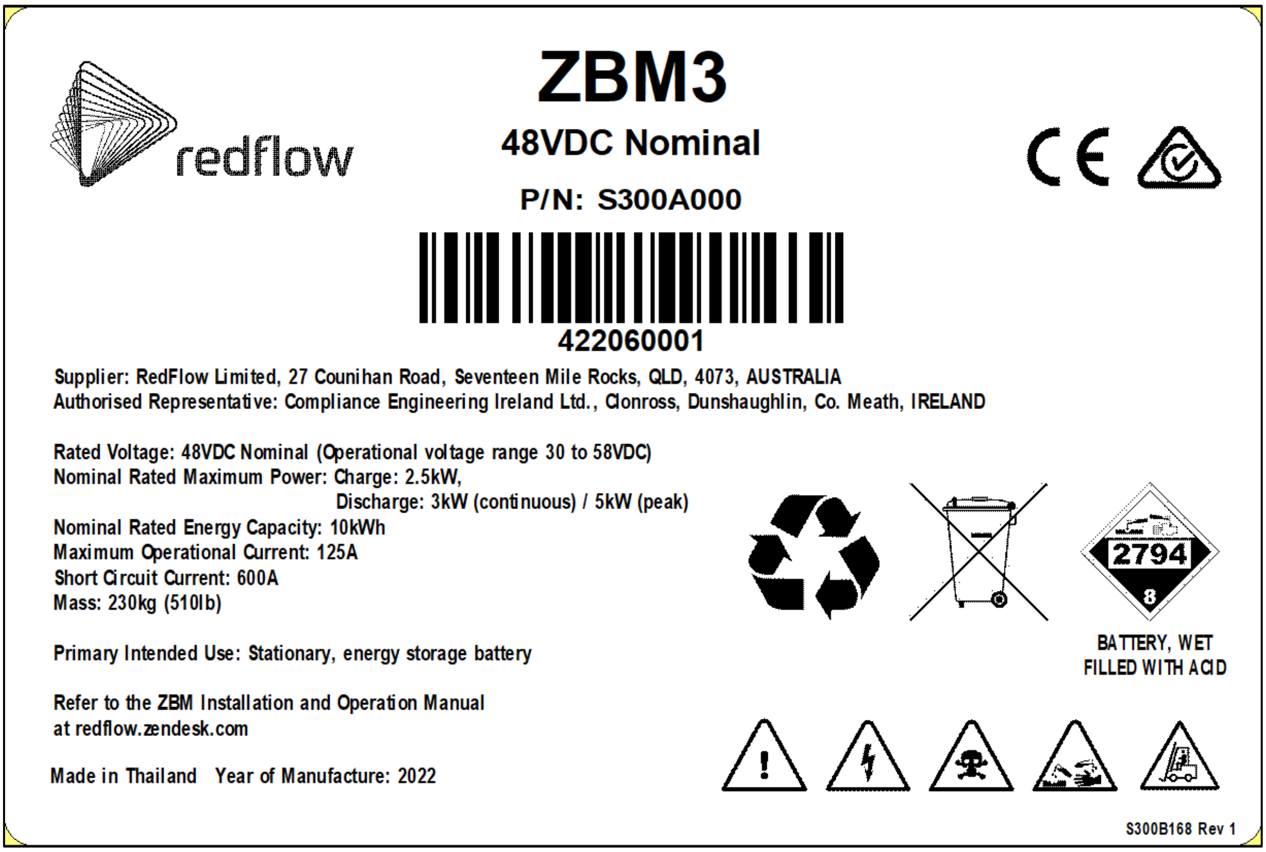


Figure 2: Example ZBM label

3 ZBM Handling

- **The ZBM must always be operated, handled, stored, and transported in the upright position.**
- **Transportation and lifting devices must be appropriately rated.**
- **The ZBM must always be discharged before transportation.**
- **The ZBM must never be lifted or manhandled via the battery stack. Always lift and handle the ZBM through the tanks.**
- **Strapping that loops around the stack and tank and around the tanks must not to be removed.**

3.1 ZBM Weights & Dimensions

Dimensions (ZBM)	LxWxH: 861 x 400 x 747 mm (34 x 16 x 30 in)
Mass (ZBM)	With electrolyte: 237 kg (523 lb) Without electrolyte: 80 kg (177 lb)
Dimensions (crated)	LxWxH: 1030 x 570 x 940 mm (40.6 x 22.5 x 37 in)
Mass (crated)	With electrolyte: 278 kg (613 lb) Without electrolyte: 121 kg (267 lb)

The ZBM is delivered in a wooden crate. The crate can be moved using an appropriately rated forklift or pallet jack.

3.2 Lifting Straps

The ZBM is supplied with two lifting straps to enable safe handling of a ZBM when it is not in an enclosure. The straps are rated to handle lifting of a ZBM filled with electrolyte and must be used to move a ZBM in an upright orientation using only a suitably rated lifting device for the ZBM's weight.

Lifting requirements:

- Lifting of the ZBM must not be done manually.
- Any handling of the ZBM must involve the use of the 2 lifting straps supplied with the ZBM under the guidance of two persons.
- Lifting straps must not be removed from the ZBM when installed as they will be required for use in removal of the ZBM.

3.3 Dry ZBMs

The ZBM will in most cases be delivered filled with electrolyte (wet), but in some cases (via air freight), the ZBM will be delivered without electrolyte. When delivered dry, the electrolyte will be delivered in separate transport containers. This requires the ZBM to be filled with electrolyte prior to use. Please contact Redflow or the appropriate Systems Integrator for an additional guide for this procedure.

3.4 Transporting ZBMs

A ZBM filled with electrolyte, as well as a ZBM that once contained electrolyte, must be handled, stored, and transported as an item with a Dangerous Goods Classification of 8 (refer to the SDS).

ZBMs that have never contained electrolyte do not require a Dangerous Goods rating or similar considerations during handling.

When transporting a ZBM, the following is required:

- ZBM must be transported in an upright position on a flat, fully-supported base surface.
- If not using the original Redflow crating, construct a crate to handle the weight of the ZBM and securely hold down the ZBM with support packaging to match or better the original crating.
- Transport of ZBMs must conform to local and/or international regulations including those applicable to electrolyte leak and spill containment, while considering the bund fitted to the ZBM as supplied.
- Storage temperature conditions, specified in Table 1, apply during transportation. Exposure to temperatures outside the specified storage temperature range voids the ZBM's warranty.

Failure to comply with transportation requirements will void the warranty.

3.5 Storing ZBMs

ZBMs can generally be stored for up to 12 months in their wet state but must always be fully discharged. Wet ZBMs are classified as Dangerous Goods Class 8.

In all cases, ZBMs must be stored on a flat, stable and fully-supported base surface in an upright position. The storage area must be dry and ventilated; closed cycle air-conditioned spaces are not suitable. ZBMs must be stored in areas that do not receive direct sunlight, as ultraviolet rays can break down ZBM components.

The ambient temperature should adhere to the storage temperature range specified in Table 1. Storage for longer than 12 months or in conditions that do not conform to the above will void the ZBM warranty.

The ZBM, as supplied, is fitted with a bund to help manage electrolyte leaks. Ensure that leak and spill containment measures are in place and comply with all relevant regulations.

4 ZBM Components

The key components of the ZBM are shown in the following figure.

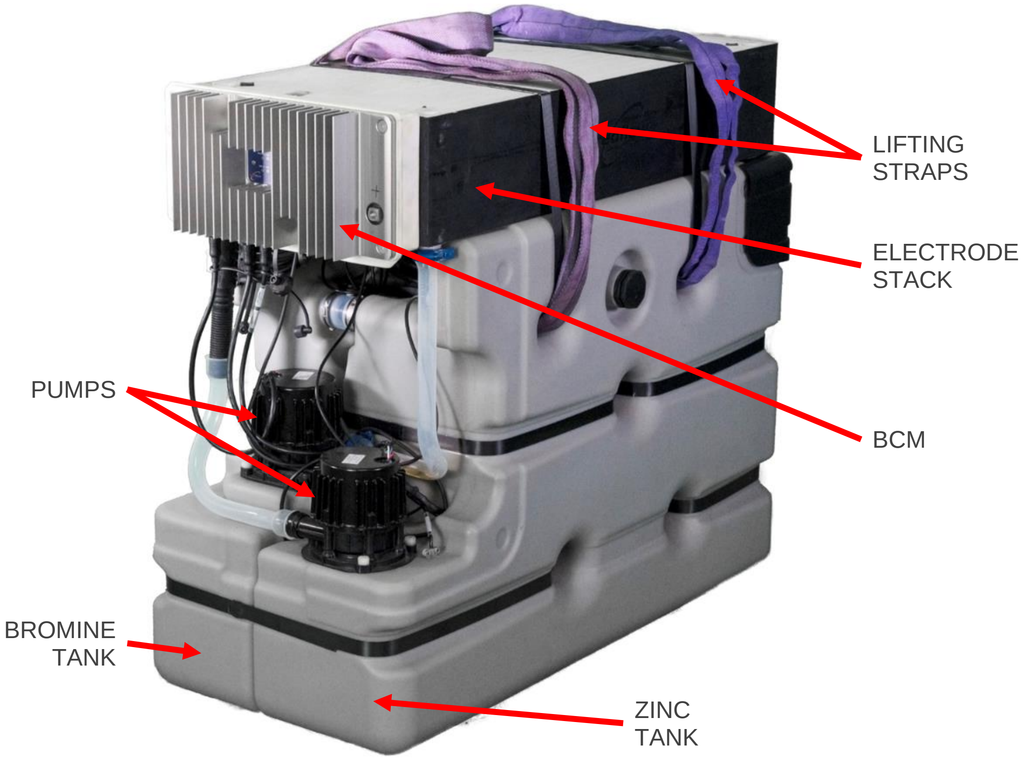


Figure 3: ZBM key components

4.1 Electrode Stack

The Electrode Stack contains the electrochemical cells that convert electricity into chemical energy and vice versa. Each cell contains an electrode with a positive (bromine) side and a negative (zinc) side. The stack consists of multiple connected cells where the electrolyte is circulated to enable the electrochemical reaction to occur on the electrode in each cell.

4.2 Electrolyte and Tanks

The ZBM uses a water-based zinc-bromide electrolyte that includes additional supporting agents The electrolyte is stored in 2 tanks; the left-side tank is referred to as the bromine tank and the right-side tank is referred to as the zinc tank. The tank name relates to the side of the electrode in a stack cell that the electrolyte is pumped into. The amount of electrolyte is sized to allow the delivery of 10kWh of energy when fully charged.

4.3 Battery Control Module

The Battery Control Module (BCM) provides the in-built intelligence to protect the battery and allows the user to manage the ZBM's operation. Communication with the BCM is most effectively done using the Battery Management System (BMS, see Section 4.11). The BCM is mounted on to the stack terminals (+BAT, -BAT), which are fitted with terminal caps. The BCM provides connection points for the electrical bus (+BUS, -BUS), ZBM components, and external systems as shown in Figure 4 and Figure 5.

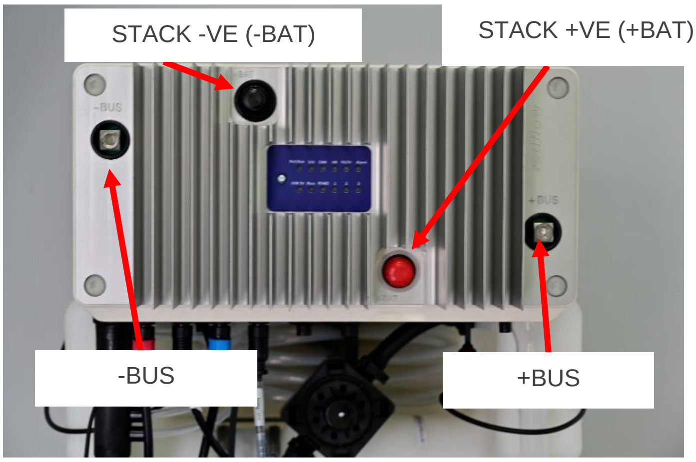


Figure 4: Location of ZBM terminals

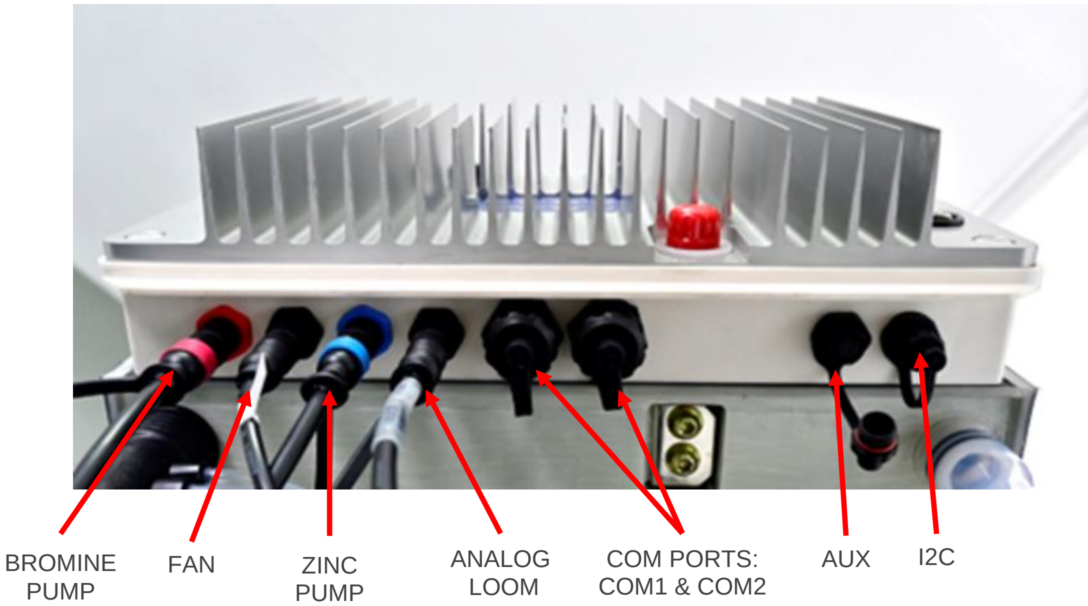


Figure 5: BCM connections (viewed from underneath)

4.4 Pumps

The ZBM has 2 pumps (one in each tank) that are used to pump the electrolyte into the stack. The pumps are powered from the BCM via cables connected to the base of the BCM. The cables and BCM are labelled to enable correct connection. The speed and operation of the pumps are controlled by the BCM.

4.5 Catch Can and Pressure Relief Valve

The Catch Can is connected to the Pressure Relief Valve (PRV), which is connected to the bromine tank. Any gas released from the pressure relief valve flows into the Catch Can, which captures gases using activated carbon, to reduce the concentration of any emissions that exit the ZBM. The Catch Can is located between the tanks.

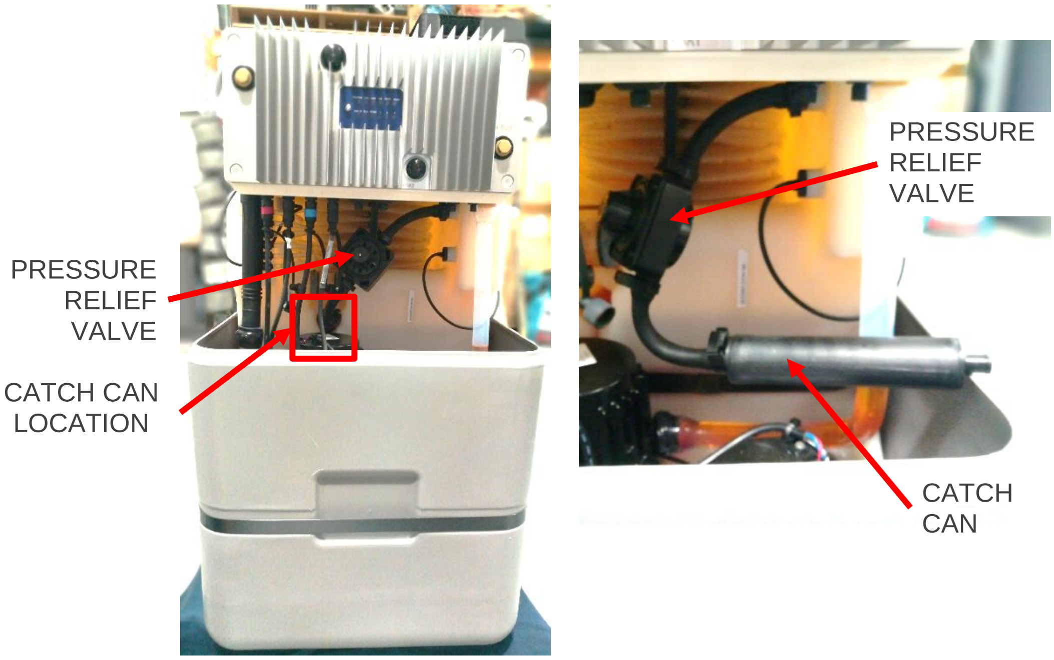


Figure 6: Catch Can and Pressure Relief Valve

The barb at the rear of the Catch Can provides a connection point for a hose to direct any uncaptured gas to an area safe to vent (e.g. outside in open air).

4.6 Fan

The fan draws air from the rear of the ZBM and blows it over the cooling tubes. The operation of the fan is controlled by the BCM. It turns the fan on, and controls fan speed based on the battery and air temperature measured by the Battery and Ambient Temperature Sensors.

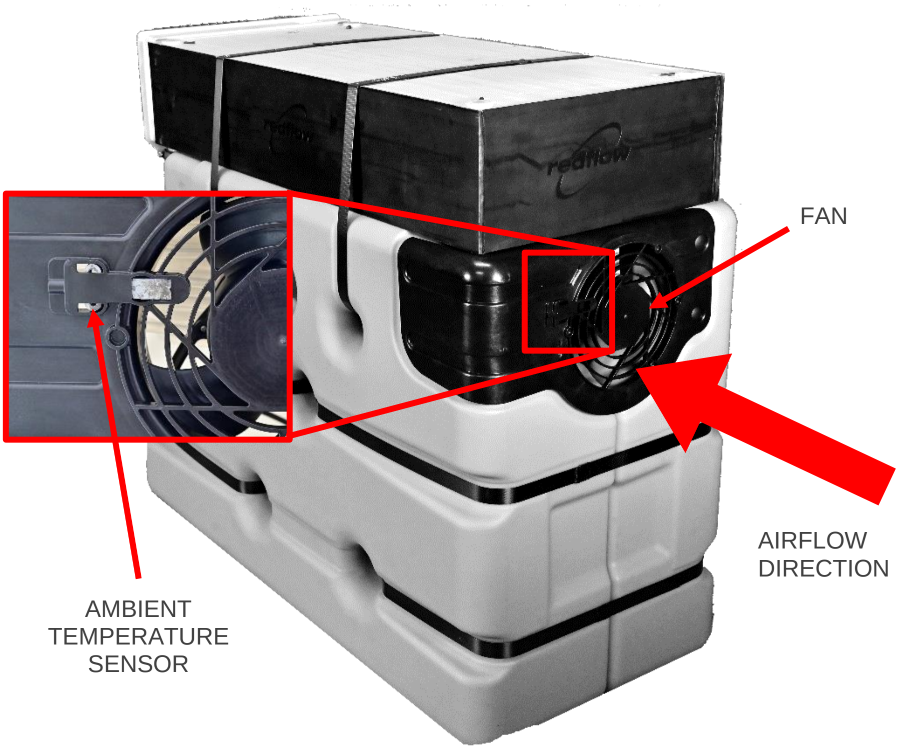


Figure 7: Fan, ambient temperature sensor, and direction of airflow

The fan assembly includes an integrated IP2X-rated cover to guard against direct contact with the fan blades, which can present a cutting hazard. The fan cover should never need to be removed from the fan. The fan cover is shown in Figure 7.

DANGER

The fan cover shall only be removed when a fan needs to be replaced. In this case, the whole fan assembly must only be removed once the ZBM has been de-energised as described in section 7.4. A new fan with fan cover must always be correctly secured before re-energising the ZBM.

4.7 Cooling Tubes

The ZBM uses the cooling tubes to cool the ZBM by pumping electrolyte through the tubes while the fan is blowing air over them. The cooling tubes are in a cavity under the stack and between the tanks.

4.8 Analog Loom

The Analog Loom has the following sensors: Leak Sensor, Ambient Temperature Sensor, and Battery Temperature Sensor (see Figure 8). The Analog Loom 12-pin UT Connector connects to the Loom terminal on the base of BCM.

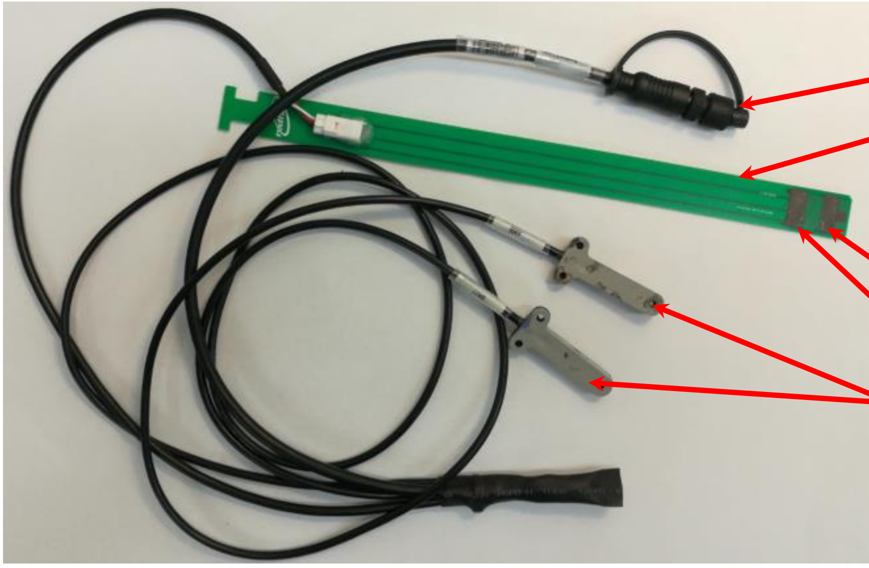


Figure 8: Sensor analog loom

The sensor information provides inputs to the BCM to make decisions on the operation of the ZBM. The locations of the sensors are described in Section 5.2.

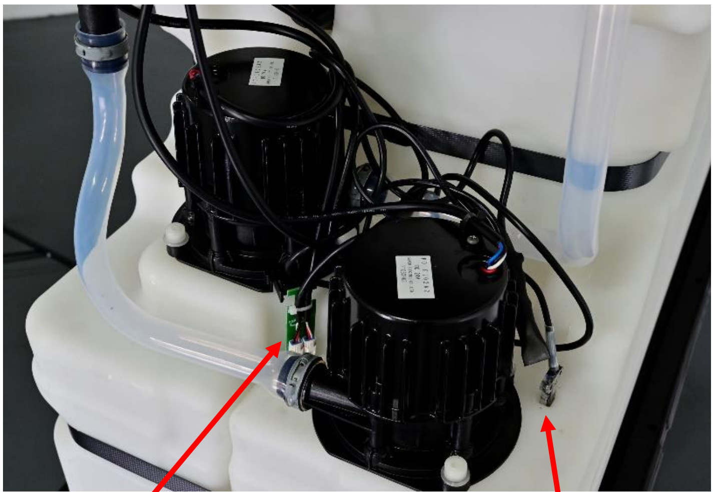


Figure 9: Leak sensor and battery temperature sensor locations

4.8.1 Leak Sensor

The leak sensor is used to determine if an electrolyte leak has occurred from the ZBM and is located beside the zinc pump. The following should be noted about the leak sensor:

- The leak sensor uses two level sensors: Leak 1 and Leak 2 (shown in Figure 8). Leak 1 signifies a lower level of electrolyte, and therefore a less significant leak than detected by the Leak 2 reading.
- The BCM reads the status of the sensor and if a leak has occurred, operation of the ZBM will be shut down.

4.8.2 Temperature Sensors

The ZBM has a battery temperature sensor and an ambient temperature sensor. The battery temperature sensor measures the temperature of the electrolyte and is fitted to the zinc tank (refer to Figure 9). The ambient temperature sensor is fitted beside the fan to measure the temperature of the air being blown over the cooling tubes (refer to Figure 7).

4.9 Power Cables

The ZBM includes three Power Cables with waterproof connectors that provide DC power from the BCM to ZBM components:

- Cooling Fan (4-pin connector)
- Zinc Pump (5-pin connector)
- Bromine Pump (5-pin connector)

4.10 Lifting Straps

The ZBM's lifting straps are provided with the ZBM to enable movement of the ZBM with appropriate lifting devices (see Section 3.2 for more detail). They must not be removed.

LIFTING STRAPS

4.11 Battery Management System

Redflow offers an additional accessory for use with the ZBM called the Battery Management System (BMS, see Figure 10). When powered and provided with an internet connection, a single BMS allows the user to monitor, log, and control operation of up to 12 ZBMs via an online interface. A minimum of one BMS is required for every site installation.

Figure 10: Redflow BMS

See Section 5 for connection information, and Sections 7.3, 7.4, and 9.1 for operational information.

5 ZBM Installation and Connection

Note: For an example installation setup, refer to Appendix D.

This section lists the steps to perform to install and connect a ZBM into an energy storage system. Installation in compliance with these instructions by suitably qualified and Redflow trained personnel is a condition for a valid warranty.

DANGER

> **DC cabling must conform to local standards and regulations, for a maximum battery current of 125A or lower.**
>
> **Ensure all connecting systems are completely de-energised during this process – do not start power until all steps in this section have been completed.**
>
> **This process must only be performed by personnel with the appropriate qualification as per local regulations and who have also received ZBM training. This is a warranty condition.**

5.1 Remove the Transport Crate

The ZBM is to be removed from its crate using the following procedure:

1. Confirm that the lifting devices can handle the weight of the ZBM and a crated ZBM.
2. Remove the strapping that secures the crate lid to the base of the box.

Figure 11: Crate with strapping removed

3. Remove the crate lid with one person lifting at each end.

Figure 12: Lifting crate lid

4. Undo the plastic bag and remove. Ensure the two lifting straps are fitted through the locating holes of the tank.

Figure 13: Plastic bag removed, lifting straps in place

5.2 Perform Pre-installation Checks

STEP 1 Check for any electrolyte leaks both visually and by the presence of a chlorine-like smell. If a leak is present, do not operate the ZBM and contact Redflow. Contact details are provided on the rear cover of this manual. Leaks must be cleaned up in accordance with Appendix A. The SDS provides information for the electrolyte as well as global emergency contact details.

STEP 2 Use a multimeter to check that the ZBM is fully discharged by ensuring the voltage across the positive and negative bus terminals (+BUS, -BUS) shown in Figure 14 is 0V.

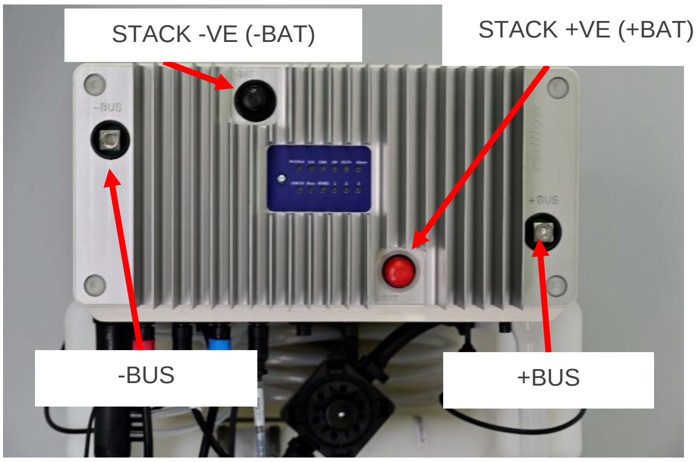


Figure 14: Positive and negative ZBM terminals

STEP 3 Check that the torque marks on nuts on the ZBM stack terminals (+BAT, -BAT) line up correctly. If the torque marks do not line up correctly, re-torque to 10Nm (7.4 lb-ft) and re-mark. Ensure terminal caps are refitted.

STEP 4 Inspect to make sure that the ZBM Viton capillary tubes (see Figure 15 for examples) have not been damaged or kinked during transportation or installation. Also check to make sure each end of the tubes is securely connected.

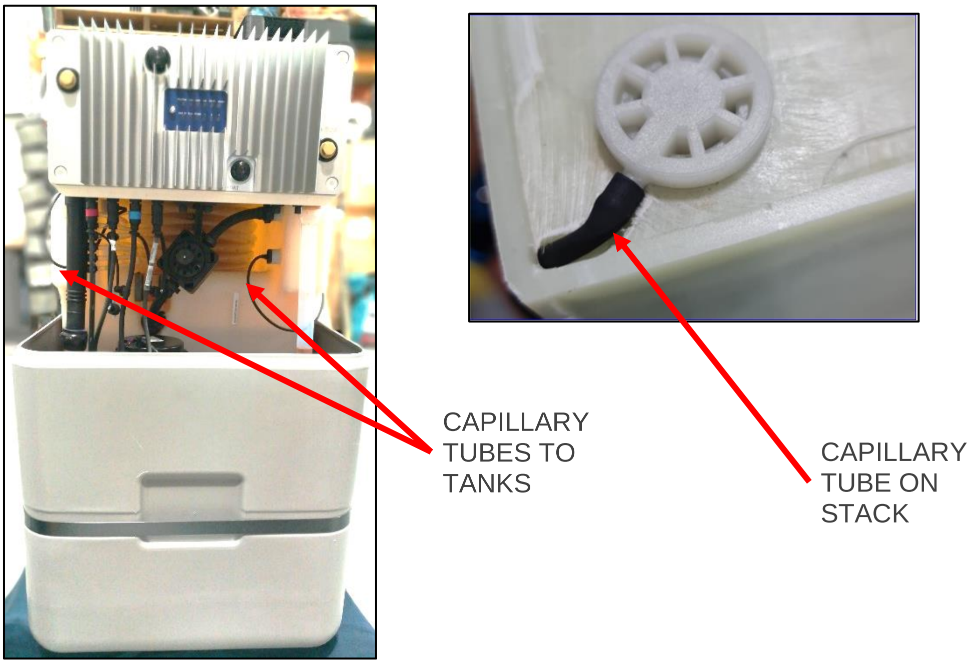


Figure 15: Example capillary tubes

STEP 5 Remove the leak sensor from the plastic bag then install the sensor beside the zinc pump (see Figure 16).

STEP 6 Ensure all elements of the sensor analog loom are in the correct positions. The temperature sensors should already be installed in their correct locations (see Figure 16). Ensure the analog loom is securely connected to its terminal on the base of the BCM (see Figure 17) via the UT connector.

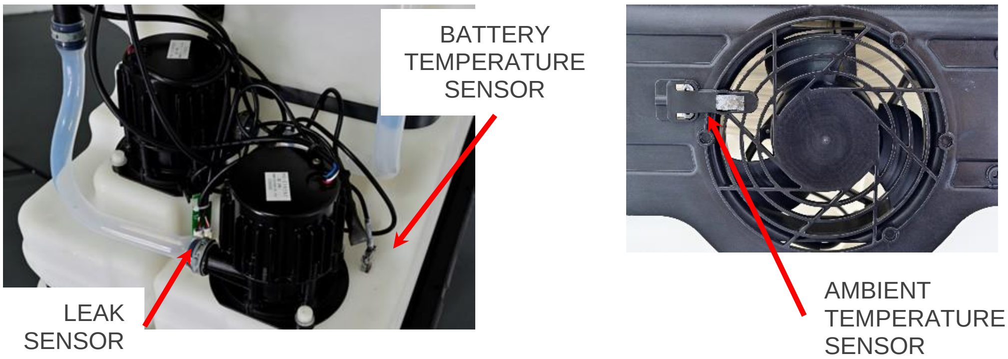


Figure 16: Leak Sensor and Temperature Sensors locations

STEP 7 Ensure the power cables are securely connected to their corresponding BCM connections (see Figure 17):

- The 5-pin connector of the bromine pump.
- The 4-pin connector of the fan cable.
- The 5-pin connector of the zinc pump.

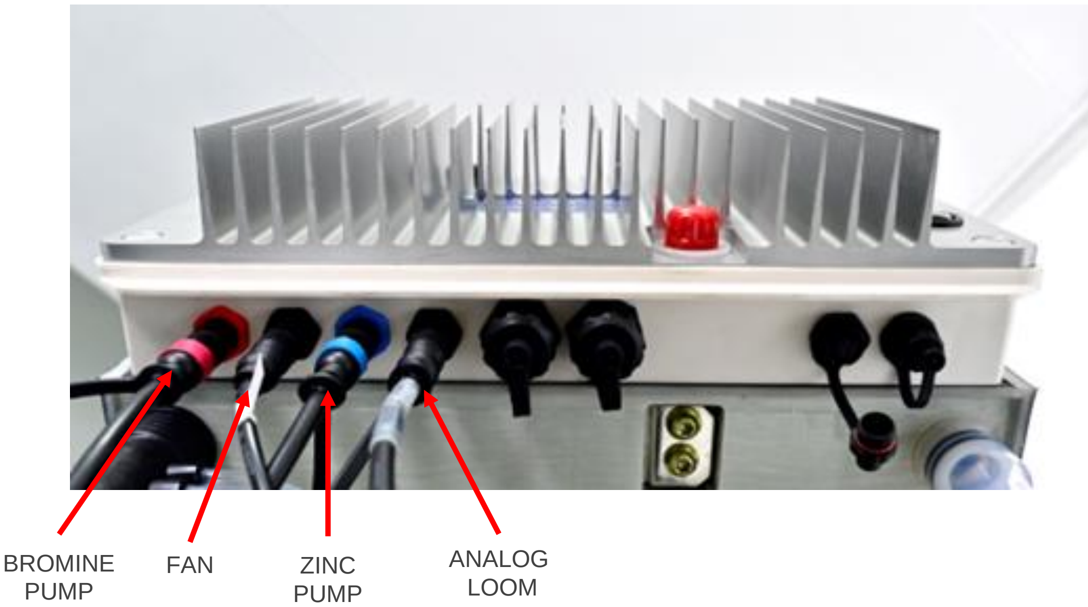


Figure 17: BCM connections

5.3 Lift the ZBM into Place

Note: The location for the ZBM needs to have a flat, stable, and fully supported surface.

STEP 1 Check the two lifting straps are correctly connected to the lifting device. Each end of a lifting strap must be fitted separately to the lifting device. The lifting mechanism must lift both straps at the same time securely, and in such a way as to keep the ZBM level with a minimum amount of swaying.

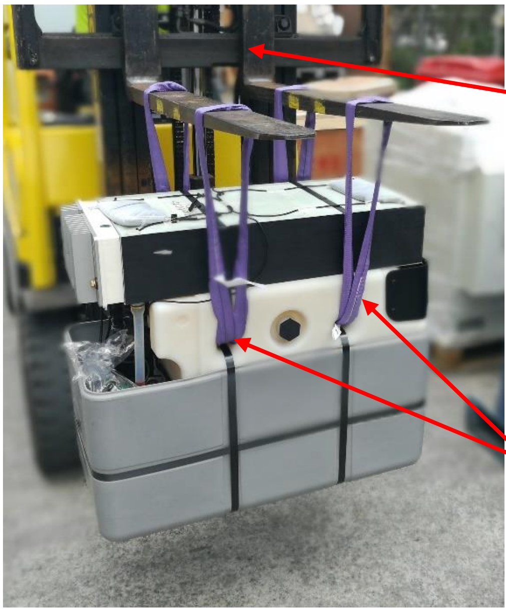


Figure 18: Lifting the ZBM

STEP 2 Using a suitable lifting device (as shown in Figure 18), place the ZBM into the prepared location. Ensure care is taken to avoid excessive force or damage to the ZBM during movement and when placing the ZBM on to the prepared location.

It is recommended that pre-installation checks (refer to section 5.2) are repeated once the ZBM is in its required location.

STEP 3 Tidy the ZBM's lifting straps away neatly beside the ZBM (the straps remain on the ZBM).

5.4 Install and Connect the BMS

STEP 1 Connect the BMS to the ZBM via a Communication port on the BCM (see Figure 21. This is done by using the supplied Cat6 cable and cutting the RJ45 connector off one end. Using the standard colour coding in the cable, strip the blue/white, solid blue, and brown/white wires. Connect these wires to the B, A, and SH terminals, respectively, of the 485 section on the BMS as shown in Figure 19.

Connect a 9-65VDC power supply, isolated via a 1A inline fuse breaker (not supplied), to the + and – ports of the BMS in the 9-65VDC section.

Connect a network cable (not supplied) from a network modem/router port with an open internet connection to the RJ45 port of the BMS as shown in Figure 19.

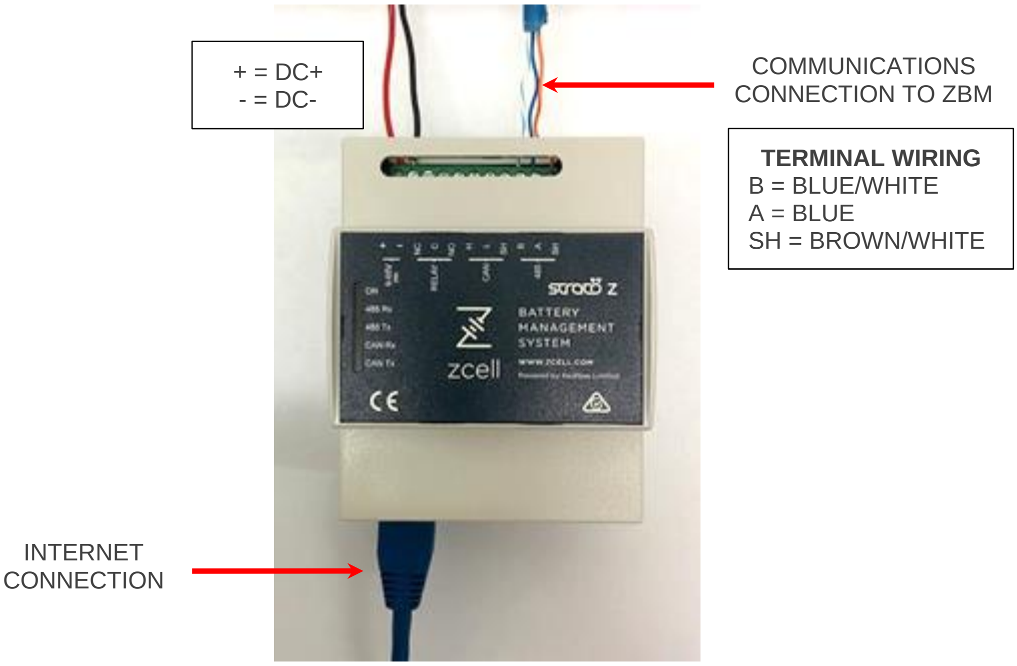


Figure 19: BMS connections

STEP 2 To connect to the BCM, connect the Cat6 cable from the BMS through the RJ45 boot in the following sequence (with reference to Figure 20): feed the Cat6 cable through the waterproof cap (A), followed by the rubber grommet (B) and the cable mount (C).

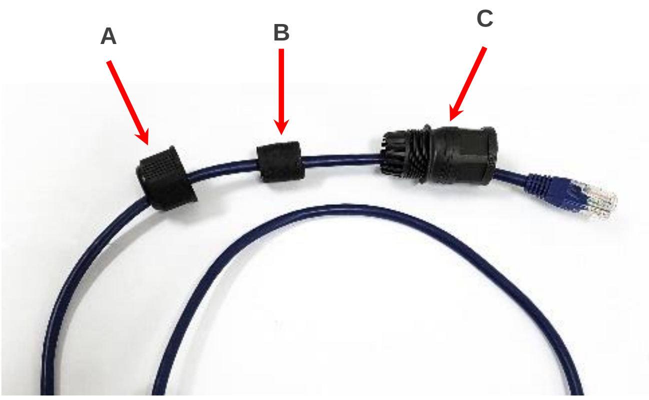


Figure 20: Cat6 cable assembly

STEP 3 Use the data plug inside the rubber boot on the end of the Cat6 cable to plug into the BCM in the COM1 (or COM2) port. Tighten all parts of the RJ45 Boot to ensure the cable is secure and waterproof. Cover the unused communications port with an RJ45 cap if using a single battery.

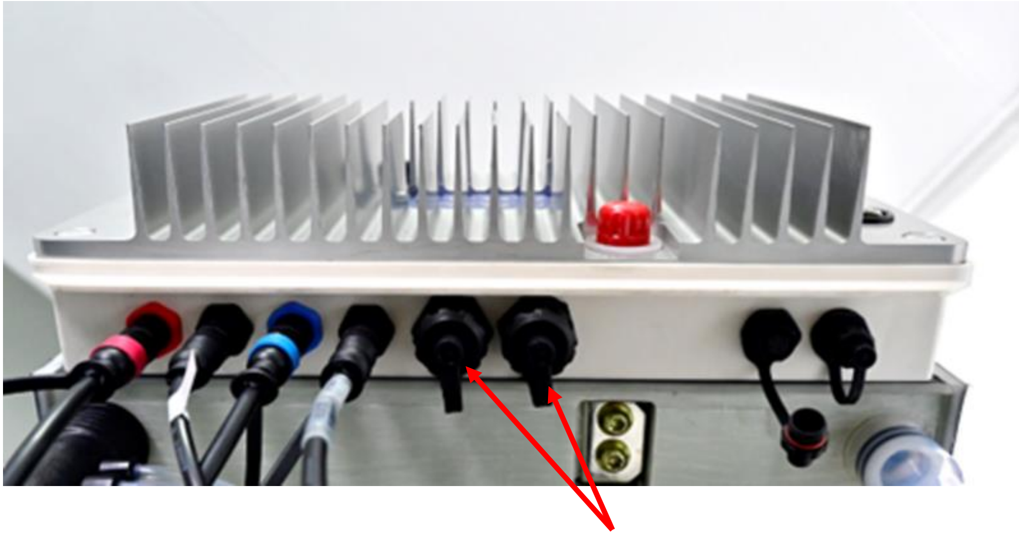


Figure 21: BCM connection ports for the BMS

To connect multiple ZBMs, daisy chain the ZBMs by plugging one end of a Cat6 cable into the COM2 port of a BCM and the other cable end into the COM1 port of a subsequent BCM. Ensure the unused Communication Port of the last ZBM in the chain is covered with an RJ45 cap.

5.5 Connect the ZBM to the DC Bus

Connect positive and negative cables to the input DC bus terminals on the front of the BCM (refer to Figure 22) then to appropriately sized circuit breakers (maximum rating 125A). The bus cables and circuit breakers are not provided with the ZBM, and the cables must be appropriately sized. The bus cables must be terminated with 8mm eyelets.

STEP 1 To connect the positive bus cable, remove the washer and bolt from the bus terminal (refer to Figure 22).

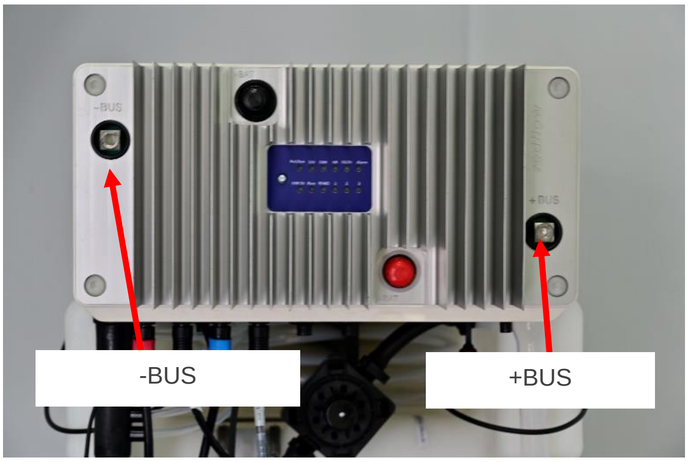


Figure 22: Bus cable connections

STEP 2 Ensure the Belleville washer on the bolt is fitted with the raised surface closest to the bolt head (see Figure 23). Apply conductive carbon grease to the bolt thread. Select the positive boot (red), slide the eyelet of the bus cable through the boot then onto the bolt, insert the bolt into the positive bus terminal (+BUS), and use a torque wrench with a 13mm attachment to **tighten** to **10Nm** (**7.4lb-ft**). Apply a torque mark, then fit the boot over the terminal.

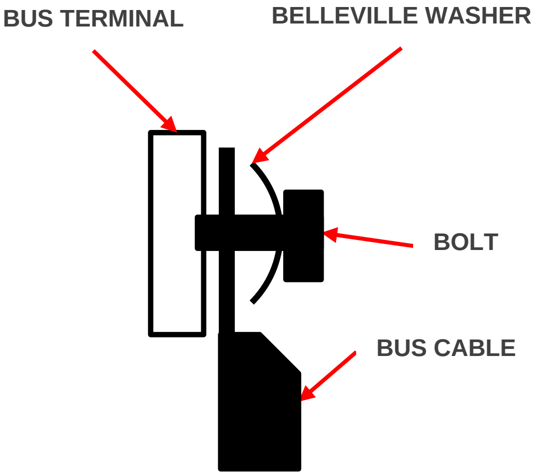


Figure 23: Bolt, cable, and washer arrangement for bus terminal

STEP 3 Repeat above steps to fit the negative bus cable on the negative bus terminal (-BUS) with a negative boot (black).

STEP 4 Connect the DC bus cables from the ZBM to the ZBM circuit breakers (ensure correct polarity).

6 Commission a Battery

Note: An open internet connection is required from a network modem/router connected to the BMS.

Important: Ensure each battery is isolated from the DC bus.

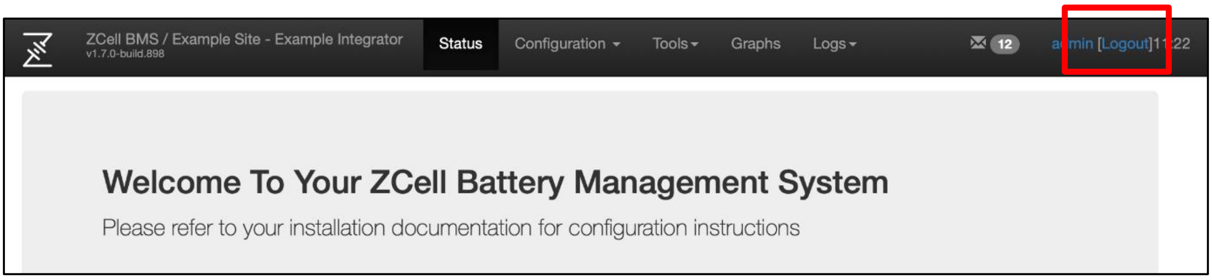
6.1 Configure the BMS Settings

Power on the BMS.

6.1.1 Connect to the BMS

Use the local WiFi network generated by the BMS to connect to the BMS. To do this:

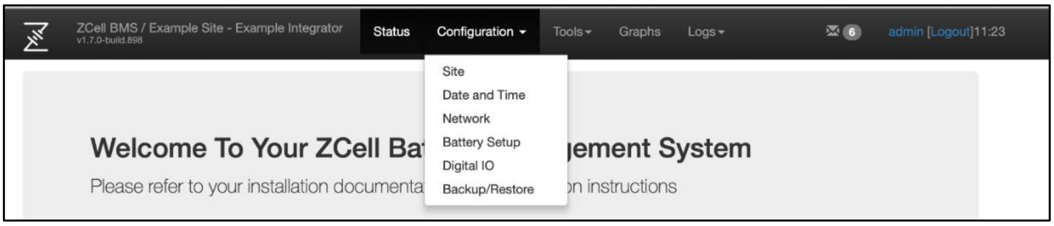
1. Go to WiFi settings on your device (laptop or mobile device).
2. Look for a WiFi network named “zcell-BMS-XXXX”, where XXXX is a four-character code.
3. Connect to this network using password **zcellzcell** (case sensitive).
4. Using a browser, navigate to IP address **172.16.29.241:3000**.
5. The *Welcome* window displays.



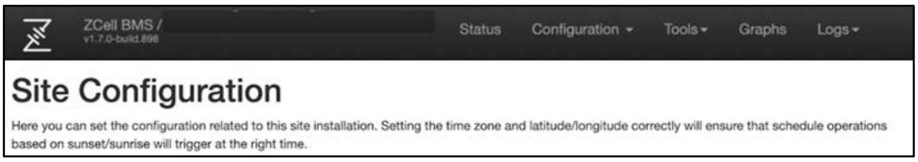
6. Select the **[Login]** button at the top right of the window and enter **admin** in the **Username** and **Password** fields.

6.1.2 Set the BMS Settings

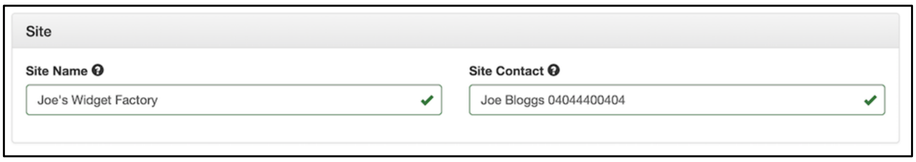
1. From the **Menu** bar, select **Configuration** > **Site**.



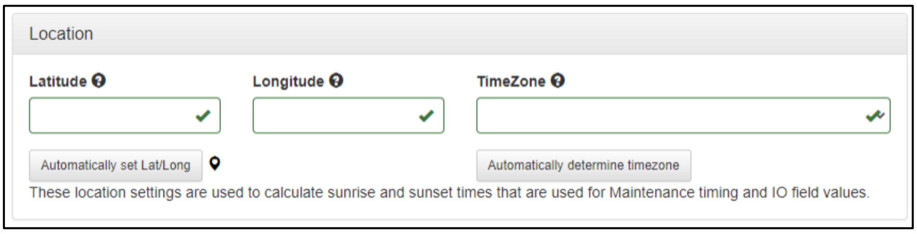
The *Site Configuration* window displays:



2. In the *Site* section, enter the details.



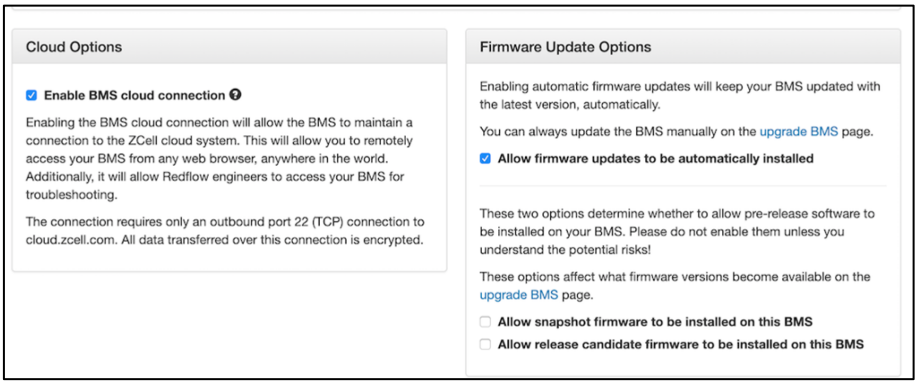
3. In the *Location* section, enter the details including the time zone.



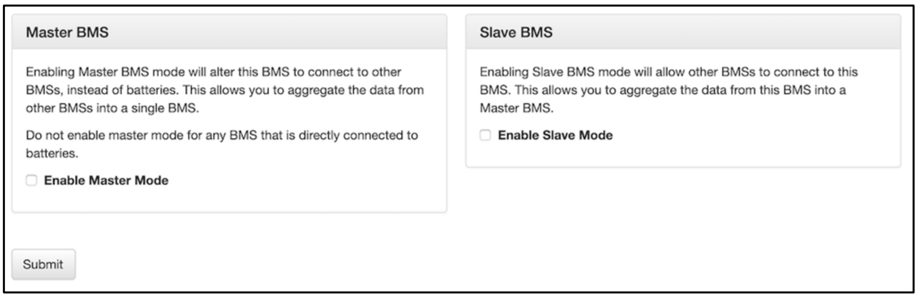
4. In the *Cloud Options* and *Firmware Update Options* sections, select:

- **Enable BMS cloud connection**
- **Allow firmware updates to be automatically installed**

Do **not** select the options for pre-release software.



5. Unless advised otherwise, do **not** select the options in the *Master BMS* and *Slave BMS* sections.



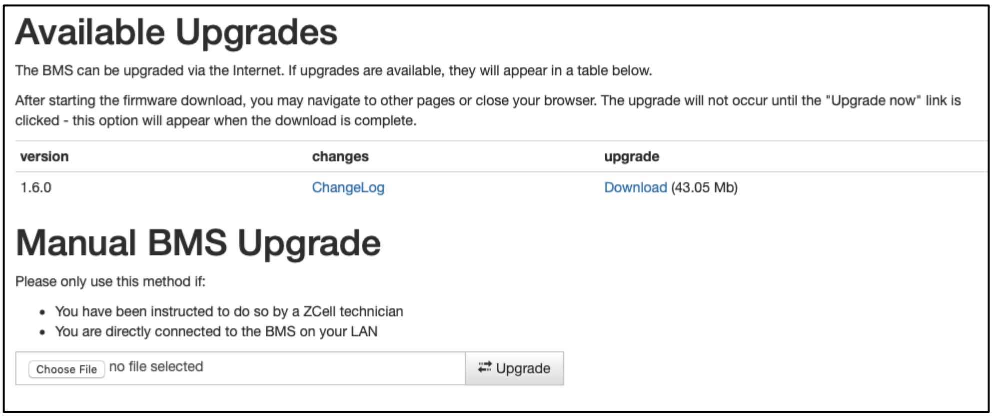
6. Select the **Submit** button at the bottom of the window.

6.1.3 Update BMS Firmware

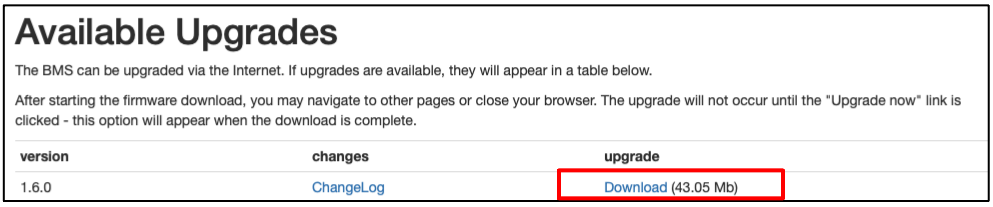
The BMS firmware may need to be updated to the latest release to commission the ZBM.

To update the BMS firmware:

1. From the **Menu** bar, select **Tools** > **Upgrade BMS**. The *Upgrades* window displays.

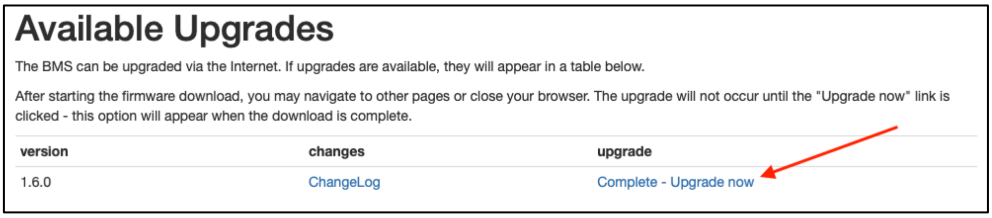


2. Select the **Download** link for the latest version.



The system displays a progress bar indicating that the software is downloading.

3. When the download completes, select the **Complete – Upgrade Now** link to install the software.

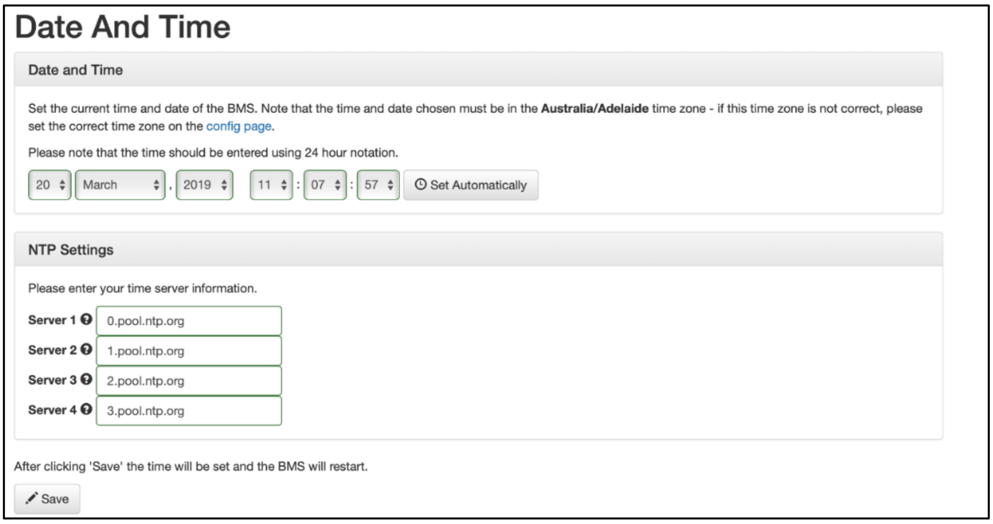


A progress window displays. Wait for the BMS to restart and display the Status page.

6.1.4 Check BMS Date and Time

Check the date and time:

1. From the **Menu** bar, select **Configuration** > **Date and Time**



2. Confirm the date and time are correct.

6.2 Set Up a Battery

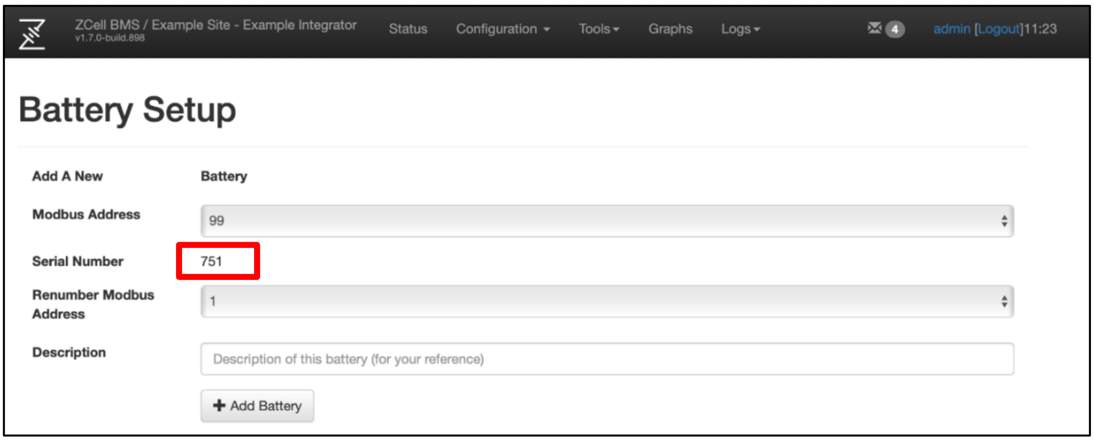
Note: Where multiple batteries are installed, these batteries are connected to the BMS in a daisy-chain fashion (refer to section 5.4).

Important: Ensure each battery is isolated from the DC bus.

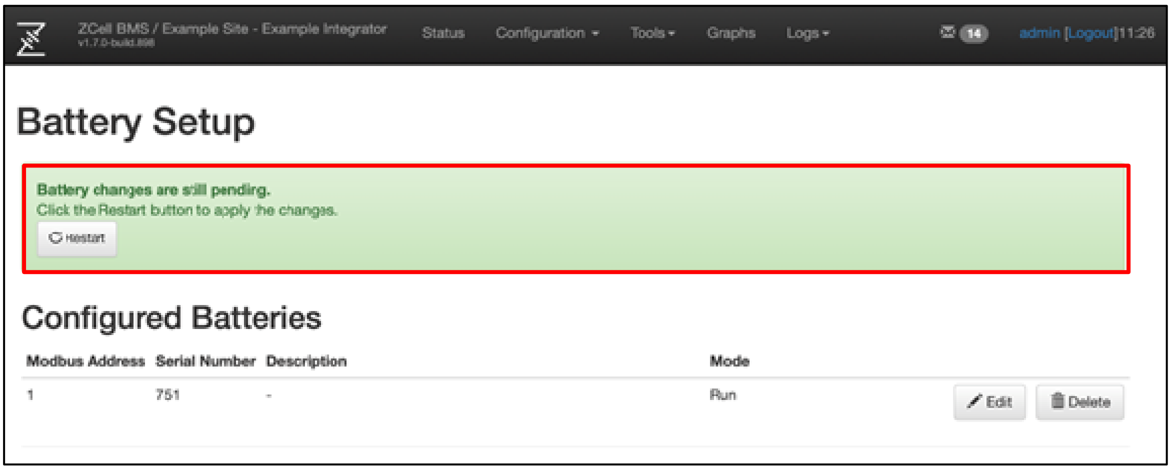
Each battery requires a unique Modbus address to enable the BMS to access the battery. Typically, set a battery as unit 1 (the default factory setting is 99), and increment the unit number as additional batteries are installed. The BMS automatically proposes the next available address, starting from 1.

To set the battery Modbus address:

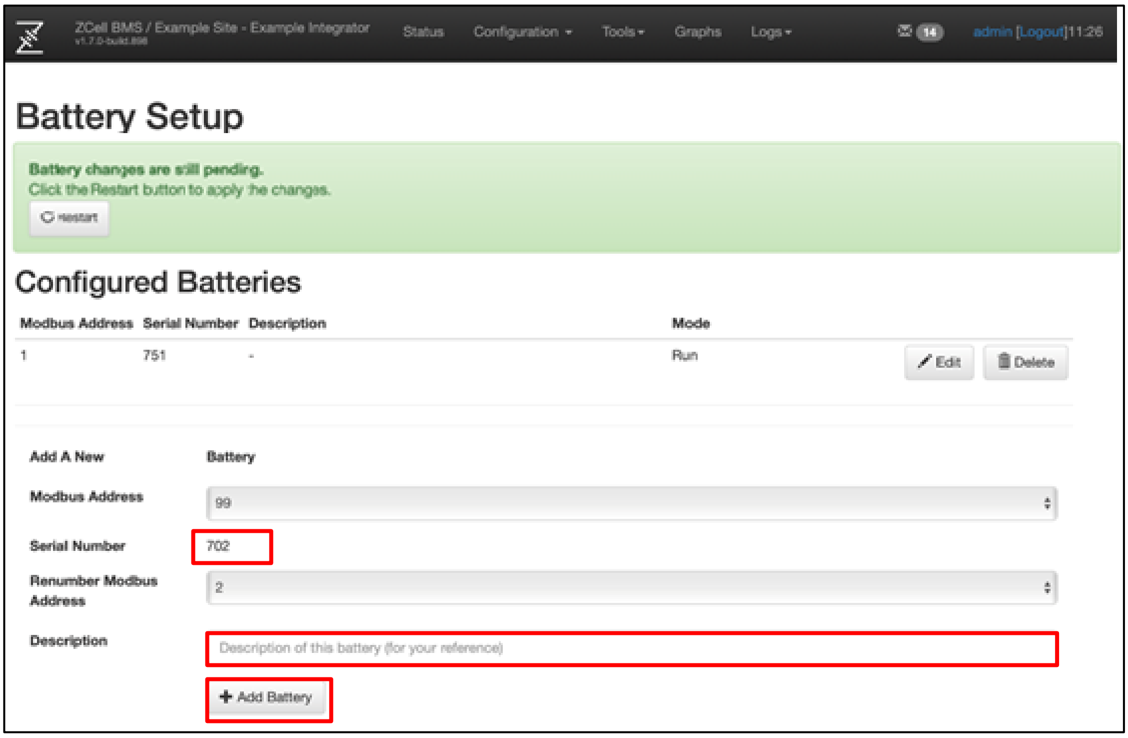
1. Connect power to the battery from the DC bus.
2. Select **Configuration** > **Battery Setup**. Wait for the serial number to display to indicate that the battery has started and is communicating with the BMS.



3. Input the **Description** field.
4. Select the **Add Battery** button. The battery is added to the *Configured Batteries* section and the pending changes dialog displays.

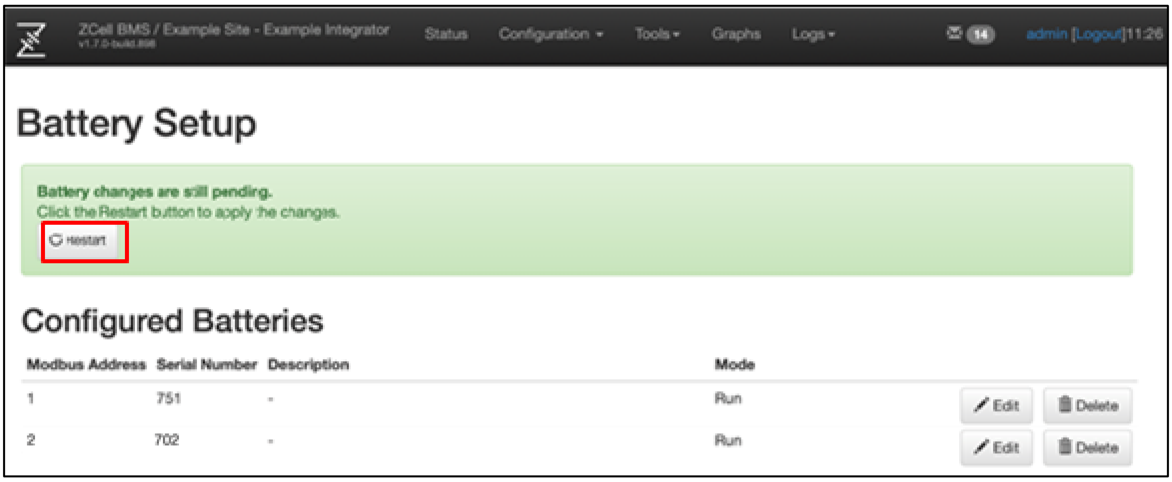


5. For any additional batteries:
   a. Connect power to the battery.
   b. Wait for the serial number to display to indicate that the battery has started and is communicating with the BMS.



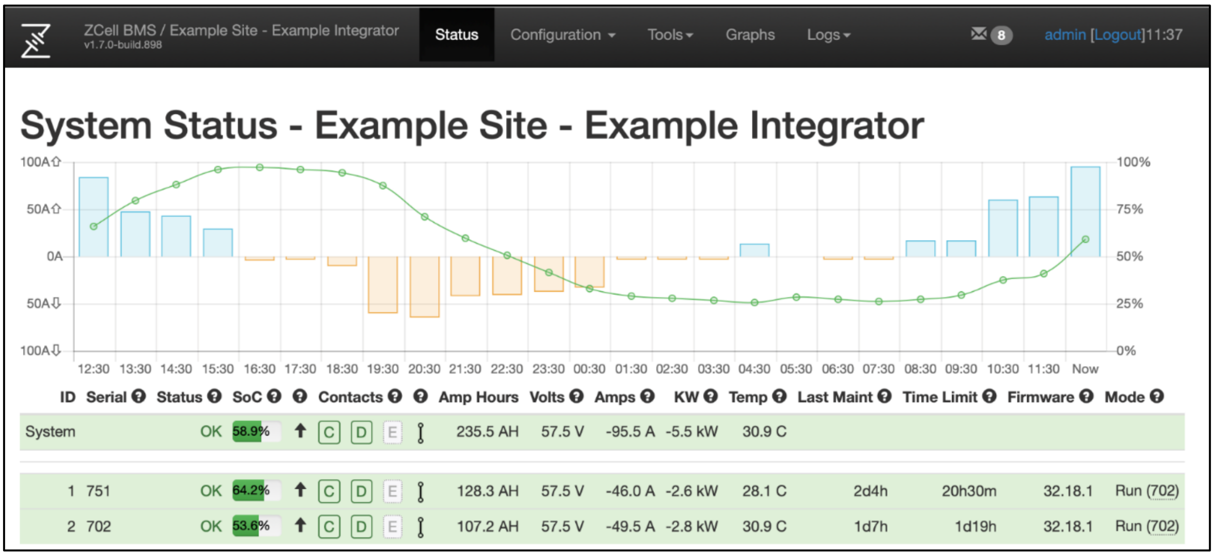
   c. Input the **Description** field, then select the **Add Battery** button.

6. In the pending changes dialog, select the **Restart** button.



6.3 Check Visibility of a Battery in the BMS

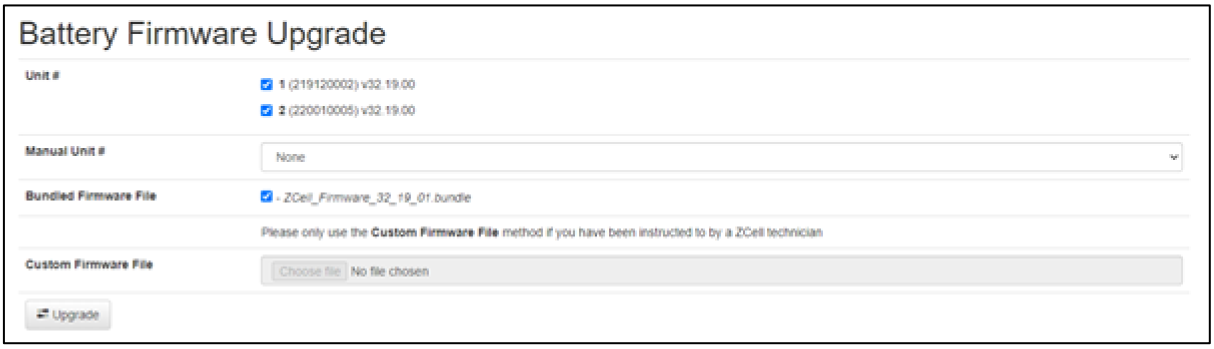
1. Wait a few minutes for the battery settings to be activated in the BMS.
2. On the **Menu** bar, select the **Status** option. The BMS displays each battery that it can connect to.



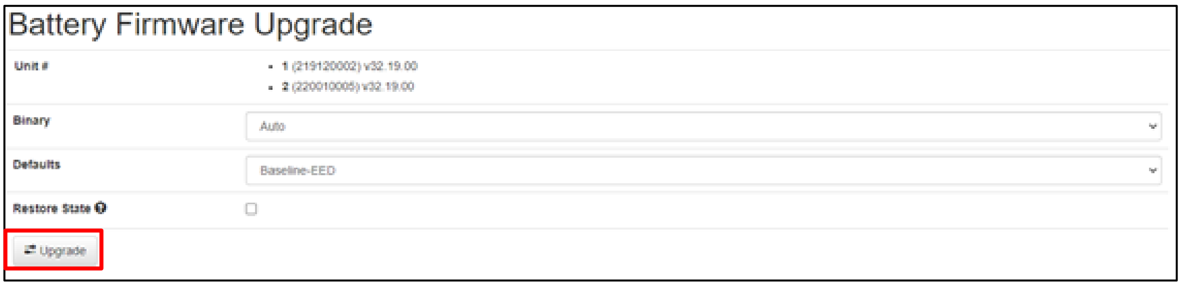
6.4 Upgrade Battery Firmware

Upgrade each battery to the latest firmware release.

1. From the **Menu** bar, select **Tools** > **Upgrade Battery**. The *Battery Firmware Upgrade* window displays.



2. If not selected, select the checkbox for each battery.
3. Select the **Upgrade** button.
   The upgrade parameters window displays.



4. Select the **Upgrade** button.
   A progress bar dialog displays; once the upgrade is indicated as complete, close the progress bar dialog.

7 ZBM Operation

This section provides information about the operation of the ZBM. At all times, the ZBM must remain intact, with all fittings and components connected as new.

7.1 Operating “From Empty”

The ZBM’s default state of charge is fully discharged, and it can remain in this state indefinitely. ZBMs are charged from 0% state of charge up to the desired capacity at or below 100%, and then discharged from there. Typically, constant power charge and discharge modes are used, but the variable supply from a PV array on a cloudy day is equally effective.

7.2 ZBM Operating Modes

The ZBM operates in one of two modes: Run Mode and Offline Mode.

- **Run Mode** is the standard mode in which the ZBM is available to be charged and discharged, and self-manages its regular maintenance cycle requirements and any operational issues. The ZBM will automatically disconnect from the DC bus in a number of operational events, such as overcurrent and overcharge.
- **Offline Mode** can be set by the user to make the ZBM unavailable for use (will not respond to requests until it is placed back into Run Mode) but will still be self-managed to ensure the ZBM is in a safe state.

7.3 Startup Procedure

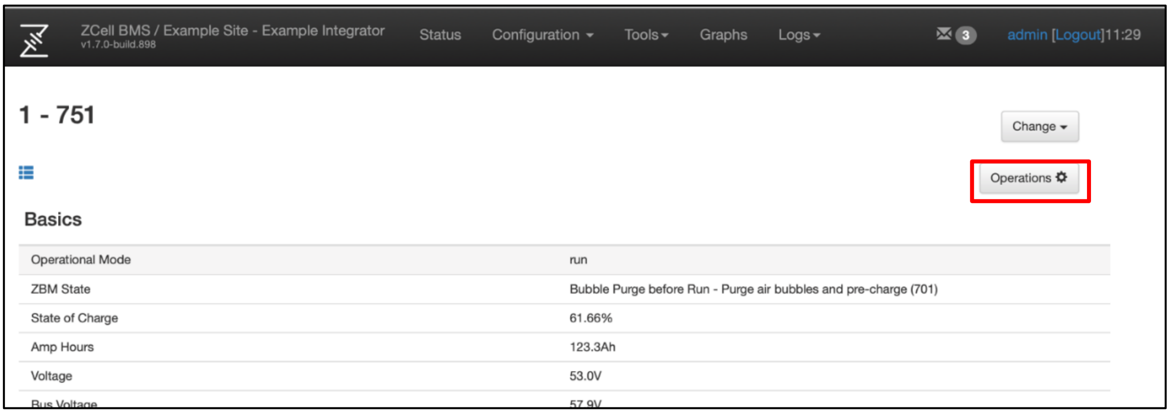
After a ZBM has been installed and connected, the ZBM can be put into operation.

Use the BMS online interface:

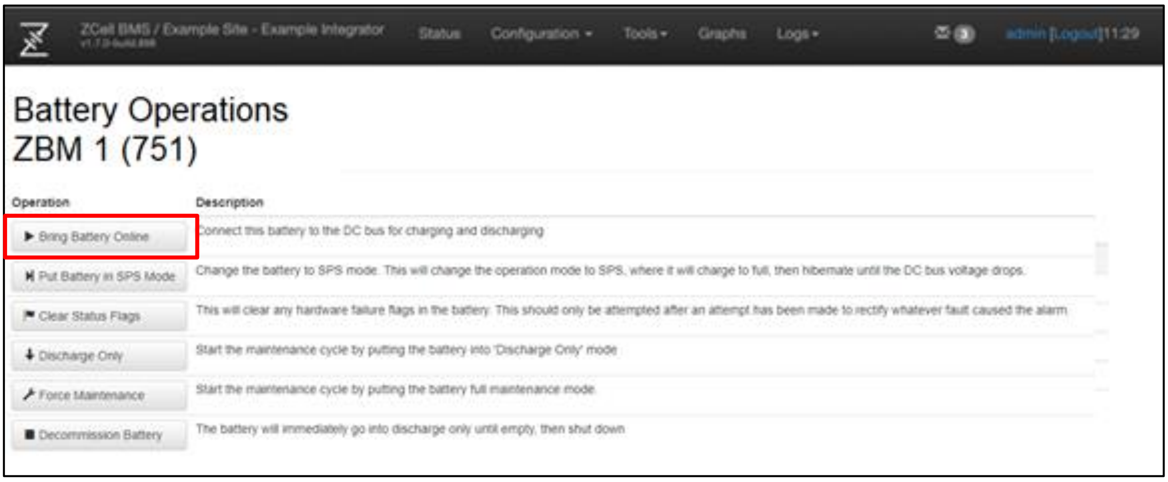
1. From the **Menu** bar, select **Status**.
   The batteries for the BMS display.
2. Select a battery row.

ID	Serial	Status	SoC		Contacts		Amp Hours	Volts	Amps	KW	Temp	Last Maint	Time Limit	Firmware	Mode
System		OK	58.9%	↑	C D E		235.5 AH	57.5 V	-95.5 A	-5.5 kW	30.9 C				
1	751	OK	64.2%	↑	C D E		128.3 AH	57.5 V	-46.0 A	-2.6 kW	28.1 C	2d4h	20h30m	32.18.1	Run (702)
2	702	OK	53.6%	↑	C D E		107.2 AH	57.5 V	-49.5 A	-2.8 kW	30.9 C	1d7h	1d19h	32.18.1	Run (702)

The battery detail displays.



3. Select the **Operations** button.
   The *Battery Operations* window displays.



4. Select the **Bring Battery Online** button.
5. Repeat the preceding steps for each battery.

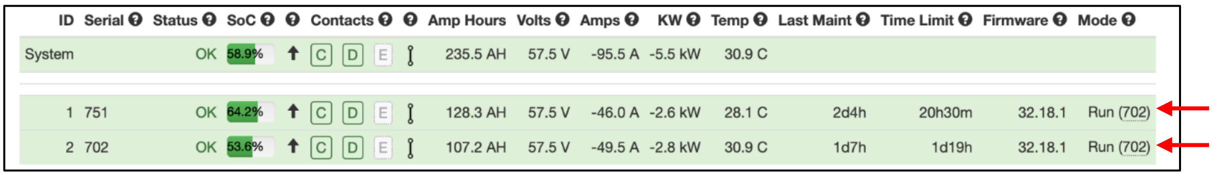
7.4 Shutdown Procedure

The complete shutdown procedure below must be used when shutting down the system for storage, shipping, de-energised maintenance, or ZBM replacement.

Ensure a load is present on the DC bus (to discharge the energy to). Decommission the ZBM, which performs a self-maintenance cycle to fully discharge the battery then shuts down. Decommissioning will take at least 2 hours plus the time to discharge the stored energy.

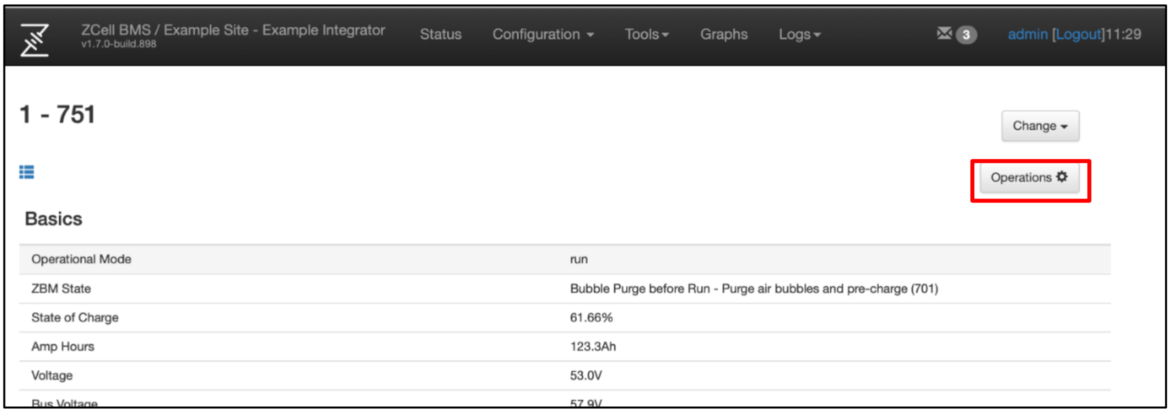
1. Discharge the stored battery energy.
2. Use the BMS online interface to decommission the battery.
   a. From the Menu bar, select Status.

      The batteries for the BMS display.



ID	Serial	Status	SoC		Contacts		Amp Hours	Volts	Amps	KW	Temp	Last Maint	Time Limit	Firmware	Mode
System		OK	58.9%	↑	C D E		235.5 AH	57.5 V	-95.5 A	-5.5 kW	30.9 C				
1	751	OK	64.2%	↑	C D E		128.3 AH	57.5 V	-46.0 A	-2.6 kW	28.1 C	2d4h	20h30m	32.18.1	Run (702)
2	702	OK	53.6%	↑	C D E		107.2 AH	57.5 V	-49.5 A	-2.8 kW	30.9 C	1d7h	1d19h	32.18.1	Run (702)

   b. Select the battery row.
      The battery detail displays.



c. Select the **Operations** button.
   The *Battery Operations* window displays.

d. Select the **Decommission Battery** button.

Operation	Description
Take Battery Offline	Disconnect this battery from the DC bus so it can't be charged or discharged
Put Battery in SPS Mode	Change the battery to SPS mode. This will change the operation mode to SPS, where it will charge to full, then hibernate until the DC bus voltage drops.
Discharge Only	Start the maintenance cycle by putting the battery into 'Discharge Only' mode
Force Maintenance	Start the maintenance cycle by putting the battery full maintenance mode.
Decommission Battery	The battery will immediately go into discharge only until empty, then shut down

e. From the **Menu** bar, select the **Status** option.

f. The **Mode** field changes to **Decommissioned**.

g. Wait until mode changes to **Stopped**.

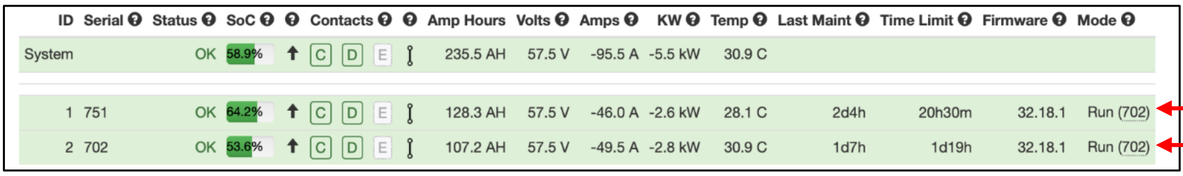
3. Disconnect the ZBM by switching off the bus circuit breakers.
4. Use a multimeter to measure the voltage across the battery's bus terminals to confirm that the ZBM's voltage is approximately 0V.

7.5 Start Battery Discharge and Self-maintenance Cycle

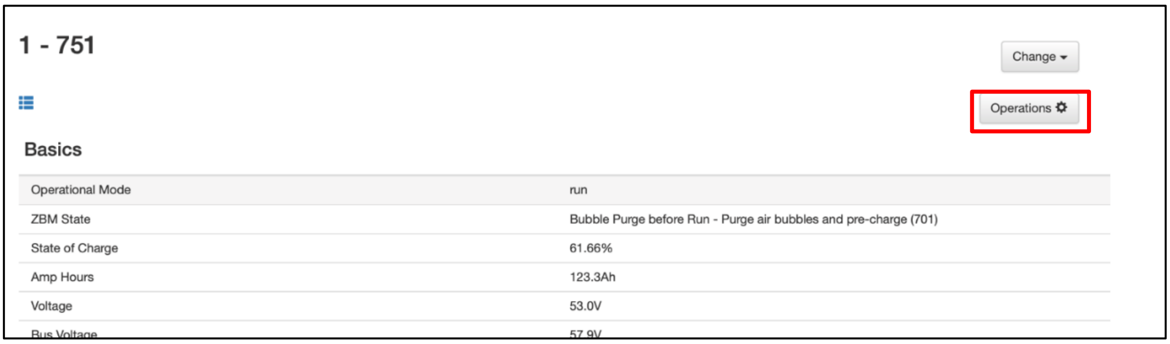
It is a warranty requirement that if a charged ZBM has been offline for more than one month then the ZBM must be discharged and complete a self-maintenance cycle. This is done to ensure the State of Charge (SOC) calculation is correct.

Use the BMS online interface:

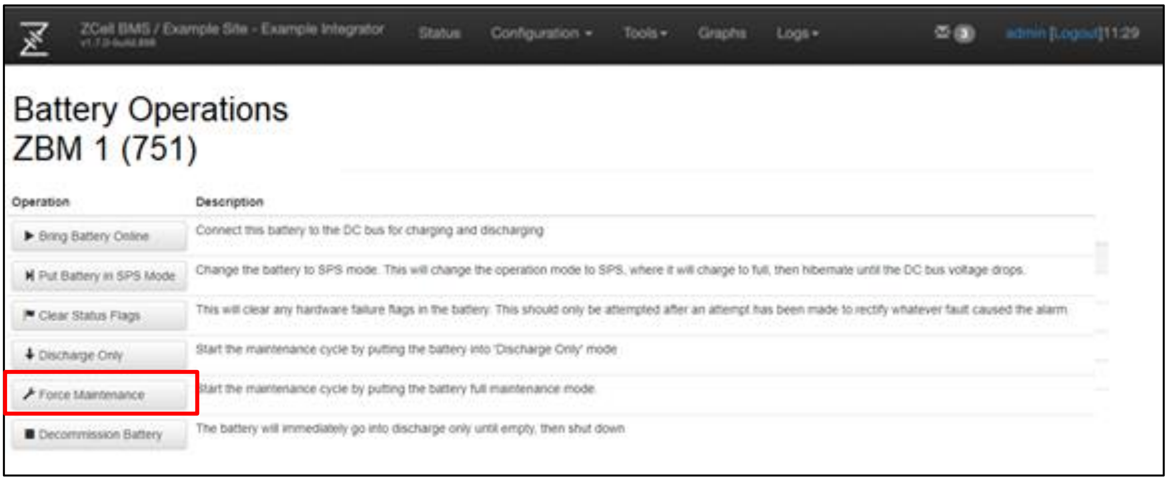
1. From the **Menu** bar, select **Status.**
   The batteries for the BMS display.
2. Select a battery row.



   The battery detail displays.



3. Select the **Operations** button.
   The *Battery Operations* window displays.



4. Select the **Force Maintenance** button.

8 ZBM Wear and Failure Processes

8.1 Leaks

The ZBM is packaged in a bund to contain a minor leak. In the event of a major leak, electrolyte could overflow so secondary containment should be used, and this should be considered in system design (see Section 10.1.2).

The ZBM includes leak detection to prevent damage to ZBMs if leaks occur. This functionality detects the presence of a leak in or near a ZBM via the use of the leak detectors on the Analog Loom. In the event that a leak is detected, the BCM internals will disconnect the charge/discharge contactor and stop both pumps.

8.2 Stack Degradation

Gradual reduction in electrode conductivity occurs as the ZBM is used. This is the normal life limiting process in the ZBM. Eventually, the electrode resistance increases to the point where the electrode stack needs to be replaced. If this occurs, contact Redflow for an approved part replacement and procedure.

8.3 Incorrect Operation

The battery can be damaged due to incorrect handling and operation. These are addressed throughout this Manual and must be adhered to during design, transport, installation, commissioning, and operation of all Energy Storage Systems using ZBMs. Incorrect handling and operation will void the warranty.

8.4 Electrolyte Contamination

Electrolyte contamination can occur when the tank is not properly sealed, or from copper exposure during some stack short circuits. The ZBM implements functionality to halt operation of a ZBM before a stack short circuit occurs.

Minimise the risk of electrolyte contamination by avoiding the disconnection of any parts involved in the hydraulic circuit (pumps and tubes). Unless contamination of the electrolyte has occurred as a direct result of a defect that originated during manufacturing or workmanship by a Redflow authorised representative, the electrolyte contamination will void the warranty.

8.5 Pump Failures

The ZBM implements pump failure detection to prevent damage to ZBMs when pumps operate incorrectly. This functionality will detect if pumps have seized or if they are running when they are not supposed to be doing so. In the event that abnormal pump operation is detected, the charge/discharge contactors will be disconnected, and the Zinc pump will run (if that pump is still operational). If this occurs, contact Redflow for an approved part replacement and procedure.

8.6 Electronics and Electrical

These components have been designed to ensure sources of failure are minimised. It is important to follow the instructions in this manual to ensure that the ZBM is not subjected to potentially damaging electrical connections. During operation, the ZBM continually monitors hardware status and operational parameters for unexpected issues. This information can be monitored with the BMS online interface (see Section 9.1 for more information). The ZBM will attempt self-protection from specific failures but may require manual intervention in some cases.

8.7 Over Temperature

Over temperature inside the ZBM can damage the battery. The built-in cooling fan will automatically begin operation when the battery temperature exceeds 30°C (86°F), with control also dependent on ambient air temperature. If the battery temperature exceeds 50°C (122°F), operation will then be automatically suspended. If the temperature of the electrolyte continues to significantly increase, this may result in high pressures inside the ZBM as gases are evolved (see Section 10.3 for related design considerations).

9 ZBM Maintenance

A systematic approach to preventative maintenance of the ZBM is required for warranty validity. Maintenance procedures are separated into condition monitoring and periodic procedures. A checklist is provided in Appendix B that must be used to record maintenance activities.

A fully completed and up-to-date checklist (provided in Appendix B), along with any supporting documentation for any abnormalities, is required to qualify for any ZBM warranty claim.

If a part replacement is required, only Redflow-approved parts may be used; this is a requirement for any warranty claims. If replacements are necessary, contact the supplier of the ZBM.

It is recommended that adequate space be provided in all installations to at least access the BCM end of the ZBM for electrical connections. **There should also be adequate space provided to allow individual ZBMs to be removed and/or replaced at end of life, or for servicing of individual components.**

9.1 Ongoing Maintenance

Ongoing condition monitoring maintenance involves remote monitoring of ZBM performance. If an operational or hardware issue occurs with the ZBM, a warning or failure alarm will be shown in the BMS online interface. The Status page shows these alarms at a high level, as shown in Figure 24.

Figure 24: BMS interface showing warning and failure alarms on the Status page

The individual Battery Pages show more detail about these alarms, as shown in Figure 25. These alarms must be responded to in a timely manner and any external issues addressed. If left unattended, these could cause damage to the ZBM and void any warranty claims.

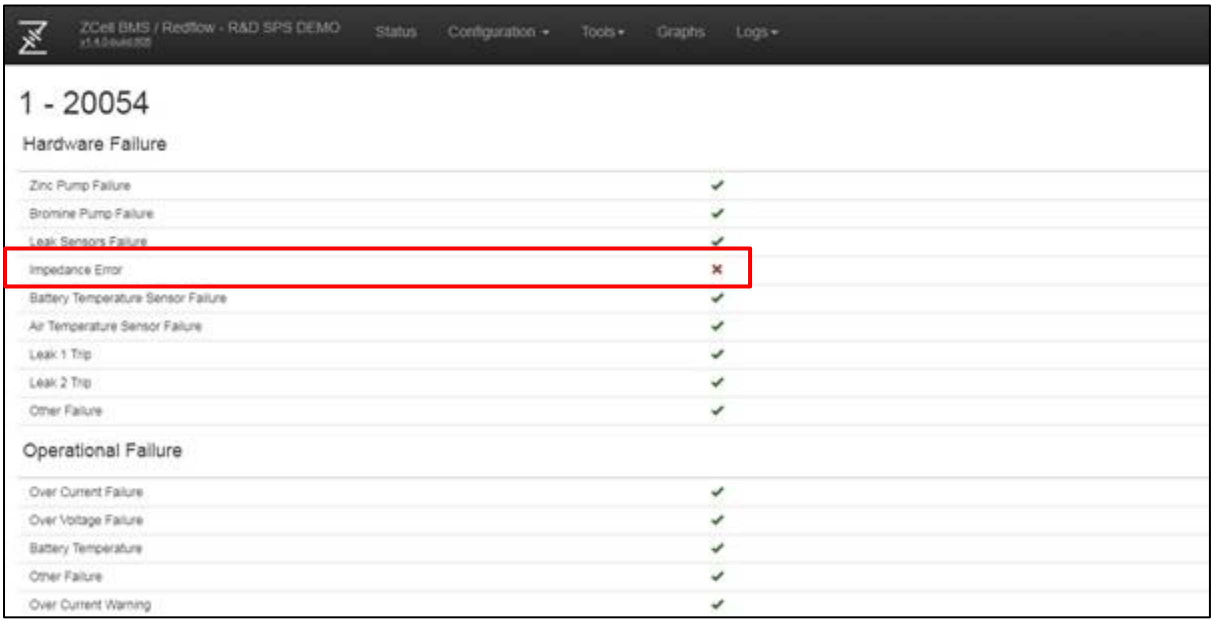


Figure 25: BMS interface showing details, warnings, and failures on the Battery Status page

9.2 Periodic Maintenance

At least at annual intervals, the following maintenance tasks must be undertaken. Periodic maintenance must be recorded in the checklist provided in Appendix B. If the ZBM is operating in areas of high concentration of dust and dirt, it is recommended that on-site maintenance is performed at shorter intervals.

DO NOT SHORT CIRCUIT BATTERY TERMINALS.
Any tools used MUST BE insulated and suitably rated and eye protection MUST BE worn. Remove all jewellery before performing any maintenance.

- Check the BMS interface to ensure the ZBM is running with no faults.
- Check the battery temperature reading is correct.
- Check the air temperature reading is correct.
- Check the cooling fan (part of the ZBM) operates correctly.
- Check the zinc electrolyte pump operates correctly.
- Check the bromine electrolyte pump operates correctly.
- Check the pH and adjust if necessary.

If any of the above checks identify defects, contact the supplier of the ZBM for Redflow-approved part replacement and procedures. Untrained maintenance on any of these parts voids the ZBM warranty.

Ensure that the ZBM has been fully discharged, a regular maintenance cycle has been run, and shutdown has occurred as specified in Section 7.4 before the following maintenance tasks are undertaken.

- Check the ZBM for any electrolyte leaks visually and by the presence of a chlorine-like smell. If a leak is present, Appendix A provides more information on how to clean up electrolyte spills.
- Check all components of the ZBM, including the pumps and analog loom, for signs of corrosion.
- Ensure there are no kinks in the Catch Can and Pressure Relief Valve hoses.

If any of the above checks identify defects, contact the supplier of the ZBM for Redflow-approved replacement parts and procedures. Untrained maintenance on any of these parts voids the ZBM warranty. If defects are identified, operating the battery for 30 or more days after detection without rectification voids the ZBM warranty.

Then, continue with the checks:

- Check all ZBM hose clamps are securely fitted.
- Check the ZBM connections are securely fitted.
- Check that the ZBM stack and bus terminals are correctly torqued at 10Nm (7.4 lb-ft). A thermal imaging camera can be used to monitor ZBM performance (energised) to ensure there are no hot spots, especially arising from incorrectly torqued battery terminals.
- Replace the carbon sock.
- Clean the ZBM of any dust or dirt that has built up.
- Check and remove any animal ingress.

9.3 Cleaning

No cleaning of the externals of the ZBM should be required. However, it is especially important that users *DO NOT USE* the following liquids to clean a ZBM:

- Soapy water
- Alcohol
- Any other detergents

Use of the above listed parts voids the warranty.

Tap water may be used to clean the ZBM if required. The ZBM must be dried before packing.

10 ZBM System Integration

This section outlines some general guidelines for system integrators when using the ZBM in energy storage systems (ESS).

10.1 System Design Guidelines – Safety

There are several potential safety issues to consider when using the ZBM in an ESS:

- ZBM terminal voltage up to 58V DC during charge
- Short circuit current of up to approximately 600A DC – conductors and protective devices need to be designed accordingly
- ZBM electrolyte is conductive and corrosive (1-3 pH) – avoid wetting electrical components
- Secondary containment for electrolyte (max 100L per ZBM) is recommended (see Section 10.1.2)
- Charged electrolyte contains bromine complex – manage fume risks (see Section 10.1.3)
- ZBM operation may evolve hydrogen – manage explosive atmospheres (see Section 10.1.3)

The following safety systems should be designed into ZBM-based ESS.

10.1.1 Shutdown Systems

Automatic, manual, and remote shutdown capabilities should be implemented in any ESS. Guidance on the ZBM shutdown procedure can be found in Section 7.4.

10.1.2 Spillage Management System

The presence of liquid electrolyte in the ZBM means that there is potential for a spill to occur. While the ZBM's own bund can hold an amount of electrolyte from minor leaks, external spill management equipment should be considered for the full electrolyte volume of 100L (26.5 US gal). The ESS should include secondary spill containment to prevent any environmental contamination in the case of spillage from the ZBM batteries. The electrolyte itself is water-based and can be diluted with water. Any polyethylene container, bunding or bag can be used to contain the electrolyte. Other plastics compatible with ZBM electrolyte include polypropylene, PVC and other materials including PVDF, Teflon and Viton. Note that many plastics including nylon, acetal and neoprene are not compatible with the bromine-rich electrolyte. More detail on spills and managing them can be found in Appendix A.

10.1.3 Hydrogen & Bromine Gas Management/Detection System

Low levels of gas may be evolved during operation of the ZBM. As with all batteries that use water-based electrolyte, some hydrogen can be generated inside the ZBM during operation. While ZBMs are sealed systems, they have a pressure relief valve to manage internal pressures, which can result in hydrogen and bromine gas being emitted during operational issues that result in high pressures inside the ZBM. Further, any spills or leaks of electrolyte will result in some bromine gas. The levels of these gases are safe during normal operation with no requirements for personal protective equipment (PPE, see Section 2.1.3) unless there is an operational issue.

If gases are emitted, the risks associated with hydrogen gas include a potentially explosive environment in high concentrations, and the risks associated with bromine gas can be found in the SDS. As such, an ESS should include adequate ventilation (see Section 10.2.3) and be monitored to ensure these gases remain at safe levels.

Further, each ZBM is equipped with a Catch Can (see section 4.5) to capture gases generated during operation. The barb at the rear of the Catch Can provides a connection point for a hose to direct any uncaptured gas to an area safe to vent (e.g. outside in open air). This hose must be made from non-kinking PVC, or compatible compound, and is not supplied with the ZBM.

Refer to Section 10.2.3 for more information about Ventilation Requirements.

10.1.4 Fire Control System

An automatic fire control system may be required according to local regulations. However, the likelihood of a fire generated inside the ZBM is quite low. As a precaution, naked flames or any glowing heaters and other devices must not be used in the vicinity of ZBM enclosures or battery rooms. Fire extinguishers should also be installed in any ESS as a precaution and be chosen for the materials in the ESS.

10.1.5 Noise

Noise associated with the ZBM's operation is minimal and has been measured to be maximum 77.0dB at one metre with background noise of 54.8dB. If noise is a concern, this should be accounted for in the system design.

10.2 System Design Guidelines – Mechanical

Locating the ZBM inside an enclosure or a dedicated battery room needs to take into consideration a range of issues.

- ZBM weight
- ZBM physical size
- The ZBM is only designed for stationary applications. It contains different fluids that need to separate and blend during different stages of ZBM operation. There are no baffles installed in the electrolyte tanks to control the electrolyte in non-stationary applications.
- The ZBM must be upright for operation, transportation and storage and be situated on a flat, level surface. While it is a sealed system and will not leak if it is on its side, the ZBM is not specifically designed to operate or remain for any length of time in these conditions.
- The ZBM is not intended to withstand large forces and weights. Standing or leaning on the ZBM must not occur.
- The ZBM should be installed in an area that has sufficient ambient light and/or a similar level of sufficient artificial light in order to allow for safe installation, operation and maintenance.
- The ZBM must be installed in clean and dry conditions and protected from the natural elements and falling items.
- Adequate insulation for the operating voltages and currents must be used on all materials in the ESS.
- Secondary containment: required in case of electrolyte spills or leaks.
- Enclosures must meet relevant standards and local environmental conditions.
- Adequate airflow is provided to the ZBMs and electronics (see Sections 10.2.1 and 10.2.3).
- Correct ZBM orientation and adequate physical clearance should be provided around ZBMs to allow for easy maintenance and visual access (see Section 9 for maintenance requirements).
- System design must not restrict the flow of electrolyte in any piping or tubing included with the ZBM, this is a warranty condition.

10.2.1 Separation of ZBMs and ESS Electronics

The ZBM must be installed in a section of the ESS separate from the other electronics (with no common flow of air), and with its own ventilation (see Section 10.2.3). However, in the case where power electronics must be situated in very close proximity to ZBMs, airtight enclosures for the power electronics must be used. This is to prevent exposing the power electronics to hydrogen or bromine gas.

10.2.2 Corrosion Protection

Due to the corrosive nature of the ZBM's electrolyte, any metals or similar materials that may corrode should be corrosion-protected.

- Copper bus bars should be Zinc plated and/or coated with polyethylene.
- Do not use uncoated steel including stainless steel. Coating options are: PVC, powder coating, zinc plating, hot dipped galvanised.
- Do not use stainless steel fasteners: use zinc plated or galvanised fasteners.
- Aluminium should be anodised (>20 micron).
- Cables ties must be polypropylene not nylon.

If building an enclosure, contact Redflow for further support.

10.2.3 Ventilation Requirements

The ZBM is not intended for use in explosive environments. ZBMs must never be installed in airtight enclosures. Ventilation of any enclosures or battery rooms containing ZBMs is required both for thermal management (see Section 10.3) and management of hydrogen and bromine gases that can be emitted during some operational issues. As a guide for gas management, the IEC Standard, IEC 62485-2, should be followed as ZBM gas emissions are similar to those for lead-acid batteries. Issues to be considered include adequate free space between ZBMs and other components, adequate airflow (e.g. via the use of fans), and adequate placement of vents, windows, and other openings.

The recommended airflow rates outlined in Table 2 (50l/s/ZBM) for thermal management far exceed the airflow requirements to address any gas emissions. Airflow must be directed in such a way so as not to oppose the ZBM's cooling fan path as shown in Figure 7.

Due to the risks posed by inadequate airflow leading to a build-up of gases during an operational issue, it is highly recommended that any ESS including ZBMs be fitted with an airflow sensor at least for those ESS relying on artificial (not natural) airflow, to alert users if the ZBM installation is not receiving adequate airflow.

10.2.4 Securing ZBMs

The ZBM is not supplied with any specific lock-down mechanisms as it is designed for stationary applications. If the system is required to be rated for high vibration or earthquake zones, then additional mechanical methods of securing the ZBM will need to be implemented. Personnel should not approach or be in the vicinity of the ZBM when it is experiencing high vibrations.

10.3 System Design Guidelines – Thermal Management

Management of the thermal load generated as the battery discharges and charges is normally achieved through fan-forced ventilation and by allowing the battery electrolyte temperature to rise during operation.

The most important criterion is to design for a sufficient flow of air through the ZBM's fan cooling system. The ZBM is not a battery that can be installed in a sealed container since a significant amount of heat needs to be dissipated. The discharge of a single ZBM can generate as much as 2kWh of heat. If this discharge occurs over 2 hours, then heat is being generated at 1kW per hour.

Thermal design considerations include:

- Enclosures and battery rooms are designed for at least the airflow rate stated in Table 2 for adequate thermal management.
- The presence of fans can have implications on the noise level generated by the ESS, and this needs to be taken into consideration during enclosure design, especially if the ESS is to be installed in close proximity to work or sleeping areas.
- An air-conditioned enclosure can be utilized; however, the same ventilation requirements are required as for sealed lead-acid batteries.
- The thermal mass of the ZBM will absorb some of the heat generated during operation.
- ZBM operating temperature range (see Table 1).
- Cables and their insulation connecting to the ZBM should be capable of withstanding temperatures of 70-110°C as cables may reach these temperatures at high currents.

Significantly high ZBM temperatures can lead to gas evolution, high internal ZBM pressures and in extreme cases, a rupture to relieve pressure should the pressure relief valve fail.

10.3.1 Temperature Considerations

ZBM operation will automatically be suspended when the battery temperature reaches 50°C (122°F) to prevent the ZBM operating in extreme ambient temperatures. Depending on a range of operating parameters, including enclosure design, ventilation and charge/discharge rates, the battery temperature is in most cases higher than the ambient temperature.

The most effective way to maintain the ZBM within its acceptable temperature range is for the ESS to use fan ventilation when ambient temperature conditions are hot. Well-ventilated enclosures or battery rooms and slower charge/discharge rates will also result in lower battery temperatures. Active cooling with chillers or air conditioners is generally not required. When the ambient temperature is cold, it is advised that heaters should be used to raise the ambient temperature around the ZBM. Further, operating the ZBM, especially at full power, will raise its internal temperature compared to when it is not operational.

10.4 System Design Guidelines – Electrical

A typical ZBM-based ESS, which is developed by System Integrator partners, consists of:

- Batteries, either single or multiple ZBMs, or a combination of ZBMs and other types of batteries.
- BMS for communication with the ZBMs (see Sections 4.10 and 10.5 for more information).
- A bi-directional Power Conversion System (PCS) that may be DC-AC for typical grid-connected applications or it may be DC-DC for some off-grid applications, e.g. Telecom applications.
- A Unit Master controller with an appropriate communications link and user interface to allow the end customer to operate the ESS.
- Grid-interconnection components as required by the application (e.g. transformers).

It is a warranty requirement that operational electrical parameters specified in Table 1 must be adhered to.

10.4.1 Voltages

A critical element when designing for the use of ZBMs is to understand the charge and discharge voltages of the ZBM. While the ZBM has been designed to operate with nominal 48V devices (such as inverters), the voltages produced can be outside the voltage ranges of some systems that have been designed specifically for 48V lead-acid batteries. Figure 26 shows the typical voltages produced by the ZBM during charging and discharging. The ZBM can be discharged down to a voltage of 40V at which point the battery automatically disconnects from the DC bus.

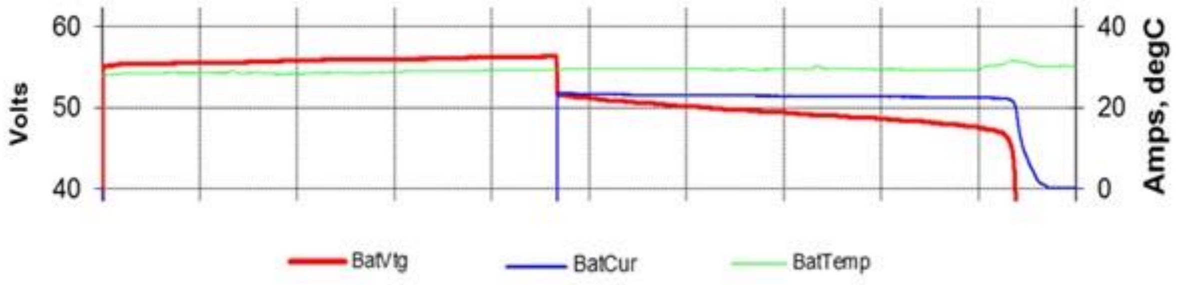


Figure 26: Excerpt from Figure 27 showing ZBM voltage profile

While the battery voltages are classified as extra low voltage (ELV) in Australia, care should be taken in design to ensure systems are safe according to local regulations.

10.4.2 Currents

The charge current needs to be limited to conform to the maximum charging power limit per ZBM specified in Table 1. The BCM will disconnect from the bus if a charge current above 50A or a voltage above 60V is measured, so the maximum charging current should be set to a value below 50A.

The discharging current at which the BCM will disconnect from the bus is 125A. The disconnection will occur after detecting a current of:

- 125A for 13 minutes, or
- 126A for 60 seconds, or
- 128A for 5 seconds, or
- instantaneously for 130A or above

Operating the ZBM at higher currents than those listed above will void the ZBM warranty.

All fault protection equipment (such as fuses and circuit breakers) should be chosen and designed for fault currents of 125A and above, while considering the level of normal operating currents stated in this section.

When multiple ZBMs are operated in parallel, the maximum charge and discharge currents are cumulative, e.g. two ZBMs can be charged with a maximum of 100A (50A each). If one of the multiple ZBMs disconnects from the bus (e.g. because it has reached 100% SOC or it requires self-maintenance soon (see Section 10.4.7)), then the maximum charging current will reduce by 50A. As such, any chargers connected to the bus must be able to prevent a higher power still being pushed into the bus (e.g. by voltage control or by limiting the charger current based on the number of ZBMs connected to the bus).

10.4.3 Power Output

The ZBM's power ratings are stated in Table 1. The duration of the ZBM's peak discharge power depends on various parameters including the battery's current state of charge, age, and temperature.

10.4.4 Energy Output

The ZBM energy capacity is stated in Table 1. Unlike lead-acid batteries, the ZBM is designed to provide 100% of the available energy.

10.4.5 Response Time

The full load response time of a ZBM is fast when the pumps are running but requires a short start-up period when operating from standby. The ZBM operates in the same manner as any other battery and can swap from full power charging to full power discharging almost instantaneously.

10.4.6 Efficiency

Stack DC-DC energy efficiency of the ZBM is up to 80% without ancillary components. However, the cumulative effect of inverters, cooling systems, and additional power electronics will reduce overall round-trip efficiency to lower levels.

10.4.7 Self-Maintenance

Self-maintenance is the process of stripping all zinc from the electrodes of the ZBM. The ZBM needs to be used in such a way that it can undergo self-maintenance regularly. It is a condition of any warranty claim that the ZBM has undergone self-maintenance at the frequency specified in Table 1. The self-maintenance process in a standard ZBM cycle is shown in Appendix C. Normally the maintenance cycles are scheduled by the site BMS which is highly configurable to match the site's requirements.

Key aspects of the self-maintenance process include:

- The ZBM will automatically enter, run, and exit self-maintenance mode using its BCM. The user has control over the timing of the self-maintenance cycle by utilising the BMS interface. This is accessed by navigating to the Battery Maintenance page in the Configuration drop down menu.
- In the event that the communication link between the BMS and ZBM is lost, the BCM has an inbuilt safety measure to ensure self-maintenance is performed at sufficient intervals to prevent damage to the ZBM.
- To minimise time to complete the maintenance cycle the ZBM must be fully discharged before entering self-maintenance mode.
- When required, the ZBM will flag that it needs to start the self-maintenance process in the next 24 hours. It will automatically prevent further charging and only allow discharge to occur. The ZBM will then continue to discharge until it is sufficiently discharged to automatically enter the Self-Maintenance state, or the 24 hours has elapsed.
- When it is not connected to a BMS, if the ZBM is not fully discharged when the 24 hours has elapsed, the ZBM will disconnect from the bus and use its own pumps and fan as loads to fully discharge. Note that this can take several days if the ZBM is fully charged.
- When connected to a BMS, the ZBM will continue to remain in the discharge-only phase past the 24-hour time period until such time that the ZBM has been fully discharged.
- After discharge is completed, excess zinc is automatically stripped from the ZBM's electrodes. The user should allow two to three hours for a full self-maintenance cycle to be performed by a ZBM after it has discharged.
- During the self-maintenance cycle the stack will discharge down to 0V so the 40V required to run the pumps will need to be provided externally. This could be other ZBMs on the same DC bus.
- If there is no external power available to the ZBM when it begins the self-maintenance cycle or external power is lost during self-maintenance, the ZBM will power down. When external power is returned, the ZBM will continue where it stopped in the self-maintenance cycle.

If the application requires a continuous source of battery power to be available, the system should be designed with at least 2 ZBMs or as a hybrid with a different form of power back-up.

- Single ZBM ESS – means that periodically there will be no voltage from the bus terminals during the self-maintenance cycle.
- Multi-ZBM ESS – the BMS can arrange the self-maintenance program such that only one ZBM is undergoing self-maintenance at a time and the remaining ZBMs are available.

Self-maintenance can be optimised by the BMS noting the following:

- Discharge all stored energy into the load prior to running the self-maintenance cycle. This means that the stored energy can be used in a "useful" way (i.e. it is not wasted) and the ZBM will not be out of service for any additional period of time to self-discharge.
- Self-maintenance cycles can be run during times when the battery does not need to operate but a power source is still available. In a grid-connected solar shifting application, the self-maintenance cycle can be done in the early hours of the morning when the battery has been completely discharged, there is no solar power available to charge the batteries and grid power can be less expensive.

10.4.8 Parallel Arrangements of ZBMs

Multiple ZBMs can be connected in parallel arrangements. The optimal arrangement often depends on the voltage, current and other power electronics requirements of the ESS. ZBMs must not be connected in series.

10.5 System Design Guidelines – Communications

Communication with each ZBM is done using a BMS with an internet connection. This provides an online interface to one or multiple ZBMs in a system and can communicate with each ZBM individually using unique MODBUS addresses.

It is important to note that 1 BMS can be used to communicate with up to 12 ZBMs in one system. If the system designed has more than 12 ZBMs contact Redflow for the best recommended solution.

The BMS can also connect to other components in the larger energy system, including energy management systems and inverters, to enable control of the ZBMs from those components.

The full ZBM warranty is dependent upon the ZBM BMS remaining connected to the internet for the duration of the warranty. A shorter warranty will apply for ZBMs without a BMS or whose BMS does not remain connected, as specified in the warranty.

Appendix A Addressing ZBM Electrolyte Spills/Leaks

This section provides guidance on how to assess the severity of an electrolyte spill or leak, and how to manage the clean-up.

1. Electrolyte Spill or Leak Classification

It is necessary to assess and classify the severity of an electrolyte spill to be able to address it effectively. The table below provides guidelines for determining if the spill or leak is minor or major.

Characteristic	Minor Spill/Leak	Major Spill/Leak
Volume	Less than 1 (one) litre	More than 1 (one) litre
Flow Rate	Slow drip or no visible flow	High flow rate
Smell	No strong smell	Strong chlorine-like smell
Colour	Clear or light yellow	Deep red
Location	No liquid is near electrical connections	Liquid is near electrical connections

2. Electrolyte Spill or Leak Clean Up

This section provides guidelines for cleaning up a ZBM electrolyte spill or leak. All personnel involved in clean-up activities must be aware of the content of the ZBM SDS.

Step 1 Assess the Severity of the Spill/Leak

Using the information in the table above, assess the severity of the spill or leak as minor or major.
If the spill/leak is minor, proceed to Step 2.
If the spill/leak is major, proceed to Step 3.

Step 2 Minor Electrolyte Spill/Leak Clean Up

Step 2.1 Apply personal protection equipment.

Step 2.2 If the spill/leak is associated with a ZBM, pause the operation of the ZBM (if the BCM has not already done this).
Inspect the ZBM for the cause or source of the leak.
Using rags or disposable wipes, clean up the visible electrolyte.
Discharge the ZBM safely.
Manage all clean up materials as hazardous waste by placing them in an acid debris waste accumulation container.
Contact Redflow support for advice on how to proceed.

Step 2.3 If the spill is not associated with a ZBM, for example, electrolyte is spilt from its container, use rags or disposable wipes to clean up the electrolyte.
Apply absorbent (as specified in Section *3 Clean Up Materials*) to neutralise remaining electrolyte.
Manage all clean up materials as hazardous waste by placing them in an acid debris waste accumulation container.

Step 3 Major Electrolyte Spill/Leak Clean Up

Step 3.1 Alert colleagues that the electrolyte spill/leak has occurred and if a strong chlorine-like odour is evident, evacuate the hazardous area.

Step 3.2 Apply personal protection equipment.

Step 3.3 If the spill/leak is associated with a ZBM, stop the operation of the ZBM.
Isolate electrical connections.
Inspect the ZBM for the cause or source of the leak and, if possible, prevent further leakage from occurring.
Using rags or disposable wipes, clean up the visible electrolyte.
Apply absorbent (as specified in Section *3 Clean Up Materials*) to neutralise remaining electrolyte.
Manage all clean up materials as hazardous waste by placing them in an acid debris waste accumulation container.
If possible, discharge the ZBM safely.
Actively ventilate the affected area.
Contact Redflow support for advice on how to proceed.

Step 3.4 If the spill/leak is not associated with a ZBM, inspect for the cause or source of the spill and, if possible, prevent further spillage from occurring. This may require the use of other appropriate (e.g. polyethylene) containers to contain the spill.
Using rags or disposable wipes, clean up the visible electrolyte.
Apply absorbent (as specified in Section *3 Clean Up Materials*) to neutralise remaining electrolyte.
Manage all clean up materials as hazardous waste by placing them in an acid debris waste accumulation container.

3. Clean Up Materials

Note:

- All materials that are to be in future contact with electrolyte need to be rinsed of any acid, ammonia, or other neutralising agents prior to re-use to avoid chemical imbalance in the electrolyte.
- Disposal of materials that have contacted with electrolyte must be performed according to local laws and regulations.

Rags and disposable wipes are suitable for cleaning up electrolyte.

Neutralising Electrolyte - uncharged

Commercial absorbents or acid neutraliser absorbents (that have a significant colour change to signify complete neutralisation of acids) can be used for electrolyte clean-up. Lime or baking soda can also be used to neutralise acid and therefore an electrolyte spill.

Neutralising Electrolyte – charged

⚠ CAUTION	**Mixing ammonia solution with electrolyte can cause a violent exothermic reaction: add ammonia solution slowly.**

Household grade ammonia (~10%) solution can be used to neutralise bromine complex or charged electrolyte spills. To prevent a violent exothermic reaction, add ammonia solution slowly to the spilt electrolyte.

Appendix B Maintenance Checklist

Warranty is voided if annual maintenance checks are not done.

ZBM Annual Checks												
Maintenance Technician:	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Date	/ /	/ /	/ /	/ /	/ /	/ /	/ /	/ /	/ /	/ /	/ /	/ /
Check the BMS interface for any warning or failure alarms	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check the battery temperature reading is correct	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check the air temperature reading is correct	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check the cooling fan operates correctly	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check the zinc electrolyte pump runs	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check the bromine electrolyte pump runs	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check the pH and adjust if necessary.	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done
Check the ZBM for any electrolyte leaks visually and by the presence of a chlorine-like smell.	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check the ZBM for signs of corrosion	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check hoses connected to the catch can are not kinked.	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check ZBM hose clamps are securely fitted	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check the ZBM circuit protection is maximum of 125A	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Check that the ZBM BCM stack and bus terminals are correctly torqued at 10Nm (7.4 lb-ft).	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass	□ Pass
Replace the carbon sock.	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done
Clean the ZBM of any dust or dirt	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done
Check and remove any animal ingress	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done	□ Done

Appendix C Standard Test Cycle

Figure 27 shows Redflow's Standard ZBM test cycle that is run in the case of a warranty claim. The standard test cycle starts with a fully discharged ZBM.

There are two operating modes that the ZBM goes through during this standard cycle at 25 °C:

1. Charging (9.2-hour period from 0 to 9.2 hours):
   - Current (blue trace, using right axis) at -25A DC (negative = charging) for 9.2 hours.
2. Discharging (10-hour period from 9.2 to 19.2 hours):
   - Current ranges from 25A DC to 0A DC as the voltage (red trace, using left axis) falls from 52V DC to 0V DC.
   - The ZBM continues to discharge until the battery current is very close to 0A, and the ZBM is empty.

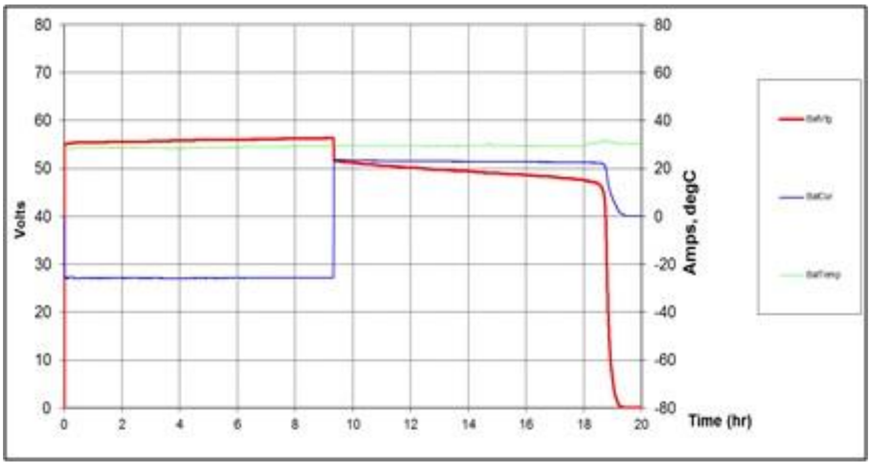


Figure 27: ZBM Standard Test Cycle

Appendix D Example Setup: Inverter and Load

The diagram below presents an example circuit that can be used to operate a ZBM (see Figure 28).

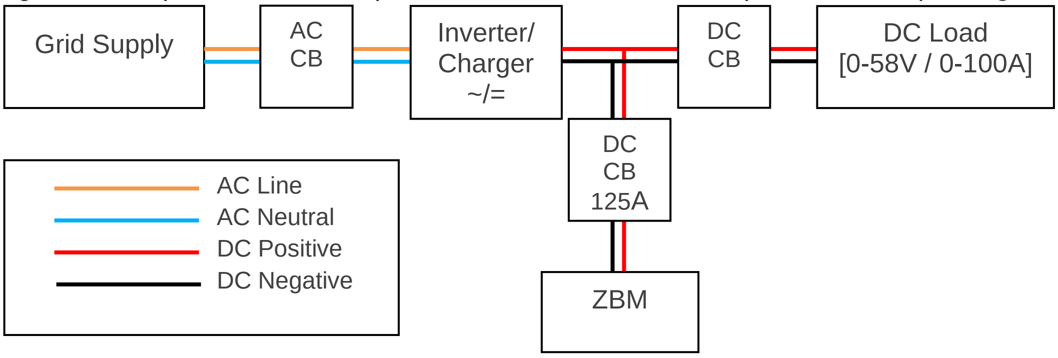


Figure 28: Example connections ZBM

An explanation of each of the elements in **Figure 28** is given below.

- **Grid supply:** provides the power needed to support the load and charge the ZBM.
- **Circuit Breaker (CB):** circuit protection for AC/DC. These should be sized appropriately for the inverter and load.
- **Inverter/Charger:** converts the AC grid supply to DC for the ZBM.
- **ZBM:** charges when power is applied to terminals, and discharges when a load is connected and no other adequate source of power is available. Multiple ZBMs could be connected in parallel.
- **DC Load:** the load that the battery and inverter need to supply.

It is also important to note the following operational guidelines:

- In order for the ZBM to undergo its Self-Maintenance Cycle (see Section 10.4.7 for more information), it must first be completely discharged. This will occur automatically either through an external load connected (faster and more efficient solution) or through its own pumps and fan load (when no load is available). A fully charged battery will take approximately 7 days to fully discharge using its own pumps and fan as load.
- In order for the ZBM to complete its Self-Maintenance Cycle (see Section 10.4.7 for more information), it must have external power from the inverter. This is to enable the ZBM's pumps and BCM to operate even though the terminal voltage is ~0V.
- The ZBM can be continuously powered without damage as it will automatically disconnect the battery terminals from the bus when fully charged but will still source auxiliary power from the bus.
- Control and monitoring of the performance of the ZBM is done using Redflow's BMS product.

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