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Orion BMS Operation Manual
Rev 2.1

The Orion BMS by Ewert Energy Systems 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.

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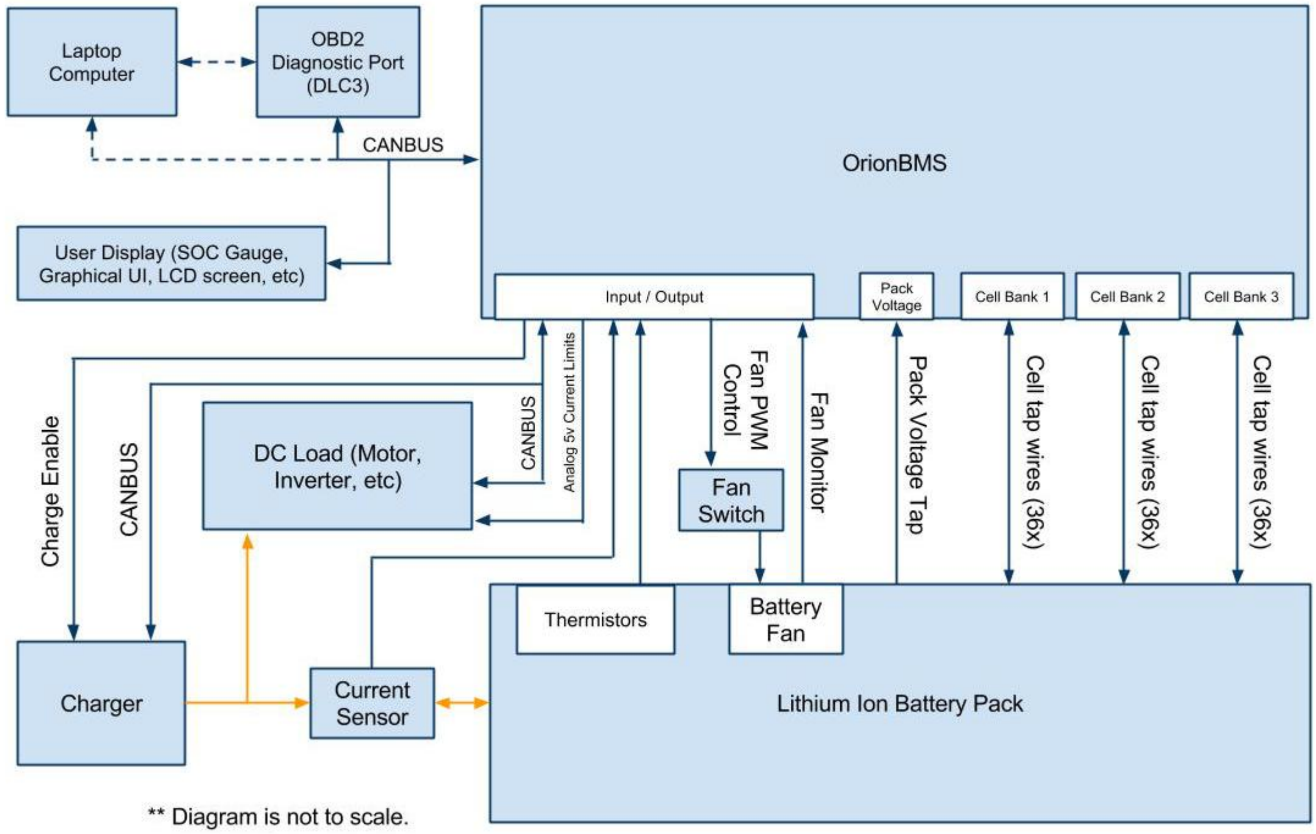


The Orion BMS protects and monitors a battery pack by monitoring sensors and using outputs to control charge and discharge into the battery. The BMS measures inputs from cell voltage taps, the total pack voltage tap, a hall effect current sensor, thermistors, a multi-purpose input, and an isolation fault detection sensor. 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 CAN bus or via analog reference voltages or through simple on/off digital signals depending on which style is appropriate for the application. The BMS relies on the user to integrate the BMS with other external devices that respect the current limits set by the BMS to protect the batteries. During and immediately after charging, the BMS will balance the cells using internal shunt resistors based on the programmed settings.

The Orion unit monitors the voltage of each individual cell (though the cell tap wires) to ensure cell voltages remain within a specified range. Using the collected information which includes parameters such as minimum and maximum cell voltages, temperature, and state of charge, the BMS calculates amperage limits for both charge and discharge. These charge and discharge current limits are then transmitted to other external devices digitally via CANBUS, via 0 to 5 volt analog signals, or via on/off outputs. The BMS also calculates the state of charge of the battery pack and monitors the state of health of the individual cells and battery pack.

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 than 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 charge safety relays are used, ensure that they are operating by carefully monitoring the battery pack during the first full cycle (full charge and discharge) to 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 Works

(Detailed Theory of Operation)

Changing and Uploading Settings

The Orion BMS must be programmed in order to operate. A complete set of settings is called a profile. Settings are edited on a personal computer using the Orion BMS 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. Setting profiles can also be downloaded from the BMS to be edited.

Basic Data Collection

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

Cell Voltages - First and foremost, 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 into 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 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 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, but the maximum recommended size is 1000A. Current sensors sold with the BMS are able to measure amperages up to 120% of their rated maximum, but accuracy is reduced above 100%.

Current sensor data is primarily 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 battery temperatures directly from up to 4 thermistors to determine the average temperature of the battery pack. If additional temperature sensing is 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 up to 804 temperatures per BMS unit. Thermistors on both the main unit 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 has the option to directly measure the total pack voltage using the total pack voltage sensor on the BMS unit. The voltage from this optional sensor can be compared to the sum of all individually measured cell voltages to verify that they are consistent with each other. If the voltages differ by more than the amount, an error code is set and the BMS goes into a fail safe mode. This voltage measurement is intended only to measure for gross differences between the total pack voltage and the sum of all cells and is not intended to be used for accurate total pack voltage measurements. The accuracy of this sensor is typically within 5%, but in some situations with certain kinds of noise / transients, the sensor accuracy may be worse than 5%. This sensor is often not used in production environments as this data is available from the sum of all cell voltages. This sensor can be ignored in software (firmware versions 2.6.8 and above). If this sensor is ignored, the BMS will instead use the sum of all cell voltages, which is far more accurate.

Isolation Fault Sensor - Unless ordered without this feature, the Orion BMS 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. This sensor measures the isolation between the 12 volt ground (pin 12 on the BMS Main I/O connector) and the negative of the total pack voltage sensor. This circuit can be ignored in software. 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 a multi-purpose input which can be used for various functions, and analog voltage input used to monitor the health of a battery cooling fan (optional).

CHARGE and READY Modes

The BMS has two modes of operation: charge mode and ready mode. The BMS will enter into charge mode any time +12v 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 "Maximum Amperage While Charging."
7. The maximum allowable cell voltage is limited to the "Max. Voltage While Charging" parameter.

Charge Interlock

In the event that the BMS detects both CHARGE and READY power at the same time, the BMS can 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. When the BMS detects a condition where both CHARGE power and READY power are present at the same time, a few things can happen:

1. The BMS can be configured to turn on the error status, even though an actual lasting fault code is not set.
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 interfaces.
4. The multi-purpose output 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 to prevent the vehicle from driving away while a cord is connected, but not powered.

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 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. The BMS's decision whether to allow charge or discharge is available on the CANBUS and also on the charge enable and discharge enable outputs. The exact conditions for this are discussed in the Relays section of this manual.

How the BMS Calculates Current Limits

The charge and discharge limits are both calculated using the same methodology. The charge current limit takes into account the settings and parameters related to charging and the discharge takes into account the settings and parameters related to discharging. For simplicity, all criteria described below are for the discharge current limit. However, the same methodology applies to the charge current limit.

The BMS starts the current calculation by loading the maximum continuous discharge current limit programmed into the BMS. This setting is the maximum continuous discharge rating that the cell can sustain safely. The maximum current a cell can discharge is defined by the cell manufacturer, and the value in the BMS should never exceed the maximum limit given by the cell manufacturer, though in some cases, it may be desirable to use a lower value than specified by the cell manufacturer for increasing 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 (requires firmware 2.7.0 or newer), 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 the 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 set by specifying a minimum and maximum temperature to start de-rating current and then a number of amps per degree Celsius to de-rate by when the temperature is outside of this range. Minimum and maximum battery operating temperatures for cells are enforced by ensuring that the current limits are reduced to 0 amps at the minimum and maximum temperatures. Ensuring temperature limits are 0 amps at the minimum and maximum temperatures also ensures that under all situations the charge enable, discharge enable, and charger safety enable outputs are all off if a thermistor ever exceeds a maximum temperature or a minimum temperature. (Note: an exception is if a thermistor reads a value less than -41C or greater than 81C at which point the BMS will disregard the value of the thermistor as faulty.)
2. ***State of Charge*** - The BMS will lower the current limits based on the calculated 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. For most applications, this feature is not used and should be disabled to prevent errant SOC calculations from altering the us-

able 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.

3. ***Cell Resistance*** - The BMS reduces the current limit to ensure that, if a load or charge is placed on the battery pack, the load or charge would not cause the 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 and also results in a 0 amperage discharge or charge current limit in the event a cell voltage drops below the minimum or goes above the maximum voltage respectively.
4. ***Pack resistance*** - If enabled, the BMS performs the same calculations as in point 3, but for the minimum and maximum pack voltages and reduces current limits to maintain these values.
5. ***Cell Voltage*** - In the event that the above calculation were to ever be inaccurate due to incorrect data such as an incorrect cell resistance or incorrect open circuit, or if the current limit is ignored by the external device, 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 cut the respective current limit by one fifth of the current limit at the time the out of range cell voltage is measured 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 cut the current limit by one fifth 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 ensures 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 enabled, the BMS performs the same calculations as in part 5, using the pack voltage limits rather than the cell voltage limits. In firmware 2.6.5 and earlier, the total pack voltages are measured using the total pack voltage sensor. Starting in versions 2.6.8, total pack voltages are calculated based on the sum of the individual cells. 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.
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 go into 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. The gradual reduction allows a vehicle time to pull over and safely stop. The speed 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 occurred.

With firmware versions 2.6.5 and newer, 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 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. In some cases the manufacturer will specify a “C” rate. 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 [firmware 2.7 and newer] - This feature should be disabled unless the cell manufacturer specifies a pulse charge or pulse discharge current limit. Never assume a cell can handle pulse currents. Pulsing may lead to internal damage and plating of the cell, which can lead to a fire risk. 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) [firmware 2.7 and newer] - 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. 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 times the temperature range for charging is usually more restrictive than the temperature for discharging. Some cells are not permitted to be charged below a certain temperature. For example, many iron phosphate cells cannot be safely charged below freezing. 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. For both charge and discharge settings, select a temperature at which the maximum amperage should be reduced. This value should be programmed into the BMS utility, and an amps per degree Celsius value should be calculated to ensure that the slope of the line intercepts 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!*

In a very limited number of applications, it may be necessary to allow a minimum charge or discharge value at all temperatures. If this is the case, the “Never reduce limit below xx amps for temperature alone" setting can be used. *Warning: if the "never reduce limit below" setting is anything other than zero, the BMS will not protect for over or under temperature!*

Note: While the maximum amperage can be specified for a specific temperature, the BMS may still use a lower current limit 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 respectively than the state of charge where the line intercepts zero amps.

While this feature can be helpful for certain applications, it should be left disabled when not required. State of charge of the battery is calculated by the BMS. 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.

Other related settings - Cell resistance settings are not directly related to the current limits, but they can impact the current limits. The nominal cell resistances are loaded into the BMS when it first turns on and are used initially for the cell resistance current limit calculation. The BMS will switch to using measured cell resistances as soon as that information is available, but current limits may be incorrect when the BMS is first turned on if the default resistance settings are incorrect.

State of Charge Calculation

Note: The Orion BMS cannot calculate state of charge without a current sensor!

The Orion BMS calculates a battery pack's state of charge (SOC) primarily by coulomb counting, or by keeping track of how much current 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 things include inaccurate current sensors, cells with a different capacity than expected (e.g. from low temperature or weak cells), or the BMS memory being reset or reprogrammed.

To deal with these issues, the BMS has an SOC correction algorithm which compares measured open circuit cell voltages to known state of charge points. These points are called "drift points" and are programmed into the BMS when it is setup. Drift points are specific voltages that are known to correlate to a specific state of charge and will vary from chemistry to chemistry. If the open circuit cell voltage is measured to be at one of these specific "drift points," the BMS knows what the state of charge of the battery is supposed to be. In the event that the BMS's calculated state of charge is higher or lower at one of these points, the BMS will adjust the calculated state of charge to the correct value.

Drift points are usually selected at locations along the cell's discharge graph where the cell's state of charge is obvious in a manner to avoid drifting incorrectly. For iron-phosphate cells, this means that really only the upper 10-15% and lower 10-15% of the cell can be used for drift points due to the flat shape of the discharge curve. For other chemistries, additional points throughout the full range of state of charge may be possible, improving the accuracy of the drifting.

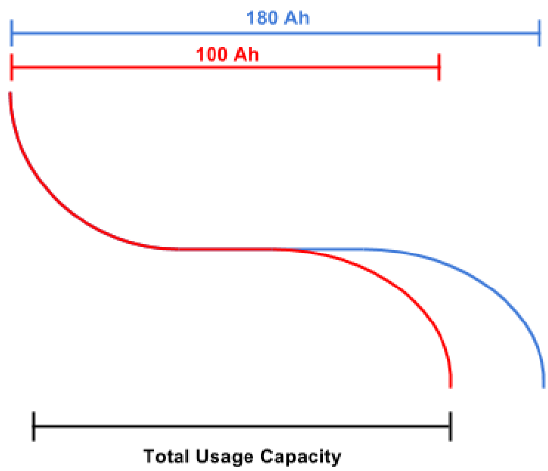
Drift points are specified to only drift up or only drift down. The BMS will always uses the highest open circuit cell voltage and lowest open circuit cell voltage for these calculations such that that the pack is properly protected.

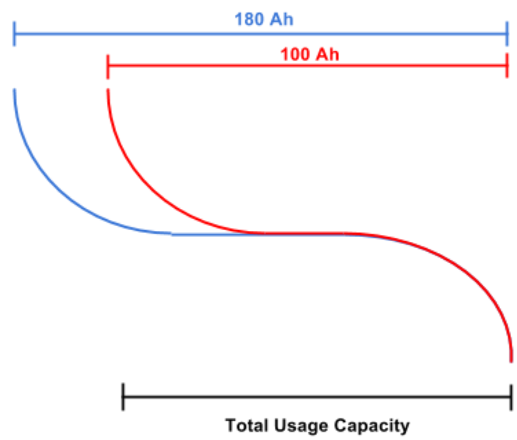
In addition to the drift points that are programmed in, the BMS also knows what state of charge the battery is at when a charge cycle completes. Since the BMS is controlling the battery charger, the BMS will set the state of charge to the "Charged SOC" value to indicate a full charge whenever it turns 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

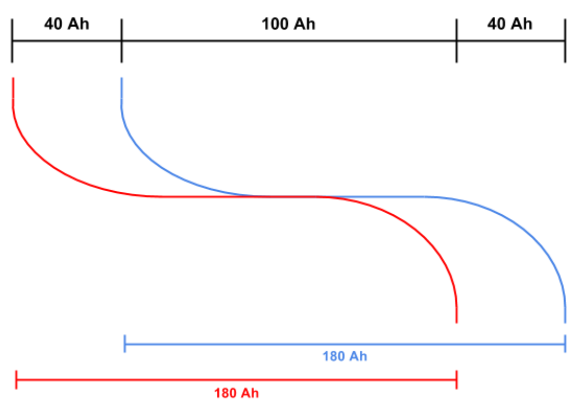
Correction drifts generally occur for one the following reasons:

1. A drift may occur if one or more cells within the battery pack has a lower capacity than the others. The battery pack is only as strong as the weakest cell, because the weakest cell cannot be over charged or over discharged. If a 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 depending on how the cell is balanced. The 2 images below show 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 occur if the battery pack is out of balance. 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 below, while the cells are 180 amp hours in size, two cells are 40 amp hours out of balance with each other and only 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) have a restricted range in the cold which can be as little as 50% of the normal capacity. Newer versions of the Orion BMS firmware have compensation for this effect to avoid SOC drift, but if this is not setup, 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, which can be a result of an inaccurate current sensor. This can also happen 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. When the BMS is powered up for the first time, it will not know the state of charge of the battery pack. In these cases, the BMS defaults 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.

5. If the pack capacity is lower than the capacity programmed into the BMS unit.

6. If the 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.

7. Inaccurate open circuit voltage calculations due to an incorrectly installed or defective current sensor.

Note: The Orion BMS cannot calculate state of charge without a current sensor! In the event that a current sensor is not connected, the Orion BMS will display a very inaccurate state of charge based strictly on instantaneous cell voltages. This method is very inaccurate - 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 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 established, some tweaking may be required to maximize performance.

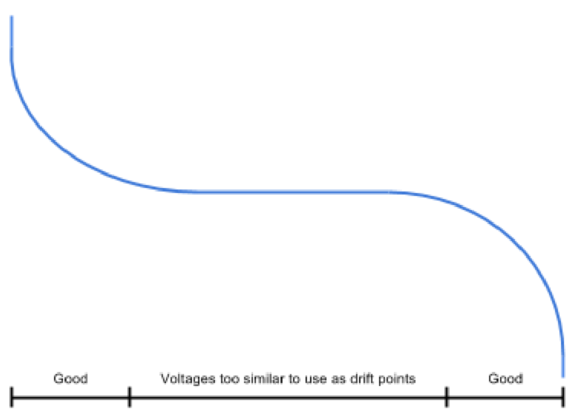
Ewert Energy maintains a database of state of charge drift points for many common cell types. This information can be automatically entered into the battery profile by using the “profile setup wizard” in the BMS utility.

For cells that are not in the database, Ewert Energy 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.

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. 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 gathered. 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.

Drift points should be established at places on the discharge curve where the voltage change is most significant. For example most iron phosphate cells stay at 3.3v for the majority 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 as the open cell voltage of a battery will drift up and down slightly under load due to a temporary voltage depression (e.g. under a 100A load a battery’s open cell voltage may drop from 3.3v to 3.2v, though it will gradually return to 3.3v once the load is removed).



A state of charge drift point consists of two items, an *open cell voltage* and a corresponding *state of charge* percentage. When a cell's open cell voltage equals the open cell voltage of the programmed drift point, then the state of charge will drift to the state of charge associated with the programmed drift point. Additionally, drift points are specified as "drift up only" and "drift down only", indicating which direction they are allowed to affect drift (e.g. 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).

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

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

Temperature Capacity Reduction

Some cells, including iron phosphate cells, have a significantly lower usable capacity when cold. To compensate for this, the BMS has the ability to reduce the calculated 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. This feature was added in firmware versions 2.6.8 and settings can be configured under cell settings.

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.

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 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 measuring the relative change in voltage when a known load is applied to the cell. In order to calculate the internal resistance, the BMS depends on external changes in current. 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 calculate the resistance of cells.

Internal resistance is the main 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) 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 for the calculation of how much current a cell can handle before the minimum or maximum cell voltages would be exceeded. This information is also used in calculating the open circuit voltage of a cell, even when the cell is under load, 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 for the average temperature of the pack in the nominal resistance table programmed into the BMS. The BMS uses the default value until a real measurement can be taken.

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 generally a percentage of the total amount of the current sensor. The minimum value is generally about 20% of the value of the current sensor, 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.

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. Too high internal resistance numbers 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 as soon as current started to flow).

It is best, however, to test the resistance at least every 10 degree 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 5 or 10 degrees Celsius.

Note: Internal resistances will 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 around 50%.

Ewert Energy 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.

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. 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.

Isolation Fault Detection

The Orion BMS has an isolation fault detection circuit designed to measure and look for breakdown in isolation between the high voltage battery pack and the negative of the 12 volt system. The circuit operates by placing a small 5 volt AC signal between the high voltage battery and chassis and measuring the attenuation of the signal. This method is able to measure fairly small faults before they become large enough to cause further problems.

Only one of these style devices can be connected to the battery pack at a time. If multiple devices are connected, they may interfere with each other and cause inaccurate readings. If multiple Orion BMS units are being used in series, or if multiple BMS units are connected to the parallel packs, only one unit can have this circuit installed on the unit. Unfortunately the circuit simply being present on the battery pack may lead to inaccurate readings, and it may be necessary to order one or more BMS units without the isolation fault detection circuit if multiple BMS units are connected to the same pack. *In order to operate properly, the chassis ground must be grounded to the 12v negative source for the BMS.*

The BMS must have isolation fault detection circuit enabled in the profile settings in order to measure isolation. When this is enabled, the BMS will poll the attenuation of the 5V AC signal once every 1.5 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 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 1 volt indicates a near 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 makes decisions about whether or not the battery pack can accept charge or discharge. As the BMS does not have integrated switches or contactors, the BMS unit cannot stop current flowing in or out of the battery pack by itself. Instead, it provides signals 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 DC to AC 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 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 or discharge into the battery pack at any given time. All three outputs are open drain and are active low (pull down up to 175mA to ground when on). These outputs are on (pull down to ground) when discharging or charging is permitted. 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. Charger safety 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. 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.

Criteria for all 3 relay outputs

All 3 of the 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 percentage that is programmed in (same percentage is used for all 3 relays.) This feature must be enabled for each of the relays individually through the settings profile. This feature must be enabled for the BMS to protect against over-current. If the relay turns off due to the over-current condition, that specific relay will latch off until the BMS is reset or the power cycled.

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.

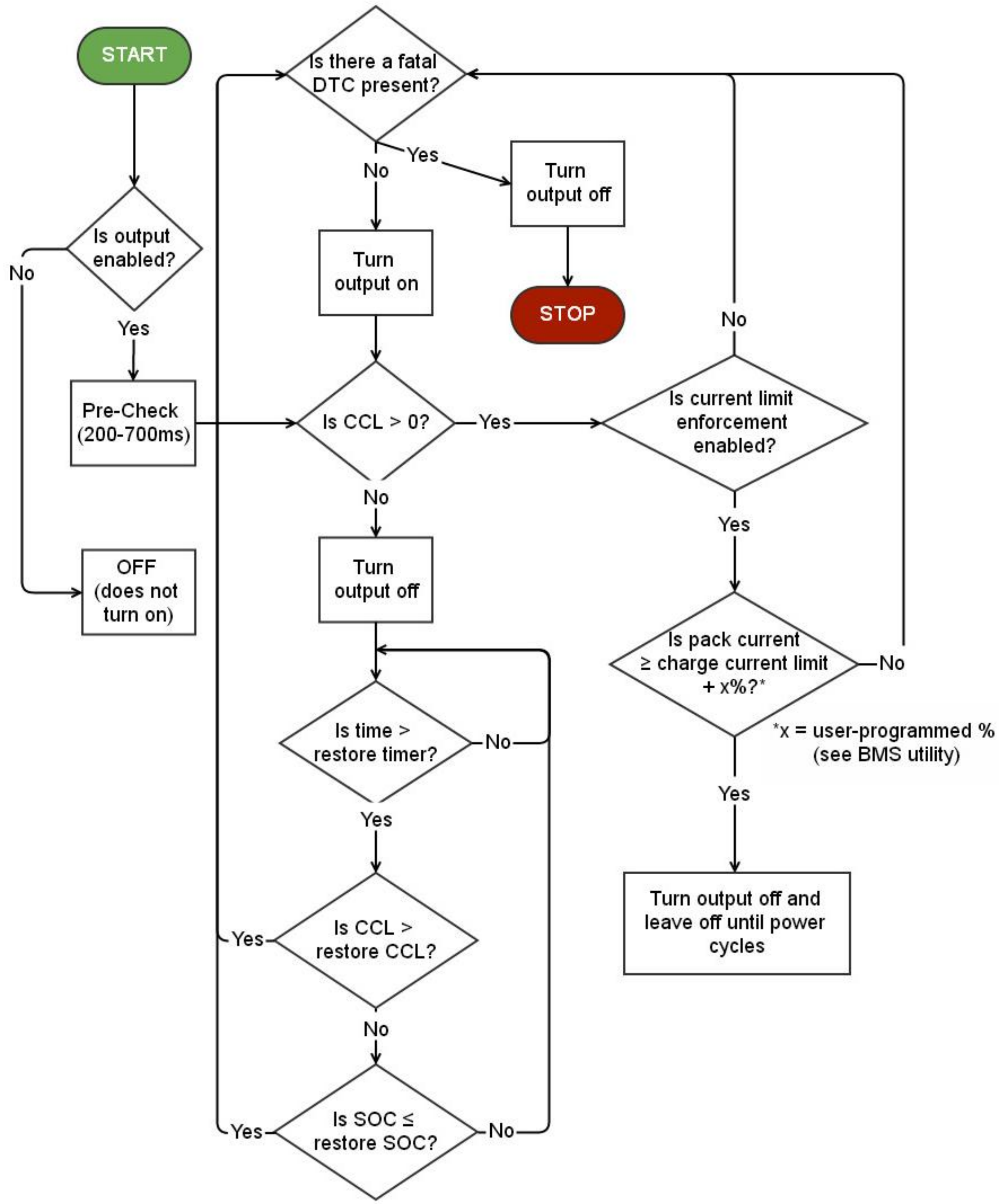
When the BMS turns off these outputs, charge or discharge must stop within a certain timeframe (about 500ms). If the BMS still measures current flowing into or out of the battery pack after this amount of time after the BMS has prohibited the respective action, the BMS will set a relay enforcement fault code. If this happens, the BMS will turn off all 3 of the relay outputs 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. (*Note:* The multipurpose output does not have this safety feature, and the status of that output is not affected by any fault status unless specifically chosen.)

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.

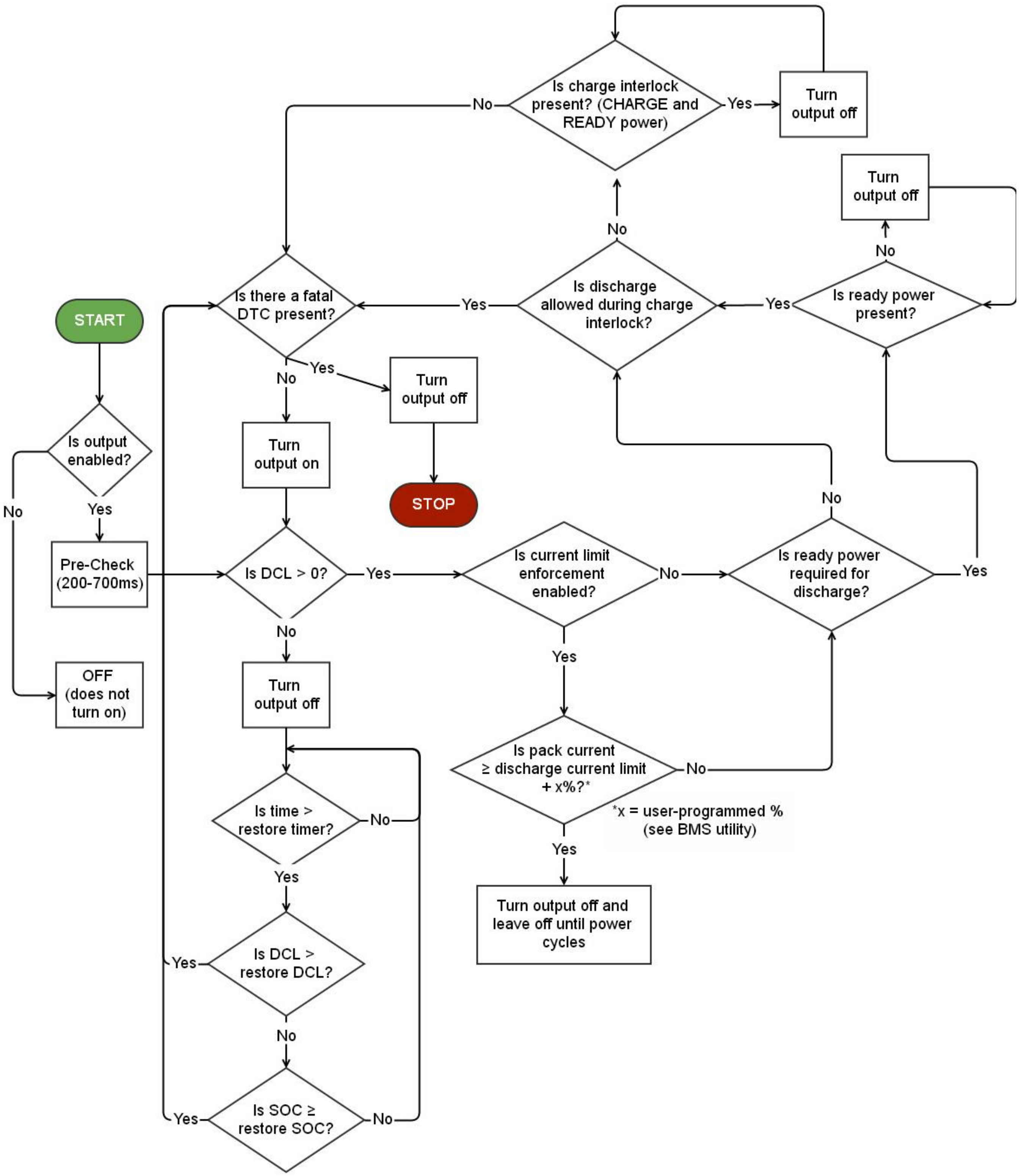
Criteria for Charge Enable and Discharge Enable - After a minimum time interval defined in the profile settings, the outputs may turn back on based on state of charge or based on the charge or discharge current limits rising back up to a set value. They are turned on when either one of those conditions are met, 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. For solar, wind and 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 Flow Chart



Discharge Enable Flow Chart

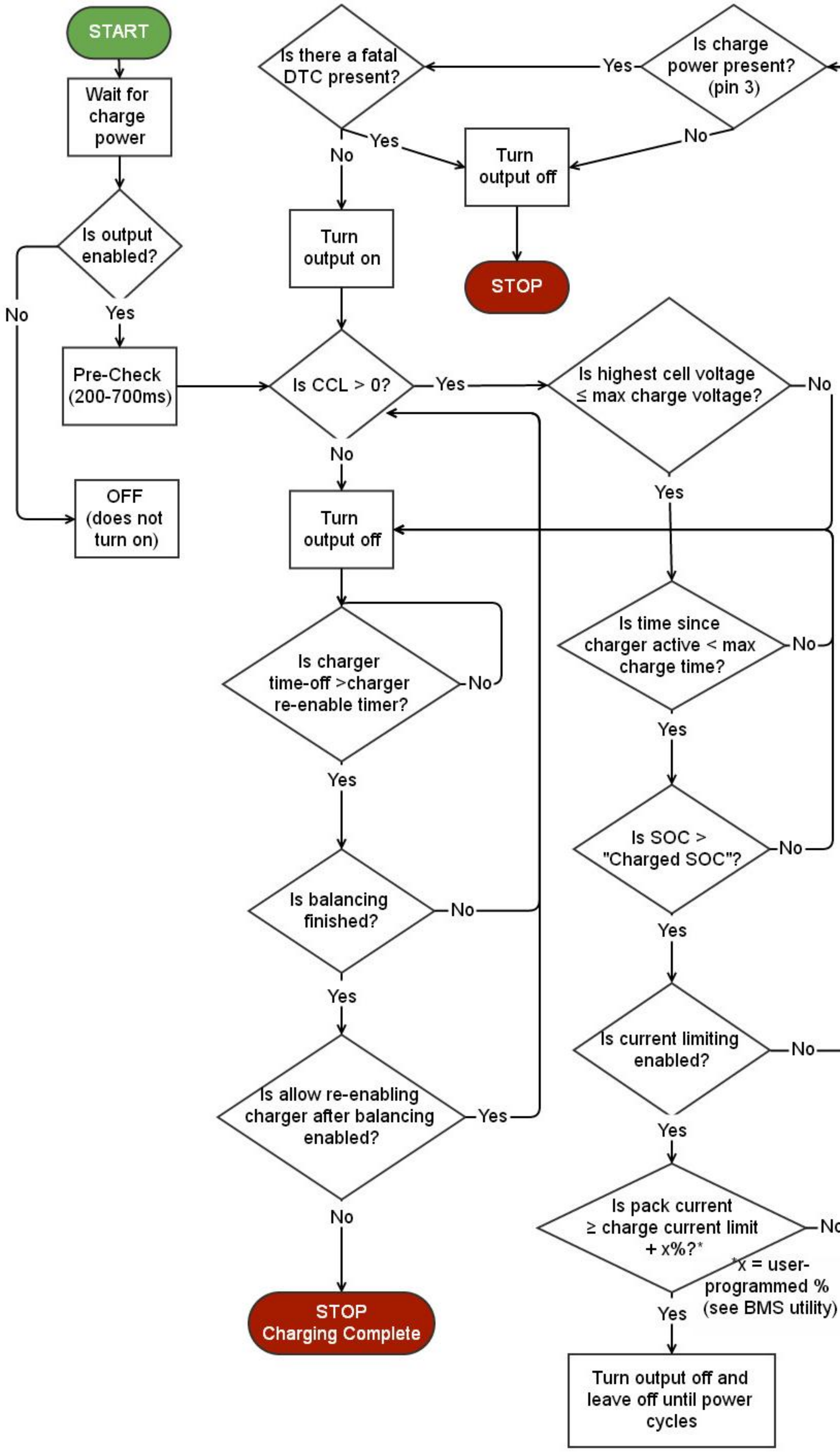


Criteria for Charger Safety - The charger safety output is only allowed to turn on when the BMS is in CHARGE mode (power is applied to Main I/O pin 3). Once this output turns off due to a cell voltage reaching the maximum cell voltage, the BMS will adjust the state of charge and latch the charge current 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, the charger safety relay may not be enabled to prevent the BMS from latching 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. 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. With firmware versions 2.6.5 and newer, 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 should not in any situation ever be allowed to continue charging at any amperage after the BMS has turned the charger off.

Charger safety 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 ten programmable CAN messages can be configured to transmit on either or both CAN interfaces. These messages are designed to be flexible to interface with other electronic control units, computer systems, display clusters, or any number of different devices. Virtually all BMS parameters are able to be programmed into these CAN messages. Please see the “Editing CAN Messages” section of the Software Utility manual for details on programming custom CAN messages.

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

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

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

Analog 5v Outputs

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

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

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

How Balancing Works

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

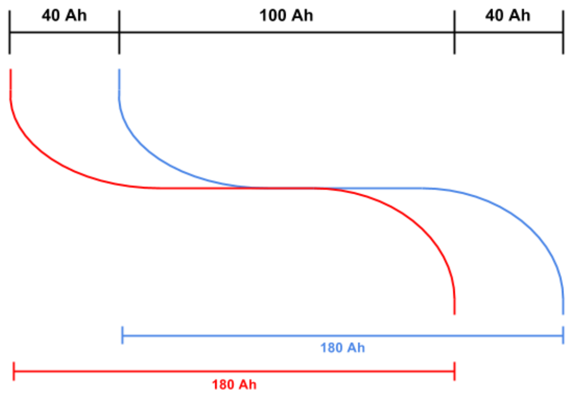
Lithium ion batteries, unlike lead-acid batteries, tend to stay in balance very well once initially balanced. Differences in self discharge rates, cell temperature and internal resistance are the primary causes of an unbalanced battery pack in a properly designed system, and these differences in self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

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

The Orion BMS uses passive balancing to remove charge from the highest cells in order to maintain the balance of the pack. The passive shunt resistors dissipate up to approximately 200mA per cell. While that amount may seem small, that current is more than sufficient for maintaining balance in very large battery packs. Difference in cell internal self discharge rates are often measured in the tens to hundreds of uA (with a uA being 1/1000 of a mA.) Even with a very 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 40 amp hour battery pack cycled once a day a typical maintenance balance completes in only about 15-30 minutes.

It should be noted that the balancing does not need to occur every cycle. Even if the battery has not had a maintenance balance in many cycles, the BMS will still protect the batteries. Except for the very extreme conditions, the majority of the battery pack capacity will remain usable even after many months without a balancing 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 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. The image below is an example of two cells grossly out of balance with each other (40 amp hours out of balance.) Although this example pack is grossly out of balance, more than 50% of the capacity is still usable. For more information on pre-balancing, please see our application note on pre-balancing cells.



Balancing on the Orion BMS 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, 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 the maximum difference in 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 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 pre-defined 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 power is removed and re-applied to pin 3 on the BMS (i.e. the next charge cycle).

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 programmer 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 below this threshold, even if a cell below this threshold 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 balancing, the balancing 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.

While the Orion BMS uses a different approach, 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 works, it is typically inefficient, requires large bypass resistors and actually unbalances the batteries before it can then re-balance them. The Orion BMS does not use this process. 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 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 not in any situation ever 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 settings for the charger safety relay settings. 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 three 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.

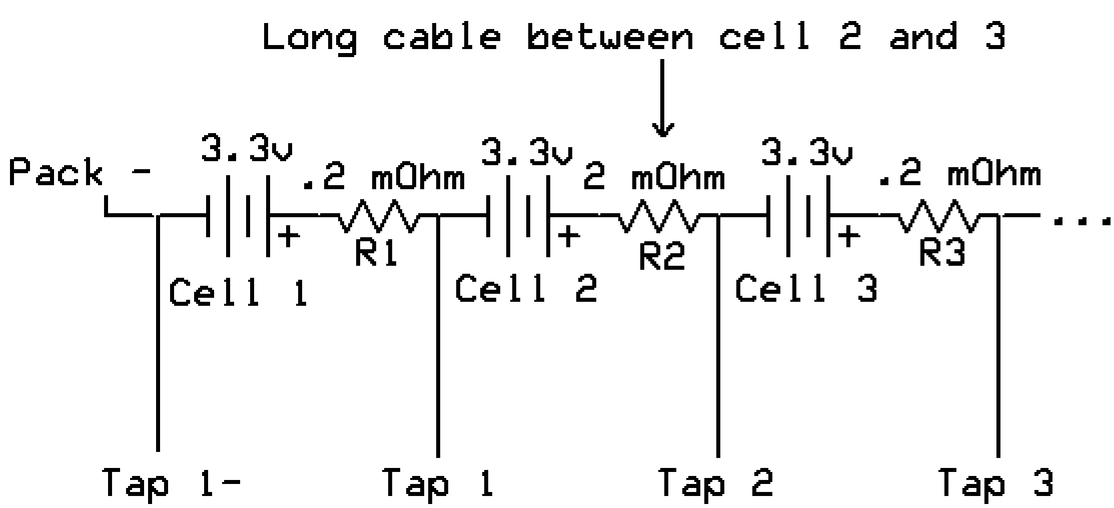
Busbar Compensation

Voltage measurements are taken by the Orion BMS 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.

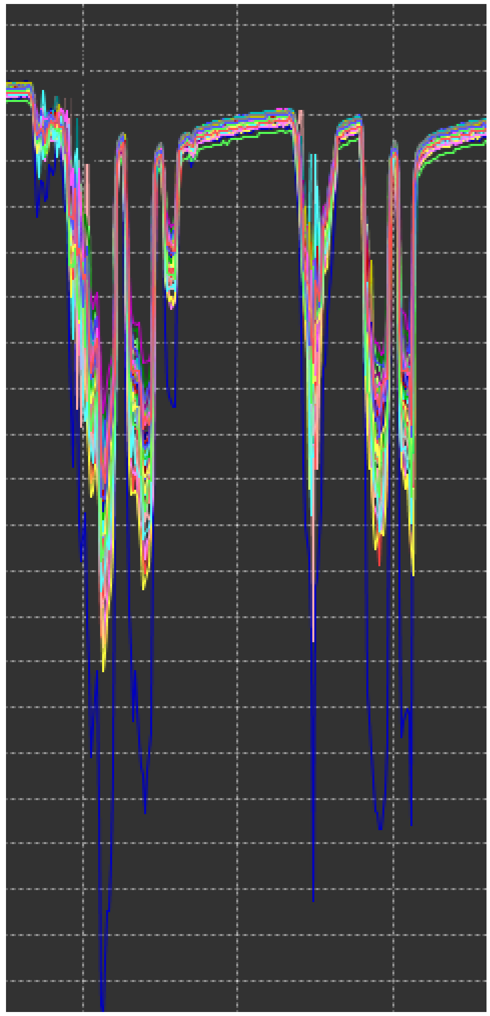
While battery cables and busbars may be very large and have a minimal resistance, all cables have some electrical resistance, and that resistance, while small, may influence the measured cell voltages while under load. The cell taps by necessity will see the additional resistance from busbars, battery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

If cell voltages are measured by the Orion BMS with no current flowing through the circuit, the voltages measured are exactly the voltage of the cells. When a current is running through the pack, the measured voltage of each cell will drop (or increase) due to the internal resistance of the cells, and the measured voltage (instantaneous voltage) and the open cell voltage of the cells will be different.

Because of the way the cells are connected, the differences in resistance from one interconnect to another will be reflected in the instantaneous voltage measurements and would show up to the Orion BMS as extra resistance for that particular cell. In the example below, all of the cells have a resistance of 3 mili-ohm, but due to the busbar resistances, the BMS sees the extra 2 mOhm resistance for a total of 5 mOhm on cell 2. Even though cell #2 is still healthy, it appears 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.



Voltage drop under load from an uncompensated high impedance busbar causing additional voltage drop (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 to look at voltage drop under load across the cable or by trial and error charting all cell voltages.

Busbar compensation generally should only be used for long cables. While the BMS has this feature, it is always better to not use it if possible and avoid the extra complexity. This is especially true for applications with rapidly changing currents.

Virtual Battery and Drive Modes

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

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

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

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

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

A typical drive mode will therefore have the following elements:

1. **A reported SOC%** - Typically a higher value indicates a higher average current draw in a PHEV application by the vehicle and a lower value results in lower current draw. The ideal value is specific to each application however.
2. **Enter/exit SOC% conditions** - These are SOC% markers that indicate when a mode can be entered or exited. This is useful for automatic mode transition when a battery depletes or becomes fully charged.

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

Thermal Management and Fan Controller

The Orion BMS measures the battery temperature through 4 main thermistors connected directly to the BMS with the option of additional thermistors through a thermistor expansion module (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 will beginning at the lowest speed. As the temperature of the battery pack rises above the threshold temperature, the fan control 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 four 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 keep 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 battery heating through electric warmers is required, a multi-purpose output may be used to turn on at a specific temperature. Please see the “Multi-Purpose Output” function for more information on that feature.

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

Multi-Purpose Input

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

1. ***Keep-alive 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 though one of the primary power sources is not available. In order for this pin to perform its function, the BMS must be connected to an always-on 12v power source on pin 1 (Always on power pin.) If this feature is not used, the always on power is not required.

2. ***Clear all error codes*** - when the BMS is configured with this option, all fault codes will be cleared in the event that the BMS senses this output turn on (note: a fault code may re-occur immediately if there is an active fault condition.)

3. ***CANBUS message*** - this feature allows the BMS to transmit different CANBUS messages only when this pin is enabled. CANBUS messages which have the “MPI Active” checkbox selected are transmitted when the multipurpose input is on. Note: This feature will still work even if another MPI functionality is selected.

4. ***Alternative charge current limit*** - this feature will change the maximum possible charge current limit to a lower value only when the BMS detects this pin is active (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.

Multi-Purpose Output

The BMS has one multi-purpose output. This open drain output can sink 175mA, is active low (pulls to ground) when on, and can be used to drive a relay or other device. The function of this is set in the BMS profile on the General Settings tab. Available functions:

1. ***Error signal output (default)*** - In the event that any fault code is present on the BMS or in the event that both CHARGE and READY power are present to the BMS at the same time, 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.

2. ***CANBUS Controlled output*** - When this option is selected, the status of this output is controlled by a CANBUS message. Note: Additional CANBUS configuration is needed and this should not be relied on for safety operations such as enabling charge or discharge.

3. ***Low SOC output*** - This output will turn on whenever the state of charge drops below the SOC output threshold. This output will turn back off once it rises above the turn-off condition. The difference between the two voltages provides hysteresis to prevent rapid oscillations.

4. ***Low Temperature Output*** - This feature will turn on the output whenever the lowest temperature (either from the 4 integrated thermistors or from an external thermistor expansion module if configured) drops below the low temperature threshold. This output will turn back off once the lowest temperature rises above the hysteresis value.

5. ***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 when this happens.

6. ***High Cell Voltage Output*** - This option will turn the multipurpose output 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 hysteresis value. Note: This output is not designed to be the primary control for discharge or charge. *The output will not turn off in the event of a critical fault, over-temperature, or other safety condition!* Use the charge enable, discharge enable, charger safety or CANBUS for primary control of charge and discharge.

7. ***Low Cell Voltage Output*** - This option will turn the multipurpose output on if the lowest cell in the pack drops below the threshold. The output will turn off when all cells have risen above the hysteresis threshold. Note: This output is not designed to be the primary control for discharge or charge. *The output will not turn off in the event of a critical fault, over temperature or other safety condition!* Use the charge enable, discharge enable, charger safety or CANBUS for primary control of charge and discharge.

8. ***Low DCL Output*** - This option will cause the multipurpose output to turn on in the event that 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 amount.

9. ***Low CCL Output*** - This option will turn the multipurpose output on in the event that 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 amount.

Power-On Signal Output

Revision D and newer BMS units contains a very simple power-on signal output. This output is on whenever the BMS is “awake” and can be used to directly drive an LED or provide a signal to another controller. This output is used for diagnostics to determine if the BMS is awake and powered.

Collected Statistics (Cell Warranty Data)

Revision D and newer BMS with firmware version 2.6.7 or higher collect usage statistics on the battery pack. These statistics are stored in non-volatile memory on the BMS. Data collected is intended to be used to track the number of events that occur including over-voltage, under-voltage, time spent above and below certain temperatures, and the number of events that occur. 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.

Parameters tracked include:

1. **Total runtime** - the total amount of time the BMS is active, stored in minutes.
2. **Total power-ups** - the number of times that the BMS unit has been powered on.
3. **Total profile updates** - the number of times that a BMS profile has been updated on the BMS.
4. **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.
5. **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.
6. **Total time over and under-voltage.** These two parameters record the total amount of time that a cell’s voltage was above or below the maximum or minimum cell voltage respectively 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.
7. **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.
8. **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.

Failure Mitigation

The Orion BMS 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 user must think through all possible failures, provide redundant systems, and determine that each failure mode is safe and acceptable. Generally speaking the worst case situations are situations where a failure can occur, and the application is not aware that the failure has occurred and therefore runs using incorrect data. Because the requirements vary from application to application, it is the responsibility of the user to determine acceptable risk and design the rest of the system to mitigate risks.

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

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

1. ***Loose / disconnected wire on cell voltage tap or failure of a cell voltage sensor*** - This is a major issue for any BMS 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 open wire detection where a small current is applied to the cell through the tap wire every so often to ensure that the connection is good. If the BMS detects that a wire has become loose, disconnected, or has sufficiently high impedance, it will set an open wire fault for the specific cell tap affected and go into a fail safe mode. 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 and the BMS will likely need 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 volt supply ground is connected to the chassis to function.

2. ***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. For this case, the BMS features a total pack voltage sensor which can be constantly compared to the sum of all cell voltages to look for inconsistencies. If inconsistencies are detected, the BMS will set a fault code and go into a voltage fail safe mode (described later). The variance allowed is a user specifiable feature in the profile and can be disabled if used in a production environment where this feature is not necessary. The total pack voltage sensor is only accurate to within about 5% and will not likely catch a single unpopulated cell, particularly if cell voltages are fairly low or if the maximum allowable variance is set high.

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

4. ***Loose / disconnected wire or failure of current sensor system*** - Most current sensor failures will be detected by the BMS and an error code will be set indicating that the BMS cannot trust the value from the current sensor. The sensors supplied with the Orion BMS are dual range sensors and the BMS can detect if just one of the 2 current sensors has failed. Most failures will result in the 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 code will be set and the BMS will enter a fail safe mode. The BMS will also enter into a current sensor fault 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 compare currents measured by the BMS with currents measured elsewhere such as at an inverter, load, or source. It should be noted that with a malfunctioning a current sensor, the BMS can still provide basic protection of the cells from over voltage and under voltage.

5. ***Disconnected wire or failure of thermistor*** - A disconnected thermistor will result in an error code by the BMS and the BMS will ignore that specific thermistor until the error code is cleared or the BMS power is reset. The BMS determines a faulty thermistor if the measured value is less than -40C or greater than +80C (a shorted or disconnected thermistor will read +81C 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.

6. ***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 the multi-purpose input. Please see the section on multi-purpose input for more information.

   Loss of all power on a revision C unit means the loss of state of charge information in addition to loss of stored fault codes, while revision D and newer are able to retain this data in non-volatile memory through a complete power loss.

   In the event the 5V analog voltage references 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 and amperage outputs since a disconnected wire could result in the application believing that the state of charge has dropped to 0% and the amperage dropped to the maximum value.

   Digital on/off outputs are 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 input 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.

7. ***CANBUS communication failure*** - While CANBUS is a very robust protocol, systems should always be designed to tolerate a total or partial CAN communication failure. CAN buses may become unreliable if another node on the bus starts transmitting and clogs the bus causing intermittent messages to get through, creates errors on the bus blocking all communications, or starts transmitting gibberish on the bus. Since CAN communications cannot be guaranteed by

their nature, 3 things should always be done when communications are necessary to prevent major failures:

1. CAN systems should always be backed up with an analog system if the failure would be catastrophic or fail in a safe manner if communication is lost. If a charger does not go into a safe failure when CANBUS communication is lost, an analog backup must 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 handful of messages are missed, the device should not trust the last known data but rather go into a failsafe mode where it operates under the assumption that values are unknown.

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

   The digital on/off safety lines are all configured as open drain outputs where they will float when off and will be pulled down to ground when enabled. It is important to note that if voltages 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 appearing 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 maximum possible voltage. This functions as a backup to prevent thermal runaway in the event that the BMS is unable to turn off the charger for whatever 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 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.

9. ***Failure of fan component or fan controller*** - While fan failure modes often are not considered to be a safety concern, they can still fail. The Orion BMS provides a fan voltage monitoring circuit that can be used in an application to determine if the fan has failed. The settings are

customizable in software in the profile. The BMS will set an error code if the voltage monitor conditions are not met.

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

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

Understanding Failure Modes

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

1. ***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, any populated cell which is reading a voltage below 0.09 volts, total pack voltage sensor reading 0 volts, or a discrepancy between the total pack voltage sensor and the sum of all the cell voltage sensors. In a multi-unit master/slave configuration, a communication failure between BMS units will also result in a voltage failsafe condition.

   Because the BMS cannot protect the cells if the accuracy of the cell voltages or the total pack voltages is compromised, the BMS is forced to enter into a non-operating failsafe mode. 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 prior to clearing the code.

2. ***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:

- Internal resistance calculations disabled (both cell and total pack)
- 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.
- State of charge. This cannot be accurately calculated and will be guessed purely on voltage and based on drift points. Drift points are based on open cell voltages, so SOC will vary considerably and should not be trusted to be totally accurate.
- Charge and discharge current limits switch to a voltage failsafe calculation mode and may be higher or lower than they should be. However, they will rapidly adjust if voltages approach minimum or maximum levels.
- The 5v analog output for amperage (pin 15 on the Main I/O) will go to 2.5V to signify 0 amps, even though current is flowing.
- Over current protection based exclusively on cell voltages
- *The BMS cannot enforce over current limit protections since current is unknown.*

3. ***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.

4. ***12v supply power failsafe (degraded operation)*** - The BMS requires a nominal 12v input main power to operate properly. For revision C units, voltages below 8V can cause operational issues for the BMS since the BMS has an internal 5V supply. The BMS is equipped with an internal voltage sensor. If internal voltages drop too low for safe operation, the BMS will enter into 12v Supply Failsafe mode. Revision D and E units can operate through voltage sags at voltages down to approximately 4.5v without causing this failsafe mode and are far less likely to experience this failsafe mode than a revision C unit.

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

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

5. ***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

P0A04 – Wiring Fault Error Code (or "Open Cell Voltage Fault")

This fault is a serious code that effectively disables the BMS and often causes many other fault codes to occur. When diagnosing errors, this error code should be corrected first. This error code indicates that the Orion BMS has determined that a cell tap wire is either weakly connected or not connected and as a result, it has determined that it cannot accurately measure cell voltages. Wiring faults can be caused by improperly wired cell taps, loose cell tap connection, cell taps that are not connected to the battery, internal fuses blown inside the BMS or other internal damage to the BMS from previous improper wiring.

For more information on what causes fuses within the BMS to blow, please see **Why Orion BMS Internal Fuses Blow**.

Note: The Orion BMS scans for this fault condition at set intervals and it may take several minutes for this error to show up depending on the severity of the fault condition. This is especially true if a wire has a high impedance connection or is intermittently failing. Certain intermittent wiring errors may not trigger this error message since the error must be present for a minimum amount of time to trigger.

Note: It is possible for a "non-populated" cell to appear under the "open wire" list on the diagnostic trouble code tab even if they are wired properly. Even though the cell may be listed, it will not set an error code.

Note: The BMS may still read a roughly correct voltage on a cell flagged as "open wire". This does not necessarily mean that the BMS is functioning correctly or that the fault code was set incorrectly. Due to the way that the BMS voltage sensing circuitry works it's possible for the BMS to read approximately correct voltages on a cell that is completely disconnected under certain circumstances. The problem arises when the cell voltages start to change under load or charge (the "open wire" fault detection circuitry is able to look for these conditions even when the battery pack is at rest).

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A1F – Internal Communication Fault

This error indicates that the Orion BMS has encountered an error trying to communicate with the isolated circuitry that measure cell tap voltages. This error can be caused by external electrical noise if the BMS is not properly grounded or by an internal hardware failure.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A03 – Pack Voltage Mismatch Error

This error code indicates that the voltage measured by the total pack voltage sensor did not match the sum of the individual cell voltage measurements. This error is triggered when the difference in voltage between the two measurements exceeds the ‘Pack Voltage Mismatch Threshold’ setting in the BMS profile (under Pack Settings).

If this error is triggered, the BMS will assume that it cannot accurately measure the voltage of the battery pack and will go into a voltage failsafe mode. The voltage failsafe mode is the most critical condition and ***the BMS will not allow charge or discharge when this error is present.***

This fault code may be the result of a wiring error on the cell taps (look for “Open wire faults”), a wiring error on the total pack voltage sensor, a cell population setting error, or an internal BMS error.

Note: Certain noise patterns have been known to affect the accuracy of the total pack voltage sensor and cause the calibration to drift over time leading to an incorrect triggering of this error message. We recommend ensuring that the “Pack Voltage Mismatch Threshold” be no less than 10% of the total pack voltage to prevent this error from occurring. We also recommend disabling the pack level voltage limits unless they are specifically necessary. To do this, check the box next to “Disable Pack Voltage Limiting” under cell settings. Please inquire if additional assistance is necessary.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0AC0 – Current Sensor Fault

A current sensor fault is triggered if the analog voltages from the attached current sensor stray outside of the normal range or if the values from the 2 redundant current sensors do not match. The current sensor may be sized incorrectly, the wiring harness may be faulty or the BMS or current sensor may be faulty.

This error code will cause the BMS to enter a current sensor failsafe mode. The BMS is fully able to protect the cells in this mode and therefore the BMS will continue to operate in a voltage based mode. ***In this failsafe mode the BMS will continue to operate and protect the cells. However, some calculations are unavailable and many features are disabled or degraded*** such as state-of-charge calculation, open cell voltage calculation, and discharge and charge limit amperages are calculated using a backup algorithm. Please see the operational manual for more detailed information on what is and what is not available in this mode.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A80 – Weak Cell Fault

This fault is triggered based on thresholds programmed into the BMS profile that indicate when a cell is "weak". While this error code is designed to indicate a cell is weak, ***this error is triggered when certain pre-programmed conditions are met and does not necessarily indicate a dead cell because it can also be triggered by loose busbars, other wiring issues or incorrect error threshold settings in the profile.***

Important Note: Weak cell faults are informational errors only and have NO DIRECT IMPACT on the operation of the BMS. This error code will NOT cause the charge or discharge enable outputs to turn off and will NOT cause the BMS to go into any degraded operating mode. While this error code will not impact the operation of the BMS, this error message likely indicates a problem exists and the actual problem itself (not this error code) may cause the BMS to limit charge or discharge current (as would be the case with a high resistance cell). If the charge and discharge limits are both zero, look for other fault codes, specifically open wire faults or total pack voltage fault codes to begin addressing the issue.

The "weak" cell fault can be triggered as the result of the following 2 conditions:

1. **High measured cell resistance –** The Orion BMS measures each cell's internal resistance and compares the measured resistance against the nominal resistance specified in the profile in the "temperature compensation" section. The current temperature is used to select the nominal resistance value to compare against. If the measured resistance is higher than the nominal resistance by the amount specified in the profile (General Settings -> Maximum Resistance [%]), a fault code will be triggered. For example, if the nominal resistance is 1 mOhm at 20 degrees Celsius and the BMS is programmed with a 400% resistance threshold, an error code will be triggered if the cell resistance is measured at more than 4 mOhm resistance at 20 degrees Celsius.
2. **Difference in open cell voltage between a cell and the rest of the pack** - In addition to measuring the resistance of the cell, the BMS also looks for significant differences between the open cell voltage of a cell and the rest of the pack. The BMS calculates the open circuit voltage of each cell (this is the voltage as if the cell were setting at rest (no load) even when a load is applied to the cell). The BMS compares each cell's open circuit voltage to the pack average open circuit voltage and if they differ more than the preset value in the profile, a weak cell fault is triggered. The setting is under the Cell Settings tab as "Max Open Cell Variance" and is in volts. This can be caused by a cell that has deteriorated disproportionally to the rest of the battery pack or by a cell balance issue.

The above criteria are what actually trigger this error code, but the following conditions may cause one of the conditions above and therefore also trigger this error:

1. **Loose busbar or interconnect cable resistance –** Because the BMS measures cell voltages by measuring the voltage between each of the cell voltage tap connections, the BMS also "sees" the resistance of the busbar or cable connecting the cell with the adjacent cell. Because of this, the busbar resistance is included in the measured cell resistance. If a busbar, cable or battery terminal is loose, corroded or oxidized, this can cause the measured resistance to rise and trigger the error based on the threshold in #1 above.
2. **Significant difference in cell capacity than other cells –** A cell with a significantly lower capacity than the rest of the pack will likely cause a large difference in open cell voltages at lower states of charge. Additionally, the internal resistance of cells typically goes up when they are at very low and high states of charge. A lower capacity cell may also trigger a weak pack error code.

3. **Cell being out of balance with the rest of the pack –** A cell that is significantly out of balance with the rest of the pack can trigger this error message for the same reason as above. For balance issues, the issue can easily be resolved by simply balancing the pack.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A0B – Internal Logic Fault Code

This error code indicates that the Orion BMS has determined that an internal hardware fault has occurred. If this error message occurs, please download the associated freeze frame data and contact the factory or authorized dealer for assistance. Please save the freeze frame data and send it along with any other relevant information to the factor as it may be crucial for appropriately repairing the unit.

P0A0A – Internal Thermistor Fault

This error code indicates that the Orion BMS has determined that an internal hardware fault has occurred. If this error message occurs, please download the associated freeze frame data and contact the factory or authorized dealer for assistance. Please save the freeze frame data and send it along with any other relevant information to the factor as it may be crucial for appropriately repairing the unit.

P0A09 – Internal Memory Fault

This error code indicates that the Orion BMS has determined that an internal hardware fault has occurred. If this error message occurs, please download the associated freeze frame data and contact the factory or authorized dealer for assistance. Please save the freeze frame data and send it along with any other relevant information to the factor as it may be crucial for appropriately repairing the unit.

P0A00 – Internal Conversion Fault

This error code indicates that the Orion BMS has determined that an internal hardware fault has occurred. If this error message occurs, please download the associated freeze frame data and contact the factory or authorized dealer for assistance. Please save the freeze frame data and send it along with any other relevant information to the factor as it may be crucial for appropriately repairing the unit.

P0AFA – Low Cell Voltage Fault

This fault code is triggered when the voltage of a cell falls below 0.09 volts (90 mV). This fault can be caused by a cell that is incorrectly set in the BMS profile as a "populated" cell, a disconnected cell wiring harness, a very dead cell, or a wiring error. In a revision E unit, this fault code can also indicate two or more cell voltage tap wires are backwards. ***If cell voltage tap wires are backwards, the cell voltage tap connectors should be immediately disconnected*** from the BMS unit until the issue is corrected as permanent damage may occur to the unit and may drain the attached cells damaging them.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0AA6 – High Voltage Isolation Fault

This code is set when the BMS measures an isolation breakdown between the high voltage battery and the 12 volt system. A breakdown in isolation can be caused by ruptured or leaking cells, high voltage cabling insulation that has rubbed off and come into contact with low voltage systems, condensation, use of non-isolated equipment, by an intentionally non-isolated design, or by other causes. **This error code may indicate an unsafe condition that exists in the battery pack and care must be taken to avoid risk of short circuit and risk of personal injury from shock while investigating the error as simply touching a cell could cause a shock.** While this error tends to indicate a real problem, there are certain situations that can cause a false positive.

This error code is an informational code only and does not change the behavior of the BMS. It will not cause the BMS to stop charge or discharge in any way (but other external controllers may be setup to do so).

The isolation fault detection circuit in the Orion BMS applies a very weak, slow (about 1 Hz) AC signal on the negative wire on the total pack voltage sensor and measures the amount of signal degradation to determine if a breakdown in isolation has occurred. The fault is triggered when the 60 second average of the "Isolation Shortest Wave" parameter drops below 3.2 (unless ordered differently from the factory). For most systems, this indicates the BMS is measuring less than about 150k ohms of resistance between the high voltage battery and the low voltage system, but external factors such as parasitic capacitance between the high voltage and low voltage systems can artificially increase or decrease the measurement.

Note: A false positive may be triggered if a large amount of capacitance is present between the battery pack and the low voltage system causing the signal to degrade. Some DC:DC converters or inverters may have large filtering capacitors which can cause false positives and other equipment designed to measure breakdown in isolation may also cause signal degradation.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A01 – Pack Voltage Sensor Fault

This fault code is set if the total pack voltage sensor reads zero volts. This error will also cause a voltage redundancy fault code. This fault code may be the result of the voltage tap connection not being connected when the BMS was turned on, a wiring error on the total pack voltage sensor, a voltage tap that is wired to the wrong location or an internal BMS error.

If this error is triggered, the BMS will assume that it cannot accurately measure the voltage of the battery pack and will go into a voltage failsafe mode. The voltage failsafe mode is the most critical condition and ***the BMS will not allow charge or discharge when this error is present.***

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A02 – Weak Pack Fault

This error code is designed to alert a user to if the battery pack has degraded and is weak, ***this error is triggered based only when pre-programmed conditions are met and does not necessarily indicate a weak is actually weak since the error threshold may be set wrong.*** This error may be falsely triggered by incorrect profile settings, a battery pack with an abnormally low state-of-charge or by malfunctioning thermistors which are not accurately reading the pack temperature.

This fault is triggered when the pack state-of-health falls below the value programmed into the BMS profile that indicates when a battery pack is considered “weak”. A low state-of-health measurement is calculated 50% based on pack capacity and 50% based on cell resistance. For more information on how state of health is calculated, please see the operational manual.

Important Note: Weak pack faults are informational errors only and have NO DIRECT IMPACT on the operation of the BMS. This error code will NOT cause the charge or discharge enable outputs to turn off and will NOT cause the BMS to go into any degraded operating mode. While this error code will not impact the operation of the BMS, this error message likely indicates a problem exists and the actual problem itself (not this error code) may cause the BMS to limit charge or discharge current (as would be the case with a high resistance cell). A degraded battery pack may result in degraded performance for other reasons such as low capacity or high resistance.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A81 – Fan Monitor Fault

This fault is triggered when the BMS requests the external fan and the voltage measured at the fan monitor pin on the BMS is below (or above if inverted) the error threshold programmed into the profile. This is used strictly for monitoring performance of an external fan and alerting a user to a fan fault. This is only used if external monitoring of a fan is needed.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

U0100 – CANBUS Communication Fault

This fault means the BMS did not ***receive*** a CANBUS message it was expecting. The fault is only enabled under 2 conditions:

Condition 1) If the BMS is specifically configured to monitor for the presence of external CAN message (heartbeat monitoring).

Condition 2) If multiple BMS units are strung together in series (master-slave mode) and communication is lost between 2 units.

This error is set if communication messages are not received after a specified amount of time. This error is most commonly caused by incorrect profile settings (i.e. a unit setup for master slave configuration when it is not actually in a master slave configuration), if the BMS and the other device are powered up or down at slightly different times (not powered by the same power rail) or if the CANBUS is not properly terminated.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0560 – Redundant Power Supply Fault

This error message is triggered when the always on power to the BMS is off while the READY or CHARGE power is on. This error is not triggered on revision D & newer units if “Disable Always On Power Supply” setting is on since revision D & newer units do not require always on power for storing data.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A05 – 12v Power Supply Fault

This fault is triggered when the voltage measured by the BMS drops below approximately 9v for 5 to 8 seconds. This code remains set even after the voltage has returned to normal.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A06 – Charge Limit Enforcement Fault

(Also P0A07 – Discharge Limit Enforcement Fault and P0A08 – Charger Safety Relay Fault)

These 3 fault codes are caused when charge or discharge current (respectively) either exceeds the limit set by the BMS or continues after the digital on/off outputs are turned off. For example, if the BMS has set a discharge current limit (DCL) of 50 amps and the BMS measures 100 amps for an amount of time exceeding the limit in the profile, it will set the discharge limit enforcement fault since more current is being drawn than is allowed. The same fault will get set if the BMS turns off the discharge enable output and any current is discharged after the set amount of time passes. Charge limit enforcement corresponds to charge current; discharge limit enforcement corresponds to discharge current. *This error can be falsely triggered if the current sensor polarity is backwards.*

When this error is triggered, the BMS is put into a failsafe mode and all 3 charge / discharge / charger enable outputs are turned off in the event the outputs are wired backwards. The failsafe condition will reset when power is cycled.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A9C – Thermistor Fault

A thermistor fault is triggered detected if the analog voltage measured from the thermistor is outside of the normal thermal operating range. This error can be triggered if the temperature of the thermistor rises above 81C or drops lower than -41C. A shorted or open wire can result in artificially high or low measurements that would result in this error code. The use of an incompatible thermistor can cause inaccurate readings and trigger this error code.

When this error code is set, the Orion BMS will disregard the value of the affected thermistor, using the values of the other thermistors and continue to operate normally.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A07 – Discharge Limit Enforcement Fault

(Also P0A06 – Charge Limit Enforcement Fault and P0A08 – Charger Safety Relay Fault)

These 3 fault codes are caused when charge or discharge current (respectively) either exceeds the limit set by the BMS or continues after the digital on/off outputs are turned off. For example, if the BMS has set a discharge current limit (DCL) of 50 amps and the BMS measures 100 amps for an amount of time exceeding the limit in the profile, it will set the discharge limit enforcement fault since more current is being drawn than is allowed. The same fault will get set if the BMS turns off the discharge enable output and any current is discharged after the set amount of time passes. Charge limit enforcement corresponds to charge current; discharge limit enforcement corresponds to discharge current. *This error can be falsely triggered if the current sensor polarity is backwards.*

When this error is triggered, the BMS is put into a failsafe mode and all 3 charge / discharge / charger enable outputs are turned off in the event the outputs are wired backwards. The failsafe condition will reset when power is cycled.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.

P0A08 – Charger Safety Relay Fault

(Also P0A06 – Charge Limit Enforcement Fault and P0A07 – Discharge Limit Enforcement Fault)

These 3 fault codes are caused when charge or discharge current (respectively) either exceeds the limit set by the BMS or continues after the digital on/off outputs are turned off. For example, if the BMS has set a discharge current limit (DCL) of 50 amps and the BMS measures 100 amps for an amount of time exceeding the limit in the profile, it will set the discharge limit enforcement fault since more current is being drawn than is allowed. The same fault will get set if the BMS turns off the discharge enable output and any current is discharged after the set amount of time passes. Charge limit enforcement corresponds to charge current; discharge limit enforcement corresponds to discharge current. *This error can be falsely triggered if the current sensor polarity is backwards.*

When this error is triggered, the BMS is put into a failsafe mode and all 3 charge / discharge / charger enable outputs are turned off in the event the outputs are wired backwards. The failsafe condition will reset when power is cycled.

For information on addressing this diagnostic trouble code, please see http://www.orionbms.com/troubleshooting.