www.orionbms.com

Orion 2 BMS Operation Manual

The Orion BMS 2 by Ewert Energy Systems is the second generation of the Orion BMS. The Orion BMS 2 is designed to manage and protect Lithium ion battery packs and is suitable for use in electric, plug-in hybrid and hybrid electric vehicles as well as stationary applications.

Major key additions in the Orion 2 BMS are:
- Significantly improved cell voltage measurement accuracy & resolution (0.1mV resolution)
- Lighter weight, smaller and more optimized mechanical design
- Compatibility with both 12-volt and 24-volt power supplies
- Ability to directly drive contactors on select outputs (limitations apply)
- Integrated J1772 & CHAdeMO charging interface support
- Significant algorithm improvements
- Expanded diagnostic capabilities
- Significantly improved multi-unit operation with remote modules
- New inputs and outputs
- Up to 8 thermistor inputs now directly on the BMS (previously 4)

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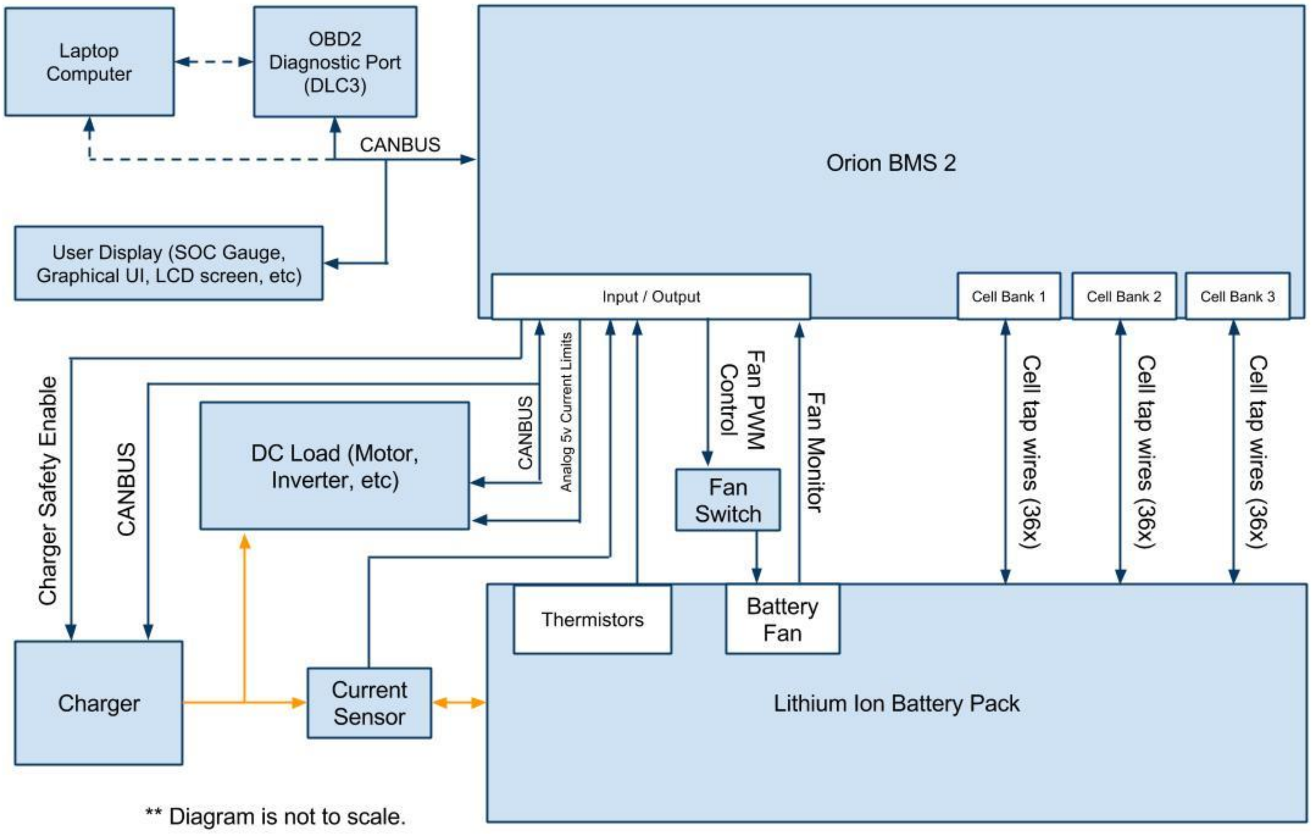
Overview of Theory of Operation



The Orion BMS 2 protects and monitors a battery pack by monitoring several sensors and uses several outputs to control charge and discharge into the battery. The BMS measures inputs from cell voltage taps, the total pack voltage tap, a hall effect current sensor and thermistors. Using the programmed settings, the BMS then controls the flow of current into and out of the battery pack through broadcasting charge and discharge current limits (via the CANBUS or via analog reference voltages) or via simple on/off digital signals depending on which style is appropriate for the application. The BMS relies on the user to provide external controls that respect the current limits set by the BMS to protect the batteries as the BMS does not have integrated switches. During and immediately after charging, the BMS will balance the cells using internal shunt resistors based on the programmed settings.

The Orion BMS monitors each individual cell tap to ensure that cell voltages are not too high or too low (in accordance with the values programmed in). Using the temperatures, cell voltages, the amperage going in and out of the pack (provided by the current sensor) and programmed values in the battery pack profile the BMS calculates the pack and individual cell's internal resistance, and open cell voltages. From those calculations, the maximum charge and discharge current limits are determined and adjustments are made to the pack's calculated state of charge if necessary. These calculations are also used in monitoring the health of the pack. Charge and discharge current limits are provided on the

CANBUS and can be programmed to trigger on/off digital outputs to allow or deny charging and discharging of the battery pack.

The BMS also performs other functions such as cell balancing by removing charge from cells which are higher than the rest of the battery pack. The BMS will interface with J1772 AC charging stations as well as off board CHAdeMO chargers.

Setting up the BMS

Wiring

Please see the wiring manual for information regarding wiring the BMS into the application. The wiring manual can be downloaded from www.orionbms.com/downloads.

Software

Please see the software manual for information on setting up specific software parameters and battery profile information. The BMS must be connected to a personal computer using the CANdapter (CAN to USB adapter) and programmed using the Orion BMS software utility before it can be used. The settings profile must be setup correctly for the specific battery used and the application. The settings profile controls parameters such as maximum and minimum cell voltages and external interfaces such as CAN interfaces and digital I/O. The software and software manual can be found at www.orionbms.com/downloads.

Testing

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. This is particularly important with respect to any potentially catastrophic failures, such as failures 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. Ensure that the BMS is setup in such a manner that testing will not cause immediate danger to the battery pack.
2. Ensure that cell voltages are being read correctly and that no critical fault codes are present. The BMS cannot properly read cell voltages if unit and batteries are not wired correctly. Double checking cell voltages with a multimeter will help verify that the BMS is measuring voltages correctly.
3. Ensure that the current sensor is reading the correct values and that current going into the battery pack (charge) shows up as negative and that current leaving the battery pack (discharge) shows up as positive.
4. If the charge enable, discharge enable, or charger 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 check 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 enforce those limits are actually respecting them.

How the Orion BMS 2 Works

(Detailed Theory of Operation)

Changing and Uploading Settings

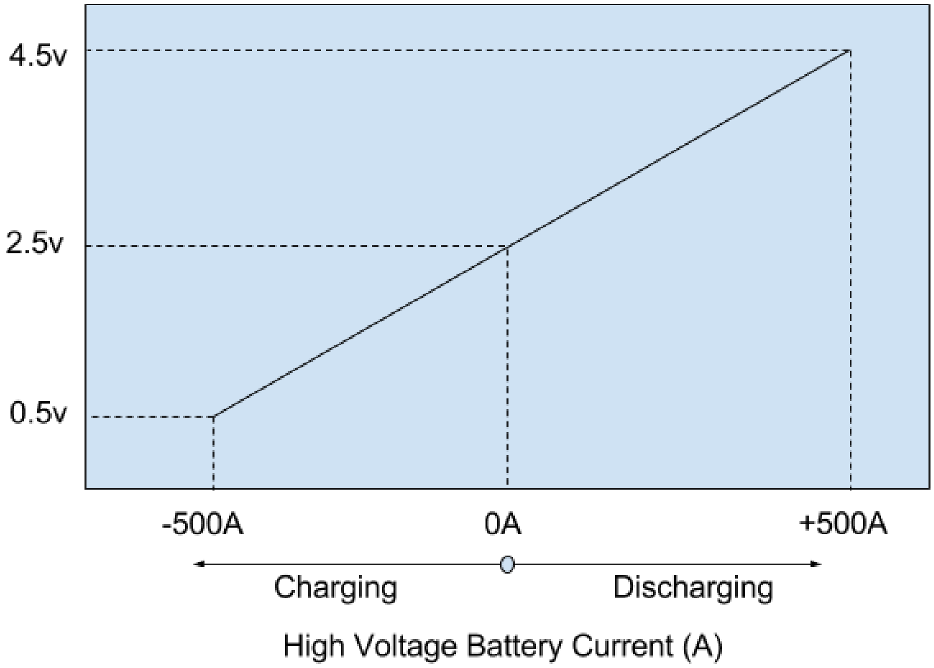
The Orion BMS 2 must be programmed in order to operate. A complete collection of settings is called a **Battery Profile**. Profiles are edited on a personal computer using the Orion BMS 2 Utility software and then are “uploaded” to the BMS via CANBUS. Profiles can optionally be locked into the BMS with a password to prevent end users from modifying or viewing settings. Uploading and downloading settings require the use of a CANdapter (a CAN to USB adapter) sold by Ewert Energy Systems. Battery profiles can also be downloaded back from the BMS to be edited.

Basic Data Collection

The Orion BMS 2 collects data from a number of different sensors for use in calculations and decision making.

Cell Voltages - Each cell’s voltage is measured approximately every 30 mS by sensing the voltage at the cell voltage tap connector. The BMS measures the difference in voltage from one tap wire to the next to measure a cell's voltage. Unless busbar compensation has been configured, the BMS will display and use the actual measured values for cell voltages (otherwise compensated values are used). Only the cell voltages which the BMS has been programmed to monitor in the cell population table are monitored while the other cell voltages are ignored.

Current (Amperage) - The current going in and out of the battery pack is measured every 8mS using the external hall effect sensor. The hall effect sensor is clamped around a wire carrying all current into and out of the battery pack and converts the measured amperage into two 0 - 5 volt analog voltages. One channel is used for measuring smaller amperages to ensure high resolution for small currents and the other channel is used for measuring larger currents. These two analog voltages are measured by the BMS and converted into an amperage value which the BMS uses for various calculations. The diagram below demonstrates how the feedback voltage from the larger channel correlates with the actual current being measured (a 500A sensor is used for demonstration purposes).



This figure demonstrates the relationship between the voltage output and current measured on the current sensor

The currents sensors sold with the Orion BMS are available in sizes up to 1000A. The BMS can be configured to use 2 parallel current sensors to measure amperages up to 2000A, however the maximum recommended size is 1000A. Current sensors sold with the BMS are able to measure amperages up to 120% of their rated maximum, though accuracy is reduced above 100%.

Current sensor data is used in calculating the battery pack's state of charge (via coulomb counting) and ensuring that the attached application is staying within the correct current limits. The measured current is also used in calculating the internal resistance and health of the cells in the battery pack.

Temperatures - The BMS measures up to 8 thermistors directly connected to the main unit to determine the average (rough) temperature of the battery pack as a whole. If additional remote modules are used for monitoring additional cell taps, an additional 8 thermistors per remote module are provided. If a greater number of temperature sensing inputs are required, the BMS can be connected to up to 10 thermistor expansion modules which measure up to 80 thermistors each, allowing the BMS to monitor over 800 temperature inputs. Thermistors on the main unit, remote modules and any expansion modules may be left 'unpopulated' meaning that the BMS will ignore the value of those thermistors. This allows the BMS to be configured to use as few or as many thermistors as necessary. One of the thermistors may be specified as an ambient temperature thermistor which, if enabled, allows the BMS to determine the effectiveness of turning on an optional external battery cooling fan. This feature also allows the BMS to use the same fan to blow warm air over the batteries if the batteries are cold and ambient air is warmer.

Total Pack Voltage – The Orion BMS 2 measures the total pack voltage by adding the individual cell voltages together. This method differs from previous revision of the Orion BMS and produces much more accurate total pack voltage numbers. No additional wires are necessary for monitoring the pack voltage.

Isolation Fault Sensor - Unless ordered without this feature, the Orion BMS 2 has a sensor that measures the electrical isolation between the battery pack and the chassis of the vehicle. This sensor is used to ensure that a breakdown in electrical isolation has not occurred between the chassis and a live part of the battery pack. Specifically, it measures the isolation between the input power ground (pin 12 on the BMS Main I/O connector) and the cell tap 1- (negative) on the first cell group connector. An internal isolation relay allows this circuit to be disabled by software or the unit can be special ordered with this feature permanently enabled or permanently disabled. See the “Isolation Fault Detection” section below for more information on this sensor.

Other Inputs - The BMS has the ability to sense the status of the 3 power supplies (Always On, READY power and CHARGE power) which determine what mode the BMS is in. The BMS also has 3 multi-purpose inputs which can be used for various functions including interfacing with J1772 charging stations, and an analog voltage input used to monitor the health of a battery cooling fan (optional).

CHARGE and READY Modes

The BMS has two primary modes of operation: **Charge Mode** and **Ready Mode**. The BMS will enter into Charge Mode any time 12 - 24v is applied to the CHARGE power pin (Main I/O pin 3), regardless of whether READY power is also present or not.

The following functions are enabled (or change) when the BMS is in Charge Mode:

1. The charger safety output is allowed to turn on if enabled and if all criteria have been met.
2. The BMS will cap the state of charge to the value specified as the "Charged SOC" percentage. Even if the battery is charged in such a way that would normally cause the SOC to rise above this value, the value will not exceed the "Charged SOC parameter" while the BMS is in charge mode.
3. When any cell voltage hits the maximum cell voltage (resulting in the BMS turning the charger off), the BMS will immediately adjust the state of charge to the "Charged SOC" value since the BMS knows that the battery pack is fully charged at this time.
4. The cell balancing algorithm is enabled and will begin balancing as soon as any cell voltage goes above the "Start Balancing" voltage. Balancing will continue until all cell voltages are balanced to within the balance delta voltage parameter. See the “How Balancing Works” section for more information on cell balancing.
5. Certain CANBUS messages may be transmitted or not transmitted depending on whether the BMS is in CHARGE mode or not (if configured).
6. The maximum possible current limit for charging is limited to the "Maximum Amperage While Charging" parameter available on the “Charge Limits” profile settings tab.
7. The maximum allowable cell voltage is limited to the "Max. Voltage While Charging" parameter available on the “Cell Settings” profile settings tab.

Charge Interlock

In the event that the BMS detects both CHARGE and READY power at the same time, the BMS can optionally be configured to indicate it is in an interlock mode. Interlock mode is generally used to prevent a vehicle from driving away while it is still plugged in. The BMS can also be configured to enter charge interlock mode when a connector is detected in the J1772 inlet via the proximity detect. When the BMS detects a condition where either the J1772 inlet is active or both CHARGE power and READY power are present at the same time, a few things can happen:

1. The BMS can be configured to set a temporary (non-latching) fault code (P0ACA).
2. The BMS can be configured to not allow any discharge while in this mode.
3. The BMS can transmit the status of charge interlock via one or more CANBUS messages.
4. One of the multi-purpose outputs can be configured to indicate the status of charge interlock.

Note: While the BMS can accurately detect the presence of CHARGE and READY power, the BMS cannot detect a cord which is plugged into a vehicle that is not powered. It is often best to use additional external systems, such as the J1772 charging standard, to prevent the vehicle from driving away while a cord is connected but not powered.

Note: If desired, the charge interlock feature can be disabled in the settings profile such that the BMS will operate normally when CHARGE and READY power are both supplied at the same time. This is accomplished via the “Fault Settings” tab in the profile settings.

Charge and Discharge Current Limits

For Lithium-ion cells, limiting cell voltages to within a specified voltage range is essential for protecting the cell from damage. However, there are many other parameters, such as temperature and current limits, which must also be monitored to protect the cells. To be able to control more than one parameter at once, the BMS incorporates different parameters into a maximum allowable charge and discharge current limit. Charge and discharge limits can be thought of as the realistic maximum amperage limits that a battery can discharge or charge at any given moment (expressed in 1 amp increments). Current limits are especially useful for variable current applications such as electric vehicles, because they allow these applications to slowly reduce current as a battery pack is emptied and therefore increase the usable range of a battery pack.

The charge and discharge current limits can be transmitted digitally from the BMS to other devices if the external device supports this. For example, most CANBUS enabled motor controllers and CANBUS enabled battery chargers support this. When a motor controller receives the current limit from the BMS, the motor controller knows that it cannot exceed the maximum current limit sent by the BMS even if the operator of the throttle calls for more power. *Because the BMS incorporates many factors into the maximum current limit, ensuring the current does not exceed this calculated current limit also ensures all the other associated battery parameters (such as minimum cell voltage, temperature, maximum C rate, minimum state of charge, etc) are enforced.*

While some motor controllers or chargers don’t support CANBUS, they may support an analog voltage input that represents the current limit. The Orion BMS has 0 to 5 volt analog outputs which represent the maximum current limits in an analog voltage. This operates the same way as the CANBUS support, but is less accurate and less desirable than CANBUS control.

When a load does not support variable current limiting and can only be turned fully on or fully off (such as a resistive load or a non-intelligent DC to AC inverter), the BMS must operate in an on/off mode to control the load. In this case, the BMS still uses the charge and discharge current limits as the basis for making decisions about when the BMS will allow charge or discharge. The relay outputs will turn off whenever the associated current limit drops to 0 amps at any point (for example, the Discharge Enable relay will turn off when the Discharge Current Limit drops to 0A). The status of these relay outputs are available to be included in CANBUS messages if they need to be sent digitally. The exact conditions for this are discussed in the Relays section of this manual.

How the BMS Calculates Current Limits

The BMS continuously calculates both the Charge Current Limit (the amount of current, expressed in amps, that can safely go into the pack at this precise moment) and Discharge Current Limit (the amount of current, expressed in amps, that can safely leave the pack at this precise moment). These calculations are performed based on the data and parameters entered on the Charge Limits and Discharge Limits pages in the profile settings section of the utility.

In principle, both the Discharge Current Limit and Charge Current Limit are calculated the same way with the clear difference that Charge Current Limit is looking to limit the maximum voltage a cell can reach whereas the Discharge Current Limit is to limit the minimum cell voltage. Because of this significant similarity, all criteria described below are for the Discharge Current Limit to simplify the explanation (though the information for Charge Current Limit can be easily extrapolated).

The BMS starts the current limit calculation by loading the maximum continuous discharge current limit programmed into the BMS (which is the highest current that the cell can safely sustain for extended amounts of time). This value is provided by the cell manufacturer and should not be exceeded or increased beyond the manufacturer's recommendations (though there are certain cases where it may be advisable to reduce this limit to extend the lifespan of the cells).

Some cells support short pulses at higher currents than their maximum continuous rating (such as a higher amperage pulse for up to 10 seconds). For many cells, after a pulse occurs, a rest period is required for the cell to recover without damage. If pulse currents are enabled in the BMS profile, the BMS will determine if the battery pack can accept a pulse or not. If the BMS determines that the battery pack is in a condition where it can accept a pulse, the maximum current limit is increased to the maximum pulse current limit indicating that the battery may draw the pulse current. Otherwise, it is left at the maximum continuous rating. If the BMS determines that a pulse in amperage has recently occurred and the battery pack is still in the rest period recovering from a previous pulse current, the BMS will instead lower the maximum current limit to the resting current limit programmed into the BMS profile to allow the battery pack to recover safely.

The above calculations establish the absolute maximum allowable current under ideal conditions. However, the BMS may reduce those limits further for several reasons. If any of the below calculations result in a calculated current limit lower than the absolute maximum, the BMS will use the lowest of the calculated limits as the current limit.

1. ***Temperature*** - The BMS will lower the current limits based on the temperature limitations programmed into the BMS profile. The temperature limits are established in the settings profile with a maximum amperage limit for every 5 degrees Celsius (the BMS will use the closest temperature to the actual pack temperature when applying the limits). Amperage limits are

typically reduced for both high and low temperatures. Minimum and maximum battery operating temperatures for cells are enforced by the separate maximum / minimum temperature parameters. **Setting maximum and minimum temperature values for both limits is extremely important to ensure that the battery cells are not operated outside of specification. Operating batteries outside of the manufacturer specified temperature ranges can cause permanent, irreversible damage to them and may result in risk of fire.**

2. ***State of Charge*** - The BMS can be setup to lower the current limits based on the State of Charge of the battery pack. Just like the temperature settings above, the BMS can reduce the maximum current limits based on the programmed values in the profile settings. In this case, for the discharge current limit, a state of charge is specified where to begin reducing the discharge current limit along with a value of amps per percentage state of charge. This is most commonly used to reduce the amperage limits when a vehicle is approaching a low state of charge such as to slow a vehicle when the battery is low. For most applications, this feature is not required and may be disabled to prevent possibly errant SOC calculations from altering the usable range of the pack unless there is a specific reason for enabling it. This feature may be required, however, if the battery pack must be kept within a certain state of charge. Typically, it is advisable to limit charging based on the maximum cell voltage as opposed to a specific State of Charge percent as this will generally be more reliable.
3. ***Cell Resistance (based on each individual cell voltage)*** - The BMS will measure the voltage and resistance of each individual cell in the battery pack and perform a calculation for how much current that cell can accept (charge) or provide (discharge). The BMS will reduce the overall pack current limit based on the weakest cell to ensure that, if a load or charge is placed on the battery pack, the load or charge would not cause any cell to exceed the maximum cell voltage or drop below the minimum cell voltage. This calculation uses the internal resistance of the cell and the open circuit voltage of the cell. This can be thought of as an ohm's law calculation where the BMS is solving for the maximum possible amperage that will still keep the cell voltage inside the safe range. This calculation preemptively keeps the cell voltage within specifications.
4. ***Pack resistance (based on pack voltage)*** – Pack voltage limits are optional because the BMS is already enforcing individual cell voltage limits which will inherently maintain a minimum and maximum pack voltage (minimum cell voltage x number of cells and maximum cell voltage x number of cells). In some cases, a more restrictive pack voltage is desired. If pack voltage limits are specified, the BMS performs the same calculations as above in point 3, but using the minimum and maximum pack voltages and reduces current limits to maintain these values.
5. ***Cell Voltage*** - If the above calculation was to ever fail to adequately reduce the current limit for any reason, the BMS contains a backup algorithm for reducing the current limits if a cell voltage limit is exceeded. If the BMS measures a cell voltage above the defined maximum cell voltage or below the defined minimum cell voltage, the BMS will reduce the respective current limit by 20% in an attempt to restore the voltage to a safe level. If this fails to bring the cell voltage back to within the defined range, the BMS will again reduce the current limit by 20% of the maximum continuous amperage and try again. This will happen very rapidly up to a total of five times. If the voltage is still outside of the range, the BMS will have reduced the current limit to zero amps which prohibits all discharge or charge (depending on if the cell voltage was too low or too high

respectively). _This ensures that under all circumstances, if a cell voltage is ever above the maximum limit or below the minimum limit, the BMS will always have a zero amp charge or discharge current limit which prohibits all charge or all discharge respectively._ This means that the charge enable, discharge enable and charger safety enable outputs are all off if a cell ever exceeds a maximum cell voltage or drops below a minimum cell voltage.

6. ***Pack Voltage*** - If pack voltage limits are set, the BMS performs the same calculations as in part 5, using the pack voltage limits rather than the cell voltage limits. For best reliability, pack voltage limiting should only be used when it is necessary to restrict the pack voltage more than the individual cell voltage restricts the pack voltages. For example, if a pack has 10 cells and the cell voltage limits are 2.5v and 3.65v, the pack voltage is already inherently limited to 25v to 36.5v due to the cell voltage limits.
7. ***Critical Faults*** - In the event that the BMS detects a critical fault relating to the ability of the BMS to monitor cell voltages, the BMS will enter a voltage failsafe condition. The specific possible causes of the voltage failsafe mode are defined in the “Understanding Failure Modes” of this manual. If one of the critical faults that cause a voltage failsafe condition occurs, the BMS will immediately start gradually reducing both the charge and discharge current limits to zero which prohibits all charge and discharge. This allows a vehicle time to pull over and safely stop. The rate at which the limits are reduced is programmable in the BMS settings. The relay outputs will be turned off only after the gradual de-rating has completed.

Diagnostic information is provided from the BMS in the live text data tab in the utility as to which of the above reasons the BMS is limiting current.

Selecting Current Limit Settings

The Orion BMS 2 utility has data for many common cell types already pre-loaded into the utility. These can be accessed by using the Profile Setup Wizard in the BMS utility. For cells which are not listed, or if custom settings are required, the following guidelines may be helpful for selecting proper values.

Maximum Continuous Amperage Setting - The continuous maximum amperage should be set at or below the maximum allowable continuous amperage as specified by the cell manufacturer. In some cases, it is desirable to use a lower value than what the manufacturer specifies in order to extend the lifespan of the cells. It is possible that the manufacturer will specify a “C” rate rather than an actual current limit. To convert a “C” rate to an amperage, simply multiply the C rate by the amp hour capacity of the cell. For example, a 100 amp hour cell with a 2C continuous discharge rating is has a maximum continuous discharge rate of 200 amps.

Pulse Current Limit Settings - This feature should be disabled unless the cell manufacturer specifies a pulse charge or pulse discharge current limit rating. Never assume a cell can handle pulse currents unless specifically stated. Pulsing may lead to internal damage and plating of the cell, which can result in the risk of fire. If a cell manufacturer specifies a pulse limit, calculate how much over the standard continuous amperage limit the pulse limit is as a percentage. For example, if a cell has a 50 amp continuous limit, but a 100 amp pulse limit, the pulse limit is 200% of the standard. This value should be entered into the utility. The time limit specified by the cell manufacturer for maximum duration of the pulse must also be entered into the utility.

Rest Current Limit (after pulse) - This feature allows the battery to “rest” after a pulse charge or discharge occurs. Many chemistries require a “rest” period after a full pulse has occurred in order for the cell to thermally recover so as not to cause permanent damage to the cell (or to meet minimum thermal dissipation requirements). The rest period and rest amperage are defined by the battery manufacturer. The rest amperage is programmed in as a percentage of the maximum continuous amperage.

Current Limit Temperature Settings - All cell manufacturers specify a minimum and maximum operating temperature for charge and discharge. Often the temperature range for charging tends to be more restrictive than the temperature for discharging. Some cells are not permitted to be charged below a certain temperature. For example, many lithium iron phosphate (LiFEPO4) cells cannot be safely charged below freezing (0C). Additionally, it may be desirable to further limit the amperage at low or elevated temperatures since high charge and discharge rates at such temperatures may reduce the lifespan of the cells.

Temperature limits must ensure that no charge or discharge is permitted below the minimum or above the maximum temperatures. Temperature limits are specified in a table for the Orion BMS 2 (in previous products this was specified as a linear function, however the new table method allows for significantly more control over the actual limits as they relate to temperature). Current limits must be selected so they are zero amps at the desired cutoff temperature. This should be done for both high and low temperature limits for both charge and discharge current limits. **Warning: If the temperature de-rating line does not intercept zero, the BMS will not protect for over or under temperature!** The Orion BMS utility features an interactive chart on the configurations page that allows the operator to visualize this and should be used to confirm that the settings are correct.

Note: While the maximum amperage can be specified for a specific temperature, the BMS may still reduce the current limit to be lower than the programmed value if it determines a cell resistance cannot support a current limit. Most lithium ion cells have a significantly higher resistance in the cold and may be limited by cell performance rather than by these settings.

State of Charge Current Limit Settings - These settings allow the BMS to gradually reduce the maximum allowable amperage based on the calculated state of charge of the battery pack. If this line intercepts zero amps, the BMS will prohibit all charge or prohibit all discharge if the SOC is higher (or lower, for the discharge limit) than that state of charge. The Orion BMS utility features an interactive chart on the configurations page that allows the operator to visualize this and should be used to confirm that the settings are correct.

While this feature can be helpful for certain applications, it may be appropriate to leave it disabled when not required. State of charge of the battery is calculated by the BMS and it is possible for this calculation to become inaccurate for a variety of reasons, such as a current sensor fault, incorrectly set

SOC drift points, a low capacity cell, or if the BMS memory has been reset since the last full charge or discharge. If this feature is used, care must be taken to ensure that the SOC drift points are setup correctly and that the application will not become unresponsive if the SOC becomes incorrect for any reason.

Other related settings - Cell resistance settings are not directly related to the current limits, but they can still have a profound impact on them. When the BMS first turns on it will initially use the programmed nominal cell resistance values (from the Cell Resistance table in the configuration settings) for the current limit calculations. The BMS will switch to using measured (observed) cell resistances as soon as that information is available (cell resistance is measured when there are distinct changes in amperage in and out of the battery pack), but current limits may be incorrect when the BMS is first turned on if the default resistance settings are incorrect.

State of Charge Calculation

Important Note: The Orion BMS cannot calculate state of charge without a current sensor or if there is a current sensor fault present!

The Orion BMS 2 calculates a battery pack’s state of charge (SOC) primarily by coulomb counting (keeping track of the amount of current that has entered or left the battery pack). This method requires the use of a current sensor and generally tracks the state of charge of the battery pack quite well provided that the capacity of the battery is known, and the current sensor is accurate. While coulomb counting is an accurate method, there are several things that can cause this calculation to become inaccurate. These include inaccuracies in the current sensor itself (temperature drift, miscalibrations, etc), cells with a different capacity than expected (e.g. from low temperature or weak cells), out of balance cells within the battery pack or the BMS memory being reset or reprogrammed.

To deal with these possibilities, the BMS uses a secondary SOC correction algorithm to perform dynamic adjustments. This algorithm uses the measured open circuit voltage of the highest and lowest cells (the voltage as if the cell were at rest) and compares them to a table of known voltages. These known voltage points are called “SOC correction drift points” (or drift points for short) and are part of the battery profile configuration settings as these voltages are specific to the type of cell being used. If these voltages are reached, the BMS knows that the state of charge must be at least so high or at least so low. For example, with an iron phosphate cell, if the BMS sees a cell in the battery pack which has an open circuit (resting) voltage of 3.5v, it knows that the cell is nearly completely charged. If the BMS has previously been calculating the state of charge at a lower value, it can correct the state of charge calculation based on this information. This helps improve the accuracy of the calculated state of charge.

Correction drift points are usually selected at locations along the cell’s discharge graph where the cell’s state of charge is obvious in relation to the voltage to avoid drifting incorrectly. While every effort is made to calculate the open circuit voltages accurately, in some cases, the voltages may have a small error, so the correction drift points must be chosen such that there is some overhead to allow for measurement accuracy. For iron-phosphate cells, this means that really only the upper 10-15% (voltages above 3.45v) and lower 10-15% (voltages below 3.1v) of the cell can be used for drift points due to the flat shape of the discharge curve in the middle. For other chemistries, additional points throughout the full range of state of charge may be possible, improving the accuracy of the drifting.

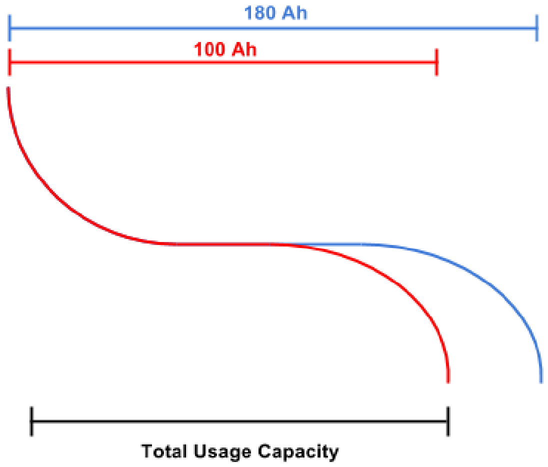
Drift points must be specified to only drift up or only drift down. The BMS will always uses the highest open circuit cell voltage (to drift up) and lowest open circuit cell voltage (to drift down) for these calculations such that that the pack is properly protected. The Orion BMS 2 allows various options for the speed at which the drift corrections happen and a delay. These hysteresis settings help prevent short term inaccuracies in calculations from causing sudden state of charge jumps.

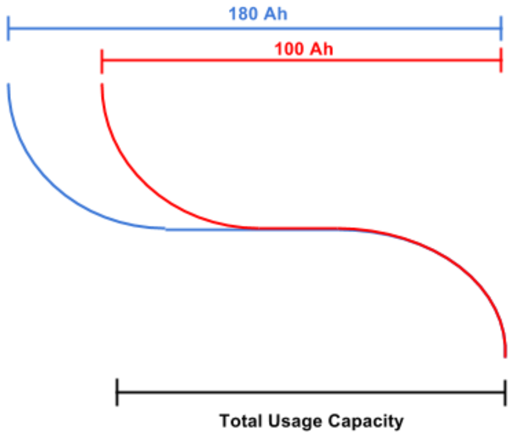
In addition to the correction drift points that are programmed in, the BMS can also correct the calculated state of charge when a charge cycle completes. Since the BMS is controlling the battery charger, the BMS will set the state of charge to the “Charged SOC” value to indicate a full charge whenever it turns the charger off due to a full charge. It should be noted that this only occurs when the BMS is in CHARGE mode and actually turns the charger off due to a full charge.

Why SOC Correction Drifts Happen

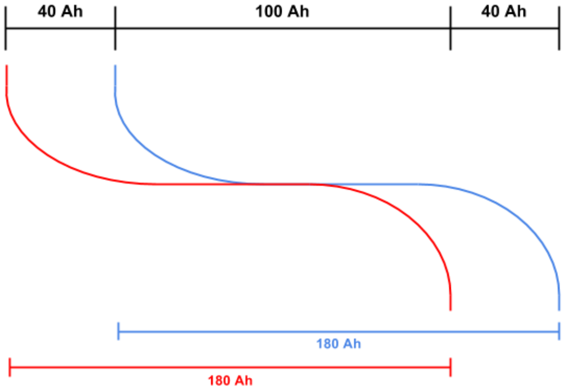
Correction drifts generally occur for one the following reasons:

1. A drift may occur if one or more cells within the battery pack has a lower capacity than the others. Because the weakest cell must never be over-charged or over-discharged, the battery pack is only as strong as the weakest cell. If one particular cell has a lower capacity than the rest of the pack, the weak cell will cause the BMS to correct the state of charge on the high end or on the bottom end (or both) depending on how the cell is balanced. The 2 images below show the voltage curves of a top balanced and bottom balanced iron phosphate cell. A drift will occur at 100 amp hours in both cases since the weakest cell is only 100 amp hours. The remaining 80 amp hours is not usable since one cell's voltage would exceed the allowable range.





2. A drift may also occur if the battery pack is out of balance. For example, if one cell is at 70% state of charge, and another cell is at 30% state of charge, less than 50% of the battery is usable without one of the cells getting too high on the high end or too low on the low end. This limits the usable range of the battery and results in a lower capacity than the BMS is expecting, which requires the BMS to adjust the calculated state of charge. During discharge, as the BMS sees the lowest cell's open circuit voltage drop to a known drift point, the BMS will correct the state of charge showing that the battery is nearly depleted. The same will happen during charge due to a high cell voltage. In the example voltage curve below, while the cells are 180 amp hours in size, two cells are 40 amp hours out of balance with each other and only the middle 100Ah is usable before a cell voltage becomes too high or too low. In this example, SOC corrections would occur at the both ends of the 100Ah usable range. This would be due to the blue cell on the high voltage and the red cell at low voltage.



3. A correction drift may occur if the capacity of the cells has changed due to cold temperatures. Some cells (notably iron-phosphate cells) will exhibit a temporarily lower capacity in the cold which can be as little as 50% of the normal capacity. The Orion BMS 2 has programmable compensation for this effect to expect the lower capacity and avoid an SOC drift (programmed in under cell settings). If these settings are not configured, an SOC correction will occur due to the reduced capacity in the same way it does for the above issues.

4. A correction drift may occur if the calculated SOC does not actually match the state of charge of the battery pack. This most frequently happens if certain settings on the BMS have been changed, if the BMS has been reset by software, or if the BMS has just been connected to the battery pack for the first time. In these cases, the BMS does not know what the state of charge of the battery is and the BMS will default to 50% state of charge, and a state of charge drift is almost certain to occur within the first cycle to correct the state of charge unless the battery happened to be at exactly 50% state of charge. The accuracy of the state of charge calculation can also be impacted over a long period of time from the relatively small measurement errors in the current sensor.

5. If the pack capacity is lower than the capacity programmed into the BMS unit this will also cause an eventual drift. This can be largely mitigated by making use of the capacity degradation and temperature to capacity adjustment algorithms. The Orion 2 BMS will automatically track capacity degradation over the lifespan of the pack. This information is available via the "Adaptive" SOC and capacity parameters published by the BMS (the normal SOC and capacity parameters will always reflect the initial programmed capacity).

In addition to the above criteria, there are also several cases where the State of Charge might drift incorrectly. These include:

1. If minimum and maximum cell voltages are restricting the usable range of the pack and the SOC settings programmed into the BMS don't reflect the lower usable range.
2. If the BMS has been programmed with incorrect nominal cell resistance data which causes the open circuit cell voltage calculation to become inaccurate.
3. If there is a significantly loose busbar, terminal or cable on a cell or if there is a long cable linking two cells together in the middle of a cell group. These can all cause resistance calculation errors which can lead to incorrectly calculated open circuit voltages.

4. If the BMS is inaccurately calculating open circuit cell voltages due to an incorrectly installed or defective current sensor (or if the incorrect current sensor is selected in the configuration settings).

Important Note: The Orion BMS cannot calculate state of charge without a current sensor. In the event that a current sensor is not connected or if one is connected but has an associated current sensor fault, the Orion BMS will display a very inaccurate state of charge based strictly on instantaneous cell voltages with relation to the drift points. This backup method is very inaccurate as the state of charge calculation may oscillate wildly and should not be used for any calculations. This mode exists only as a backup algorithm for specific applications and is not designed for normal use.

Determining State of Charge Correction Drift Points

Every battery chemistry will have different state of charge correction drift points. Unfortunately, cell manufacturers typically do not provide this information and it often has to be determined either from experimenting or from performing careful analysis and running charge and discharge cycles. While the points can be fairly easily established, some tweaking may be required to maximize performance.

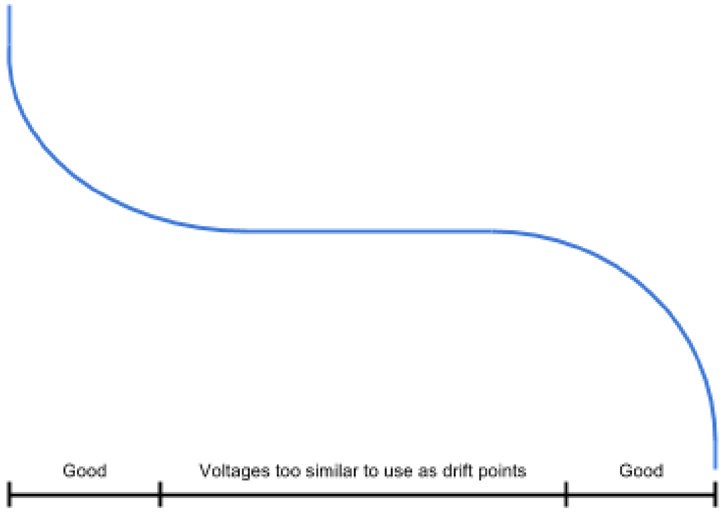
Ewert Energy Systems maintains a database of state of charge drift points for many common cell types. This information can be automatically entered into the battery profile by using the “Profile Setup Wizard” in the BMS utility.

For cells that are not in the database, Ewert Energy Systems offers a service to characterize cells. This service will produce default settings for cell resistance measured at different temperatures, SOC settings, and standard voltage settings. This service requires at least one sample cell and the manufacturer datasheet. For common cells which are not in the database yet, the service may be discounted or free. Please contact Ewert Energy Systems directly for details and pricing on this service.

To determine approximately where the drift points should be, take a sample cell and charge it up to 100% SOC (following manufacturer's recommendations). After the sample cell is fully charged, discharge it to 0% (following manufacturer specs for the minimum cell voltage and discharge rate) at a very low amperage to get as close to an open cell voltage curve as possible (avoiding voltage drop and charge / discharge polarization effect). Once the discharge is complete, graph the cell voltage vs. amp hours discharged, and there should be a fairly clear discharge “curve” (can be very different shapes depending on the chemistry). From this data, approximate SOC to voltage data can be determined. Overhead must be added in to account for accuracy of the open circuit voltage measurement calculation. For example, an iron-phosphate cell could use a drift point of 3.0v for 15% even though the voltage for 15% may actually be higher than 3.0v. This ensures that the drift point does not incorrectly trigger when it shouldn't. Some trial and error may be necessary to fine tune the drift points.

While datasheets from the battery cell manufacturer may be useful in calculating rough drift points, they often contain graphs with instantaneous voltages at higher C rates which have added voltage drop from the cell resistance included. The values for SOC drift points are the open circuit voltage of a cell which is the voltage of the cell at rest and does not include the voltage drop due to charge or discharge.

Drift points should be established at places on the discharge curve where the voltage change is most significant. For example, most iron phosphate (LiFEPO4) cells stay at 3.3v for most of the discharge curve and suddenly start to rapidly drop at 3.0v. 3.0 volts is a good place to set a point. If the drift points are set too close together (e.g. if a drift point is set at 3.4v and 3.2v and the battery spends most of its time at 3.30-3.35v) then they may trigger SOC drift prematurely. This happens when the open cell voltage of a battery will drift up and down slightly under load due to a temporary charge polarization (or temporary voltage depressions). For example, 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.



An example of acceptable drift point areas on the voltage curve of a LiFEPO4 cell

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 after the specified waiting period.

It is important to have a sufficient number of state of charge drift points to both protect the battery and 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 Orion BMS 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 Orion 2 BMS allows the operator to specify the rate (speed) of this drift process as well as the amount of time (delay) that the drift criteria must be satisfied before being initiated.

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. For example, 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).

“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.*

Temperature Capacity Reduction

Many lithium ion cells, including iron phosphate (LiFEPO4) cells, have a significantly lower usable capacity when cold. To compensate for this, the BMS has the ability to reduce the expected capacity of the battery pack based on the temperature of the cells such that the calculated state of charge of the cell better matches the actual usable range. Different capacities can be specified for different temperatures.

Capacity reduction works by sensing the temperature, looking up the usable capacity at the specific temperature and using this capacity (instead of the maximum capacity) for calculating the state of charge. When the battery warms back up and more capacity is usable, the BMS will increase the usable capacity in accordance with the capacity reduction table.

This compensation table is configured on the “Cell Settings” section of the battery profile configuration settings.

Lifetime Capacity Loss Tracking

In contrast to temporary capacity loss at low temperatures, the battery pack will eventually begin to experience permanent capacity loss as it is used. This loss can be caused by a number of factors including (but not limited to) total number of cycles put on the pack, exposure to extreme temperatures, regularly pushing the cells to their maximum ratings or long-term storage at extreme states of charge.

Over time this capacity loss can accumulate to the point where it has a significant impact on the State of Charge calculation (the pack is regularly relying on the State of Charge drift points to correct the State of Charge calculation). To address this, the Orion 2 BMS has separate “adaptive” capacity and State of Charge parameters that will dynamically (and automatically) adjust themselves over time to more accurately reflect the actual battery pack conditions. These parameters are always enabled and can be requested from the BMS through the software utility or be regularly transmitted via the custom CANBUS message table (to allow them to be sent to equipment like motor controllers or user displays).

The BMS will slowly adjust the adaptive capacity figure over time to prevent any sudden jumps in capacity. The calculated value is stored in non-volatile memory to persist across power losses (it can, however, be reset through the BMS utility [“File” menu -> “Reset Learned SOC Information”]). This adjustment is performed by tracking the actual amount of capacity in the battery pack each cycle (that is, the actual observed amount of energy leaving the battery pack during a normal cycle) and comparing it with the expected capacity. Using a weighted filter, the BMS will slowly adjust the "Adaptive Total Capacity" to be closer to this observed value.

The "Adaptive State of Charge" parameter uses the "Adaptive Total Capacity" parameter as the maximum capacity (rather than the programmed in nominal capacity parameter that the normal "State of Charge" parameter uses). State of Charge drift (which is described elsewhere in this document) may still occur on the "Adaptive State of Charge" parameter, though the extent should be greatly reduced from the standard "State of Charge" parameter.

The "Adaptive Total Capacity" figure will still take into account any programmed temperature compensation. This means that if the pack is cold (and is expected to have lower capacity in the cold), this reduction will still be factored in to the "Adaptive Total Capacity" value, just like it is in the normal capacity value. The BMS will factor this temperature compensation back out again before performing any adjustments to the "Adaptive Total Capacity" figure. This allows for more accurate tracking of capacity, even at cold temperatures.

NOTE: The standard "State of Charge" parameter will always be calculated from the nominal (programmed) pack capacity. This parameter is never adjusted for lifetime degradation or capacity loss. **Only the "Adaptive State of Charge" and "Adaptive Total Capacity" figures are adjusted to account for lifetime degradation and capacity loss.** This is done to maintain backwards compatibility with older Orion products. **For applications where the State of Charge should be adjusted over time for long term capacity loss, please use the "Adaptive State of Charge" and "Adaptive Total Capacity" figures.**

State of Health Calculation

The Orion BMS determines the State of Health of the battery pack primarily by examining both the Internal Resistance and the observed capacity (measured in amp-hours) of the battery pack. 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, loose busbars or terminals, or improper wiring can also cause this calculated value to drop prematurely or incorrectly.

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. For an application such as an electric vehicle the minimum state of health may higher, so the pack may need replacing sooner than in other applications. A minimum state of health threshold can be programmed into the BMS. If the state of health drops below this value, a weak pack fault code will get set. This fault code is informational only to indicate that the battery pack should be inspected and will not alter the behavior of the BMS in any way. Although the fault does not alter the behavior of the BMS in any way, a high resistance cell or a cell with a lower capacity than expected could impact operation in other ways.

Internal Resistance

The Orion BMS measures the internal resistance of each cell by observing the relative change in voltage when a significant load (or charge) is applied to the cell. This means that the BMS depends on external changes in current in order to calculate the cell internal resistance values. The BMS cannot directly measure the internal resistance without changes in current being applied to the cells, and if external changes in current are not available or not suitable, the BMS may not be able to regularly calculate the resistance of cells.

The amount of change in current required to calculate cell resistance values depends on the size of the current sensor being used with the BMS. Typically, it is at least 20A for most supported current sensors. This current requirement gets reduced at extreme temperatures (where the pack may be limited to lower than 20A output / charge).

Internal resistance is the primary reason cell voltages change nearly instantly when a load or charge is applied to the cell. When current is applied to the cell, the resistance inside the cell causes a voltage drop (or rise for charging) with respect to the amount of current flowing through the cell. When the current stops flowing through the cell, the voltage will go back to the open circuit voltage. For example, if a battery has an internal resistance of 2 mOhm (0.002 Ohm) and starts off at 3.3v, the instantaneous cell voltage will be 3.5v while a 100A charge current is applied (a 0.2v voltage “drop” since 100amps * 0.002ohms = 0.2volts, E = I * R). When the pulse is finished, the instantaneous cell voltage drops back to about 3.3v. Knowing the internal resistance for each cell allows the BMS to calculate how much current a cell can handle before the minimum or maximum cell voltages would be exceeded. This information is also used in back-calculating the open circuit voltage of a cell (even when the cell is actively in use) which is used for state of charge correction drift points. Cell resistances are also useful for measuring the amount of energy loss. Internal resistance is often expressed in milliohms (mOhms) or one thousandth of an ohm.

How the BMS Calculates Internal Resistance

The Orion BMS depends on external changes in current to be able to back calculate the resistance of each individual cell. Therefore, the BMS does not initially know the cell resistances and will begin by using pre-programmed default resistances based on the temperature of the cells. To do this, the BMS takes the average temperature of the pack and looks up the nominal resistance for the cell at that temperature in the nominal resistance table programmed into the BMS (available in the Cell Settings section of the battery profile configuration settings). The BMS uses the default resistance values until real cell resistance measurements can be taken (at which point it will discard the default values and use the real values).

Only certain changes in current are used by the BMS for determining internal resistance. The changes in current must be sudden enough, large enough, and stable enough within a set amount of time for the BMS to use them in the calculation. A minimum of two changes of current are needed within a set amount of time for the BMS to update the resistance data. The calculated current trigger is typically a percentage of the total amount of the current sensor. The minimum value is generally about 20% of the maximum value of the current sensor, but the minimums are adjusted automatically by the BMS based on other factors such as temperature as the cell may not be able to output enough power to meet the 20% standard threshold when cold or hot.

The BMS will prefer to use calculated internal resistance values, but 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 sources. Since temperature can significantly alter the internal resistance of a cell, the BMS will also use default values when a significant change in temperature has occurred since the last known calculated internal resistance value.

Determining Nominal Resistance

Internal resistances of cells 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 a lower resistance in extremely hot temperatures.

The Orion BMS allows the user to specify the nominal 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 its 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 as accurate as possible. If the internal resistance numbers are set too high it can cause the initial calculated current limits to be too low and can also cause the BMS not to set weak cell faults when it should. Internal resistance numbers set too low can result in false positive “weak cell faults” and the BMS initially calculating that a battery pack can supply a higher amperage than it actually can (the BMS would update the current limit soon after current started, however this reduction in output power can be unexpected).

It is strongly recommended to test the cell resistance at least every 10 degrees Celsius over the entire usable range if possible. After a few points are collected at different resistances, an exponential curve should begin to emerge and in some cases, it may be possible to extrapolate some data without testing at every 10 degrees Celsius by using a best fit exponential curve.

Note: Internal resistances can be significantly higher at full state of charge and empty state of charge. When determining nominal internal resistance values, the resistance should be measured at a normal state of charge such as between 40% and 70%.

Ewert Energy Systems offers a service for measuring internal resistance from sample cells at temperatures across the working range of the cell and turns this data into settings for the BMS profile. For more information about this service, please contact Ewert Energy Systems.

To determine the nominal resistance for a battery 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 (eg: between 40% and 70% SOC). 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 cell very accurately. 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 to the cell.
5. After 10 seconds, take another voltage measurement.
6. Measure the actual amperage leaving the battery to increase the accuracy of the calculation.
7. Subtract the 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 10 second DC internal resistance (DCIR) expressed in Ohms. (convert to milliohms by dividing by 1,000)

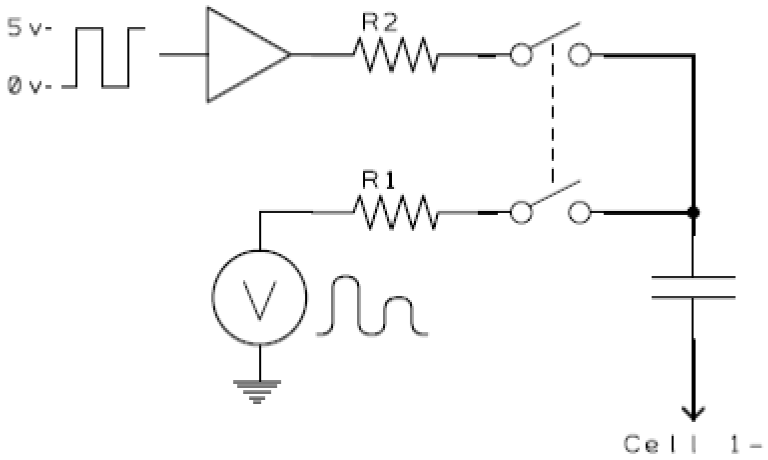
Example: Assume a battery is observed at 3.3v resting. A 20 amp load is applied to the battery at which point the measured voltage drops to 3.0v. The internal resistance can be computed by taking 3.3v - 3.0v = 0.3v / 20 = 0.015 Ohm or 15 mOhm at the specific temperature the reading was taken.

The Orion BMS itself can be used to perform these calculations when used in a controlled environment. Using the Orion BMS to determine internal resistances has the added advantage of being able to calculate the AC vs. DC internal resistance ratio as well: The same procedure is used above, but with the BMS measuring the cell voltages and current. Instead of a single 10 second pulse, a 10 second pulse should be applied first, followed by a series of 5 or so quick 1 to 2 second pulses. The addition of the 1-2 second pulses helps ensure that the BMS is able to accurately calculate the AC internal resistance. The manually calculated value after 10 seconds is compared to the value that the BMS calculates after all the pulses are complete. The difference between these two internal resistance values is the AC vs. DC resistance ratio.

IMPORTANT NOTE: It is virtually impossible to manually measure the AC (fast) cell resistance without the use of either the Orion BMS or other fast-reaction equipment because the voltage drop occurs over such a short period of time (~50mS). If this test is being performed using hand-held equipment such as a multi-meter, the AC (fast) resistance may need to be inferred from the DC (slow) resistance.

Isolation Fault Detection

The Orion BMS has an integrated isolation fault detection circuit designed to measure and identify breakdown in isolation between the high voltage battery pack and the negative of the 12/24v power input. The circuit operates by transmitting a weak 5 volt AC signal across an isolation capacitor separating the high voltage battery and the 12/24v power supply negative and then measuring the attenuation of the signal. This method is able to measure fairly small faults before they become large enough to cause further problems.



Simplified isolation fault detection schematic

Isolation is measured from the 12v – 24v power supply negative to cell tap 1- (negative most cell in the battery pack). ***IMPORTANT NOTE: For the isolation fault detection circuit to work properly, cell 1 must be the most negative cell in the battery pack such that cell tap 1- is connected to pack negative.*** Since the measurements are made against the 12v – 24v power supply negative, and most isolation faults occur to the vehicle or equipment chassis, the chassis must be connected to the 12v - 24v negative ground to properly measure a breakdown in insulation.

Only one isolation fault detection system can be installed on a DC bus at any given time as the detection circuit AC signal will interfere with other systems and produce invalid or unreliable results. If the BMS will be used in a system where other isolation fault detection devices are used, the circuit on the BMS must be physically disabled. The Orion BMS 2 contains an internal latching relay that can be used to physically disconnect the circuit through the software settings. This relay is designed to be operated during setup and is not designed to be switched on and off regularly during operation. While the latching relay is periodically pulsed to ensure it is in the desired state, the relay status can be flipped if the unit is exposed to very large g forces due to significant mechanical shock, such as the unit being dropped. The BMS may be ordered with the isolation fault detection circuit permanently enabled or permanently disabled, which is recommended if the feature will always be used or will not be used (in larger volumes there are cost savings for ordering without this relay feature). **If the BMS is expected to be used in environments where significant mechanical shock is possible or likely, the unit should be special ordered with the circuit permanently enabled or permanently disabled.**

The isolation detection strategy used in the Orion 2 BMS is a very common method for measuring breakdown in isolation between a battery pack and a chassis. One side effect of this method is that the isolation capacitors will have a very small leakage current. This small leakage may cause voltage to be measured between the battery pack and the chassis. Although the voltage can be measured, the current is very weak.

The BMS must have the isolation fault detection circuit enabled in the battery profile configuration settings in order to measure isolation (available on the Fault Settings section of the battery profile configuration settings). When this is enabled, the BMS will poll the attenuation of the 5V AC signal once every 0.4 seconds. The instantaneous value is reported in the live text data tab on the utility as the "shortest wave". This value is then averaged out over time, throwing out values with clipped data, and that value is reported as the averaged isolation value. If the averaged value is lower than the error threshold, a fault is set. The threshold for setting an isolation fault is determined by the sensitivity chosen.

In some cases, it may be desirable or necessary to use a different method for determining if there is an isolation fault detected. In these cases, the shortest wave parameter can be transmitted over the CANBUS and an external controller can average the values.

When troubleshooting isolation fault issues, looking at the shortest wave data may be very helpful as it shows the measured isolation at any time. A value above 4.5 volts indicates good isolation. A value of 2.5v or lower indicates a near or dead short. Values may vary significantly with changing currents. Humidity or condensation may also be responsible for isolation problems.

Controlling Loads and Chargers

The Orion BMS is continuously tracking whether or not the battery pack can actively accept charge or discharge. As the BMS does not have integrated switches or contactors, the BMS unit cannot directly stop current flowing in or out of the battery pack by itself. Instead, it provides signal outputs to externally connected devices instructing them to either turn on and off, and for devices which support it, it provides a maximum allowable current limit. *The BMS must be properly integrated with all current sources and loads connected to the battery being protected. Failure to do this may lead to a battery fire and/or permanently damaged cells.*

Devices typically fall under two categories. Devices that can only be turned on or off (such as generators or certain inverters) and devices which can be variably limited (such as motor controllers or many battery chargers). While the BMS may be setup differently depending on which type of device it is controlling, the methodology for both is based on calculated current limits.

Digital On/Off Outputs (Relay Outputs)

Three primary on/off outputs are provided on the Orion BMS for controlling chargers and loads. Conceptually these outputs can be thought of as whether the BMS is allowing charge into or discharge out of the battery pack at any given time. All three outputs are open drain and are active low (pulled down to ground when ON and float high when OFF). This means that these outputs are on (pulling down to ground) when discharging or charging is permitted respectively. For more information on the electrical specifications and wiring procedures for these outputs, please see the wiring manual.

Each of the on/off relay outputs are designed to control different types of devices. Charge Enable and Discharge Enable share the same algorithm for turning on and off while Charger Safety uses a slightly different algorithm.

- The Discharge Enable output is designed to control any load on the battery pack.
- The Charge Enable Output is designed to control devices which may alternate between charging and discharging, such as regenerative braking in a vehicle. It is also used when the BMS must allow charge to re-occur once the battery pack has been discharged a certain amount, such as in solar, wind, and some standby power applications.
- The Charger Safety output is designed to control a battery charger when used in a defined charging period where a user input starts the charging process such as when an electric vehicle is stopped and plugged in.

Criteria for all 3 relay outputs

All 3 of the on/off relay outputs will turn off if their respective current limit reaches zero amps (Charge Enable and Charger Safety both use the Charge Current Limit, while Discharge Enable uses the Discharge Current Limit). In addition to other criteria, the Charge Current Limit will always reach zero amps if any cell voltage exceeds the programmed maximum cell voltage, thereby turning off both the Charge Enable and Charger Safety outputs. Likewise, the Discharge Current Limit will always reach zero amps if any cell voltage ever drops below the programmed minimum cell voltage, turning off the Discharge Enable output.

All 3 of these outputs can also be programmed to turn off in the event that the measured current exceeds the current limit imposed by the BMS by a certain amperage threshold that is programmed in (this threshold can be different for Charge Current and Discharge Current). This feature must be enabled for each of the relays individually through the settings profile and must be enabled for the BMS to protect against over-current. If the relay turns off due to over-current, the BMS can be configured to allow it to turn back on after certain criteria are met (ie: current limit is above a programmed point, SOC is above a certain percentage, etc). The BMS also provides the ability to restrict the total number of times a relay can turn back on within a minute to prevent relay chatter. If this count is exceeded within a minute the relay will latch off and require the BMS to be power cycled in order to turn back on.

While these relays can help enforce a current limit, they are not intended to / cannot protect a battery pack against a short circuit. **Using a relay output with current limit enforcement enabled is NOT a substitute for a proper circuit breaker or fuse.**

In the case of all three relay outputs, minimum and maximum temperatures can be specified by ensuring that the charge and discharge current limit settings programmed into the BMS de-rate the maximum possible amperage to zero amps at the desired temperatures. The same can be enforced for state of charge. This, along with other programmable criteria for controlling the charge and discharge current limits, is discussed in more detail in the “How the BMS Calculates Current Limits” section above.

When the BMS turns off these outputs, charge or discharge must stop within a certain timeframe (typically about 500ms). If the BMS still measures current flowing into or out of the battery pack after this amount of time after the BMS has prohibited the respective action, the BMS will set a relay enforcement fault code. If this happens, the BMS will turn off all 3 of the relay outputs plus the multi-purpose enable output in a last-ditch effort to stop all charge and discharge, and the outputs will latch off until the fault is cleared or the unit is power cycled / reset. This functionality is accomplished with an internal watchdog safety circuit.

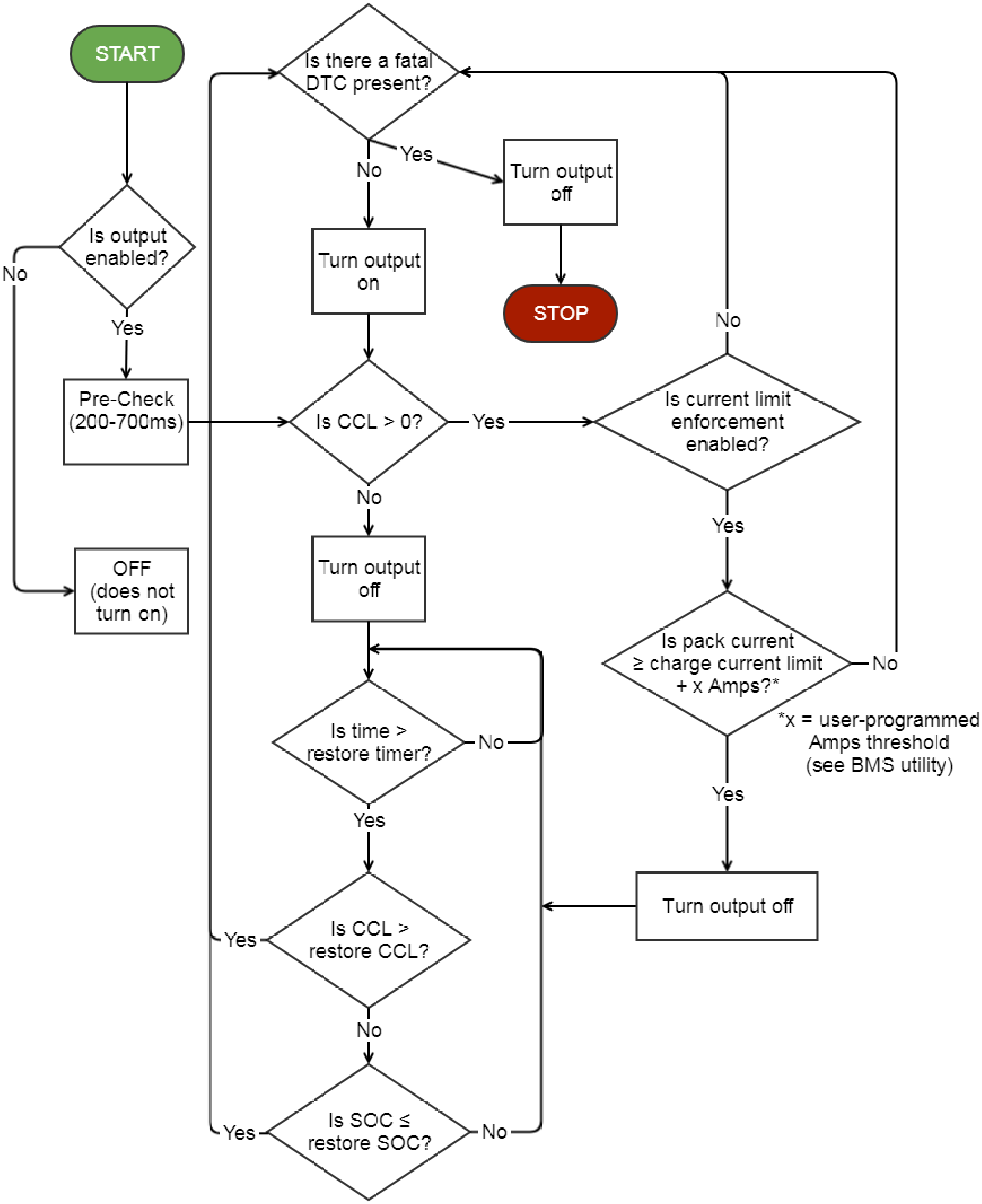
IMPORTANT NOTE: While the multi-purpose enable output has the internal watchdog safety feature, none of the other multipurpose outputs have this safety feature, and the status of those outputs is not affected by any fault status unless the specifically chosen behavior includes turning off due to certain errors.

Once the relay outputs turn off due to the current limit being zero amps (and not due to a fault condition or over-current condition), they may be programmed to turn back on again after a minimum amount of time when certain criteria are met. By default, the outputs will remain off until the BMS is power cycled or reset. The criteria for the charge enable and discharge enable outputs are the same, but charger safety is different.

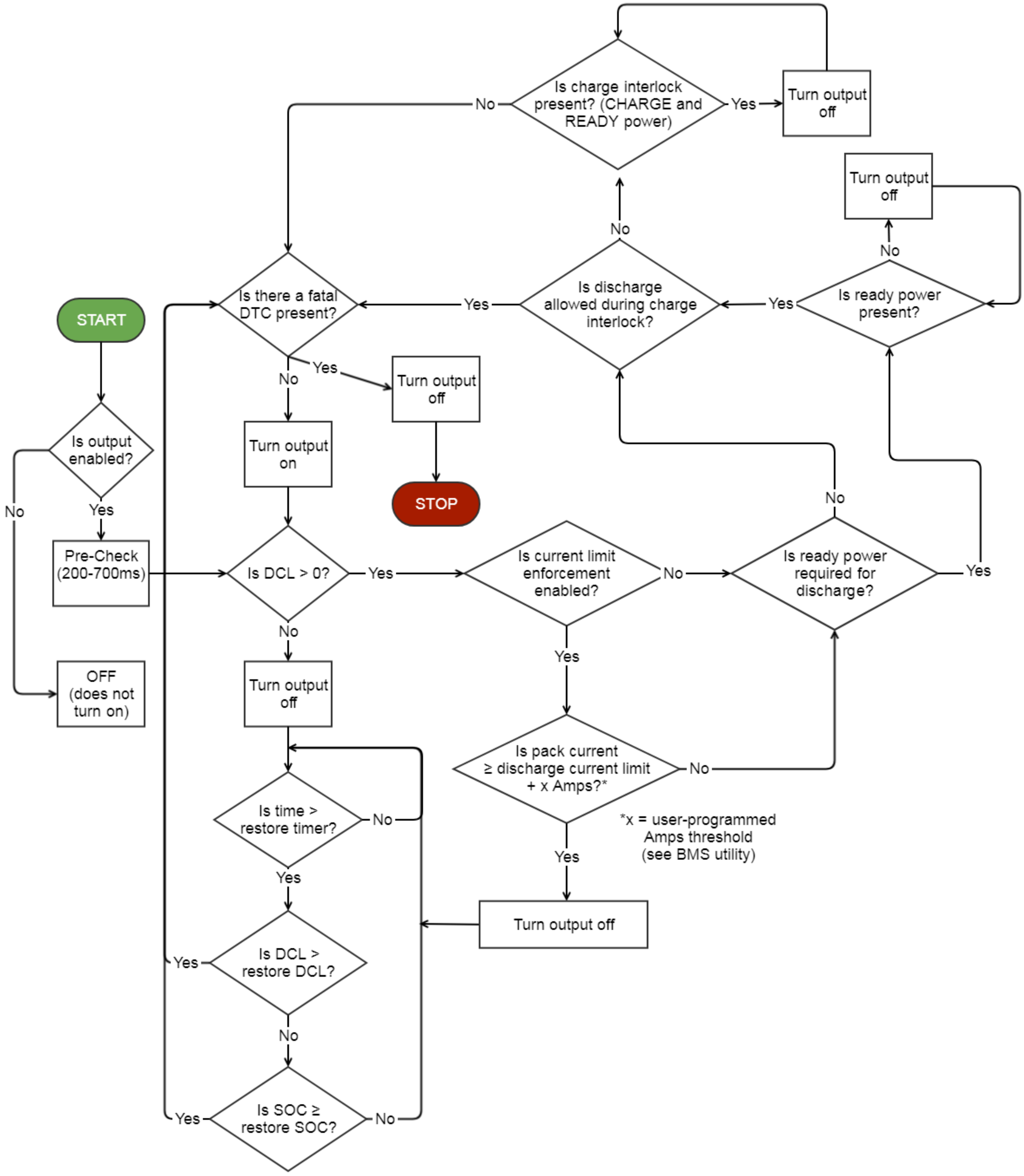
Criteria for Charge Enable and Discharge Enable - After a minimum time interval defined in the profile settings has expired, the outputs may turn back on based on state of charge or based on the charge or discharge current limits rising back up to a set value. They are turned on when both of those conditions are met (if both are enabled), though usually only one condition is used. Care must be taken to prevent oscillations, so values must be chosen far enough apart as not to allow the output to turn on again immediately. Typically, this would be a gap of 5% to 10% SOC, however for certain applications like solar, wind or standby power systems, the output is usually turned back on based on state of charge dropping at least 1% or 1.5% SOC. For applications requiring a certain amount of amperage to turn back on, turning the relay output back on based on the calculated current limit may be more appropriate.

The discharge enable output can also be configured to turn off in the case that the BMS is in charge interlock mode (detects power on both the READY and CHARGE power sources at the same time). It can also be configured to require READY power to turn on. Both of these options are useful for ensuring that a vehicle does not drive away at the same time it is being charged.

Charge Enable Output Flow Chart



Discharge Enable Output Flow Chart

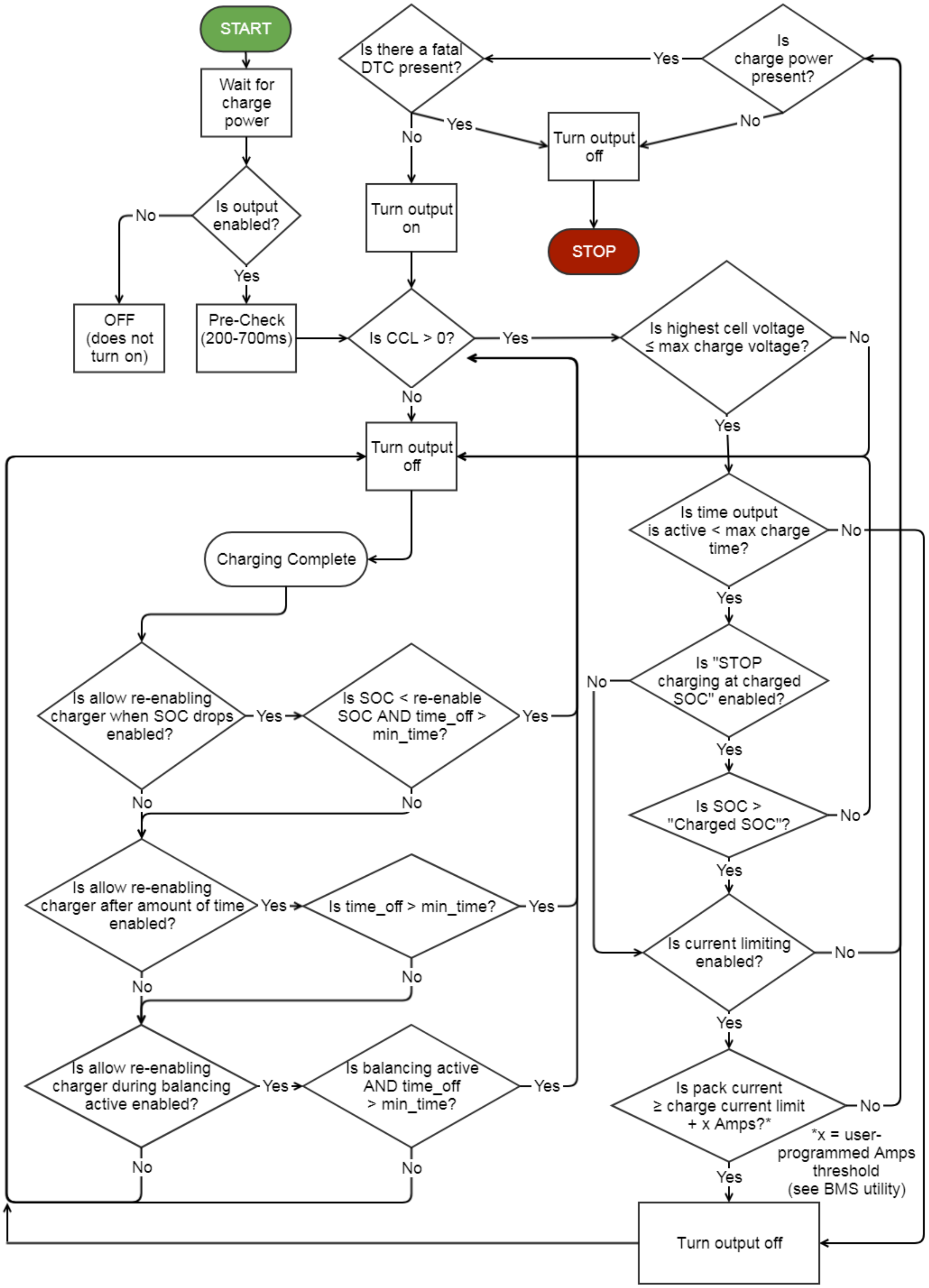


Criteria for Charger Safety - The charger safety output is only allowed to turn on when the BMS is in CHARGE mode (power is applied to Main I/O pin 3). Once this output turns off due to a cell voltage reaching the maximum cell voltage, the BMS will adjust the state of charge to “Fully Charged SOC” (available on SOC Settings section of the battery profile configuration settings) and latch the charge current limit at zero amps since the battery is full. If the charger safety relay is not enabled in software, then BMS does not latch the current limit to zero after a charge is completed. For this reason, in some applications such as solar, wind, and standby power, it may not be desirable to enable the Charger Safety Relay in order to prevent the BMS from latching the Charge Current Limit off.

By default, the charger safety output latches off until power is removed from the CHARGE pin on the BMS and is re-applied (for a vehicle application, this generally corresponds to someone unplugging the vehicle and plugging it in again the next time they wish to charge). This output can be configured to turn back on every so many minutes while the balancing algorithm is active or indefinitely even after balancing has finished. It can also be configured to turn back on if the State of Charge drops below a certain percentage and a certain amount of time has passed. If the relay turns back on due to one of these settings, the charge current limit will be restored while the relay is back on and will latch to zero amps again when the BMS turns the charger off next. The BMS will provide a diagnostic parameter in the live text data tab of the utility to indicate that the charge current limit is latched to zero because the charge is complete. This may be useful if attempting to determine if the BMS turned the charger off.

While the BMS can turn on the charger again to continue balancing if it is allowed to do so in the settings, the Orion BMS switches off the charger completely when a cell reaches the maximum voltage and will continue to balance the pack after the charger has turned off. **It is essential that the Orion BMS is able to completely turn off the charger when it calls for an end of charge by turning off the charger safety output. Failure to do this will result in damaged cells.** The charger must never be allowed to continue charging at any amperage after the BMS has turned the charger off.

Charger Safety Output Flow Chart



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 fifteen (15) programmable CAN messages that can be configured to transmit on either or both CAN interfaces. These messages are designed to be flexible in order 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 must always be exactly two 120 ohm 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 an internal terminator resistor already loaded on CAN interface #1. However, CAN interface #2 does not have an internal terminator resistor loaded.** This is done by default so that the standard unit can be used in any application regardless of 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. Settings (also known as battery profile) and firmware updates can be performed from either interface on the Orion BMS 2 (this differs from previous revisions of the Orion BMS).

Cell Broadcast Option - The BMS can be configured to rapidly transmit cell voltages onto the CANBUS in increments of 4ms. This is useful when data logging as it is the fastest method for the BMS to transmit cell voltages.

Analog 5v Outputs

Three (3) 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. Therefore, CANBUS communications are the preferred method of setting external current limits if possible.

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 battery profile configuration settings). 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 analog output represents the state of charge. The state of charge analog output will vary between 0 and 5 volts representing between 0% and 100% state of charge respectively.

How Balancing Works

The Orion BMS 2 takes an intelligent approach to balancing that works to maintain and improve balance from cycle to cycle.

Lithium ion batteries, unlike lead-acid batteries, tend to stay in balance very well once they are 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, and these differences in self discharge rates are typically measured in micro amps (uA). The BMS must be able to correct these discrepancies in order to keep the cells balanced.

The purpose of balancing a battery pack is to maximize the usable capacity. Even in an ideal battery pack, all cells will have slightly different capacities and will be at slightly different balance points. 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.

The Orion BMS 2 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). Even with an extremely high difference in self discharge rate of 1mA, the 200mA balancing current is still 200 times that of the discharge rate. While every battery pack is different, for a 200 amp hour battery pack cycled once a day a typical maintenance balance completes in only about 10-15 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 in very extreme conditions, the majority of the battery pack capacity will remain usable even after months without a balancing cycle. 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 2 is not designed to do an initial balance on a battery pack that is more than about 10-15 amp hours out of balance. In those cases, the battery pack should be pre-balanced by either charging the cells to roughly the same SOC one by one or by charging / discharging the lowest and highest cells so that they are roughly at the same SOC (for more information on pre-balancing, please see our application note on pre-balancing cells). The image below is an example of two cells that are grossly out of balance with each other (40 amp hours out of balance). Despite the significant imbalance, more than 50% of the capacity is still usable.

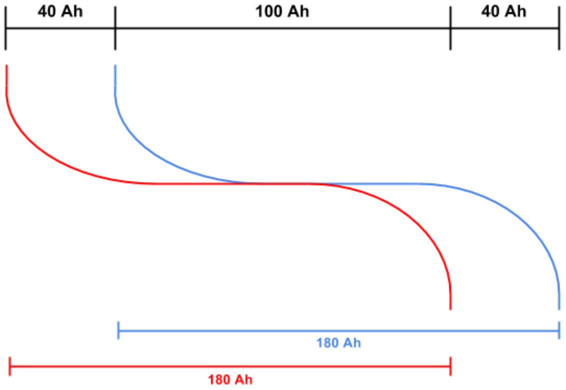


Diagram: Example of two cells that are significantly out of balance

Balancing on the Orion BMS 2 only occurs when the BMS is powered in CHARGE mode (powered by pin 3 on the Main I/O connector). When any one cell in the battery pack exceeds the “Start Balancing” voltage (found on the Cell Settings section of the battery profile configuration settings), the BMS will begin the balancing algorithm for all cells. The BMS will look for the lowest cell and then place a load on all cells which are more than a programmable amount of voltage above the lowest cell. For example, if a battery pack consists of 4 cells at 3.5, 3.51, 3.65 and 3.49 volts and the maximum difference (delta) in voltage is configured for 10mV (0.01 volts), the BMS would only apply a load to the cell which is 3.65v, to bring it down to within 10mV with the rest of the cells. **This algorithm continues until all cells are balanced to within the programmed maximum difference in voltage and continues even after the BMS has switched off the charger**. Once all cells are within this voltage, balancing will stop until the start balancing criteria are met again.

The BMS has a safety feature to prevent over-discharging any cell during balancing in the event of a defective or dead cell. A minimum balancing voltage threshold allows the operator to specify a voltage threshold at which the BMS is not allowed to remove energy from a cell. While the rest of the cells will continue to balance, the BMS will not place a load on any cell which is lower in voltage than this threshold, even if that cell needs to be balanced. The purpose of this feature is to protect the cells from over-discharge and to prevent a possible race condition where the BMS removes charge from alternating cells.

The start balancing voltage setting should typically be configured to a voltage that indicates a cell is within approximately 5-10% of the maximum state of charge. For iron phosphate this is typically about 3.5v and varies with other chemistries. The maximum delta voltage (difference in voltage from the highest to lowest cell) recommended is 10mV for most lithium ion chemistries such as iron phosphate, but may be adjusted slightly lower for certain chemistries with a linear discharge curve (such as many manganese or polymer type cells). A value too low will cause a race condition, reducing or eliminating the effectiveness of the balancing algorithm, and 10mV is recommended unless research has been done on a lower setting. When balancing a grossly out of balance pack, choosing a higher number such as 20mV may increase the speed of bulk balancing, but should then be reduced back to 10mV for finer balancing.

The minimum balancing voltage setting is simply to prevent cells from becoming over-discharged. This value can be set to a fairly low voltage, often a voltage corresponding to around 25% state of charge. For iron phosphate a voltage of 3.0 to 3.2v is appropriate. The minimum balancing voltage setting must be low enough to allow the BMS to effectively perform balancing and must be below the “settling” voltage.

While the BMS is actively balancing, the balancing circuit will pause every so often to allow cell voltages to settle and to re-evaluate the balance of the cells in the pack. This is a normal part of the balancing algorithm and happens at set intervals. If the BMS unit itself is at an elevated temperature, the BMS will pause for a longer period of time to prevent overheating. To prevent a burn hazard, the BMS will not balance at all when the heatsink temperature is above 50C.

While the BMS is most effective and is normally usually used to perform “top balancing” (synchronizing all cell voltages at full state of charge), it is possible for the BMS to be used for “middle balancing” or “bottom balancing” by adjusting the balancing voltage thresholds and in some cases, by using an external controller to signal the BMS when to balance. Whenever possible, top balancing is strongly recommended, particularly for applications which are rarely at a low state of charge.

Some other 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 clamping the voltage and burning off the difference between the energy the charger is supplying and what the cell needs. While this approach can work under specific circumstances, it is typically inefficient, requires large bypass resistors and usually unbalances the batteries before it can then re-balance them. Because of these limitations, the Orion BMS does not use this process. Instead, it switches off the charger completely when a cell reaches the maximum voltage and will continue to balance the pack after the charger has turned off. *It is essential that the Orion BMS be able to completely turn off the charger when it calls for and end of charge. Failure to do this will result in damaged cells.* The charger should never be allowed to continue charging at any amperage after the BMS has turned the charger off.

The Orion BMS can be configured to turn the charger back on at set intervals if necessary to continue the balancing process. This is configured in the Relay Settings section of the battery profile configuration settings under the Charger Safety Relay sub-tab. For certain chemistries it may be desirable to turn the charger back on every 30 minutes to an hour to aid in the balancing process. This is especially true for iron phosphate cells where the difference in state of charge is not evident unless the cell voltages are over approximately 3.4 volts. By turning the charger on every so often during the balancing process, the difference in voltage will become greater and allow for finer tuned balancing. The Orion BMS has four options for turning the charger back on: Disabled, every *n* number of minutes while balancing is still active, and every *n* number of minutes even after the battery is balanced and when the SOC drops below a programmed percentage. The specifics of the application will determine which of these strategies is most appropriate.

The Orion BMS 2 performs self-tests on the balancing circuitry every time it powers up (including waking from low power sleep). This test will briefly (~100ms in duration) turn the balancing circuits on for each cell in order to verify that they are operating properly by looking for an expected voltage drop. This is performed equally on all cells to prevent loading some cells more than others. If the BMS detects an anomaly with one or more balancing circuits during this test it will set a fault code to alert the operator.

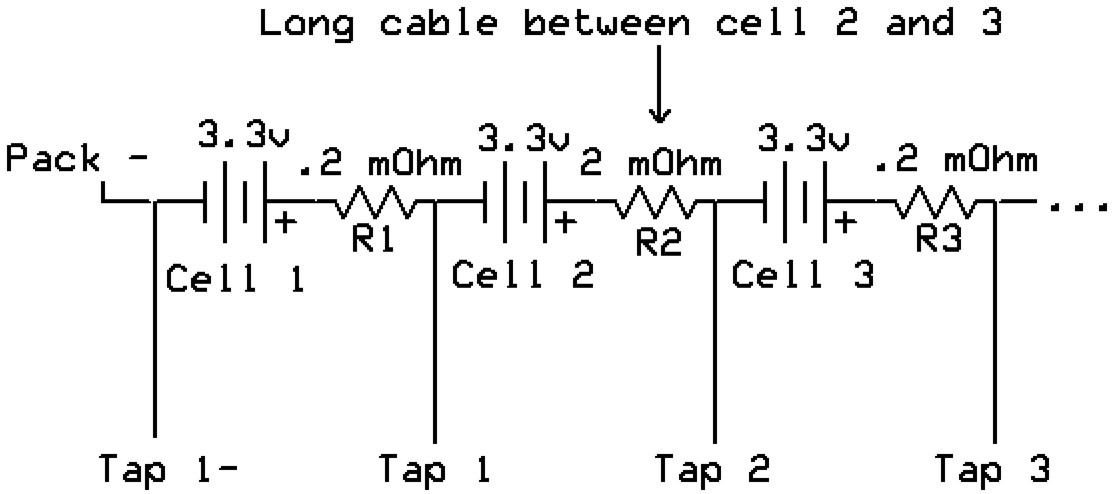
Busbar Compensation

Voltage measurements are taken by the Orion BMS 2 with respect to the next lowest cell or the negative wire in each cell group. For example, when the Orion BMS measures cell 1's voltage, it measures the voltage between tap 1- and 1. Likewise, for cell 2, the voltage is measured between cell tap 1 and tap 2 to determine cell 2's voltage.

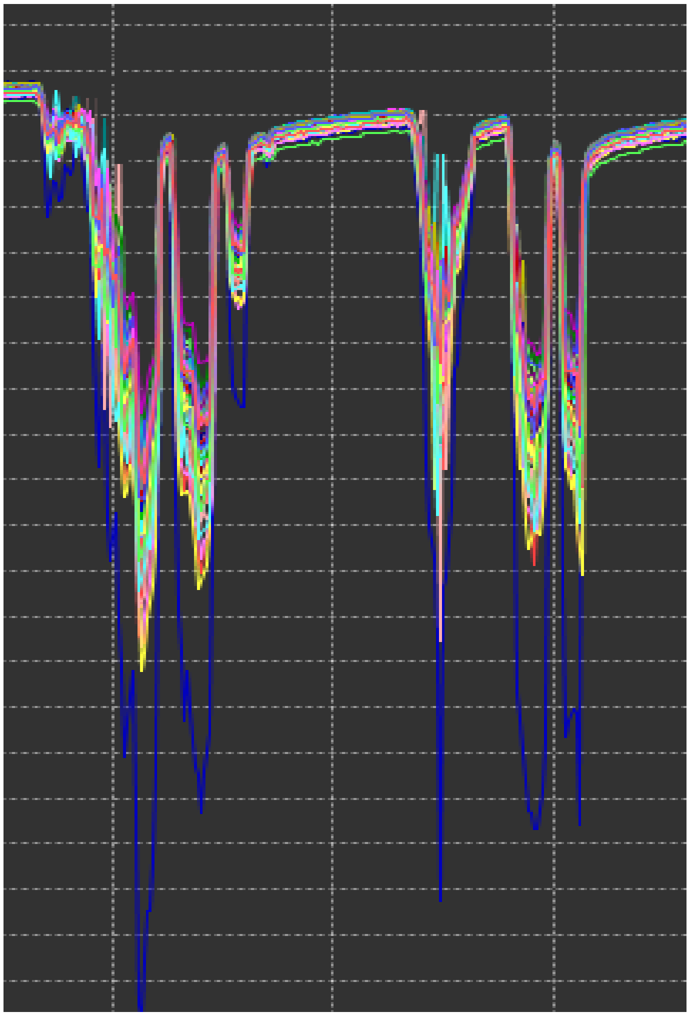
While battery cables and busbars may be very large and have a minimal resistance, all cables have some electrical resistance, and that resistance, while small, may influence the measured cell voltages while under load. The cell taps, by necessity, will see the additional resistance from busbars, battery interconnects, and cables unless they fall between cell groups (12 cells). The diagram below shows the first 3 cells wired in a group.

When there is no current flowing through the battery pack, the cell voltages that the BMS measures are called the "resting" or "open" cell voltages. When a discharge current is run through the pack, the cell voltages will artificially read lower than the sitting voltage due to the internal resistance (impedance) of the cells. This change in voltage is called voltage drop (or voltage rise, for charging). Once the current is removed or turned off, the cell voltage will eventually recover back to the resting voltage.

Cell interconnects (busbars) also have a measurable resistance and voltage drop. Because of the way the cells are connected in series, the differences in resistance from one interconnect would also be visible to the Orion BMS as extra resistance for that particular cell. In the example below, all of the cells have a resistance of 3 milli-ohm (not labeled in the drawing), but due to the busbar resistances, the BMS sees the extra 2 mOhm resistance on cell #2 for a total of 5 mOhm. Even though cell #2 itself is still healthy, it appears to the BMS to be a weak cell due to the resistance of the long cable. This is where busbar compensation comes in.



For relatively lower resistance, this extra resistance can be compensated out by the BMS using “busbar compensation” (see the software manual for information on setting up busbar compensation). For high resistance busbars / cables (or higher amperage applications), it is possible for the voltage drop (or voltage increase if the battery is being charged) to be large enough that it can cause the voltage at the tap to exceed 5V or drop below 0V (which are the maximum and minimum voltages for the Orion BMS.) If the voltage can swing outside those maximum voltages, the Orion BMS must be wired such that the cable falls between a cell group break (every 12 cells) and be wired such that voltage drop induced by the busbar cannot be seen by the Orion BMS. Whenever possible, it is best to wire the cell taps such that the BMS cannot see the extra resistance.



An uncompensated high impedance busbar causing additional voltage drop under load (blue line)

The BMS allows busbar compensation to be added to specific cells in the cell population table. The compensation must be applied to the cell where the extra resistance shows up. This depends on the physical placement of the cell tap wires as the tap could be placed before or after the long cable.

The amount of busbar compensation is sometimes difficult to get correct on the first try. While it is possible to calculate the theoretical resistance of the wire based on the gauge and length of the cable, it is often difficult to calculate any extra resistance from crimp connectors and terminals. It may be necessary to measure the actual resistance using Ohm’s law (Vdrop = IR) to look at voltage drop under load across the cable or by trial and error charting all cell voltages.

Busbar compensation works only when DC loads and sources are connected to the battery. **Busbar compensation cannot be used when fast pulsing currents such as those generated by most AC inverters or AC inverter/chargers are connected** (see 'using the Orion BMS with AC inverters' for more information on integration with AC inverters). Unfiltered high frequency inverters which place a significant AC component on the DC bus or excessively noisy motor controllers / inverters may also be problematic for busbar compensation due to back EMF. In such cases, busbar compensation cannot be used, and cables must be installed between cell groups. If the noise causes skin effect, filtering may be necessary to be able to use with the Orion BMS.

Although busbar compensation is able to compensate out extra resistance from short cables, for best results, we recommend placing any cables between cell groups whenever possible.

Thermal Management and Fan Controller

The Orion BMS measures the battery temperature through 8 main thermistors connected directly to the BMS with the option of additional thermistors through any connected remote cell tap modules or any connected thermistor expansion modules (sold separately). The BMS calculates the minimum, maximum, and average temperature of the battery pack based on the attached thermistors and can make decisions about turning on an external fan for warming or cooling the battery pack. A fixed speed (on/off) or variable speed fan can be used. If the fan supports a voltage feedback, the BMS can determine if the fan is correctly working by checking a feedback voltage from the fan.

The fan is configured to turn on at a certain temperature in the programmed settings. Once the battery pack has reached this temperature, the fan control output will turn on, with the PWM output (if enabled) will beginning at the lowest speed. As the temperature of the battery pack rises above the threshold temperature, the fan enable output will remain on, and the PWM speed increases in accordance with the rate programmed into the BMS settings. Once the temperature drops below the threshold temperature, the fan control output will turn off and the PWM output will cease. The BMS can optionally check the health of the fan by monitoring a feedback voltage and generate an informational fault code in the event the fan fails.

While the BMS generates a PWM signal for use with variable speed fans, only the fan control output is necessary to control a fixed speed fan. The fan control output can also be used for controlling liquid cooling systems or other cooling methods.

One of the eight thermistors on the main Orion BMS unit may be configured as an ambient 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. If the ambient air going into the battery pack is hotter than the battery itself, the BMS can use this ambient temperature to stop the fan from running since the battery would in fact be heated rather than cooled.

In some cases, it may be desirable to warm the batteries, such as when the cells are too cold to operate well, and the ambient air is warmer than the cells. With one thermistor dedicated to the intake air temperature, the BMS can also be configured using the "Enable Battery Warming" option to turn on the battery fan in cold temperatures if the ambient air temperature is detected to be warmer than the battery pack. If this is done, care must be taken to ensure condensing humidity will not be problematic. If battery heating through electric warmers is required, one of the multi-purpose outputs may be used to turn on at a specific temperature. Please see the “Multi-Purpose Output” functions for more information on that feature. For more information about the hardware interface for the fan controller, please see the wiring manual.

Multi-Purpose Inputs

The BMS has three (3) multi-purpose input pins which can be used to trigger a few different functions. The function of this input pin is defined in the BMS settings (under the General Settings tab). The functions available are:

Keep-Awake Signal (default) - This is used to keep the BMS from going to sleep in the event that both READY power or CHARGE power are available. This is useful when the optional redundant Always-On power source is used to allow the BMS to continue operating even if one of the primary power sources becomes unavailable. In order for this pin to perform its function, the BMS must be connected to an Always-On power source on pin 1 of the Main I/O harness (Always-On Power pin). If this feature is not used, the Always-On power source is not required and can be disabled in software on the Fault Settings section of the battery profile configuration settings.

Clear Error Codes - When the multi-purpose input is configured with this option, all fault codes will be cleared when this input becomes energized (note: a fault code may re-occur immediately if there is an active fault condition).

Alternate Charge Current Limit - This feature will change the maximum possible charge current limit to a lower value only when the BMS detects this input is energized (the alternate value can only lower the maximum charge current limit). This feature may be useful when the user needs to select between two different charging speeds such as a standard charge or a fast charge.

Alternate Minimum Cell Voltage - When this function is selected the BMS will use the Alternate Minimum Cell Voltage value (specified in the utility) for the minimum allowable cell voltage when the Multi-Purpose Input signal is INACTIVE (off). The Alternate Minimum Cell Voltage value must be higher than the actual Minimum Cell Voltage value programmed into the BMS. Once the Multi-Purpose Input signal is raised high (ON) then the BMS will revert to enforcing the actual Minimum Cell Voltage value. This can be useful if the operator wants to momentarily allow the pack to be discharged further than normal under certain circumstances.

J1772 Control Pilot / Proximity Detect – If selected, these options will use two of the multi-purpose input pins (MPI2 & MPI3) for J1772 EVSE charging station interaction. The BMS can turn on the EVSE and intelligently limit charging current based on the EVSE charging station capability (if supported by the charger). See the “J1772 Interface” section of the Orion 2 BMS wiring manual for more information.

Fan Monitor Input - This function allows the BMS to monitor the voltage feedback signal from a PWM controlled fan to ensure that it is operating properly. The full functionality for this feature is configurable on the “Thermal Settings” section of the configuration settings. Please see the Orion 2 BMS wiring manual for more information.

Charger Plugged In Status - This allows one of the multi-purpose inputs to be used to indicate whether an AC mains charger is plugged in for enabling the Charge Interlock failsafe condition (to help prevent driving away with a vehicle still plugged in). Typically, this is accomplished by the Charge Power input being energized (Main I/O harness pin 3) however in some situations this may not be possible and so this input function allows for an alternate method to do so.

Multi-Purpose Output / Multi-Purpose Enable

The Orion BMS 2 has four general purpose multi-purpose outputs plus one Multi-Purpose Enable output (MPE). The Multi-Purpose Enable output is backed by a watchdog and will turn off in the event of certain critical faults, while the four standard multi-purpose outputs are not watchdog backed and may remain on in a critical fault. All of these outputs are open drain output and are active low (pull to ground) when on. They can be used to drive a relay or other device (see the wiring manual for wiring information) and the function of this is set in the battery profile configuration settings on the General Settings tab.

The available programmable functions for these outputs are:

Error Signal Output (default) - In the event that any fault codes are present on the BMS or in the event that both CHARGE and READY power are present to the BMS at the same time (if this behavior is enabled), this output will turn on. It can be used to drive an LED, buzzer or other device (additional components may be required, see the wiring manual for details). The basic analog display module makes use of this multi-purpose output function.

CANBUS Controlled Output - When this option is selected, the status of this output is controlled by a CANBUS message. For example, when a particular byte on a CANBUS message is 1, this output would turn on. Note: Additional CANBUS configuration is required to specify the ID and byte of the message which will turn this output on. This should not be relied on for safety operations such as enabling charge or discharge.

Low SOC Output - This output will turn on whenever the state of charge drops below the pre-defined SOC threshold. This output will turn back off once the calculated state of charge rises above the pre-defined turn-off condition. The difference between the turn on and turn off values provide hysteresis to prevent rapid oscillations.

Low Temperature Output - This feature will turn on the output whenever the lowest temperature (from any of the 8 integrated thermistors or from any attached external thermistor expansion modules) drops below the low temperature threshold. This output will turn back off once the lowest temperature rises above the specified turn on value. The difference between the turn off and turn on values provides hysteresis to prevent oscillations.

Charge Interlock Output - This option will cause the multipurpose output to turn on in the event that the BMS detect both CHARGE and READY power at the same time. While powering CHARGE and READY power at the same time poses no problem for the BMS, sometimes it is desirable to inhibit driving via an external means or illuminate an LED when this happens.

High Cell Voltage Output - This option will cause the output to turn on if the highest cell in the pack reaches the high cell voltage threshold. The output will turn off when all cells have fallen back down below the turn off value. The difference between the turn on and turn off voltages provides hysteresis to prevent oscillations. **NOTE:** This output is not designed to be the primary control for discharge or charge. Use the charge enable, discharge enable, charger safety or CANBUS for primary control of charge and discharge.

Low Cell Voltage Output - This option will cause the output to turn on if the lowest cell in the pack drops below the threshold. The output will turn off when all cells have risen above the turn off threshold. The difference between the turn on and turn off voltages provides hysteresis to prevent oscillations.

NOTE: This output is not designed to be the primary control for discharge or charge. Use the charge enable, discharge enable, charger safety or CANBUS for primary control of charge and discharge.

Low DCL Output - This option will cause the multipurpose output to activate if the calculated discharge current limit from the BMS falls below the threshold. The output will turn off when it rises again above the pre-defined value.

Low CCL Output - This option will activate the multipurpose output if the calculated charge current limit from the BMS falls below the threshold. The output will turn off when it rises again above the pre-defined value.

***Contactor Enable Output* –** This output provides a means to control a system level contactor sometimes referred to as a system enable contactor. This feature is designed to provide be a backup shutoff mechanism to fully disable all charge and discharge currents from the battery by disconnecting the battery itself, although the output can also be used as a backup shut off for a battery charger for example.

This output can trigger based on the following criteria:

1. Any cell above the specified voltage for more than 10 seconds
2. Any cell below the specified voltage for more than 10 seconds.
3. Any temperature reading above the specified maximum temperature (for 10 seconds, if enabled).
4. Any temperature reading below the specified minimum temperature (for 10 seconds, if enabled).
5. A critical fault code occurs. These faults are: **P0A06 / P0A07** (a charge / discharge enforcement fault is detected), **P0AC0** (a problem with the current sensor is detected), and **P0A04 / P0AFA / P0A01 / P0A03** (a critical voltage sensing fault is detected).

The polarity of this output can be toggled in software (except when it used on the multi-purpose enable output) to allow controlling a normally open or normally closed contactor. A normally open contactor is strongly recommended since a power failure would open the contactor. **This output takes longer to turn off in the event of a failure and is designed to be used as a backup to a primary control method. This function is not designed to be used as the primary or sole control method.**

***Output Function Disabled* –** This option disables the output if it is not being used.

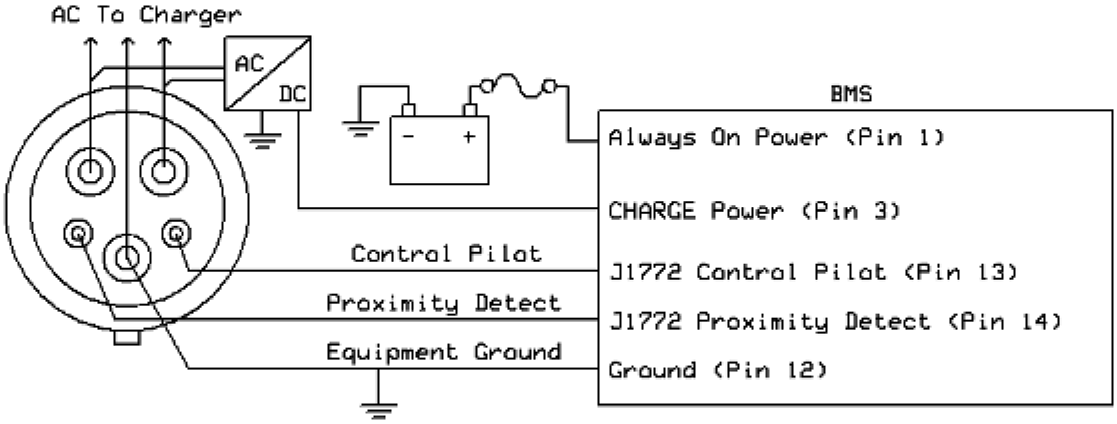
***Isolation Fault Output* –** This option will output the status of the isolation fault detection circuit. If an isolation fault occurs (P0AA6), this output will turn on.

***Idle Timeout* -** When in this mode, the output will remain active (ON) as long as the BMS detects at least a certain amount of current activity within the battery pack (**EITHER** charging **OR** discharging). The timeout period (in minutes) and the idle amps threshold (in amps) are both programmable. This output can be used to open a relay cutting power from the battery to preserve battery power.

***J1772 Charging Station Active* -** This output reflects whether the BMS has completed all J1772 negotiation and has successfully turned the EVSE charging station on. This option requires J1772 support to be enabled, but it is informational only and it is not required to be able to use J1772.

J1772 EVSE Interface

The Orion 2 can directly interface with a J1772 vehicle charging inlet to enable level 1 and level 2 AC charging (J1772 DC fast charging is not supported). This feature must be enabled in the software, and the level of support varies by charger from simple on/off control to variable current limiting based on the provided EVSE (charging station) capabilities.



J1772 connections to the BMS (AC wiring is simplified, fuses may be required)

Wiring the J1772 involves connecting 2 control wires and ensuring that the J1772 earth ground is solidly connected to the BMS ground. **Ensuring that the J1772 ground pin is connected to the BMS ground is essential for proper operation!** If the ground becomes disconnected, the J1772 will not work. **Always on power (Main I/O Pin 3) is required for use with J1772.** This is to bootstrap the process since the BMS must be powered to able to sense the inlet even when it is not on. When enabled in software, the J1772 uses both multi-purpose inputs #1 and #2 as shown above.

NOTE: In addition to requiring Always On power, the BMS must still be connected to CHARGE power when power is present on the J1772 inlet. This is usually accomplished by using a small 12-24V power AC to DC power supply as shown below. **Ensure that all power sources share the same ground.**

Any devices connecting to the J1772 AC power must be able to accept 120V AC nominal and 208V – 240V AC nominal voltages. Since the J1772 inlet can be connected to a level 1 (120V AC) or Level 2 (208 – 240V AC) EVSE charging station in an unpredictable manner, all devices must automatically adjust to the supplied voltage without user intervention. Because of this, the use of switching mode power supplies and dual voltage chargers is required for operation with J1772.

The J1772 standard specifies that the EVSE (ground mounted charging station) will provide a maximum current limit to the vehicle. To comply with standards, it is essential that the sum of all loads being connected to the J1772 charging station (EVSE) does not ever exceed the AC current limit set by the EVSE. The current limits vary based on the size of the charging station being connected to. In order to address this, the Orion BMS 2 can be configured to work in two ways.

The first method is for the BMS to dynamically adjust the charging current for the charger based on what the charging station can provide. This is preferred because it allows seamless charging at the maximum amount possible while still allowing charging at charging stations capable of only small currents. When used with supported CANBUS enabled chargers, the BMS can calculate a DC charging current limit based on the J1772 AC limit received from the EVSE. This configuration allows the vehicle to charge at any station, even if the station cannot supply sufficient power to allow the charger to run at maximum power (this is better because in the case of a simple on / off approach, this would cause the charger not to be able to charge at all). Only specific chargers are supported for dynamic current calculations as the chargers must be capable of CANBUS current limiting and must provide the BMS with AC Mains voltage information. Please see application notes on www.orionbms.com for more information about which chargers are supported.

The second method is to either simply allow or deny charging based on the J1772 AC current limits. If the charging station is able to supply enough current for the attached charger (plus any auxiliary loads), charging can proceed. Otherwise, the BMS would prohibit all charging to prevent an over-current situation on the AC mains circuit. For example, if the vehicle's charger is a simple charger that only operates at one speed and requires 12 amps, but the EVSE indicates it can only source 8 amps, the BMS can deny charging until the vehicle is connected to an EVSE that is able to supply at least 12 amps. The worst-case amperage required for the charger to operate (for any possible voltage - 120V, 280 - 240V) must be manually pre-calculated and provided in the settings profile.

Only small loads other than a battery charger should be connected to the J1772. Inrush must be kept to a minimum, and chargers must stop charging immediately when the BMS commands them to stop to prevent wear and tear on EVSE contactors and connectors. **Do not use J1772 with non-isolated chargers.**

It is the sole responsibility of the integrator to research and comply with all applicable laws, regulations, standards, and codes for the specific application.

Please see the “J1772 Interface” section of the Orion 2 BMS wiring manual for details on how to connect the wiring for the J1772 interface.

CHAdeMO Interface

CHAdeMO is a popular DC fast charging protocol. This charging method connects the DC battery on the vehicle directly to a high power off board DC power supply. The BMS transmits instructions to the CHAdeMO station regarding the maximum voltage and current rate that it is allowed to charge at.

Support for CHAdeMO is largely provided through the 2nd CANBUS interface. See our application note on www.orionbms.com for interfacing with CHAdeMO chargers for information on wiring for CHAdeMO.

Collected Statistics (Cell Warranty Data)

The Orion BMS 2 collects cumulative usage statistics about the battery pack. This data is stored in non-volatile memory on the BMS and does not reset when power is cycled. Data collected is intended to be used to track both the number of events that occur including over-voltage, under-voltage, as well as cumulative time spent above and below certain temperatures. Three histograms show the distribution of temperature, state of charge and C rate (amperage) over the lifetime of the battery. The BMS also keeps a list of the last 100 events that occurred such as various inputs and outputs turning on and off. Collected cell data can be reset through the BMS utility, but total runtime, total power-ups and total profile updates cannot be reset by any means. Data is tracked while the BMS is powered and is not collected while the BMS is off. These items are all described in more detail in the following sections.

Lifetime Parameter Tracking

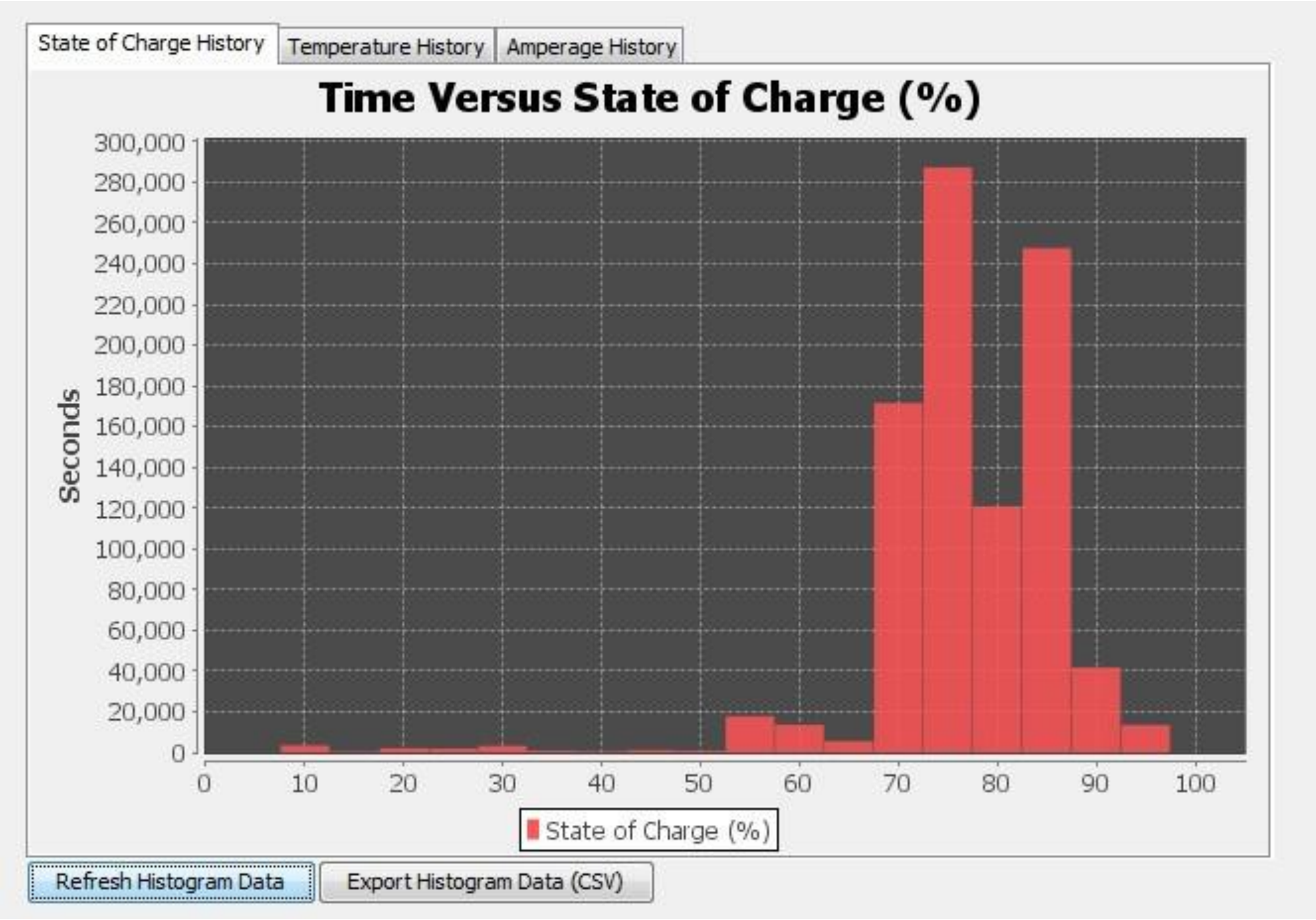
The following counter parameters are tracked internally on the BMS for the life of the battery pack:

- **Total runtime** - The total amount of time the BMS is active, stored in minutes.
- **Total power-ups** - The number of times that the BMS unit has been powered on.
- **Total profile updates** - The number of times that a BMS profile has been updated on the BMS.
- **Total pack cycles** - The cumulative number of cycles placed on the battery pack. One cycle is calculated by summing the current in and out of the pack and dividing by the amp hour capacity of the pack. For example, if a battery pack is charged 50 amp hours and discharged 50 amp hours and it is a 100 amp hour pack, the BMS records this as a half of a cycle.
- **Total time above 45C, 60C and below -20C** - These three parameters store the cumulative time that the BMS was powered and the battery pack was measured exceeding any of those temperatures. This is useful for battery warranty information as cell lifespan can be significantly reduced due to elevated temperature. Events are only recorded if they last more than one second and are not recorded if all thermistors are in an active fault state.
- **Total time over and under-voltage** - These two parameters record the total amount of time that a cell’s voltage was above the maximum or below the minimum cell voltage while the BMS was powered. This information is useful for cell warranty as it can be used to show if a cell was damaged due to over or under voltage. Time is only accrued if the cell voltage event lasts more than one second.
- **Total over and under-voltage events** - These 2 parameters show the number of times that a cell’s voltage has exceeded the maximum voltage or dropped below the minimum cell voltage for one second or longer. The number of events can be used to help determine if a cell was regularly overcharged or over-discharged.
- **Total charge and discharge enforcement events** - These 2 parameters record the number of times the BMS turns off either charge enable or discharge enable outputs but the BMS continues to sense charge or discharge currents into our out of the pack. Events are not recorded if a current sensor fault is present.

Battery Histogram Data

The Orion BMS will also track a number of vital usage statistics and figures across the entire lifetime of the battery pack in order to help installers warranty the battery pack. These metrics include the following:

- Total amount of time the pack has spent at different temperatures (expressed in seconds per 5 degrees Celsius)
- Total amount of time the pack has spent at different states of charge (expressed in seconds per 5% SOC)
- Total amount of time the pack has spent at different charge / discharge C-rates (expressed in seconds per 0.5C increments with higher resolution between -1C and 1C)



This data is collected in order to give a much more comprehensive picture of how the pack was used than simply tracking the number of battery cycles. These three metrics are specifically tracked because they represent several of the largest contributors to cell aging:

- **High Temperatures:** Storage or usage of the battery pack at elevated temperatures can dramatically accelerate cell aging. Certain chemistries are more affected by this than others, but virtually all lithium cells are negatively impacted by high temperatures. Tracking the time spent at different temperatures allows the operator to determine whether the pack may have been operated outside of temperature specifications.

- **High or Low State of Charge:** Storing or using a battery pack for extended periods of time at very high or very low states of charge can also accelerate aging as it causes excess wear on the internal chemistry. Most lithium cells will last the longest when they are used in a narrow band. Tracking how much time is spent at different states of charge can help determine whether the cells were properly stored.
- **High Discharge or Charge Current Rates:** Regularly pushing batteries to their physical output or charging limitations causes significantly more stress and wear on batteries than if they are operated at lower current rates. Most lithium cell lifespans are estimated based on regular usage at or below 1C and this lifespan estimate can drop dramatically if the average C-rate for the pack is significantly higher. Tracking the amount of time spent at various current rates allows the operator to identify if the battery pack was frequently fast-charged or routinely discharged at a higher rate than is recommended or expected.

This data is stored internally on the BMS itself in non-volatile memory storage that persists across complete power loss, reset or reprogramming. The data can be manually reset by the operator through the BMS utility, however installers can set a password on the device to prevent unauthorized persons from doing so without the authorization of the installer.

Many battery manufacturers require detailed information like this regarding the history of the battery pack before honoring a warranty claim. Ewert Energy Systems cannot guarantee that this histogram data will satisfy all battery manufacturer's requirements, however.

IMPORTANT NOTE: Battery histogram data, as well as all lifetime parameters tracked by the BMS, are only recorded while the BMS itself is powered up and awake. **The BMS will not track or accumulate this data while it is in low power sleep or powered off entirely.**

Internal Event Log

In addition to the tracked data points and metrics described above, the Orion BMS also maintains a rolling Event Log. This log includes many common events that occur regularly during normal operation and can be extremely helpful for diagnosing short term issues or behavior within an application. It is stored in non-volatile memory and persists across power loss or reset.

These logged events include:

- Relay outputs turning on and off
- Inputs being energized / de-energized
- Fault codes being set
- State of Charge drift corrections being executed
- Cell balancing engaging

- Low power sleep mode entrance
- Power cycles (reboots)
- Battery profile settings being updated

Additional Data Logging Methods

While the internal data logging capabilities of the Orion BMS are extensive, there are times when more sophisticated logging is required. There are several ways to do more exhaustive logging of data being produced by the BMS.

These additional data logging methods include:

- Data logging through the Orion BMS Utility: The software utility provides multiple ways to take more detailed logs of the battery related data produced by the BMS. First there is the “Live Graph & Data Logging” tab (available at the top of the utility) which allows the operator to specify several live parameter fields to regularly log which is very helpful for logging specific fields or groups of fields. The utility will indefinitely log this information to the computer in a CSV (comma-separated-value) format for easy processing. Second, there is the “Live Cell Data” tab (also available at the top of the utility) which has a dedicated logging function (a record button is present in the bottom right corner of the screen). This performs high speed logging on the individual cell voltages as published by the BMS, in addition to other important parameters like State of Charge, Pack Current, Charge / Discharge Current Limit and relay output statuses. Logs generated from this screen are also output in a CSV (comma-separated-value) format and are very helpful for general purpose diagnostics.
- For long term data logging where a computer would be less practical, there are 2 expansion module devices that can directly interface with the Orion BMS: The Data Logging Display Module and the Orion Connect WiFi Module. The Data Logging Display Module communicates with the Orion BMS via CANBUS and allows for logging of data to an onboard SD card. It also allows for displaying the State of Charge by an internal LED bargraph. The Orion Connect WiFi Module also allows for logging of data to an onboard SD card in addition to being able to transmit this data to the Orion Connect Cloud servers via WiFi. This allows for data to be viewed remotely wherever an internet connection is available.
- Data logging can also be performed by third party devices. The CANBUS interfaces on the Orion BMS can be fully customized to allow it to conform to a number of standards or protocols.

Failure Mitigation

The Orion BMS 2 features several failsafe modes to protect the battery pack should something go wrong. Although these internal redundancies and protection procedures are provided, it is the responsibility of the user 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 operator / installer must account for 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 the application is not aware that a failure has occurred and therefore runs using incorrect data. Because the requirements vary from application to application, it is the responsibility of the installer / operator 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 incorrect configuration of the polarity.

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

> ***Loose / disconnected wire on cell voltage tap or failure of a cell voltage sensor*** - This is a major issue for any BMS system since the BMS cannot measure cell voltages for cells that it is not connected to. The Orion BMS provides several lines of defense against open wires.
>
> If a cell tap wire becomes disconnected or intermittently disconnected (loose connection), the BMS features an open wire detection circuit where a very small current is applied to the cell through the tap wire every so often to ensure that the connection is good. The Orion BMS 2 tests this by pulsing current both into and out of the battery (this differs from previous models). 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 affected and go into a failsafe mode (which will disable the 3 primary Enable relay outputs). 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 connect unused taps to the cells as described in the wiring manual. Additionally, the BMS features internal self-checking of the cell voltage sensors to detect errors with the sensors themselves as well.

It should be noted that the BMS contains internal non-user serviceable fuses on cell voltage tap connections. When a fuse is blown (usually due to reverse polarity, over-voltage, or improper location of a safety disconnect / fuse causing current to flow through the BMS), the BMS normally detects a blown fuse as an open wire. Even though the wiring harness may be fine, the BMS may have internal damage leading to an open wire fault.

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 likely cause damage to the BMS requiring it to be serviced.

If a wire anywhere in the high voltage battery 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 250K ohm, depending on the application and the configuration. This feature requires that the BMS 12 / 24 volt supply ground is connected to the chassis to function.

Improper software setup of the BMS resulting in not all cells being monitored - While this is not a condition that would be expected in a production environment, if the BMS is not setup to monitor all cells, it cannot protect the battery pack correctly. It is very important to verify that the BMS is properly setup to monitor all the attached cells and that the configured battery profile settings are appropriate for the cells being used.

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 sensor channels have failed by comparing the values for both sensors. Most failures will result in the current sensor reading +/-120% of the maximum value of the current sensor (for example, a 500A sensor might read -600A or +600A consistently). If this happens, or if the BMS detects an internal error, a current sensor fault code will be set and the BMS will enter a current sensor failsafe mode. The BMS will also enter into a current sensor failsafe mode if the actual current measured is greater than 120% of the maximum rating of the current sensor.

The worst-case scenario 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 or partially disconnected wire between the BMS and the current sensor. In this instance, the BMS will continue to protect cells based on maximum and minimum cell voltages, but calculations based on current sensor values such as internal resistance, open cell voltages, state of charge, and charge and discharge current limit values may become inaccurate. If additional redundancy is necessary for an application, an approach for increasing redundancy is to externally compare currents measured by the BMS with currents measured elsewhere such as at an inverter, load, or source. It should be noted that even with a malfunctioning a current sensor, the BMS will still provide basic protection of the cells from over voltage and under voltage.

Disconnected wire or failure of thermistor - A disconnected thermistor will result in a fault code being generated by the BMS and the BMS will ignore that specific thermistor until the error code is cleared or the BMS power is reset. The BMS determines a faulty thermistor if the measured value is less than -40C or greater than +85C (a shorted or disconnected thermistor will read +86C or -41C). A thermistor failure (such as the use of an incorrect type of 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.

Loose / disconnected wire on main I/O connector or loss of all power - 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 both the READY and CHARGE power will cause the BMS to go into sleep mode unless configured with the redundant power supply option. The BMS features a keep awake option which optionally uses the always on power supply to keep the BMS awake and operating in the event both READY and CHARGE are lost. This optional feature requires a separate “keep awake” signal to one of the multi-purpose inputs. Please see the section on multi-purpose inputs for more information.

In the event the 5V analog voltage outputs are disconnected, the application must be setup in such a way the application goes into a safe failure mode. This is particularly true of the state of charge output since a disconnected wire could result in the application believing that the state of charge has dropped to 0%.

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

The multi-purpose inputs and outputs on the BMS must also be setup such that a failure or disconnection of one of the wires would leave the application in a safe state.

CANBUS communication failure - While CANBUS is a very robust protocol, systems should always be designed to tolerate a total or partial CAN communication failure. CANBUS networks may become unreliable if another node on the bus transmits too fast, clogs the bus causing intermittent messages to get through, or 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 or fail in a safe manner if communication is lost. If CANBUS is being used to control a charger then a backup shutoff mechanism must always be used.

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 certain number of messages are missed in a row, 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.

   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. There should always be at least 2 redundant methods for disabling charge, discharge, or any external battery charger. 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 (usually about a half second), 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 installer's / operator's responsibility to ensure that the application respects the commands issued by the BMS.

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

   When the BMS is controlling a battery charger, the charger should be configured with a maximum voltage that will shut down the charger if the voltage of the pack ever exceeds the voltage limit set by the BMS. This functions as a backup to help reduce the likelihood of thermal runaway in the event that the BMS is unable to turn off the charger for any reason. Likewise, loads such as motor controllers should be configured for a minimum voltage at which they will shut off as a redundant safety whenever possible. These should only be used as redundant backups and never be relied upon for normal operation as a single cell may become too high or too low and will not be noticeable when only looking at the pack voltage.

   Failure of fan component or fan controller - While fan failure modes often are not typically 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.

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 application will end up in a safe state. Additionally, if the 5v analog outputs become damaged (miswired, shorted, reversed polarity, over-voltaged, etc) the application should have a failsafe allowing the BMS to shut down 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.

Voltage failsafe (non-operating) - 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 (disconnected) tap wire (an open wire fault code), any populated cell which is reading a voltage below 0.09 volts or if a cell voltage reads over 5 volts. In a configuration with remote modules, a communication failure between the main BMS unit and any remote unit will also result in a voltage failsafe condition.

Because the BMS cannot protect the cells if the accuracy of the cell voltages is compromised, the BMS is forced to enter into a non-operating failsafe mode. When the BMS enters into this voltage failsafe condition, the BMS will begin to gradually de-rate the charge and discharge current limits from their last known value down to 0 to prevent charging and discharging. The amount of time to de-rate the limits is specified in the profile and is designed to provide some usable time of the battery after the failure has occurred. The gradual current limit reductions are intended to alert the operator to the fact there is a problem while providing enough power to allow the application to come to a safe stop. 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, and the cause corrected prior to clearing the code or continued use of the battery.

Current sensor failsafe mode (degraded operation) - 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 *or if the BMS is configured for no current sensor*. In this mode, the current sensor is disabled and will measure 0 amps. 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:

1. Internal resistance calculations disabled (both cell and total pack)

2. Open cell voltage calculations disabled for both pack and individual cell calculations. The open cell voltages will read the same as the instantaneous voltage readings. This results in highly inaccurate state of charge drifts.

3. 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.

4. 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.

5. Over current protection is effectively turned off (cell voltages may provide some level of current limiting, but this is only based on cell voltages and not measured current). **The BMS cannot enforce over current limit protections since current is unknown in the event of a current sensor fault.**

Digital on/off or Relay failsafe - The Relay failsafe mode is triggered when the BMS turns off a digital on/off output, and the BMS continues to measure current flowing into or out of the battery respectively. This failsafe mode is triggered if current does not stop within 500mS after the output has been turned off. In this failsafe mode, all digital on/off relays are turned off and latched off until the fault code is reset or the BMS is power cycled. A diagnostic trouble code is stored when this happens. This failsafe will only activate if the offending relay is enabled in the settings profile (disabled relays are ignored).

12 / 24v supply power failsafe (degraded operation) - The BMS requires a nominal 12v - 24v input main power to operate properly. The BMS is equipped with an internal voltage sensor. If internal voltages drop too low for continuous operation, the BMS will enter into Input Power Supply Failsafe mode. Orion BMS 2 units can operate through voltage sags (cold cranking) at voltages down to approximately 4.5v for brief periods less than 5 seconds without causing this failsafe mode. This fault will set if the measured input voltage is less than 8v for more than 8 seconds. If this failsafe mode occurs, charge enable, discharge enable and charger safety outputs will turn off. This is done because a contactor powered by the same power source as the BMS may fail to operate, or may intermittently operate at too low of a voltage.

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

This failsafe mode will set a diagnostic trouble code which will remain for later diagnostics but will automatically restore normal operations once normal operating voltage has been met.

Internal memory failsafe (non-operating mode) - 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.

Diagnostic Trouble Codes

For the most up-to-date information regarding the available diagnostic trouble codes, as well as for instructions on how best to troubleshoot them, please visit the Troubleshooting section of the Orion BMS main website available below.

Troubleshooting Guide Link:
http://www.orionbms.com/troubleshooting