Orion BMS

Operation Manual.

(Preliminary Version 0.5)

This operational manual is preliminary and will be updated with more information as it becomes available.

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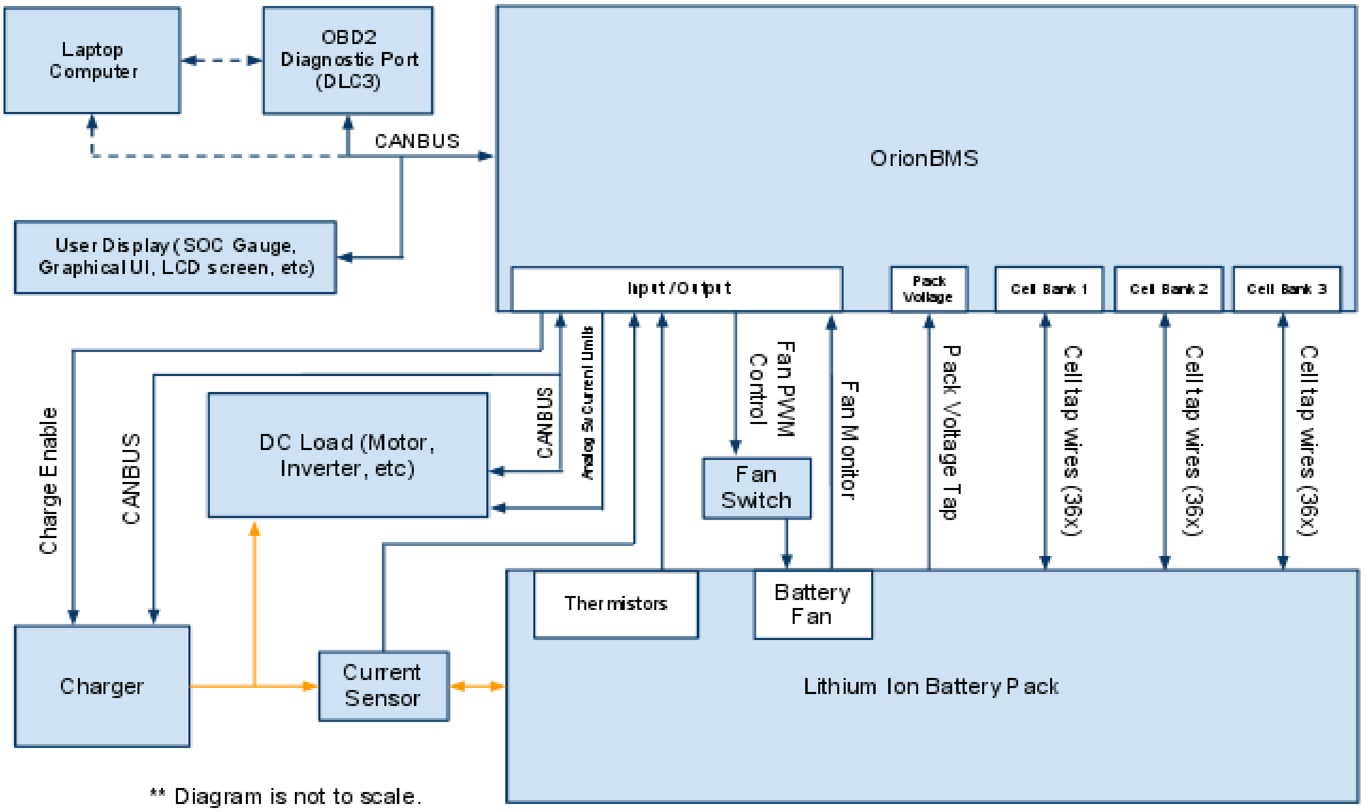
System Overview



** Diagram is not to scale.

The Orion BMS is designed to be connected externally to a lithium ion, NiMH or NiCAD battery pack. The BMS relies on many inputs such as cell voltage tap sensors, a total pack voltage sensor, current sensor, thermistors, and data provided by the user to calculate safe limits for the battery pack. The Orion BMS then provides that information to external components such as loads, sources and battery chargers to protect, manage, and monitor the battery. The BMS relies on the external components to respect the limits set by the BMS. It cannot directly cut charge or discharge currents to protect the battery and relies on the end user to provide appropriate controls.

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Planning

Please see the Orion BMS wiring manual, software manual and purchasing guide for more information about selecting the correct BMS unit.

Failure Mitigation

The OrionBMS features several comprehensive failsafe modes to protect the battery pack should something go wrong. Although these internal redundancies and protection procedures are provided, it is the users's responsibility to ensure that the BMS is configured, connected, and used in a manner in which failures are properly mitigated and handled.

For any application where a battery pack is used, the user must think through all possible failures, provide redundant systems, and determine that each failure mode is safe and acceptable. Generally speaking the worst case situations are situations where a failure can occur and the application is not aware and trusts incorrect data. Because the requirements vary from application to application, it is the responsibility of the user to determine acceptable risk and design the rest of the system to mitigate risks.

Any application should be setup such that a disconnected or loose wire should cause a safe failure (that is to say, if a failure occurs it should not be able to damage the battery or other parts of the application). For this reason, the BMS's digital on/off outputs are setup to be active low to **enable** charge or discharge. While the settings for when to enable charge and discharge can be changed, the polarity of the enable digital output cannot be changed for the purpose of preventing accidental mis-configuration of the polarity.

While the following is not an exhaustive list, here are common failures to consider:

1. **Loose / disconnected wire on cell voltage tap or failure of a cell voltage sensor**
   This is a major issue for any BMS since the BMS cannot measure cell voltages for cells that it is not connected to. However the Orion BMS provides several lines of defense against open wires. If the wire becomes disconnected or intermittently disconnected (loose connection), the BMS features open wire detection where a small current is applied to the cell wire every so often to ensure that the connection is good. If the BMS detects that a wire has become loose, disconnected, or has sufficiently high impedance,

it will set an open wire fault for the specific cell tap effected and go into a fail safe mode. It should be noted that the BMS contains internal non-user serviceable fuses on cell voltage tap connections and if a fuse is blown (reverse polarity, over-voltage or improper location of a safety disconnect / fuse causing current to flow through the BMS), the BMS should detect a blown fuse and read that cell tap as an open wire. If a wire which is not being used as a cell tap (for example if a cell group only has 10 cells connected, wires 11 and 12 in that case would not be actively being used) comes loose or disconnected, it may cause voltage reading inaccuracies that the BMS cannot detect. For this reason (and for improving accuracy of voltage readings in general), 2 or more wires should be used to connected unused taps to the cells as described in the wiring manual. As a second line of defense for all the above conditions, the BMS also has a total pack voltage sensor which is constantly compared to the sum of all cell voltages to look for inconsistencies. If inconsistencies are detected, the BMS will set a fault code and go into a voltage fail safe mode (described later). The variance allowed is a user specifiable feature in the profile and can be effectively disabled by setting a high value should this behavior not be needed or desired. The total pack voltage sensor is not guaranteed to catch a loose wire, particularly if cell voltages are fairly low or if the maximum allowable variance is set high.

If a cell voltage tap wire becomes loose and makes contact with another cell at a different potential (either more positive than 5v or negative with respect to the potential it is supposed to be connected to), it will cause damage. If that occurs, the BMS has over voltage protection and integrated fuses to protect the more expensive electronics. However, the BMS will likely need to be serviced.

If a wire becomes shorted to the chassis or ground, the BMS also has integrated isolation fault detection which can be configured to set a fault code to alert the user that a short has occurred. The BMS is capable of detecting isolation faults as small as 1 Meg Ohm, depending on the application and the configuration (that feature does require that the battery pack be isolated from the chassis or ground under normal conditions).

2. **Loose / disconnected wire on pack voltage tap or internal voltage sensor fault**

   Generally speaking, a loose or disconnected wire on the total pack voltage tap or a failure of the voltage sensor will cause a noticeable error in the total pack voltage sensor. As such, if the reading is 0 volts or if the reading varies enough from the summed up cell voltages, an error code is set and the BMS will go into a voltage fail safe mode since it cannot trust voltage readings which are a critical part of the BMS's data collection system.

3. **Loose / disconnected wire or failure of current sensor system**
   Most current sensor failures will be detected by the BMS and an error code will be set indicating that the BMS cannot trust the value from the current sensor. The sensors supplied with the Orion BMS are dual range sensors and the BMS can detect if just one of the 2 current sensors has failed. Most failures will result in the BMS reading positive or negative the maximum value of the current sensor (for example, a 600A sensor might read -600A or +600A consistently.) If this happens or if the BMS detects an internal error, a current sensor code will be set and the BMS will enter a fail safe mode.

   The worst case is if the current sensor malfunctions in a manner where values appear to be consistent but are incorrect and the BMS cannot detect a failure. Such a failure could result from a high impedance wire in the 5v or ground wires going to the current sensor for example. In this instance, the BMS will continue to protect cells based on maximum and minimum cell voltages, however calculations based on current sensor values such as internal resistance, open cell and charge and discharge current limit values may be wrong. If additional redundancy is necessary for an application, an approach for increasing redundancy is to compare currents measured by the BMS with currents measured elsewhere such as at an inverter, load or source. It should be noted that with a malfunctioning a current sensor, the BMS can still provide basic protection of the cells from over voltage and under voltage.

4. **Disconnected wire or failure of thermistor**
   A disconnected thermistor will result in an error code by the BMS and the BMS will ignore that specific thermistor until the error code is cleared or the BMS power is reset. A thermistor failure where the temperature is read incorrectly (such as the use of an inappropriately sized thermistor) can result in the temperature being read incorrectly and current limits being imposed on the battery pack incorrectly. Thermistor measurements can be viewed in the BMS utility to help locate thermistor failures.

5. **Loose / disconnected wire on main I/O connector**
   The main I/O connector contains wiring for both CAN interfaces, the fan interface, 5v analog interfaces, power and charge, discharge and charger safety digital on/off outputs. Loss of one of the power signals may cause the BMS to go into sleep mode. Loss of the always on power when the BMS has no other power sources will cause the BMS to reset and lose state of charge information in addition to error codes. Loss of the 5V analog lines must be planned for in the application such that if a wire becomes disconnected, the application goes into a safe failure mode. This is particularly true of the state of charge and amperage outputs since a disconnected wire could result in the application believing that the state of charge has dropped to 0% and the amperage dropped to the

maximum value. Digital on/off outputs are setup such that they are "on" (active low) only when they are enabled, such that a disconnected or loose wire will cause them to fail in an off condition and by default not allow charging or discharging.

6. **CANBUS communication failure**
   While CANBUS is a very robust protocol, systems should always be designed to tolerate a total or partial CAN communication failure. CAN buses may become unreliable if another node on the bus starts transmitting and clogs the bus causing intermittent messages to get through, creates errors on the bus blocking all communications or starts transmitting gibberish on the bus. Since CAN communications cannot be guaranteed by their nature, 3 things should always be done when communications are necessary to prevent major failures:

   1.) CAN systems should always be backed up with an analog system if the failure would be catastrophic. For example, if a CAN based battery charger is used, the charge safety digital on/off output should be used as a backup such that if CAN communication is lost that the BMS can safety shut off the charger such that the battery pack is not overcharged.

   2.) Any critical CAN system should always verify checksums at the end of the message before accepting data from that message. If a node on the bus is garbling messages or if electrical noise enters the CAN wires, messages can become distorted and bits may be incorrectly received.

   3.) Any system that accepts CAN messages should feature a timeout such that if a handful of messages are missed, the device should not trust the last known data but rather go into a failsafe mode where it operates under the assumption that values are unknown.

7. **Digital on/off safety relay failures**
   The digital on/off outputs are designed to be a last line of defense. However, they are often connected directly or indirectly to external relays which can fail. Ewert Energy strongly recommends providing at least 2 redundant methods for disabling charge, discharge, or any external battery charger since the BMS is unable to force a relay to turn off if it has failed. After the Orion BMS attempts to turn off one of the relays (charge enable, discharge enable, or charge safety), it will continue to monitor to ensure that current flow has stopped. If current flow has not stopped within a pre-defined amount of time, the BMS will go into a relay failsafe condition where all digital on/off outputs are set to zero in an attempt to protect the batteries (mostly helpful in the event where a relay is wired to the wrong digital on/off output.) Ultimately it is the user's responsibility to ensure that the application respects the BMS's command.

The digital on/off safety lines are all configured as open drain outputs where they will float when off and will be pulled down to ground when enabled. It is important to note that if voltages excede 30V on any of the digitial on/off lines, protection diodes inside the BMS will cause current to flow and will result in the output appearing to turn on, so it is therefore imperative to ensure that the operating voltage never exceeds 30V, even briefly.

8. **Failure of fan component or fan controller**
   While fan failure modes often are not considered to be a safety concern, they can still fail. The Orion BMS provides a fan voltage monitoring circuit that can be used in an application to determine if the fan has failed. The settings are customizable in software in the profile. The BMS will set an error code if the voltage monitor conditions are not met.

   Proper mitigation of a fan failure should include thermal protection of the battery. The profile allows for setting maximum charge and discharge current limits based on over and under temperature.

9. **Failure, shorting or disconnection of analog 5V output**
   If the 5V analog outputs are used to control applications, proper failure mitigation must be designed such that if the 5V analog wires become disconnected or shorted to 0V that the failure will be safe. Additionally, if overvoltage or reverse voltage is applied to the pins on the BMS and internal damage occurs resulting in inaccurate output voltages, the application should have a failsafe allowing the BMS to shutdown operation in a safe manner.

Understanding Failure Modes

The Orion BMS has several failsafe software modes to ensure that the batteries are protected against internal and some external failures of the BMS. These modes are designed to place the priority on protecting the battery.

1. **Current sensor failsafe mode**
   This failsafe mode is triggered when the BMS determines that the current sensor is either unplugged or has otherwise become inaccurate and cannot be trusted. In this mode, the current sensor is disabled and will measure 0 amps. The result of this mode

is that the BMS will continue to operate and protect the batteries purely using voltage based conditions. However, all functions relying on the current sensor are disabled. Care should be taken to correct this issue as quickly as possible, but it is possible to continue using the battery pack in this failsafe condition.

The changes made in this failsafe mode:

- Internal resistance calculations disabled (both cell and total pack)
- Open cell voltage calculations disabled. They will read the same as the instantaneous voltage readings. True of both the total pack and individual cells.
- State of charge. This cannot be accurately calculated and will be guessed purely on voltage and based on drift points. Drift points are based on open cell voltages, so SOC will vary considerably and should not be trusted to be totally accurate.
- Charge and discharge current limits switch to a voltage failsafe calculation mode and may be higher or lower than they should be. However, they will rapidly adjust if voltages approach minimum or maximum levels.
- 5v analog output for current will go to 2.5V (0 amps)
- Over current protection based exclusively on cell voltages.

2. **Voltage failsafe**

This is the most serious failure mode and is triggered when the BMS has determined that it no longer has accurate cell or total pack voltages. This can be caused by an open cell tap wire, cell reading 0 volts, total pack voltage sensor reading 0 volts or a discrepancy between the total pack voltage sensor and the sum of all the cell voltage sensors.

Because the BMS cannot protect the cells if the accuracy of the cell voltages or the total pack voltages is compromised, the BMS is forced to enter into a non-operating failsafe mode. In this failsafe condition, the BMS will gradually derate the charge and discharge current limits from their last known value down to 0 to prevent charging and discharging. The amount of time to derate the limits is specified in the profile and is designed to provide some usable time of the battery after the failure has occurred. This is particularly useful if the application is an electric vehicle or application where having some available power for a short period of time may be useful. This error condition should always be investigated prior to clearing the code.

3. **12v supply power failsafe**

The BMS requires a nominal 12v input main power to operate properly. Voltages below 8V can cause operational issues for the BMS since the BMS has an internal 5V supply. The BMS is equipped with an internal voltage sensor. If internal voltages drop too low for safe operation, the BMS will enter into 12v Supply Failsafe mode.

In this failsafe mode all digital on/off outputs are set to off and charge and discharge limits are set to zero immediately because sensors cannot be trusted. The 5V analog outputs remain active but cannot be guaranteed to be accurate.

This failsafe mode will set a diagnostic trouble code but will automatically restore normal operations once normal operating voltage has been met. A diagnostic trouble code will be set if this failsafe mode is triggered and can be retrieved later by a technician.

4. **Internal memory failsafe**
   In the event of an internal BMS memory failure (i.e. if the memory that stores the profile is damaged), the BMS will load the factory default battery profile with all outputs and inputs disabled to protect the battery. A diagnostic trouble code will be set to indicate this problem has occurred.

5. **Digital on/off or Relay failsafe**
   The Relay failsafe mode is triggered when the BMS turns off a digital on/off output and the application does not stop current flow within a specified amount of time. In this failsafe mode, all digital on/off relays are turned off until the BMS is power cycled and an error code is set.

   This failsafe will only activate if the offending relay is flagged as populated (enabled) in the battery profile. Unused or disabled relays are ignored.

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Setting up the BMS

Wiring

Please see the wiring manual for information regarding wiring the BMS into the application. The wiring manual can be located at www.orionbms.com/support .

Software

Please see the software manual for information on setting up specific software parameters and battery profile information. The profile must be setup correctly for the specific battery used and the application and controls things such as maximum and minimum cell voltages and external interfaces such as CAN interfaces and digital I/O. The software manual can be found at www.orionbms.com/support.

Testing the BMS Setup

After setting up the BMS or making any changes to the BMS settings or external hardware, the entire setup should be tested to ensure that it is functioning properly before trusting the setup. This is particularly important with respect to any failures that could be catastrophic such as ones that would lead to over charge or over discharge. It is the responsibility of the user to verify that the BMS is programmed and operating correctly with the application. At a minimum, the user should perform testing to ensure the following conditions are working properly:

1.) First and foremost, ensure that the BMS is setup in such a manner than testing will not cause immediate danger to the battery pack.

2.) Test using a voltmeter to verify that the BMS is properly reading cell voltages. The BMS cannot properly read cell voltages if wiring is not done correctly.

3.) Ensure that the total pack voltage sensor is reading the correct pack voltage (or portion of the pack voltage if more than one BMS is used in series.)

4.) If the charge enable, discharge enable or charge safety relays are used, ensure that they are operating by carefully monitoring the battery pack during the first full cycle (full charge and discharge) to ensure that cutoffs are properly working for all used outputs. Keep in mind that conditions are usually only triggered when the pack is totally charged or totally discharged. Particular attention should be paid to make sure the BMS properly shuts off a battery charger if connected or any other source or load.

5.) If charge and discharge limits are used (either via CAN or analog outputs) ensure that they behave as expected over the first full charge and discharge cycle and that any devices that must respect those limits are actually respecting them.

Additionally, the following steps are recommended:

1.) If the 5V analog outputs are used, they should also be monitored over the first full cycle to verify proper operation.

2.) Verify the working condition of the fan controller if used

3.) Verify that connected thermistors are reading proper temperatures.

4.) Verify that the current sensor is properly reading current.

How the Orion BMS Works

Basic data collection

The Orion BMS collects data from a number of different sensors for use in calculations. First and foremost, each cell's voltage is measured approximately every 30mS by sensing the voltage at the cell voltage tap connector. The voltages measured are from one tap to the next lower tap. Each group of 12 cells is isolated from the next group (see wiring manual for more information about wiring cell groups and description of the isolation.) In addition to the cell voltage taps, the total pack voltage is also measured from sensing the voltage at the total pack voltage sensor. These 2 voltages are measured and compared with each other to verify that they are consistent with each other. If the voltages differ by more than the pre-defined value stored in the profile, an error code is set and the BMS goes into a fail safe mode.

In addition to the voltages, the BMS measures current in and out of the pack every 8mS using the external hall effect current sensor. The current sensors provided with the Orion BMS are dual range sensors designed to improve accuracy and provide redundancy.

The BMS also measures battery temperatures directly from 4 thermistors. The BMS can be connected via one of the CAN interfaces to one or more of the thermal expansion modules which allows more thermistors to be measured than the base unit allows for. The BMS also measures it's own internal temperature to prevent overheating.

State of Charge Calculation

State of charge is primarily calculated using coulomb counting and is dynamically corrected using SOC drift points. Coulomb counting is a method that keeps track of current going into and out of the battery pack. Coulomb counting generally works quite well as long as the capacity of the battery is known and the current sensor is accurate enough. Because no coulomb counting system can be perfectly accurate, errors will eventually build up. To correct those errors, dynamic state-of-charge drift is used to compensate.

SOC drift points are specific points on the discharge plot of a cell where the state of charge can be roughly calculated based on the ***open cell voltage***. Many lithium ion batteries

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have a discharge plot that looks like a sideways “S” with a long flat area in the middle. In this flat middle area, determining state of charge from voltage is nearly, if not completely, impossible because a single voltage may represent more than 50% of the battery. For this reason, for common lithium ion chemistries, drift points are selected in the areas where the curve is more pronounced. Typically, these points would be around the 10%, 20%, 80% and 90% points, however, they can be specified for any SOC. The Orion BMS has up to 8 programmable SOC drift points.

Determining State of Charge Drift Points

Every chemistry will have different state of charge drift points. While manufacturers often do not have this information available, determining the state of charge drift points can be accomplished by running a cell through a charge and discharge cycle while plotting the open cell voltage on both the charge and discharge cycles. While the points can be established from this method, some tweaking may be required to maximize performance.

To determine approximately where the drift points should be, take a sample cell and charge it up to 100% SOC (follow manufacture recommendations.) After the sample cell is fully charged, discharge it down to 0% (following manufacturer specs for the minimum cell voltage and discharge rate) at a low amperage to get as close to an open cell voltage curve as possible. The voltages should be graphed during the discharge. If discharge graphing is not possible, the cell voltages must be measured by hand at consistent set time intervals and plotted.

Once the discharge is complete, there should be a fairly clear discharge “curve” (the curve can be very different shapes depending on the chemistry.). Datasheets from the battery cell manufacturer may be useful in this process if they are at a sufficiently low C rate. The voltages in most datasheets are the instantaneous voltage rather than open cell voltage and, if at a high C rate, can be misleading.

Drift points should be established at places on the discharge curve where the voltage change is most significant (EG: If a battery stays at 3.3v for the majority of the discharge curve and suddenly starts to rapidly drop at 3.0v, that would be a good place to set a point). If the drift points are set too close together (EG: if a drift point is set at 3.4v and 3.1v and the battery spends most of it’s time at 3.3v) then they may trigger SOC drift prematurely as the ***open cell voltage*** of a battery will drift up and down slightly under load due to a temporary voltage depression (EG: Under a 100A load a battery’s open cell voltage may drop from 3.3v to 3.2v, though it will gradually return to 3.3v once the load is removed).

A state of charge drift point consists of two items, an ***open cell voltage*** and a corresponding ***state of charge*** percentage. When a cell's open cell voltage equals the open cell voltage of the programmed drift point, then the state of charge will drift to the state of charge associated with the programmed drift point. Additionally, drift points can be specified as "drift up only" and "drift down only", indicating which direction they are allowed to affect drift (EG: If a drift point at 80% SOC is set to 3.5v and is flagged as "drift up only", then it cannot cause the SOC to drift down to 80% if the open cell voltage is below 3.5v). By default, a drift point will allow for the state of charge to drift up and down.

It is important to have a sufficient number of state of charge drift points to both protect the battery to maintain an accurate SOC calculation. Typically at least 4 points are used (2 on the top end and 2 on the bottom end of the curve) though this is not a minimum. For batteries which do not have a large flat portion of the "curve", additional points may be used in the middle of the battery for increased accuracy. Having a correct SOC calculation is important for maintaining the battery in a specified range, however, regardless of the state of charge calculation, the Orion BMS can still protect the battery pack from damage from over-voltage and under-voltage via monitoring the instantaneous cell voltages.

The state of charge drift points in the OrionBMS are not jump points. This means that when the open cell voltage on a particular cell reaches a drift point, it will not immediately jump to the provided state of charge. Rather, it will gradually "drift" up or down until the battery pack state of charge is equal to the target state of charge. This additional hysteresis helps make the transition smoother as well as helps eliminate "partial" drifts where the open cell voltage may only very briefly exceed the drift point voltage.

The BMS allows for State of Charge drift points to be flagged as "Drift Down Only" and "Drift Up Only". These are very helpful for situations where a battery's voltage may not stay constant at a given voltage for very long. "Drift Down Only" means that the BMS will only allow the given drift point to make the State of Charge go down (it won't make the SOC go up if the observed open voltage is higher). Likewise, "Drift Up Only" will only allow the SOC to go up and not down.

"Drift Down Only" and "Drift Up Only" are very useful settings for batteries that have a high surface charge (where the battery voltage may dip to a specific voltage but over time will creep back up). **The use of these settings is recommended for all drift points as most batteries will demonstrate at least some degree of surface charge.**

State of Health Calculation

The OrionBMS determines the ***State of Health*** of the battery pack primarily by examining both the ***Internal Resistance*** of the battery pack as well as the observed capacity (measured in amp-hours). As the observed capacity decreases from the nominal (starting) capacity and the internal resistance increases from the nominal capacity, the state of health will go down. This value is typically reflective of the age of the battery pack. However, defective cells or premature aging due to abuse and / or improper wiring can cause this to increase prematurely.

Every application will have different requirements for what state of health is acceptable. For stationary applications such as uninterruptible power supplies, a lower state of health might be acceptable. However for an application such as an automobile the minimum state of health may higher, so the the pack may need replacing sooner than in other applications. The OrionBMS provides a means to determine at what State of Health percentage an error code is set at, prompting the user to replace the battery.

Internal Resistance

Every battery pack has an ***Internal Resistance*** value. This value refers to the amount of voltage drop that occurs when current enters or exits the battery and is expressed in Ohms (E = IR, Ohms law).

Example: If a battery has an internal resistance of 2 mOhm (0.002 Ohm) and starts off at 3.3v, the cell will end up being at 3.5v if a 100A charge current is applied (a 0.2v voltage “drop”, or more accurately for this instance, voltage rise) [0.2 = 100 * 0.002, E = I * R).

Internal resistance calculation is incredibly important in batteries because it is required for determining how many amps can go in and out of a battery without exceeding it’s maximum and minimum voltage limits. It is also required for calculating the ***Open Cell Voltage*** (also referred to as the open circuit voltage, 0 current voltage or resting voltage) of a battery. It can also be used to determine the amount of energy that is burned up as heat (cell efficiency).

Determining Nominal Resistance

The internal resistance of a battery will change considerably based on temperature. Typically a battery will have a significantly higher resistance in colder temperatures than in hot temperatures. Lithium ion batteries tend to have an L-shaped resistance curve with the resistance increasing exponentially in cold / freezing temperatures and slowly approaching 0 Ohm in extremely hot temperatures.

The OrionBMS allows the user to specify the nominal (normal, starting, initial) resistance for each temperature range in increments of 5 degrees Celsius. This allows for using any type of different Lithium ion battery regardless of how unique it's resistance curve is. It is important both for the protection of the batteries as well as the determination of cell health that these figures be accurate.

It is not strictly necessary to determine the internal resistance at all possible temperatures as a pattern will likely emerge after several different points. Remember, internal resistance curves are very seldom linear. If the visual representation of the programmed nominal resistance values in the OrionBMS utility is a straight line, it is most likely not accurate.

Internal resistances will be higher at the top and bottom end of the battery. When determining nominal internal resistance values, the resistance should be measured just outside the curve of the battery.

How the BMS Calculates Internal Resistance

The Orion BMS uses changes in current going in and out of the battery pack to calculate the internal resistance of the battery pack as well as individual cells. The BMS is setup with a calculated current trigger threshold, a stable voltage threshold and a timeout threshold. It will look for changes in current caused by external loads and current sources that are larger than the current trigger and are stable for the stable voltage threshold. There must be sufficient change in current within the specified timeout threshold in order to accurately calculate internal resistance. The BMS needs a minimum of two changes in current that match the criteria to update the internal resistance calculations. Because the current through all the cells is the same, individual cells and the total pack will be updated at the same time.

The calculated current trigger is generally a percentage of the total amount of the current sensor. The minimum value is generally about 20% of the value of the current sensor, however, the minimums are adjusted automatically by the BMS based on other factors such as temperature since the discharge current limit may be below the 20% standard threshold.

The BMS will prefer to use calculated internal resistance values, however nominal resistance values must be programmed into the BMS as default values. The default values are used when the BMS is first powered up (or when power has been interrupted to all 3 power source lines) or when a significant change in temperature has occurred from the last known calculated internal resistance value and the present.

To determine what the nominal resistance for a battery is at a given temperature the following procedure should be followed:

1. Charge the battery to an appropriate state of charge where the resistance is roughly the nominal resistance. Most lithium ion cells will have a significantly higher resistance at very high and very low states of charge and those areas should be avoided for calculations. For best results, repeat this procedure at several different states of charge.
2. Let the battery sit at the desired temperature for a period of time (can be several hours depending on the mass of the battery) without any current going in or out (resting).
3. Measure the voltage of the battery cell. This will be the Open Cell Voltage of the battery since there is no current going in or out.
4. Apply a known constant load (typically 1C, eg: if a cell has 40Ahr capacity, a discharge of 40 amps would be used though a lower load can be used if needed).
5. After 5 seconds, take another voltage measurement.
6. Measure the actual amperage leaving the battery to increase the accuracy of the calculation.
7. Subtract the second voltage reading from step #5 from the voltage reading from step #2 to get the Voltage Drop.
8. Divide the Voltage Drop by the measured amperage from step #5 to determine the internal resistance expressed in Ohms.

Example: Assume a battery is observed at 3.3v resting. A 20 amp load is applied to the battery at which point the measured voltage drops to 3.0v. The internal resistance can be computed by taking 3.3v - 3.0v = 0.3v / 20 = 0.015 Ohm.

Charge and Discharge Current Limits

Charge and discharge limits are the realistic maximum amperage limits (expressed in 1 amp increments) that a battery can output (discharge) or input (charge) at any given moment without getting pulled over or under the maximum and minimum cell voltages respectively. These values are calculated real-time by the BMS using many different parameters and are updated several hundred times per second.

These limits can be transmitted to motor controllers, battery chargers and other application devices to control how much amperage is drawn or put in to a battery pack either by an analog 5v signal or digital CAN interface. It is the responsibility of the load / source (motor controller, charger, etc) to enforce these limits provided by the BMS.

Charge and discharge current limits are designed to be used in applications where it is beneficial to vary the current in or out of the battery. For applications where an on/off control is more appropriate, the BMS also provides a digital on/off signal that can be used to control charge and discharge that is describe later on.

How the BMS Calculates Current Limits

The Orion BMS uses many different factors in calculating limits, all of which are based on settings in the battery profile:

1. The temperature of the battery pack (some batteries can't handle as much current in warmer / cooler temperatures)
2. The internal resistance (sometimes referred to as impedance) of the battery pack
3. Battery pack voltages (including individual cells, both open circuit voltages and voltages under load)
4. Maximum limits provided by battery profile (BMS will not allow limits to go above maximum limits in profile)
5. Voltage failsafe conditions (failsafe conditions can cause BMS to reduce limits to protect the battery)*1

* Note 1: A voltage failsafe condition means that a problem was detected either with the voltage measurement hardware or the sense lines themselves. After such a problem is detected, the BMS goes into a failsafe mode where the limits are gradually (or immediately, depending on the profile settings) reduced to 0 in order to protect the battery as the BMS can no longer accurately measure all cells properly.

Determining Charge and Discharge Current Limits

Typically maximum charge and discharge limits are provided in a datasheet from the battery manufacturer (recommended discharge and charge rates.) If the datasheet for the battery does not specify a maximum rate for charge and discharge, they should be requested from the battery manufacture.

Digital on/off outputs

Three digital on/off outputs are provided on the Orion BMS. The purpose of the 3 outputs is to enable charge and discharge currents and to provide a safety cutoff for a battery charger. All three outputs are open drain and are active low when discharging or charging is permitted. For more information on the electrical specs, please see the wiring manual.

The three outputs are:

1) Dischage Enable Relay (DIS in software): If enabled, this relay signal will be driven low until the DCL (Discharge Current Limit) dips to 0 at which point it will float high (there is no pull-up resistor on the line). By default, this relay will remain off until the BMS goes to sleep and wakes back up. However, it can re-engage based on the Discharge Relay Restore parameter (which provides a minimum amount of time before a relay re-engages and can also require a minimum DCL).

2) Charger Safety Relay (SFTY in software): It is used by the BMS as a shutdown signal to the charger. **This relay is strongly recommended to be enabled and used**. If enabled, this relay will be driven low to allow charging until the BMS determines the charger should shut off (due to high voltage condition or the Charge Current Limit drops to 0 for example at which point it will float (there is no pull-up resistor on the line). This relay can re-engage based on the Charger Re-enable Timer parameter.

3) Charge Enable Relay (CHRG in software): *This is not the same as the charger safety relay.* This relay will be driven low until the Charge Current Limit drops to 0 at which point it will float (there is no pull-up resistor on this line). By default, this relay will remain off until the BMS goes to sleep and wakes back up. It can, however, re-engage based on the Charge Relay Restore parameter (which provides a minimum amount of time before a relay re-engages and can also require a minimum charge current limit).

Isolation And Isolation Fault Detection

The Orion BMS has an advanced isolation fault detection circuit built in. This circuit is constantly monitoring for breakdown between the insulation along the high voltage wiring and the chassis ground. **In order to operate properly, the chassis ground must be grounded to**

the 12v negative source for the BMS.

CANBUS Communication

The Orion BMS has two separate CAN (controller area network) interfaces. Both interfaces have a programmable frequency (baud-rate) and can be used independently from each other. The BMS features up to ten programmable CAN messages which are fully programmable and can be programmed to transmit on either or both CAN interfaces. These messages are designed to be flexible to be used to interface with other electronic control units, computer systems, display clusters or any number of different devices. Virtually all BMS parameters are able to be programmed into these CAN messages. Please see the "Editing CAN Messages" section of the Software Utility manual for details on programming custom CAN messages.

In a CANBUS network there are always exactly two terminator resistors. It is up to the user to ensure that there is the proper number of terminator resistors on each CAN network. **By default, the Orion BMS has a terminator resistor already loaded on CAN interface #1, however CAN interface #2 does not have a terminator resistor loaded.** This is done by default so that the standard unit can be used whether or not a terminator resistor is necessary. If specified during ordering, a different combination of terminator resistors can be provided (for example, both interfaces with or without a terminator resistor.)

The CAN interface is also used to upload settings and update the BMS firmware. While the settings (also known as battery profile) can be updated from both interfaces, **code firmware updates to the actual BMS can only be performed over CANBUS interface #1**. Firmware updates may be necessary to add additional future functionality.

Analog 5v Outputs

Four (4) analog 0-5v reference outputs are provided for the ability to set current limits for external loads or chargers as well as to provide an analog reference for state of charge and current going in or out of the battery pack. Analog voltages are not as precise as digital signals, and therefore, CAN communications are the preferred method of setting external current limits.

Two of the 5v outputs are dedicated to the charge and discharge limits respectively. The BMS will automatically output the discharge and charge limits on these 5v lines (with 0v being 0A and 5V being the maximum ***analog*** current limit set in the profile). If the application requires scaling the 5v output lines for any reason, there is a parameter in the battery profile (under the "Discharge Limits" and "Charge Limits" tabs) that allows the user to specify a maximum analog output charge limit (and discharge limit).

The other two 5v analog outputs are for state of charge and current. The state of charge will vary between 0 and 5 volts representing 0% to 100% state of charge respectively. The current analog 5v output is dependent on the current sensor setting in the battery profile, however, 0v will correspond to the maximum negative value, 2.5V will correspond to 0A and 5V will correspond to the maximum positive value. For example, if the current sensor is sized at +/-200A, 0v = -200A, 2.5v = 0A and 5V = +200A.

How Balancing Works

The Orion BMS takes an intelligent approach to balancing that seeks to maintain and improve balance from cycle to cycle.

Lithium ion batteries, unlike lead-acid batteries, tend to stay in balance very well once initially balanced. Differences in self discharge rates, cell temperature and internal resistance are the primary causes of an unbalanced battery pack in a properly designed system. The BMS must be able to add or subtract charge from the lowest or highest cells to compensate for the difference in discharge rates to keep the cells balanced.

The purpose of balancing a battery pack is to maximize the usable capacity. Even in the best battery pack, all cells will have slightly different capacities and will be at slightly different balances. The total usable capacity of the battery pack is limited to the lowest capacity cell, less the difference in balance from the strongest to weakest cell. While the proper solution for a low capacity or weak cell is to replace it, the BMS can balance the cells and can protect cells from damage from external charge or load no matter the state of balance or difference in capacity.

The Orion BMS uses passive balancing to remove charge from the highest cells in order to maintain the balance of the pack. The passive shunt resistors dissipate up to approximately 200mA per cell. While that amount may seem small, that current is more than sufficient for maintaining balance in very large battery packs. Difference in cell internal self discharge rates are often measured in the tens to hundreds of uA (with a uA being 1/1000 of a mA.) With a difference in self discharge rate of even 1mA, the 200mA balancing current is still 200 times that of the discharge rate. While every battery pack is different, for a 40 amp hour battery pack cycled once a day a typical maintenance balance completes in only about 30 - 45 minutes.

It should be noted that the balancing does not need to occur every cycle. Even if the battery has not had a maintenance balance in many cycles, the BMS will still protect the batteries. Except for the very extreme conditions, the majority of the battery pack capacity will remain usable even after many months without a balancing. For example, a battery pack with 30Ah cells and a 1% SOC imbalance from highest to lowest cell (a fairly significant imbalance) the pack will theoretically have a usable capacity of 29.7Ah. Balancing the pack perfectly would only gain 300mAh of usable capacity in this case, which is fairly negligible, but can be easily reclaimed in around 2 hours by allowing the BMS to balance the batteries.

The Orion BMS is not designed to do an initial balance on a grossly out of balance battery pack that is more than about 10-15 amp hours out of balance. In those cases, the battery pack should be roughly balanced by either charging all of the cells in parallel, charging the cells to roughly the same SOC one by one or discharging the highest cells so that they are roughly at the same SOC.

Some battery management and charging systems on the market use “bypass” regulators, which turn on a battery charger to a predetermined amperage and then “regulate” the voltage of the cell by burning off the difference between the energy the charger is putting out and what the battery actually requires to maintain a set voltage. While this approach works, it is typically inefficient, requires large shunt resistors and can actually unbalance the batteries before then re-balancing them.

Virtual Battery and Drive Modes

The virtual battery simulation and drive mode features are almost exclusively intended for aftermarket plugin hybrid (PHEV) conversions systems and hybrid vehicles where the whole battery is not used for lifespan reasons. It can be ignored for most other applications (all-electric vehicles, solar installations, etc).

Virtual battery simulation allows for the BMS to create a smaller virtual battery inside the larger battery for applications that require a small battery to operate in factory-default mode or are designed to operate in a small State of Charge band (such as a stock Hybrid vehicle that has been converted to a PHEV). This is sometimes referred to as "charge sustain", where the BMS provides the vehicle with a State of Charge range similar to the one it had when it was manufactured.

For example, a virtual battery in a Prius PHEV conversion might be set up to simulate a 6.5 Amp hour pack (the exact size of the OEM battery pack prior to modification) even though the actual battery is far larger (30 amp hours for example.) This means that while the BMS is in the "Sustain" drive mode (which will be explained below), the BMS will report a state of charge to the vehicle inside the simulated 6.5Ahr battery instead of the total pack state of charge.

A drive mode is a term used by the OrionBMS, mostly used for a Plugin Hybrid (PHEV) application. A drive mode would be used to implement charge sustain and charge deplete modes for example, but can also be used to implement more obscure modes like a charge-up mode (for using the a gas engine in a vehicle to charge up the battery.)

Typically in an aftermarket PHEV conversion application, a “fake” State of Charge (SOC) is reported to the vehicle which is different than the real SOC of the battery in order to get the vehicle to behave as requested.

A typical drive mode will therefore have the following elements:
1) A reported SOC%: Typically a higher value indicates a higher average current draw in a PHEV application by the vehicle and a lower value results in lower current draw. The ideal value is specific to each application however.

2) Enter/exit SOC% conditions: These are SOC% markers that indicate when a mode can be entered or exitted. This is useful for automatic mode transition when a battery depletes or becomes fully charged.

If the Ewert Energy Systems Hybrid Energy Manager (HEM) is also being used, drive modes can also be linked to the Hybrid Energy Manager to control how aggressively electric power is used in relation to gasoline power.

Issues paralleling strings of cells

The question of whether to parallel multiple strings of batteries or to parallel individual cells comes up frequently. While there are sometimes reasons to use both approaches, paralleled strings present many design problems and usually are not recommended if it can be avoided.

Even the best battery packs are made up of cells that have slight differences and variations. Temperature, state of charge, cell manufacturing differences and differences in capacity all affect a cells resistance thus each cell will have a slightly different resistance. Normally with a single string of cells the differences in resistance are not a problem because the current through each cell is the same and the resistance of the pack is the sum of all cells. However when multiple strings are paralleled, the two strings will have different resistances.

When current flows in or out of the paralleled strings, it is highly probable that the two strings will have different currents flowing through them due to small differences in resistance due to the reasons discussed above. Therefore one string may discharge or charge faster than another, leading to a larger temperature imbalance further exacerbating the problem. Additionally, if a string develops a faulty or shorted cell the resulting difference in the total stack voltage can force current to flow through two or more of the strings, possibly causing some cells to become overcharged or over discharged. Thermal runaway is also possible depending on how bad the fault is. Because of this, each string must have it’s own discharge and charge controls and a switch that will isolate the string from the other strings.

The Orion BMS is geared toward monitoring one pack or one string very well. It has a single current sensor input (though it is a dual redundant current sensor), a single total pack voltage sensor and the software uses those values to perform calculations for all cells connected.

Usually (for Lithium cells) the simplest and most reliable solution is to parallel the cells together and then to treat them as a single cell rather than to make separate strings of cells and then parallel those strings. While there typically are no problems with paralleling almost any type of lithium ion cells, it is always advisable to check with the manufacture first. NiMH or NiCad cells should not be paralleled unless the manufacture specifically specifies that it is safe to do so.

For applications where paralleling cells is not an option, either for reasons of reserve capacity, redundancy or due to cell incompatibility (i.e. NiMH), each string should be treated as a pack with one BMS unit per string. Each string would have it's own current sensor, thermistors, and total pack voltage monitor. With this setup, each string / battery pack then has it's own charge and discharge relay outputs to protect itself individually, has accurate internal resistance and pack health information, and accurate state of charge information and is properly protected. It is important that the BMS unit for each string be able to completely disconnect the string from both charge and discharge and isolate the string from all other strings. In this setup, it may be necessary to provide an external control system to calculate values for the total pack such as the total battery amperage, state of charge, etc.

Thermal Management and Fan Controller

The Orion BMS has a built in thermal measuring system as well as a fan control system which can turn on and intelligently throttle a fan while measuring the voltage of the fan to insure that it is functioning properly.

First, the BMS measures the battery temperature through 4 main thermistors on the BMS. If the standard 4 thermistors are not sufficient for the application, one or more external Thermal Expansion Modules can be connected to one of the CAN interfaces and used to add many additional thermistors. The BMS will determine the minimum, maximum and average battery temperatures from the thermistors connected. One of the 4 thermistors on the main Orion BMS unit can be configured to be flagged as an air intake thermistor. This allows the BMS to determine what the ambient air temperature around the pack is and allows it to determine if running the fan will actually cool the battery off. For example, if the ambient air going into the battery pack is hotter than the battery itself, the BMS can keep the fan from running since the battery would in fact be heated rather than cooled. If one thermistor is dedicated to the intake air temperature, the BMS can also be configured using the "Enable Battery Warming" option in the profile to warm the battery pack in cold temperatures if the ambient air temperature is detected to be warmer than the battery pack. This is useful in vehicles where the ambient cabin air is warmer than the battery temperature. The air intake thermistor setting is not required (it can be disabled in the profile) and if the thermistor is configured for this purpose, it is not used for calculating the temperature of the pack or used in any other calculations. If the intake thermistor option is not used, the 4th thermistor can be used as a standard thermistor.

The fan can be configured to turn on by adjusting the "Minimum Fan Temperature" parameter in the profile. The fan will turn on at the programmed minimum fan temperature and the speed of the fan can be programmed to increase as the actual battery temperature exceeds the minimum fan temperature setting. The graph on the "Thermal Management" screen can be used to visualize how fast the fan will run at a given temperature.

While the BMS has the option for using a PWM (pulse width modulation) controlled fan, it is not required and the fan can be simply turned on and off. The fan control line from the BMS is an open drain output that can be used to drive a relay to turn a fan on or off. Additionally, water cooling or other cooling or heating methods can also be controlled using this controller. The PWM signal, if used, requires an external switch and operates at 5kHz. Fans and other cooling systems must be suitable for use with that frequency.

The thermal control system also features a voltage monitor circuit. This circuit can monitor the voltage of a line to verify that the fan is operating correctly. This will vary from application to application. Both the voltage monitor circuit and the PWM polarity (for driving the battery fan switch) can be inverted through options available on the "Thermal Management" portion of the profile. The graph on the program utility can also help visualize these parameters.

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For more information about the hardware interface for the fan controller, please see the wiring manual.

Troubleshooting

High resistance cell

1.) Check the tightness of the busbars to ensure they are tight. Most of the high resistance issues turn out to be a loose connection or faulty crimps (if applicable), so it is worth checking closely. High impedance from a loose connection will usually show up in one of the adjacent cells, so that is a good thing to check first.

2.) Check the BMS configuration to ensure no busbar compensation has been enabled for the high resistance cell, unless the cell includes resistance from a high impedance busbar, in which case it is important to verify that the correct amount of busbar compensation has been applied. Open the Orion BMS utility, download the profile from the BMS if necessary, go to the cell settings tab, click cell population settings button and find the cell in question. Look in the last colomn and verify the busbar compensation setting in the last colum. Incorrect settings here can artificially cause the cell to appear as if it has a high resistance when the cell is under load.

3.) Verify that the cell voltage and the surrounding cells (ideally from the whole group of 12) are reporting correct voltages through the BMS. Keep in mind that the voltmeter and the BMS do not share the same calibration, but it should give a good idea if the voltage is significantly higher or lower than it should be. If voltages are incorrect, check the BMS for open wire fault codes, and check the continuity of cell voltage tap wires in the cell group. Also verify that the minimum number of cells in a cell group are populated and are correctly wired.

4.) If the measured voltages are correct, the next thing to check would be if the resistance of the cell is in fact high. The easiest way to do that is to manually check the voltage across the cell with a voltmeter (measuring with one probe at the physical location of the next cell lower's tap and the physical location of high resistance cell's voltage tap). Apply a constant load to the pack, calculate the resistance of the cell, and compare the manually measured voltage against the BMS reported voltage. If the voltage that the BMS and the voltmeter are reporting are consistant, look for a high impedance connection between the cells.

Appendix A: How Batteries Work

Individual cell voltages, cell limitations and internal resistance explained.

Lithium ion battery cells normally have limits for the maximum and minimum voltages. For example, a lithium ion iron phosphate cell may have a voltage range of 2.00 volts to 3.65 volts. Measuring a cell's instantaneous voltage with no load applied is called measuring the cell's *open cell* voltage. The instant voltage of the cell mostly depends on the cell's state of charge and any current going in or out of the cell. If the cell is at rest, the open cell voltage can be measured by simply taking the cell's instantaneous voltage. If a load (or charge) is applied to the cell, the instantaneous voltage of the cell will change due to the cell's internal resistance. For example, a charged iron phosphate cell may sit at 3.35 volts with no load applied. When a load is applied to the battery, the voltage of the battery will sag (say to 2.85 volts with a 100A load) due to the internal resistance of the battery. When the load is removed, the voltage will return to the sitting voltage (though it may take some time and the new voltage may be somewhat lower due to having discharged the cell.)

The internal resistance of the cell can be calculated using the formula $\Delta v = I \cdot Ri$ where Δv is the difference in voltage between the open cell voltage (no load) and the voltage under load, I is the current in amps, and Ri is the internal resistance of the cell expressed in ohms. For our example, we have a battery that measures 3.35 volts with no load applied. We apply a 100 amp load to the battery and the voltage drops to 2.85 volts. To calculate the internal resistance of the battery, the following equation is used: $(3.35 - 2.85) = 100A \cdot Ri$. Solving for Ri, we find that the internal resistance is 0.0045 or 4.5 milliohm (mOhm.)

The internal resistance is an important number for several reasons. First, it allows for monitoring of the cell's health. If one cell in a pack has a significantly higher internal resistance than the other cells in the pack, the cell may be weak, out of balance with the others or at a significantly different temperature. Temperature, state of charge, and age / health of the battery all effect a cell's internal resistance. Since the pack is only as strong as the weakest cell, identifying cells with a high internal resistance is important to preserve the performance of the battery pack. Second, knowing the internal resistance of a cell allows for calculating the maximum charge and discharge the pack can take before exceeding the voltage limits (though manufactures may specify a more strict charge or discharge limit that must be respected.) Going back to the example, if we wanted to calculate the maximum discharge, we can calculate it using the same equation, but solving for I instead of Ri. $(3.35 - 2.0) = I \cdot 0.0045.$ Solving for I, we get 300 amps. If a load of 300 amps is applied to our example battery, it will bring the voltage down to 2.0 volts. Similarly, the same can be done for the charge:

$(3.65 - 3.35) = I \cdot 0.0045$. In this case our maximum charge possible would be 77 amps. It is important to note that internal resistances (and therefore the maximum charge and discharge limits) can change with the state of charge of the battery as well as with temperature. Equally important to remember is that the cell's open cell voltage can change with state of charge. tTese calculations may need to be done using several different open cell voltages to get a good feel for how the battery will behave in the application.

While the description above is accurate for describing DC internal resistance, most batteries also have a different resistance with AC, meaning that the resistance measured after 100mS and after 10 seconds are usually different depending on the chemistry. For most applications, the DC resistance (10 seconds or more) is most applicable. It should be noted that many manufacturers will list the AC internal resistance on datasheets because it is more favorable, however DC and AC resistance numbers can be significantly different and should be tested. Manufacturers also often overstate the resistance numbers, so actual testing of the cell is strongly recommended.

Internal resistance and open cell voltages are useful for calculating maximum current limits to prevent exceeding the voltage limits for the cells. However, many cells have other limitations that have to be taken into consideration. Most cells will come with a temperature limit and maximum charge and discharge limits in addition to the voltage limits. Some cell manufacturers also specify pulse current and continuous current limits. These limits also need to be enforced. In the example above, even though we calculated a maximum discharge current of 300 amps, the cell manufacturer may specify that it allows a maximum continuous discharge limit of only 200 amps. In that case, the BMS profile must be programmed to allow a maximum of 200 amp discharge regardless of the results of the current limit calculations. Additionally, in cold temperatures, the limits may be restricted further to maintain battery life. That information would be provided either from conducting battery lifespan cycle testing or provided by the manufacture.

Building a pack of cells

There are many additional complexities that have to be considered when building a battery pack out of individual cells. Each cell in the battery pack must be protected from over voltage, over current and over temperature. Cells in the pack must be properly balanced and matched for internal resistance in order to maintain the maximum usability of the battery pack. If cells are not properly balanced, or if one cell becomes weak or warmer or colder than others and current is applied to the pack, current can be forced through weaker cells and can damage them. Additionally, if multiple strings of batteries are put into parallel, differing resistances can cause current to take the path of least resistance and cause imbalance.

Appendix B: Tips on Selecting Batteries

While this is not a guide for selecting the appropriate batteries, we provide a few helpful tips to take into account when selecting batteries for an application. This is in no way a comprehensive list and it is strictly the user's responsibility to select the correct batteries for the application.

- Select a battery with an internal resistance suitable for the application.
- Calculate the actual maximum charge and discharge amperage from open cell voltages at various states of charge using formulas found earlier in this document. Be sure to verify both charge and discharge limits (charge limits are often lower than discharge limits.) Do not trust manufacture claims for discharge or charge limits. Almost all batteries are rated for best case charge and discharge limits at ideal state of charges. Verify that the batteries will perform with typical and worst case scenarios.
- Make sure that the manufacturer specifications for discharge and charge limits will not be exceeded. Ideally select a battery with a limit a fair amount higher than you will need, as most manufacture ratings are overstated.
- Ensure that the batteries meet necessary requirements for flammability, thermal runaway and explosion resistance.
- Be sure to test batteries at all usable temperatures to verify suitability under the worst conditions.
- While manufacturers may make statements about lifespan of their cells, it is always best to verify several packs for lifespan for each specific application by cycle testing using real world conditions.

Appendix C: Terminology

State of Charge (SOC or SOC%) - How charged the battery is, expressed in percentage
Dept of Discharge (DOD or DOD%) - Most commonly used to express the percentage of the battery that is to be used, but sometimes refers to the percentage of the battery that is discharged.
Instantaneous cell voltage - The instant voltage of the cell measured at any point.
Open cell voltage - The voltage of the cell with no load or charge applied. This can be an actual measured value or a calculated value for what the cell voltage would be if no load were present.
Internal resistance - The effective series resistance of the battery.