Battery Management Systems

**battery made simple**

www.emusbms.com

EMUS

# EMUS Battery Management System Mini 3
## User Manual

# Table of contents

Release notes:

| Revision Date | Revision | Author | Changes |
| --- | --- | --- | --- |
| 2020-11-13 | 1.0 | H.S. | Initial EMUS BMS Mini 3 user manual version |
| 2021-04-20 | 1.1 | H.S. | EMUS BMS Mini 3 release user manual |

# Preface

List of Abbreviations

| | |
|---|---|
| BMS | Battery Management System |
| CR | Carrier Return |
| LF | Line Feed |
| USB | Universal Serial Bus |
| CP | Control Panel |
| PWM | Pulse Width Modulation |

# List of Figures

# List of Tables

# Introduction

The recent and ongoing development in the technology of rechargeable lithium batteries has been steadily increasing their performance and making them more safe, reliable, cheap, and easy to manufacture. All of this resulted in an increasing popularity of rechargeable lithium batteries, not only in portable consumer electronics, but also in traction, energy storage, maritime, industrial, military, aerospace and other applications, where the high energy density, negligible memory effect, low self-discharge rate, and long life cycle of lithium batteries are highly desired characteristics.

Despite the advantages, all rechargeable cells of lithium chemistry have a very strict allowed voltage range and certain charging temperature limitations. If operated outside these limits, they will fail prematurely and pose safety risks due to reactive components inside them. Also, because the mentioned applications usually require battery voltage to be significantly higher than that of a single cell, several cells must be connected in series to attain the desired voltage. This creates another problem: since lithium chemistry cells are very intolerant to overcharging, they do not have a natural equalization mechanism when connected in series (such as gassing in lead acid batteries), and any disbalance of charge between the cells will amplify with each cycle of operation if no countermeasures are taken, rapidly decreasing the usable capacity of the whole battery pack, and potentially causing its premature failure. In order to overcome these problems and to fully exploit the advantages of rechargeable lithium batteries, it is necessary to use an intelligent battery management system that can autonomously monitor the battery parameters at individual cell level in real time, and prevent them from going outside the safe operation limits.

EMUS, UAB has developed the EMUS BMS Mini 3 precisely for that purpose. It is a highly flexible, state of the art digital battery management system with a unique set of features and utility functions, that is designed to make the use of rechargeable lithium batteries straightforward and virtually maintenance-free, regardless of the battery size, cells arrangement (series or parallel), capacity, voltage, and other factors.

This document covers all aspects of using the EMUS BMS Mini 3 and aims to provide the user with an in-depth knowledge about its core functionality and utility functions, as well as with information about its proper installation and configuration together with connection diagrams, examples, and recommendations - all in order to help to utilize all of its capabilities and prevent most commonly faced issues.

**NOTE:** Using EMUS BMS Mini 3 requires at least basic knowledge in electronics and electrical engineering. The use of EMUS BMS Mini 3 in any way other than it is intended, especially if that compromises its core functions, including modification of its components, is considered improper and will void any warranty. EMUS, UAB will not be held responsible for damage to the battery or any other consequences in case EMUS BMS Mini 3 is used improperly and reserves the right to not provide any technical support in such case.

# Chapter 1: System structure overview

EMUS BMS Mini 3 is a digital, centralized topology battery management system that consists of a main controller, and few other optional components that all serve different purposes. The following subsections "System structure overview" and "Functionality overview" respectively outline the role of each of these components and describe how they function and interact with each other to execute the core and utility functions of the battery management system.

## 1.1 BMS Mini 3

EMUS BMS Mini 3 is the main controller that autonomously executes all core and utility functions of battery management. It interacts with all other first-party and third- party components in the system using various inputs, outputs and interfaces that are populated on its main connector.



Figure 1-1 EMUS BMS Mini 3 (MNC033 with Phoenix connector)



Figure 1-2 EMUS BMS Mini 3 (MNC034 with Molex connector)

Depending on their purpose, all EMUS BMS Mini 3 pins can be divided into two categories: fixed and remappable. Fixed pins that dedicated for digital communication interfaces and power supply, and their position on the connector is permanent. Remappable pins are quite the opposite – they can be mapped with various functions during configuration, meaning the default function of one pin can be remapped onto another pin. They are also further divided into general purpose and special purpose categories. A general-purpose pin has a standard set of mappable functions, while a special purpose pin can also be mapped with certain function that is unique to some pins and cannot be mapped on others. More detailed information about pin functions in chapter: (4.164 I/O ).

## 1.2 USB data interface

The EMUS BMS Mini 3 has a USB interface that is intended for quick and straightforward connection to a host device (e.g. computer, tablet, smartphone) when configuration, diagnostics, or maintenance is needed. Provided USB port is populated on the top of EMUS BMS Mini 3. Detailed information about other EMUS products can be found in their datasheet.

Although aimed for connecting to first-party applications on the host device, the USB interface can also be used with custom third-party applications developed by the users. It is based on a USB to serial converter chip from FTDI, and the required USB drivers are royalty-free. The protocol that defines the format of the data exchanged between the EMUS BMS Mini 3 and the host application is described in an openly available document called "EMUS G1 Control Unit Serial Protocol" that can be found in Support page.

## 1.3 RS232 data interface

The protocol used for data exchange over the EMUS BMS Mini 3 RS232 interface is the same as the one used in data exchange over the USB interface, thus both interfaces are functionally identical. However, RS232 is inherently more robust than USB and is therefore more suitable for continuous BMS activity monitoring – either directly by a third-party controller, or by using the optional first-party EMUS G1 BMS components that are dedicated for this purpose. The RS232 interface is populated as the "RS232_RX", "RS232_TX" and "GND" pins on the main connector of the EMUS BMS Mini 3, detailed information about other EMUS products can be found in their datasheet. The protocol that defines the format of the data exchanged between the EMUS BMS Mini 3 and the host application is described in an openly available document called "EMUS G1 Control Unit Serial Protocol" that can be found in Support page.

## 1.4 RS485 data interface

The protocol will be used for data exchange over EMUS BMS Mini 3 RS485 interface. Is the same as the one used in data exchange over the USB interface. However, RS485 is more robust than RS232 or USB and is therefore more suitable for continuous BMS activity monitoring – directly by a third-party controller. The RS485 interface is populated as the "RS485_A", "RS485_B" and "GND" pins on the main connector of the EMUS BMS Mini 3.

This interface is multipurpose, and enables the BMS Mini 3 to:

- Control certain third-party charging devices.

- Transmit BMS activity data (either periodically or by request).

- Receive new configuration parameter values and other special messages.

**NOTE**:  More detailed information about this functionality will be available in future user manual versions. For more detailed information please contact EMUS Support Team.

## 1.5 Wireless BT data interface

Enables to connect to EMUS BMS Mini 3 unit via BT protocol for monitoring, configuration, diagnostics, etc. Wireless data interface compatible to use with Android and iOS EMUS applications.

**NOTE**:  More detailed information about this functionality will be available in future user manual versions. For more detailed information please contact EMUS Support Team.

## 1.6 SD card

The SD card is used to save all sent messages from EMUS BMS Mini 3 communication interfaces and monitor all BMS status parameters. Card data will be accessible from the EMUS Control panel and directly using PC. This functionality helps to track all EMUS BMS Mini 3 activity and creates the possibility to recover all unexpected situations which occurred in past.

**NOTE**:  More detailed information about this functionality will be available in future user manual versions. For more detailed information please contact EMUS Support Team.

## 1.7 CAN data interface

Because of its popularity in automotive, industrial, and many other applications, EMUS BMS Mini 3 is also equipped with a non-isolated CAN 2.0A/B interface. It is populated in EMUS BMS Mini 3 as the "CAN_H", "CAN_L", and "GND" pins on the main connector, detailed information about other EMUS products can be found in their datasheet.

This interface is multipurpose, and enables the EMUS BMS Mini 3 to:

- Communicate with other CAN-equipped EMUS G1 BMS components.

- Control certain third-party charging devices.

- Transmit BMS activity data (either periodically or by request).

- Receive new configuration parameter values and other special messages.

The message format of the latter two follows a special proprietary CAN protocol that is described in a separate document called "EMUS G1 Control Unit CAN Protocol" that can be found in Support page. EMUS Support Team can also provide DBC file used to apply in CAN protocol described names, scaling, offsets, and defining information, to data transmitted within a CAN frame. The CAN protocol can be configured according to the customer's needs, for more detailed information please contact with EMUS Support Team at support@emusbms.com.

## 1.8 General purpose inputs and outputs

EMUS BMS Mini 3 supports remappable pins, which can be mapped with various functions during configuration. The default function of one pin can be remapped onto another pin. These pins are also further divided into input and output categories. Each pin depending on its category has a set of standard and special mappable functions.

Pins that fall into the general-purpose output category are populated on the EMUS BMS Mini 3 connector as the following:

- EMUS BMS Mini 3 (MNC033) – GPO1, GPO2, GPO3, GPO4, DUALP_HO.

- EMUS BMS Mini 3 (MNC034) – GPO1, GPO2, GPO3, GPO4, GPO5.

They all share identical internal circuitry, and depending on the mapped function, are intended for driving relays, indicators, etc., or transmitting logic signals to various third-party devices.

Likewise, pins that fall into the general-purpose input category are populated on the same EMUS BMS Mini 3 connector as the following:

- EMUS BMS Mini 3 (MNC033) – GPI1, GPI2, GPI3, GPI4, DUALP_LI.

- EMUS BMS Mini 3 (MNC034) – GPI1, GPI2, GPI3, GPI4, GPI5.

They are used by the EMUS BMS Mini 3 to read various logic signals from third-party devices. Four input pins (GPI1, GPI2, GPI3, GPI4) can be configured as peripheral input pins or analog input pins.

As mentioned already at the beginning of this subsection, general purpose inputs and outputs are remappable.

Figure 1-3 General Purpose I/O (MNC033)



Figure 1-4 General Purpose I/O (MNC034)
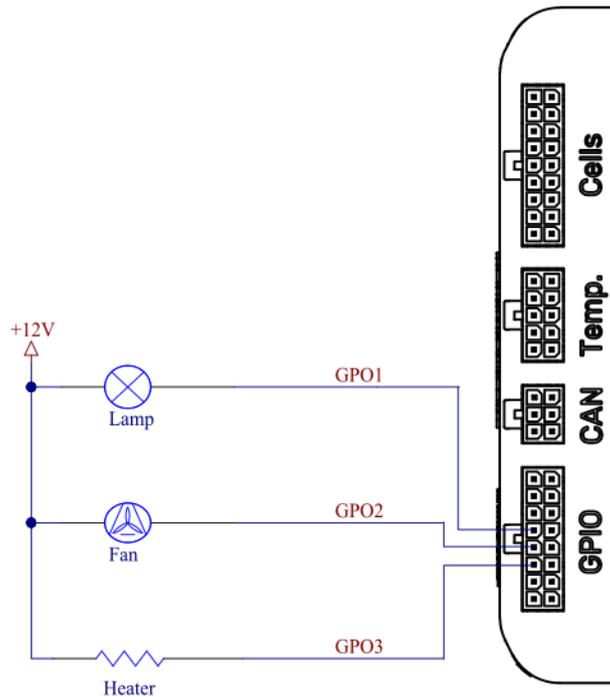
Figure 1-5 GPO external power supply

⚠️ **NOTE**: General purpose outputs must be powered externally. For more detailed information please contact EMUS Support Team.

## 1.8.1 PWM outputs

The EMUS BMS Mini 3 output pins can generate a 0-5V pulse-width-modulated signal.

Depending on which of the two special functions the pins are associated with, different signals can be used:

Driving an analog fuel gauge (SOC indicator) in such case the duty cycle of the generated PWM signal is directly proportional to the estimated battery state of charge. (Figure 1-3) shows a possible connection diagram for a fuel sensor.
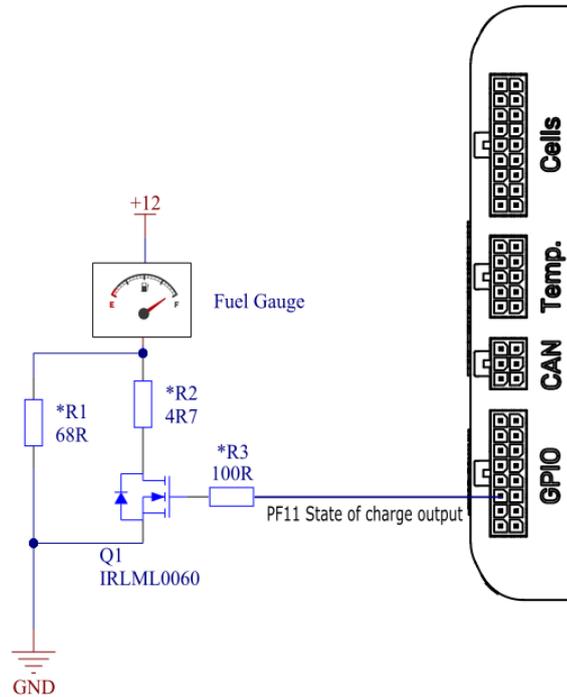
Figure 1-6 Example SOC Output connection circuit

*The values of resistors R1 and R2 depend on the resistance at which the fuel indicator indicates an empty and full tank. These values may be determined by measuring the actual fuel sensor unit of particular vehicle.

Controlling the output current of a certain type of charging devices - in this case the duty cycle of the PWM signal is proportional to the charging current requested by the BMS Mini 3.

⚠ NOTE: This functionality is not available in the current version of the EMUS BMS Mini 3. It will be available in future versions of the product. For more detailed information please contact EMUS Support Team.

## 1.8.2 Frequency measuring inputs

The EMUS BMS Mini 3 pins are wired directly to a peripheral that can measure frequency of a pulsed signal. It could be used to measure the speed of an electric vehicle.
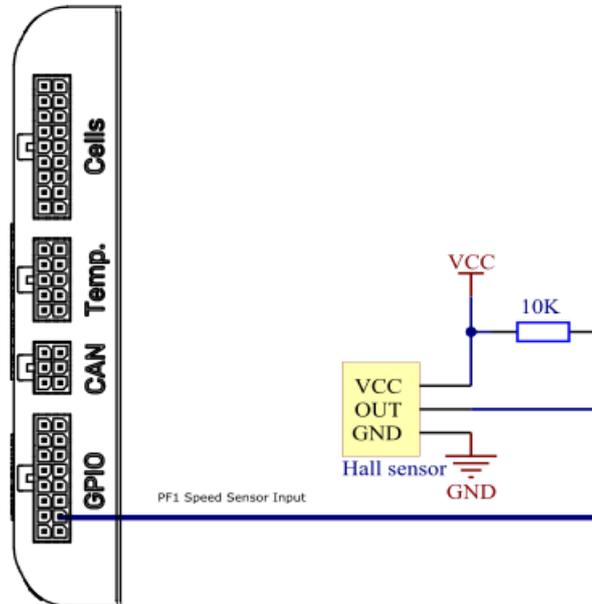


Figure 1-7 Speed IN connection diagram

⚠️ **NOTE**: This functionality is not available in the current version of the EMUS BMS Mini 3. It will be available in future versions of the product. For more detailed information please contact EMUS Support Team.

## 1.9 Current Sensor

Also, EMUS will provide an opportunity to use EMUS Mini Power board current sensors, EMUS G1 Dual Range Current Sensor and third-party CAN current sensors.

⚠️ **NOTE**: External EMUS and CAN current sensors functionality on the current EMUS BMS Mini 3 firmware version is unavailable. This functionality will be available in future versions of the product. Please contact the EMUS Support team for more detailed information

### 1.9.1 EMUS Mini Power board current sensors

EMUS BMS Mini 3 has a current sensor that measures his own current consumption. It is possible to monitor how much EMUS BMS Mini 3 system drains/charge the battery cells. In Current 1 sensor measure battery drain current, Current 2 sensor allows to monitor momentary charging current. On board current measurements also used to calculate SOC/SOH.
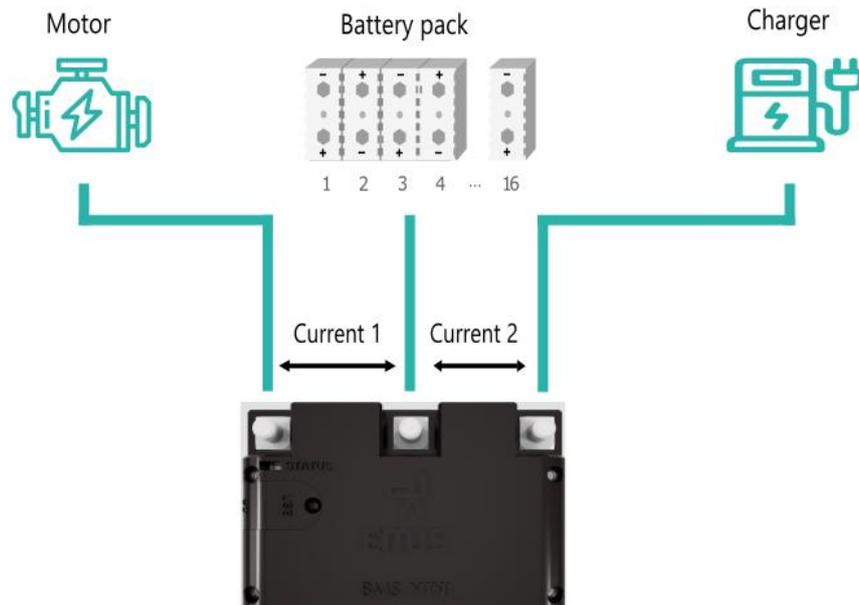


Figure 1-8 EMUS Mini Power board current sensors

## 1.10 Software

### 1.10.1 EVGUI Android and iOS applications

EMUS EVGUI (Electric Vehicle Graphical User Interface) is a freely available application for Android and iOS devices, designed specifically for monitoring the battery status in an electric vehicle. Using this application, a smartphone or a tablet can be connected to the EMUS BMS Mini 3 either via wireless BT protocol and eliminating the need for a dedicated display. In its two main views EMUS EVGUI displays the most relevant statuses, such as vehicle speed, state of charge, estimated remaining distance, power consumption, etc. More detailed diagnostic information can be found in separate menus. The application can also log BMS activity data into a file for further analysis by a technical support specialist when necessary.
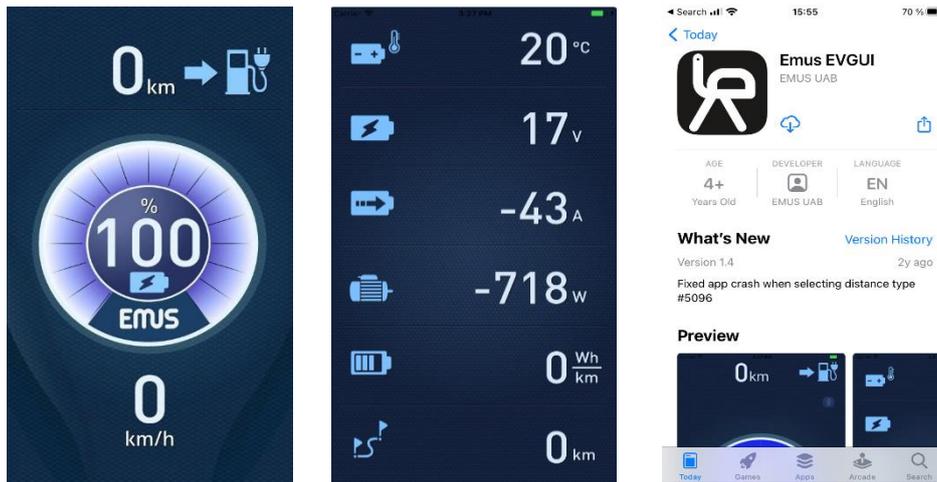
Figure 1-9 iOS EMUS EVGUI app screenshot



Figure 1-11 Download on Apple App    Figure 1-11 Get it on Google Play

## 1.10.2 Control Panel

EMUS Control Panel is the official Windows PC software tool for configuration, maintenance, and diagnostics of the EMUS BMS Mini 3. It comprehensively displays all BMS activity data received from the EMUS BMS Mini 3, gives quick and effortless access to each individual configuration parameter, and allows to perform virtually easily and safely all maintenance operations. The Control Panel is freely available online at https://emusbms.com/support.
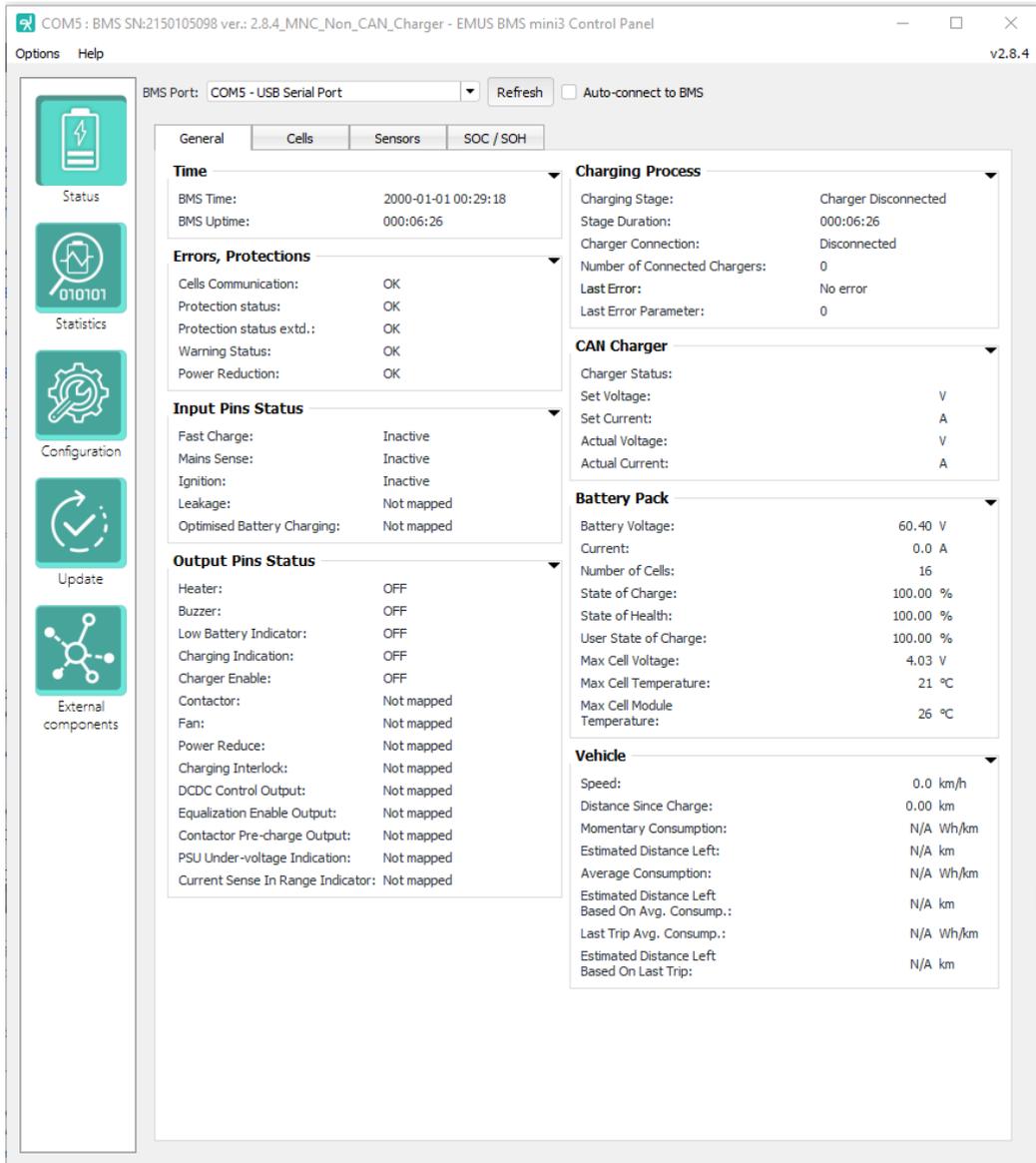
Figure 1-12 EMUS Control Panel

## 1.11 Features of future releases

Table 1-1 Features of future releases

| Feature | Description |
| --- | --- |
| EMUS Bus Bar Type current sensor support | Designed specifically for use in battery packs that consists of prismatic form factor cells. The nominal current measuring range is ±500 A, accuracy reaches 0.5 % |
| EMUS Closed Loop Type current sensor support | Allows to install the sensor directly around a power cable without exposing any conducting parts, which makes it more adaptable and does not bind it to a cell form factor. The nominal current measuring range is ±800 A, accuracy reaches 0.5 %. |
| 3rd party CAN current sensor support | EMUS supports additional types of current sensors produced by 3rd parties. One of them is IVT-S series by IsabellenHütte. |
| EMUS Display Unit support | Device dedicated to monitor battery status and other EMUS BMS Mini 3 activity data in real time. It is designed for use outdoors having glare-free, high contrast and wide viewing angle display |
| Master Slave | Master/Slave functionality allows several EMUS BMS Mini 3 systems to be connected into one network using CAN communication. It enables high modularity and high scalability, so systems could be expanded and managed more easily. |

# Chapter 2: Functionality overview

## 2.1 Cell Monitoring

Individual cell monitoring is a fundamental and one of the most important functions of EMUS BMS Mini 3. EMUS BMS Mini 3 cells connectors, once mounted on a cells, starts its work routine during which it measures the cells voltages and its own internal temperature as well as the external cells temperatures and uses the measured values to regulate the balancing current in an attempt to keep the cell's voltage lower than the balancing threshold, while at the same time keeping its own temperature lower than a certain maximum value to protect itself from overheating. All collected data used in most of the EMUS BMS algorithms starting from visual user cell data monitoring and finishing with complex master-slave EMUS BMS Mini 3 systems and SOC/SOH calculations.

### 2.1.1 Voltage monitoring

EMUS BMS Mini 3 can measure 6 to 16 battery cells with a voltage range of 2.00 - 4.55 V.

Where "Total Number of cells" is the value of a corresponding configuration parameter.

Measured battery cell voltage is used to monitor the battery cell status. The collected data is used in charging/balancing algorithms. Users can quickly select fully charged, fully discharged, and other battery cell's voltage parameters which ensure safe usage and expand battery's life.

> ⚠️ NOTE: EMUS BMS Mini 3 cells voltage measurement range will be increased to 1.000 – 4.950 V. For more detailed information please contact EMUS Support Team.

### 2.1.2 Internal temperature monitoring

EMUS BMS Mini 3 can measure his own temperature. Temperature sensor data helps to prevent self-overheating during balancing procedure and allows to control the self-temperature by using EMUS climate control feature.

### 2.1.3 External temperature monitoring

EMUS BMS Mini 3 has 5 external temperature sensors. Temperature sensors are easy to set-up because they are designed to support "Plug and Play" functionality. You just simply need to connect provided external temperature sensors to any of these slots and no further configuration is needed. Sensors are hot-swappable meaning installation can be performed while system is powered. Use the same steps when you need to remove or replace these sensors.

Measured outdoor temperature used to monitor the condition of the battery cell. The EMUS control panel allows the user to quickly configure the climate control, minimum / maximum charging temperature, according to the current battery characteristics.

## 2.2 Current measurement

### 2.2.1 EMUS Mini Power board current sensors

Using EMUS Mini 3 battery management system possible to have three onboard current sensors that measure battery pack load, charge, and EMUS BMS Mini 3 consumption currents. It becomes easy to know how much the charger is charging, the EMUS BMS Mini 3 and any other system components are draining the battery. On-board current measurements are also used to calculate SOC / SOH.

## 2.3 SOC estimation

State of Charge estimation in EMUS Mini 3 has two main algorithms: "SOC legacy adjustment" and "Integrated SOC/SOH estimator (gen)".

The coulomb counting is done in sync with the current update process: every newly determined momentary current value is multiplied by the update period, and the result, regardless of its sign, is accumulated into volatile memory as Battery Charge value (in Ah). This value is later compared to "Capacity" configuration parameter value to determine the SOC expressed in percentage.

The gen1 algorithm allows to monitor of cell degradation factors and SOC calculations depend on real cell capacity and internal cell's parameters.

### 2.3.1 SOC legacy adjustment algorithm

Coulomb Counting is a standard method of State of Charge estimation method. Yet it depends on used current sensor characteristics and setup.  It may suffer from long-term drift due to slight inaccuracies of the current measurement. Therefore, in EMUS implementation the SOC is adjusted to 100% each time the charging process successfully finishes by equating the battery charge to the value of "Capacity" configuration parameter. If such adjustment is effective in many applications, yet it may insufficient in some cases (e.g. solar energy storage, where the charging process may not finish for many consecutive days if there is not enough sunlight), the optional "Reduce SOC at Under-Voltage" feature maybe used. When its enabled, the battery charge value is adjusted in such way that the SOC would match the "SOC at Low Volt. Warn." parameter or 0% respectively whenever the Low Cell Voltage reduction or Cell Under-Voltage protection is activated. In both cases, the following conditions also need to be met for the adjustment to take place:

The battery current must stay below 0.5C for at least 5 seconds.

The currently estimated SOC value must be greater than that which would be after the adjustment.

Once the adjustment of a type takes place, it will only be repeated if the corresponding reduction or protection is cleared, and the SOC value becomes greater than the corresponding adjustment

value before the adjustment condition is met again.

## 2.3.2 Integrated SOC/SOH estimator (gen1 algorithm)

Both "Coulomb Counting" and "Adjustment by cell voltage" methods can only estimate SOC. These methods lose accuracy overtime because cell degradation factors are being ignored. To keep high estimation accuracy of SOC, and to estimate real cell capacity along with internal cell parameters, EMUS introduced advanced integrated SOC/SOH/SOP estimation algorithm.

To imitate internal chemical processes of lithium-ion cell, equivalent electrical circuit model is being used (Figure 2-11). There:

- $R_0$ – internal resistance, one of the variables calculated by cell model, first value is a reference point, with time algorithm adjusts the value. It has a direct impact on accuracy of SOC.

- $R_{1,2}$ – internal resistance of cell charge polarization used to estimate and eliminate SOC counting error. Variable calculated by creating cell model.

- $C_{1,2}$ – internal capacities of cell charge polarization used to estimate and eliminate SOC counting error. Variable calculated by creating cell model.

- $V_{OC}$ – open circuit voltage.

- $V_t$ – terminal voltage.
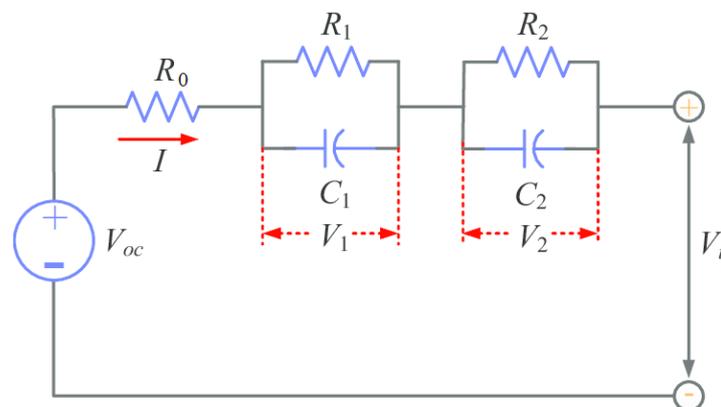


Figure 2-1 EMUS Equivalent circuit model

If accurate charge/discharge current, terminal voltage and internal cells parameters are known and monitored, the state of the battery pack can be predicted with high accuracy. The accuracy of SOC very much depends on accuracy of battery model parameters that must be measured and calculated when preparing cell installation. Also, using advanced calculations, real cells capacity along with internal cells series resistance can be estimated, which corresponds to SOH and SOP. The better current and voltage sensors are used, the higher is estimation accuracy. Good accurate

model would result SOC estimate in range of 1-3%.

To use this algorithm, internal cell parameters (R0, Rp, Cp) must be known, along with OCV-SOC dependency curve. User can use one of existing cell models, defined by EMUS, or define its own model. More about how to configure such model look at chapter 4.11.2 SOC/SOH estimator (gen1 algorithm).

While this algorithm is superior in a long run comparing to other algorithms, there are possible inaccuracies during first one or two charge-discharge cycles. In other words, convergence time is needed.

## 2.3.2.1 SOH algorithm

As battery cell ages, its total capacity decreases, and internal resistance increases. To estimate and correctly evaluate these values BMS regularly calculate these two parameters over time and estimate current state of health of a cell. To calculate the value of SOH, EMUS use this formula:

$$SOH = k * \frac{Cbat\ real}{Cbat\ reference} + \frac{1}{k} * \frac{R0\ reference}{R0\ real}$$

Figure 2-2 Formula for SOH

K is a coefficient that describes current depletion rate of a cell.

EMUS estimate that after convergence (multiple dynamic usage cycles) our SOH prediction with good model parameters is within 1-5% range.

## 2.4 Charging process and charging device control

EMUS BMS Mini 3 controls the charging process according to the measurements made for the battery cells. This ensures that the battery is charged safely, and the cell voltages are correctly balanced after the charging process is finished. Supported charging can be categorized into three distinct types based on how they are controlled:

Basic charging devices (also referred to as non-CAN charging devices). They can only be controlled by switching on and off as they do not have remote output current and voltage adjustment. Charging in this case is controlled by utilizing a special algorithm to turn the charger on an off using a switching device that is driven by a BMS general purpose output pin mapped with "PF10 Charger Enable Output" pin function. The BMS acknowledges the connection and disconnection of such charging device whenever a corresponding high/low signal is detected on a general-purpose input pin mapped with "PF3 Charger Mains AC Sense Input" function.

Charging devices equipped with a CAN interface (or simply CAN chargers). They are controlled by sending the requested output voltage and current values in a CAN message using a protocol that is specific to a charger. In this case the "PF10 Charger Enable Output" pin function is used only for

disconnecting the charger from the battery in case of a critical condition and should drive a corresponding contactor that is separate from the main contactor.

Currently EMUS BMS Mini 3 officially supports the following chargers:

Table 2-1 List of supported chargers and their communication protocols

| Charger Name | Communication Protocol |
|---|---|
| Elcon | CAN J1939-based |
| Zivan RE | CAN Zivan proprietary |
| Powerfinn | CAN |
| Delta-Q | CANOpen - based |
| Non-CAN | I/O Controlled |

**NOTE**: For all chargers recently supported please refer to https://emusbms.com . More chargers, inverters integrations are planned for the next release in Q3 2021.

The BMS detects each charger automatically and distribute the charging current among connected chargers.

The BMS acknowledges that a CAN charger is connected when it receives a CAN message from at least one charger. Depending on the charger model, the charger transmits this message either by itself (periodically), or as a response to a request CAN message from the BMS. Disconnection is acknowledged if the BMS does not receive any CAN message from the charger(s) for more than 15 seconds. Consequently, the "PF3 Charger Mains AC Sense Input" pin function has no meaning when using this type of charging device.

Charging devices of which the output current is proportional to the control signal voltage level (also referred to as analog signal-controlled chargers) are controlled by a corresponding PWM signal generated on the one of output pins of the BMS, which must be mapped with "PF18 Analog Charger Control Output" pin function for that matter. The resultant minimum and maximum voltage levels of such signal can be adjusted in between 0V to 5V range by changing the values of the corresponding "Min PWM Output" and "Max PWM Output" parameters to match the requirements of the charging device.

The role of the "PF10 Charger Enable Output" pin function when using an analog signal-controlled charger is identical to when a CAN charger is used, while the connection and disconnection is acknowledged the same way as for the non-CAN charging devices.

It is important to note that due to BMS internal memory limitations EMUS BMS Mini 3 can support only one charging device type or model at a time, and it is necessary to re-upload the BMS with a different firmware in case it is desired to change the supported type or model.

Regardless of the charging device type, the charging process begins when the BMS detects that a charging device has been connected. EMUS BMS Mini 3 divides it into six separate stages:

**"Pre-Heating" stage** is entered when the minimum cell temperature (or minimum BMS temperature

if both are available, whichever of them is lower), which is assumed to equal to the ambient temperature of the battery pack, is lower than the threshold set by "Minimum Charging Temperature" parameter (1°C by default). This points that the battery is too cold to be charged safely, therefore during this stage the BMS attempts to warm it up by activating the general-purpose output pin that is mapped with "PF5 Heater Enable Output" function. This function is intended for switching a heating device (a heater) on and off. The charging device is disconnected from the battery using the general-purpose pin mapped with "PF10 Charger Enable Output" pin function in the meantime.

**"Pre-Charging" stage** is entered when the minimum cell voltage is lower than "Pre-charge Threshold" parameter value. It is assumed that the cell is deeply discharged if this condition is met, therefore during this stage the battery is charged with a reduced current to avoid heat development inside the cells due to their increased internal resistance.

The actual charging current during this stage depends on the charging device type and several configuration parameters:

When using a CAN charger, the charging current during this stage is determined according to the following formula:

$$I_{Charging} = \frac{[Pre-charge\ Current\ \%\ configuration\ parameter] \times [Configured\ Capacity]}{100\%}; \qquad (1)$$

Where "Capacity" and "Pre-charge Current" are the values of corresponding configuration parameters;

When using an analog signal-controlled charging device, the charging current does not depend on the "Capacity" parameter, and is instead determined according to the following formula:

$$I_{Charging} = \frac{[Pre-charge\ Current\ \%\ configuration\ parameter] \times I_{Max}}{100\%}; \qquad (2)$$

Where $I_{Max}$ is the current that charger outputs when the control signal is at its maximum value (which is determined by the "Max PWM Output" parameter), and "Pre-charge Current" is the value of the corresponding configuration parameter;

When using a non-CAN charging device, the "Pre-Charging stage" is skipped because EMUS BMS Mini 3 does not have the ability to effectively reduce its output current without potentially forcing it to function outside of its normal operating conditions.

**"Main Charging" stage** is entered if the maximum cell voltage is less than "Fully Charged Voltage" parameter value and no condition to enter any other stage is present, which indicates that no special precautions are needed in order to charge safely, therefore during this stage the battery is charged with the highest possible current. The actual charging current value depends on certain EMUS BMS Mini 3 configuration parameters as well as the physical limitations of the used charging device:

When using a CAN charger, the charging current during this stage is set by either the "Fast

Charging Current" or "Slow Charging Current" parameter value depending on the state of the general-purpose input pin that is mapped with "PF2 Fast Charge Switch Input" pin function. If this function is not mapped "Slow Charging Current" parameter is used by default;

When using an analog signal-controlled charging device, the charging current during this stage is equal to the charging device's output current value to which the control signal corresponds when it is equal to "Max PWM Output" parameter value;

When using a non-CAN charging device, the charging current during this stage depends solely on its maximum output current.

During this stage EMUS BMS Mini 3 also executes the early balancing algorithm. This means that if the maximum cell voltage is higher than "Early Balancing Threshold" parameter value, and the difference between minimum and maximum cell voltages is more than "Allowed Disbalance" parameter value, the balancing threshold is set to minimum cell voltage plus 5mV, but not higher than maximum cell voltage. In result, balancing is enforced on the cells with the highest voltages, which can effectively shorten the duration of the charging process if the battery pack is significantly disbalanced (for example when being charged for the first time after installation).

**"Balancing" stage** is entered when the maximum cell voltage is more than or equal to the "Fully Charged Voltage" parameter value. At this point, the difference in stored energy between the cells is proportional to the difference in their voltages, therefore during this stage EMUS BMS Mini 3 takes several actions to eliminate that difference and balance them. Firstly, the balancing threshold is by default equal to "Fully Charged Voltage" parameter value as well, therefore the corresponding EMUS BMS Mini 3 cell's track naturally start to divert the charging current through it shunt resistor in attempt to prevent the cell voltages from rising further. Secondly, the charging current is also controlled respect into similar criteria, however this process differs depending on what type of charging device is used.

When using a CAN or analog signal controlled charger, the charging current during this stage is precisely regulated in such way that the voltages of already fully charged cells would not rise much further, but at the same time it would not be equal to zero so the cell that are not full yet could "catch up". The "Balancing stage" is over if at the moment when the charging current drops below "Charging Finished Current" parameter value the max cell voltage is equal to "Fully Charged Voltage" parameter value, the difference between minimum and maximum cell voltages is less than the value of "Allowed Disbalance" parameter, and minimum balancing rate is more than a half of maximum balancing rate.

When using a non-CAN charging device EMUS BMS Mini 3 does not have any means to regulate the charging current, therefore in such case this stage is a bit different. When it begins, the charging device is kept on until the maximum cell voltage starts to exceed the "Fully Charged Voltage" parameter value by more than 20mV, even though the corresponding EMUS BMS Mini 3 is shunting the charging current. Then the charging device is turned off and the balancing threshold is set to minimum cell voltage plus the value of "Allowed Disbalance" parameter (but not higher

than "Fully Charged Voltage" parameter value) in order to dissipate the energy difference between cells as heat. This continues until the maximum balancing rate drops to 5% or lower, but not for shorter than 10 seconds. If at the end of this phase the difference between minimum and maximum cell voltages is lower than the "Allowed Disbalance" parameter value, this stage is over, otherwise the charging device is turned on again and this process repeats.

**"Charging Finished" stage** in entered whenever the "Balancing stage" is completed. This indicates that the charging process is complete, therefore during this stage the charging device, regardless of its type, is disconnected from the battery by deactivating the general-purpose output pin mapped with "PF10 Charger Enable Output" pin function.

**"Charging Error" stage** is entered if one of several pre-defined critical conditions are met during the charging process. During this stage, the BMS attempts to protect the battery by deactivating the general-purpose output pins mapped with "PF10 Charger Enable Output" and "PF5 Heater Enable Output" functions in order to disconnect it from both the charging device and the heater. Conditions that result in transition to "Charging Error stage" are the following:

No cell communication – if cell communication is lost during any stage of the charging process, EMUS BMS Mini 3 will terminate the charging since it cannot determine the cell parameters in such case. However, if this condition is already active at the beginning of the charging process and "Cell Comm Restore" feature is enabled, EMUS BMS Mini 3 will not register a charging error for as long as the "Restore Duration" parameter value. During this time, EMUS BMS Mini 3 will go into "Pre-Charging stage" if CAN or analog signal-controlled charger is used, or into "Main Charging stage in case a non-CAN charging device is used. This way it will attempt to restore the cell communication by charging the cells, if it is not present because they are discharged too deeply, and their voltages are insufficient to power the EMUS BMS Mini 3;

Charging stage duration exceeded – if the duration of either "Pre-Charging stage", "Main Charging stage", or "Balancing stage" has exceeded the value of corresponding Max Pre- Charging Stage Duration, Max Main Charging Stage Duration, or Max Balancing Stage Duration parameter, the charging is terminated as this may indicate a bad cell, big energy leak, or simply not optimal EMUS BMS configuration;

Detected number of cells do not match "Number of Overall cells parameter – if the number of detected cells does not match "Number of Overall Cells parameter the charging is terminated, since this indicates either a EMUS BMS Mini 3 malfunction, or incorrect configuration;

Protection event occurred – if either the Charge Over-Current, Discharge Over-Current, Insulation Fault, or No Current Sensor protection is enabled and active, the charging is terminated. Conditions to enter this stage that are equivalent to other protections (except Cell Under-Voltage, Charger Connected, and Pack Under-Voltage protections) are considered to be the most critical and are checked separately in order to eliminate the possibility to turn off their checking by disabling the corresponding protection. Conditions equivalent to Cell Under-Voltage, Charger Connected, and Pack Under-Voltage protections are not checked in order to avoid blocking the

charging process;

Cell or electronics module temperature too high – EMUS BMS Mini 3 will terminate the charging if internal EMUS BMS Mini 3 temperature is higher than the value of Electronics module Over- heat protection "Activate at" parameter, or external temperature is higher than the value of equivalent Cell Over-Heat protection parameter, since this indicates that the ambient temperature is too high or that there is an unexpectedly high heat production somewhere in the battery;

Cell Over-voltage – EMUS BMS Mini 3 BMS will terminate the charging if maximum cell voltage rises above the threshold set by Cell Over-voltage protection "Activate at" parameter, as this indicates that either a charging device malfunction, or incorrect BMS configuration.

Each charging stage continues until the entering condition is no longer active, except for the "Balancing stage" case, which is already described above. Another exception is the "Charger Error stage" when it is entered due to "Charging stage duration exceeded" condition being active - in this case it is possible to clear the entering condition only by manually disconnecting and reconnecting the charging device.

The order in which the charging stages are executed is not strictly defined, and although some of the stages tend to naturally go one after another in the same order as they are listed above, it varies depending on the situation. However, there are several hard-coded rules and exceptions that affect it:

The occurrence of entering conditions of the "Pre-heating stage" and "Charging Error stage" is not directly related to the battery state of charge and is abrupt by nature, therefore these stages can take place at any point in the charging process and interrupt any other stage;

Once the "Balancing stage" has been entered, EMUS BMS Mini 3 will not go back to "Main Charging stage" directly;

Once "Charging Finished stage" has been reached, EMUS BMS Mini 3 will go not back to "Pre-Charging stage", "Main Charging stage", or "Balancing stage" directly unless the maximum cell voltage has dropped below "Charger Restart Voltage" parameter value. This also applies if "Charging Finished stage" is interrupted by "Pre-heating stage" or "Charging Error stage".

The charging process is over when the BMS acknowledges that the charging device has been disconnected regardless in which charging stage EMUS BMS Mini 3 is at the time and is not resumed but started over if the charging device is reconnected.

It is important to note that for safety reasons the BMS does not allow to change any configuration parameters during the charging process, except during "Charging Error stage", or if the parameter in question is the "Invert" option of the general purpose input pin that is mapped with "PF3 Charger Mains AC Sense Input" pin function, but only if a non-CAN or analog signal controlled charger is used.

## 2.4.1 Charging Interlock

When one of the BMS general-purpose output pins is mapped with "PF17 Charging Interlock" pin function, it generates a dedicated control signal that is active if the charging device is connected, regardless of any other condition. This feature is useful if during charging it is necessary to disable some equipment in the system (for example the motor controller) without disconnecting the main contactor and works with any type of charging device.

## 2.5 Battery protections

During discharge, EMUS BMS Mini 3 protects the battery from operation beyond certain limits of its parameters (voltage, temperature, current) by deactivating the general-purpose output pin mapped with "PF12 Battery Contactor Output" pin function. This pin function is intended for driving the main contactor that disconnects the battery from the load. There are seventeen different protection types:

Table 2-2 List of protections and their descriptions

| Protection Name | Description |
|---|---|
| Cell Under-Voltage | Prevents the battery from being discharged further if the voltage of at least one of the cells is below the threshold set by the corresponding "Activate at" configuration parameter. |
| Cell Over-Voltage | Prevent the cells from being overcharged during regenerative processes and is activated if the voltage of at least one of the cells is above the threshold set by the corresponding "Activate at" configuration parameter. |
| Discharge Over-Current | Protection is activated if the measured discharge current is above the threshold set by the corresponding "Activate at" parameter, thus preventing the battery from being discharged at a rate that is higher than specified by the cell manufacturer. |
| Charge Over-Current | Protection is activated if the measured charge current is above the threshold set by the corresponding "Activate at" configuration parameter, thus preventing the high currents during regenerative processes from potentially damaging the cells. |
| Electronics Module Under-Heat | Prevents the battery from being operated when the temperature measured by the internal EMUS BMS Mini 3 temperature sensor is below the threshold set by corresponding "Activate at" configuration parameter, which is likely to be caused by using battery management system at low temperatures, an equipment failure. |
| Electronics Module Over-Heat | Prevents the battery from being operated when the temperature measured by the internal EMUS BMS Mini 3 temperature sensor is above the threshold set by corresponding "Activate at" configuration parameter, which is likely to be caused by sparking/bad contact, an equipment failure, or a bad cell. |
| No Cell Communication | Prevents the battery from being operated if the Current Sensor is connected improperly or not connected at all. |
| Insulation Fault | Protection is activated in case an active signal is detected on a |

| | |
|---|---|
| | general-purpose input pin that is mapped with "PF15 Leakage Sensor Input" function. Such signal is meant to be generated by a third-party insulation fault detector that is selected appropriately for the application. |
| Cell Under-Heat | Prevents the battery from being operated when the temperature measured by the external temperature sensor of one of the cells is below threshold set by corresponding "Activate at" configuration parameter, which may indicate an unexpected cold somewhere in the battery; |
| Cell Over-Heat | Prevents the battery from being operated when the temperature measured by the external temperature sensor of one of the cells is above threshold set by corresponding "Activate at" configuration parameter, which may indicate an unexpected heat somewhere in the battery. |
| No Current Sensor | Prevents the battery from being operated if the Current Sensor is connected improperly or not connected at all. |
| Charger Connected | Protection is activated if the charging process is taking place. |
| Pack Under-Voltage | Prevents the battery from being discharged further if the voltage of the battery pack is below the threshold set by the corresponding "Activate at" configuration parameter. |
| Pack Over-Voltage | Prevents the battery from being overcharged further if the voltage of the battery pack is above the threshold set by the corresponding "Activate at" configuration parameter. |
| Cell Voltage Deviation | Prevents the battery from big differences between battery cells. Activating if difference between maximum and minimum cell voltages is above the threshold set by the corresponding "Activate at" configuration parameter. |
| External Temperature Sensor Loss | Prevents the battery from unexpected temperature changes if one of the cells sending invalid external temperature measurements. |
| Cell Wire Break | Protects the system from the cell monitoring broken wires from the monitoring device to the battery cells. |

All protections except "Cell Over-Heat", "No Current Sensor", "External Temperature Sensor Loss" and "Pack Under-Voltage" are enabled by default but can be disabled individually during configuration if necessary. Each protection that has an "Activate at" threshold parameter also has a separate "Deactivate at" threshold parameter that allows to create a hysteresis between activation and deactivation. Regardless of that, all protections except "Charger Connected" have configurable activation and deactivation delays. This means that EMUS BMS Mini 3 will tolerate the activation condition for as long as the corresponding "Activation delay" parameter value before activating the protection. Likewise, the deactivation condition has to persist for as long as the corresponding "Deactivation delay" parameter value for the protection to be deactivated.

It is important to note that "Cell Under-Voltage", "Cell Over-Voltage", "Electronics Module Under-Heat", "Electronics Module Over-Heat", "Cell Under-Heat", "Cell Over-Heat", "Pack Under-Voltage", "Pack Over-Voltage" and "Cell Voltage Deviation" protections will be activated only if the

corresponding cell parameter values are valid. Also, if the "No cell communication" protection is enabled, it will be active when the BMS is powered up by default, thus prevent the main contactor from closing until cell communication is established. Deactivation delay will have no effect in this case, and the protection will be deactivated immediately when cell communication is established. More about battery protections configuration you can find in chapter: (4.75 Protections).

## 2.5.1 Contactor pre-charge

In a lot of different applications, the battery that is managed by EMUS BMS Mini 3 connects to a load that has a substantial input capacitance. In such case, it is often desirable to limit the high in-rush current that occurs when the main contractor is closed in order to reduce stress to the internal components of the load device and prevent the contactor from welding. For that reason, EMUS BMS Mini 3 offers a very straightforward contactor pre-charge feature (not to be confused with "Pre-Charging stage" that occurs during the charging process).

PF26 Contactor Pre-charge Output

PF12 Battery Contactor Output

"No Cell Communication" condition
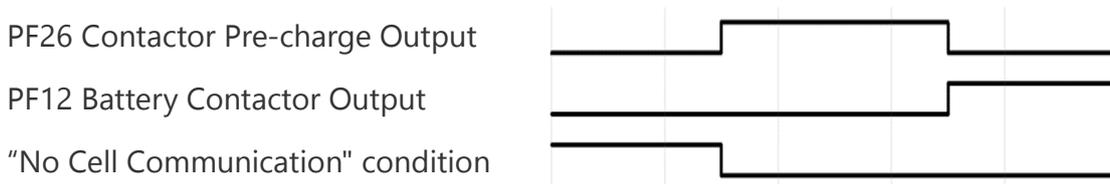
Figure 2-3 Contactor pre-charge timing diagram

This feature works by activating a general purpose output pin that is mapped with "PF26 Contactor Pre-Charge Output" pin function for a period of time that is equal to "Contactor Pre-charge Duration" parameter value whenever the main contactor needs to be closed, as shown in Figure 2-33 (i.e. during system power-up, or when a protection is deactivated). The mentioned pin function should drive a current limiting pre-charge sub-circuit that bypasses the contactor.

## 2.5.2 External contactor deactivation

In case it is desired to allow an external system that utilizes EMUS BMS Mini 3 to override the control of the main contactor without compromising the contactor pre-charge functionality, the External Contactor Deactivation feature can be used. When it is enabled, the general-purpose output pin mapped with "PF12 Battery Contactor Output" pin function remains deactivated unconditionally until the BMS receives a special activation message over the CAN interface. From that point the mentioned pin is controlled in a normal manner and becomes unconditionally deactivated again only if BMS receives a special deactivation message over the CAN interface. Alternatively, if the "Reset External Contactor Deactivation On Protection" sub-feature is enabled, the main contactor remains open every time it is disconnected due to active protection, even if the protection condition is cleared. In such case it is necessary to send the special activation CAN message again. The detailed information about the activation and deactivation messages is out of the scope of this document, and can be found in the EMUS G1 Control Unit CAN Protocol document instead.

## 2.6 Power reductions

Apart from protecting the battery during discharge by disconnecting the main contactor, EMUS BMS Mini 3 can also generate a separate "power reduction" signal on a general-purpose pin if it is mapped with "PF16 Power Reduction Output" pin function. This signal can be used both for disconnecting non-essential loads or activating a power reduction mode on the load device (e.g. motor controller), and for a second level of protection that has a different reaction time, or simply for indication. There are four reduction types:

Table 2-3 List of reductions and their descriptions

| Reduction Name | Description |
|---|---|
| Low Cell Voltage | Is activated if the voltage of at least one of the cells is below the threshold set by the corresponding "Activate at" configuration parameter. |
| High Discharge Current | Is activated if the measured discharge current is above the threshold set by the corresponding "Activate at" configuration parameter. |
| High Electronics Module Temperature | Is activated if the internal temperature of EMUS BMS Mini 3 is above the threshold set by corresponding "Activate at" configuration parameter. |
| High Cell Temperature | Is activated when the temperature measured by the external temperature sensor of one of the cells is above threshold set by corresponding "Activate at" configuration parameter. |

Similarly, to the protections, each reduction also has a configurable activation/deactivation threshold (if applicable), as well as configurable activation and deactivation delays. All reductions except "High Cell Temperature" are enabled by default but can be disabled individually during

configuration. More about battery power reductions configuration you can find in chapter: (4.86 Load power reductions).

## 2.7 Warnings

Apart from protecting the battery during discharge by disconnecting the main contactor or enabling a "power reduction" signal on a general-purpose pin, EMUS BMS Mini 3 can also send separate warning messages to Control Panel. These messages can be used to notify the user of various dangerous situations without any direct impact on the operation of the battery management system. Similarly, to the protections and power reductions, each warning message also has a configurable activation/deactivation threshold (if applicable), as well as configurable activation and deactivation delays. All warnings except "Pack Under Voltage" are enabled by default but can be disabled individually during configuration. There are thirteen warning types:

Table 2-4 List of warnings and their descriptions

| Name | Description |
|------|-------------|
| Cell Under-Voltage | Warning notifies the user if the voltage of at least one of the cells is below the threshold set by the corresponding "Activate at" configuration parameter. |
| Cell Over-Voltage | Warning notifies the user if the voltage of at least one of the cells is above the threshold set by the corresponding "Activate at" configuration parameter. |
| Pack Under-Voltage | Warning notifies the user if the total is below the threshold set by the corresponding "Activate at" configuration parameter. |
| Pack Over-Voltage | Warning notifies the user if the total is above the threshold set by the corresponding "Activate at" configuration parameter. |
| Discharge Over-Current | Warning notifies the user if the measured discharge current is above the threshold set by the corresponding "Activate at" configuration parameter. |
| Charge Over-Current | Warning notifies the user if the measured charge current is above the threshold set by the corresponding "Activate at" configuration parameter. |
| Electronics Module Under-Heat | Warning notifies the user if the internal temperature of EMUS BMS Mini 3 is below the threshold set by corresponding "Activate at" configuration parameter. |
| Electronics Module Over-Heat | Warning notifies the user if the internal temperature of EMUS BMS Mini 3 is above the threshold set by corresponding "Activate at" configuration parameter. |
| Cell Under-Heat | Warning notifies the user if the external temperature of one of the cells is below the threshold set by the corresponding "Activate at" configuration parameter. |
| Cell Over-Heat | Warning notifies the user if the external temperature of one of the cells is above the threshold set by corresponding "Activate at" configuration parameter. |
| Reduction Active | Warning notifies the user if one of the power reductions is active. |

| Cell Communication Loss | Warning notifies the user when EMUS BMS Mini 3 is not able to monitor all the cell's parameters due to a hardware malfunction or incorrect installation. |
|---|---|
| Cell Voltage Deviation | Warning notifies the user if the difference between the maximum and minimum cell voltages is above the threshold set by the corresponding "Activate at" configuration parameter. |

More about battery warnings configuration you can find in chapter: (4.9 Warnings).

## 2.8 Heater and cooling fan control

To allow safe and reliable use of lithium batteries in various climate conditions, EMUS BMS Mini 3 offers several different options to control a heater and/or a cooling device. Any of the BMS's general-purpose output pins mapped with the "PF13 Battery Fan Output" pin function will be activated whenever either the maximum EMUS BMS Mini 3 temperature or maximum cell temperature (if both are available) is above the threshold set by "Fan On Temperature" parameter. Such output is intended to control a cooling device that is used for cooling the EMUS BMS Mini 3 during the "Balancing stage" of the charging process, which allows to reduce the duration of this stage. Alternatively, it can control a cooling device that is used for cooling the whole battery, and thus diminish the accelerated aging effect that operation in hot climate has on the battery, or protect the battery from overheating if it is discharged using very high current.

Most lithium chemistry batteries cannot be charged in temperatures below 0 °C without causing irreversible loss of capacity or even a short circuit between the electrodes due to the accumulation of metallic lithium on the anode that occurs in such conditions. For this reason, EMUS BMS Mini 3 attempts to "pre-heat" the battery before charging by activating any general-purpose output pin mapped with "PF5 Heater Enable Output" pin function, which is intended for controlling a heating device. This feature is described in more detail in chapter Charging process and charging device control

## 2.8.1 Climate Control

In case it is desired to utilize a heating device for always keeping the temperature of the battery at a certain level instead of using it only for pre-heating the battery before charging, the "Climate Control" feature can be used. When it is enabled in the configuration, the general-purpose pin mapped with "PF5 Heater Enable Output" function will be active as long as both the minimum Electronics Module temperature and minimum cell temperature (if both are available) are not more than 1°C above the threshold set by either "Normal Temperature" or "Charging Temperature" parameter depending on whether charging is taking place or not. Once deactivated, it is activated again if either minimum EMUS BMS Mini 3 temperature or minimum cell temperature (if both are available) falls more than 1°C below the said threshold. Cooling device control feature mentioned in the parent chapter is separate from the Climate Control, and therefore these two features can be

used both independently and in combination. Climate Control algorithm includes several safety mechanisms to prevent the battery from being drained in case the heating device is powered directly from it, meaning that the heating device is deactivated regardless of the temperature of the EMUS BMS Mini 3(or cells) in the following cases:

If the estimated battery state of charge (SOC) is below "Minimum SOC" parameter value;

If the minimum cell voltage is less that the value of "Activate at" threshold of Cell Under- Voltage protection;

If charger is not connected for longer than the value of "Max duration when not charging" parameter.

It is also important to note that heating device control during the "Pre-Heating stage" of the charging process completely overrides Climate Control feature."

## 2.9 DC/DC converter control

In some cases, when the battery is insufficiently charged or cannot be charged soon, the battery may discharge if all the peripherals in the system are turned on. This means that if the DC / DC converter is not disconnected from the battery until the battery is fully discharged, all EMUS BMS Mini 3 peripherals remain powered and may drain the battery faster if it is not charged within that time. The EMUS BMS Mini 3 has a special function that allows you to automatically disconnect the DC / DC converter, thus reducing power consumption to avoid such situations.

The DC/DC converter control feature is active by default, without the need to be enabled in the configuration, and deactivates any EMUS BMS Mini 3 general purpose output pin that is mapped with "PF24 DC/DC Control Output" pin function if the minimum cell voltage becomes lower than or equal to the value of corresponding Active State Threshold or Passive State Threshold parameter. In this case the BMS state is active if a charger is connected or an active signal is detected on any general-purpose input pin mapped with "PF4 Ignition Key Input" pin function, and the parameter to be used is determined accordingly. The mentioned output is intended for driving a relay/contactor that disconnects the DC/DC converter from the battery and is activated again if the minimum cell voltage rises above the value of relevant threshold parameter by more than 10mV, but not sooner than 10 seconds after it was deactivated.

## 2.10 Battery contactor control by "Ignition"

PF26 Contactor Pre-charge
Output

PF12 Battery Contactor Output
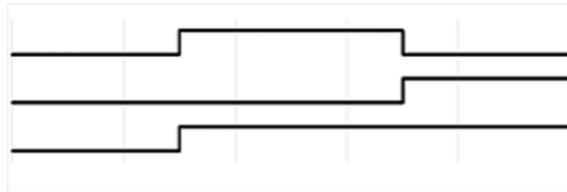


Figure 2-4 Battery contactor control by "Ignition" sequence

In applications where user has to manually control battery contactor, a pin function "PF4 Ignition Key Input" can be used. This feature automatically controls contactor's output according to an input state of "PF4 Ignition Key Input" pin. If enabled "PF26 Contactor Pre-charge Output" feature will take place before contactor control.

## 2.11 Optimized Battery Charging

In applications where battery pack does not need to be fully charged, "Optimized Battery Charging" feature can be used. During the charging process when SOC will reach setpoint, charging process will be stopped automatically. Feature need to be activated by Input PF29 Optimized Battery Charging. (Check PF number)

## 2.12 Statistics

For diagnostic purposes, EMUS BMS Mini 3 keeps track of various pre-defined battery and BMS operation statistics and stores them in its internal non-volatile memory. Each statistic, depending on its type, can consist of a corresponding main value, additional value, and a timestamp. A list of all statistics is provided in Table 2-55.

Table 2-5 List of statistics and their descriptions

| ID | Statistic | Description |
|---|---|---|
| 1 | Total discharge* | The total amount of charge transferred out of the battery in Ah (or kAh if normal range has been overflowed). |
| 2 | Total charge* | The total amount of charge transferred into the battery in Ah (or kAh if normal range has been overflowed). |
| 3 | Total discharge energy* | The total amount of energy transferred out of the battery in Wh (or kWh if normal range has been overflowed). |
| 4 | Total charge energy* | The total amount of energy transferred into the battery in Wh (or kWh if normal range has been overflowed). |
| 5 | Total discharge time* | The total amount of time when negative (discharge) current was measured is seconds (or hours if normal range has been overflowed). |
| 6 | Total charge time* | The total amount of time when positive (charge) current was measured in seconds (or hours if normal range has been overflowed). |
| 7 | Total distance* | The number of speed signal pulses registered on SPEED IN input when it is mapped with "PF1 Speed Sensor Input" pin function. |
| 8 | Max Discharge Current | The highest recorded discharge current value. This statistic also |

| | | contains the timestamp of when the value was recorded. |
|---|---|---|
| 9 | Max Charge Current | The highest recorded charge current value. This statistic also contains the timestamp of when the value was recorded. |
| 10 | Master clear count* | The number of times the master clear procedure has been performed. |
| 11 | Min Cell Voltage | The lowest recorded cell voltage. Additionally, contains the cell number and timestamp of when this value was recorded. |
| 12 | Max Cell Voltage | The highest recorded cell voltage. Additionally, contains the corresponding cell ID and timestamp of when this value was recorded. |
| 13 | Max Cell Voltage Difference | The highest recorded difference between cell voltages. Additionally, contains the corresponding minimum and maximum cell voltages, ID of the cell with minimum voltage, and timestamp of when these values were recorded. |
| 14 | Min Pack Voltage | The lowest recorded battery pack voltage. Additionally, contains timestamp of when this value was recorded. |
| 15 | Max Pack Voltage | The highest recorded battery pack voltage. Additionally, contains timestamp of when this value was recorded. |
| 16 | Min electronics module temperature | The lowest recorded EMUS BMS Mini 3 internal temperature. Additionally, contains the corresponding cell ID and timestamp of when this value was recorded. |
| 17 | Max electronics module temperature | The highest recorded EMUS BMS Mini 3 internal temperature. Additionally, contains the corresponding cell ID and timestamp of when this value was recorded. |
| 18 | Max electronics module temperature difference | The highest recorded difference between EMUS BMS Mini 3 internal temperatures. Additionally, contains the corresponding minimum and maximum BMS internal temperatures, ID of the temperature sensor with minimum temperature, and timestamp of when these values were recorded. |
| 19 | BMS start count | The number of times EMUS BMS Mini 3 has been powered up. Additionally, contains the timestamp of the last occurrence. |
| 20 | Cell under-voltage protection count | The number of times Cell Under-Voltage protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 21 | Cell over-voltage protection count | The number of times Cell Over-Voltage protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 22 | Discharge over-current protection count | The number of times Discharge Over-Current protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 23 | Charge over-current protection count | The number of times Charge Over-Current protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 24 | Electronics module overheat protection count | The number of times Electronics Module Over-heat protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 25 | Leakage protection count | The number of times Insulation Fault protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 26 | No cell comm. protection count | The number of times No Cell Communication protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 27 | Low voltage power reduction count | The number of times Low Cell Voltage reduction has been activated. Additionally, contains the timestamp of the last occurrence. |
| 28 | High current power reduction count | The number of times High Discharge Current reduction has been activated. Additionally, contains the timestamp of the last occurrence. |
| 29 | High electronics module temperature power reduction count | The number of times High Electronics Module Temperature reduction has been activated. Additionally, contains the timestamp of the last occurrence. |
| 30 | Charger connect count | The number of time charger connection has been acknowledged. |
| 31 | Charger disconnect count | The number of times charger disconnection has been acknowledged |

| 32 | Pre-heat stage count | The number of time the "Pre-Heating" stage of the charging process has been entered. |
|---|---|---|
| 33 | Pre-charge stage count | The number of time the "Pre-Charging" stage of the charging process has been entered. |
| 34 | Main charge stage count | The number of time the "Main Charging" stage of the charging process has been entered. |
| 35 | Balancing stage count | The number of time the "Balancing" stage of the charging process has been entered. |
| 36 | Charging finished count | The number of time the "Charging Finished" stage of the charging process has been entered. |
| 37 | Charging error occurred | The number of time the "Charging Error" stage of the charging process has been entered. |
| 38 | Charging retry count | The number of times the entering condition of the "Charging Error" stage of the charging process has been automatically cleared. |
| 39 | Trips count | The number of times the recorded driven distance was more than zero between two consecutive charge connection acknowledgments. |
| 40 | Charge restarts count | The number of times the charging process automatically restarted when maximum cell voltage dropped below "Charger Restart Voltage" parameter value. |
| 41 | Master/Slave configuration error count | The number of times Master/Slave configuration error protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 42 | Master/Slave common CAN Bus failure count | The number of times Master/Slave common CAN Bus failure protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 43 | Master/Slave internal CAN Bus failure count | The number of times Master/Slave internal CAN Bus failure protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 44 | Master/Slave configuration mismatch count | The number of times Master/Slave configuration mismatch reduction has been activated. Additionally, contains the timestamp of the last occurrence. |
| 45 | Master/Slave common CAN Bus malfunction count | The number of times Master/Slave common CAN Bus malfunction reduction has been activated. Additionally, contains the timestamp of the last occurrence. |
| 46 | Cell overheat protection count | The number of times Cell Over-heat protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 47 | High cell temperature power reduction count | The number of times High Cell Temperature reduction has been activated. Additionally, contains the timestamp of the last occurrence. |
| 48 | Min Cell Temperature | The lowest recorded cell temperature. Additionally, contains the corresponding cell ID and timestamp of when this value was recorded. |
| 49 | Max Cell Temperature | The highest recorded cell temperature. Additionally, contains the corresponding cell ID and timestamp of when this value was recorded. |
| 50 | Max Cell Temperature Difference | The highest recorded difference between cell temperatures. Additionally, contains the corresponding minimum and maximum cell temperatures, ID of the cell with minimum temperature, and timestamp of when these values were recorded. |
| 51 | Secure statistics resolution* | Each bit of the value stored by this statistic indicates if the normal range of the corresponding secure statistic (ID 1 to 7) has overflowed and its resolution has been decreased. |
| 52 | No current sensor protection count | The number of times No Current Sensor protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 53 | Heater activation count | The number of times the general-purpose output pin mapped with "PF5 Heater Enable Output" pin function has been activated. |

| 54 | Pack under-voltage protection count | Pack under-voltage protection count |
|---|---|---|
| 55 | CAN Comm watchdog timeout count | CAN Comm watchdog timeout count |
| 56 | Pack over-voltage protection count | The number of times Pack Over-Voltage protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 57 | Cell under-heat protection count | The number of times Cell Under-Heat protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 58 | Cell voltage-deviation protection count | The number of times Cell Voltage-Deviation protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 59 | Pack voltage-deviation protection count | The number of times Pack Voltage-Deviation protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 60 | Electronics module under-heat protection count | The number of times Electronics Module Under-Heat protection has been activated. Additionally, contains the timestamp of the last occurrence. |
| 61 | External temperature sensor loss protection count | The number of times External Temperature sensor loss protection has been activated. Additionally, contains the timestamp of the last occurrence. |

Most of the statistics can be cleared from the Control Panel or by sending a certain command to the BMS via USB, RS232, or CAN interface. However, the ones that store accumulated values and indirectly indicate the battery's state of health (marked with "*" in the Table 2-55) are considered "secure" and can only be cleared by performing the "Master Clear" procedure. More detailed information about clearing the statistics and performing the "Master Clear" procedure can be found in the "Maintenance" section.

The statistics, depending on the type of data they contain, are stored in the non-volatile memory differently:

Secure statistics are stored in the non-volatile memory identical manner as the periodically backed up non-volatile status values (such as Battery Charge);

Non-secure statistics that contain directly measured and therefore quite frequently changing values (e.g. Max Cell Voltage) are stored in a similar fashion as the secure statistics, except that they are not stored in non-volatile RAM, only in permanent memory;

All other statistics are stored directly in permanent memory.

## 2.13 Events

During operation, EMUS BMS Mini 3 keeps a log of the most recent events in its internal non-volatile memory. It consists of 32 entries, each of which stores an event type identifier and occurrence timestamp. Once all 32 entries a filled, any new event replaces the oldest entry. All event types are described in the Table 2-66.

Table 2-6 List of events and their descriptions

| ID | Event | Description |
|----|-------|-------------|
| 1 | BMS Started | BMS Unit powered up or restarted |
| 2 | Lost communication to cells | "No Cell Communication" protection has been activated |
| 3 | Established communication to cells | "No Cell Communication" protection has been deactivated |
| 4 | Cells voltage critically low | "Cell Under-Voltage" protection has been activated |
| 5 | Critical low voltage recovered | "Cell Under-Voltage" protection has been deactivated |
| 6 | Cells voltage critically high | "Cell Over-Voltage" protection has been activated |
| 7 | Critical high voltage recovered | "Cell Over-Voltage" protection has been deactivated |
| 8 | Discharge current critically high | "Discharge Over-Current" protection has been activated |
| 9 | Discharge critical high current recovered | "Discharge Over-Current" protection has been deactivated |
| 10 | Charge current critically high | "Charge Over-Current" protection has been activated |
| 11 | Charge critical high current recovered | "Charge Over-Current" protection has been deactivated |
| 12 | Electronics Module temperature critically high | "Electronics Module Over-Heat" protection has been activated |
| 13 | Critical high Electronics Module temperature recovered | "Electronics Module Over-Heat" protection has been deactivated |
| 14 | Leakage detected | The Leakage Sensor Input pin became Active |
| 15 | Leakage recovered | The Leakage Sensor Input pin became Inactive |
| 16 | Warning: Low voltage - reducing power | "Low Cell Voltage" protection has been activated |
| 17 | Power reduction due to low voltage recovered | "Low Cell Voltage" protection has been deactivated |
| 18 | Warning: High current - reducing power | "High Discharge Current" protection has been activated |
| 19 | Power reduction due to high current recovered | "High Discharge Current" protection has been deactivated |
| 20 | Warning: High Electronics Module temperature- reducing power | "High Electronics Module Temperature" protection has been activated |
| 21 | Power reduction due to high Electronics Module temperature recovered | "High Electronics Module Temperature" protection has been deactivated |
| 22 | Charger connected | EMUS BMS Mini 3 has acknowledged charger connection |
| 23 | Charger disconnected | EMUS BMS Mini 3 has acknowledged charger disconnection |
| 24 | Started pre-heating stage | Pre-heating charging stage has been started |
| 25 | Started pre-charging stage | Pre-charging charging stage has been started |
| 26 | Started main charging stage | Main charging charging stage has been started |
| 27 | Started balancing stage | Balancing stage has been started |
| 28 | Charging finished | Charging process has successfully completed |
| 29 | Charging error occurred | Charging process has stopped unexpectedly due to an error |
| 30 | Retrying charging | Charging error condition has been cleared, charging process has been resumed |
| 31 | Restarting charging | Charge restart condition was met, charging process has been restarted |
| 32 | Master/Slave configuration mismatch detected | "Master/Slave configuration mismatch" reduction has been activated |
| 33 | Master/Slave configuration mismatch recovered | "Master/Slave configuration mismatch" reduction has been deactivated |
| 34 | Master/Slave configuration error | "Master/Slave configuration error" protection has been activated |
| 35 | Master/Slave configuration error recovered | "Master/Slave configuration error" protection has been deactivated |
| 36 | Master/Slave common CAN bus malfunction | "Master/Slave common CAN bus malfunction" reduction has |

| | detected | been activated |
|---|---|---|
| 37 | Master/Slave common CAN bus malfunction recovered | "Master/Slave common CAN bus malfunction" reduction has been deactivated |
| 38 | Master/Slave common CAN bus failure detected | "Master/Slave common CAN bus failure" protection has been activated |
| 39 | Master/Slave common CAN bus failure recovered | "Master/Slave common CAN bus failure" protection has been deactivated |
| 40 | Master/Slave internal CAN bus failure detected | "Master/Slave internal CAN bus failure" protection has been activated |
| 41 | Master/Slave internal CAN bus failure recovered | "Master/Slave internal CAN bus failure" protection has been deactivated |
| 42 | Cell temperature critically high | "Cell Over-Heat" protection has been activated |
| 43 | Critically high cell temperature recovered | "Cell Over-Heat" protection has been deactivated |
| 44 | Warning: High cell temperature - reducing power | "High Cell Temperature" protection has been activated |
| 45 | Power reduction due to high cell temperature recovered. | "High Cell Temperature" protection has been deactivated |
| 46 | No current sensor protection | "No Current Sensor" protection has been activated |
| 47 | No current sensor recovery protection recovery | "No Current Sensor" protection has been deactivated |
| 48 | Pack under-voltage protection | "Pack Under-Voltage" protection has been activated |
| 49 | Pack under-voltage protection recovery | "Pack Under-Voltage" protection has been deactivated |
| 50 | CAN Comm watchdog timeout | CAN Comm watchdog timeout counter has been increased |
| 51 | Pack over-voltage protection | "Pack Over-Voltage" protection has been activated |
| 52 | Pack over-voltage protection recovery | "Pack Over-Voltage" protection has been deactivated |
| 53 | Cell under-heat protection | "Cell Under-Heat" protection has been activated |
| 54 | Cell under-heat protection recovery | "Cell Under-Heat" protection has been deactivated |
| 55 | Cell voltage-deviation protection | "Cell Voltage-Deviation" protection has been activated |
| 56 | Cell voltage-deviation protection recovery | "Cell Voltage-Deviation" protection has been deactivated |
| 57 | Pack voltage-deviation protection | "Pack Voltage-Deviation" protection has been activated |
| 58 | Pack voltage-deviation protection recovery | "Pack Voltage-Deviation" protection has been deactivated |
| 59 | Electronics Module under-heat protection | "Electronics Module Under-Heat" protection has been activated |
| 60 | Electronics Module under-heat protection recovery | "Electronics Module Under-Heat" protection has been deactivated |
| 61 | External temperature sensor loss protection | "External Temperature Sensor" protection has been activated |
| 62 | External temperature sensor loss protection recovery | "External Temperature Sensor" protection has been deactivated |

## 2.14 Vehicle speed measurement

Using the EMUS BMS Mini 3 one of the inputs mapped with the corresponding "PF1 Speed Sensor Input" pin function, the BMS can register the pulses of the vehicle's speed signal as well as the duration between them. This data is sampled at a rate of 100Hz (in sync with the current measurement), and each time the ratio between the pulse count and the total duration between them is divided by the value of "Pulses per Distance Unit" parameter to determine the momentary vehicle speed. This value is not essential to the core functions of the BMS, however it is used for

keeping track of the total driven distance and distance since charge, calculating the energy consumption per distance unit, and estimating the remaining distance. All of these values can be read from the BMS through one of its digital interfaces and monitored in real time on EMUS G1 Display Unit or a third-party display, which eliminates the need for a separate electronics for these functions and allows to simplify the electrical system of the vehicle.

> ⚠️ **NOTE**: This functionality is not available in the current version of the EMUS BMS Mini 3. It will be available in future versions of the product. For more detailed information please contact EMUS Support Team.

## 2.14.1 Energy consumption calculation

EMUS BMS Mini 3 uses the measured vehicle speed or other values derived from it to calculate three different types of energy consumption per distance unit:

- Momentary Consumption;
- Average Consumption;
- Last Trip Average Consumption;

Momentary Consumption is updated every 10 milliseconds by using the formula ( 3 )

$$Momentary\ Consumption = \frac{I_{Momentary} \cdot V_{Pack}}{V_{Momentary}}; \qquad (\ 3\ )$$

Where $I_{Momentary}$ is the momentary current value, $V_{Pack}$ is the momentary battery pack voltage value, and $V_{Momentary}$ is the momentary vehicle speed value.

A digital, first order low pass Butterworth filter with a cutoff frequency of 0.03Hz is also applied before storing the final result in the volatile memory in order to smooth out any fluctuations. In case the momentary vehicle speed value is equal to zero, the momentary consumption is set to 0xFFFFFFFF, which should be interpreted as N/A (not available).

Average Consumption is calculated using the formula ( 4, in which Total discharge energy is the momentary value of the corresponding statistic, and Discharge energy at the end of last charge is a non-volatile status value that is updated each time a charger disconnection is acknowledged. In contrast to periodically backed up non-volatile statuses like Battery Charge, this value belongs to another group of non-volatile status values that don't change too often and are therefore stored directly in permanent memory.

$$Average\ Consumption = \frac{"Total\ discharge\ energy" - "Discharge\ energy\ at\ the\ end\ of\ the\ last\ charge"}{"Distance\ Since\ Charge"}; \quad (\ 4\ )$$

Distance Since Charge is a periodically backed up non-volatile status value that is updated with each registered pulse of the vehicle speed signal, and cleared by setting to zero each time charger is connected. Similarly, to Momentary Consumption, Average Consumption is set to 0xFFFFFFFF to

indicate that it is not available if Distance Since Charge is equal to zero or not available.

Last Trip Average Consumption is calculated using the formula ( 5 ), in which Last Discharge Energy is another non-volatile status value stored directly in EEPROM, that is updated by subtracting the Discharge energy at the end of last charge value from the value of Total discharge energy statistic each time a charger connection is acknowledged

$$Last\ Trip\ Average\ Consumption = \frac{\text{"Last Discharge Energy"}}{\text{"Previous Driven Distance"}};\qquad (5)$$

Previous Driven Distance is an EEPROM-only non-volatile status value too, and is updated every time a charger connection is acknowledged by copying the Distance Since Charge value just before it is cleared. Just as with the other two types of energy consumption, Last Trip Average Consumption is set to 0xFFFFFFFF to indicate that it is not available if Previous Driven Distance is equal to zero or not available.

## 2.14.2 Remaining distance estimation

EMUS BMS Mini 3 estimates the remaining distance based on the calculated values of energy consumption per distance unit, and by assuming that the ratio between the energy remaining in the battery and energy already used in during the current trip is equal to the ratio between the remaining SOC and SOC used since the start of the trip. It results in three different values of remaining distance, all of which are determined using the formula ( 6 ), in which SOC At Start Of Trip is a periodically backed up non-volatile status value that is updated each time charger disconnection is acknowledged, by copying the SOC value that is present at that time.

$$Distance\ Left = \frac{\text{SOC}\cdot\left(\substack{\text{"Total discharge} \\ \text{energy"}} - \substack{\text{"Discharge energy at the} \\ \text{end of the last charge"}}\right)\cdot\left(100-\substack{\text{"Safety} \\ \text{Margin"}}\right)}{100\ \cdot\text{"Consumption"}\cdot(\text{SOC At Start Of Trip}-\text{"SOC"})};\quad (6)$$

Safety Margin is the value of a corresponding configuration parameter which allows to reduce the result as a precaution from possible estimation inaccuracy. Consumption in each particular case is equal to the value of Momentary Consumption, Average Consumption, or Last Trip Average Consumption. In case this value is not available or equal to zero, or SOC At Start Of Trip is equal to SOC, the corresponding Distance Left is set to 0xFFFFFFFF to indicate that it is not available.

## 2.15 Communication with external devices

EMUS BMS Mini 3 Serial and CAN communication protocols are open source. These protocols can be integrated into external devices to provide direct communication with EMUS BMS Mini 3. Protocols are available in our website https://emusbms.com/manuals-downloads

## 2.16 Indication

EMUS BMS Mini 3 can provide an audiovisual charging and critical condition indication when connected to the appropriate pins. Each case can be identified by a different pulse pattern. All available indications are described in further sections.

## 2.16.1 Charging status indication

An LED or a lamp connected to any general-purpose output pin mapped with "PF9 Charging Indication Output" pin function will visually indicate the charging status by blinking certain patterns. The blinking patterns are shown in the Figure 2-5 Charging indicator .

- Charger Disconnected
- Pre-heating stage
- Pre-charging stage
- Main charging stage
- Balancing stage
- Charging stage
- Charging error
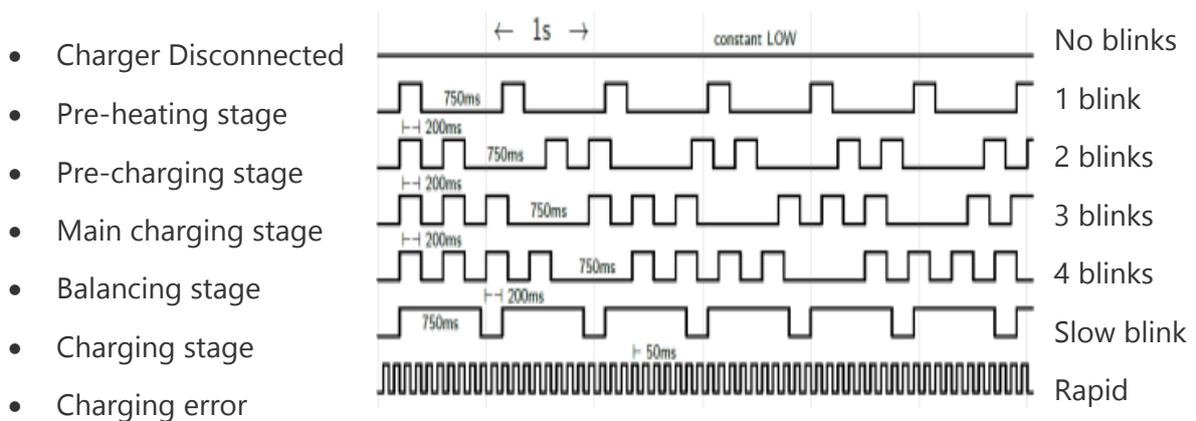
Figure 2-5 Charging indicator timing

## 2.16.2 Buzzer

A self-oscillating buzzer connected to any general-purpose pin mapped with "PF7 Sound Buzzer Output" pin function will provide an audial indication of the following conditions:

"Low Cell Voltage" reduction is active.

Charging error occurred.

Pulse patterns are shown in the Figure 2-6 Sound indicator timing

- "Low Cell Voltage" Reduction
- Charging Error occurred
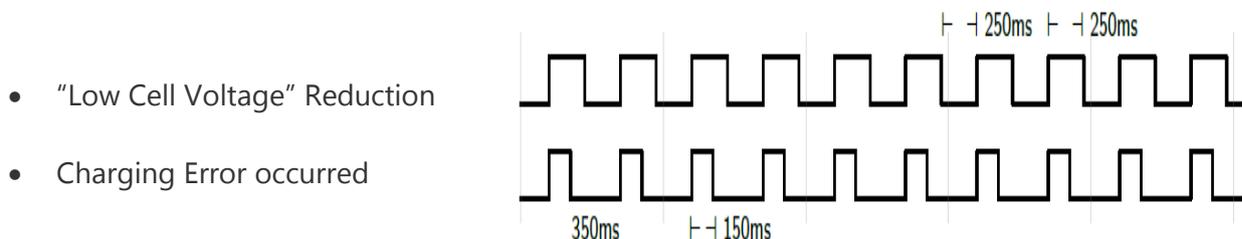
Figure 2-6 Sound indicator timing

## 2.16.3 Low battery indication

An LED or a lamp connector to any general-purpose output pin mapped with "PF8 Battery Low Indication Output will visually indicate the following conditions:

Minimum cell voltage is below the "Low Cell Voltage" reduction "Activate at" threshold.

Average cell voltage is below the "Low Cell Voltage" reduction "Activate at" threshold.

Pulse patterns are shown in the Figure 2-7 Low battery indicator timing.

- Minimum cell voltage is below the "Low Cell Voltage" reduction "Active at" threshold

- Average cell voltage is below the "Low Cell Voltage" reduction "Active at" threshold
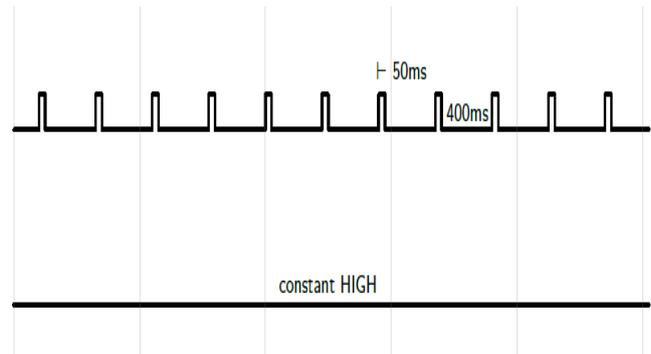


Figure 2-7 Low battery indicator timing

# Chapter 3: Installation

Correct EMUS BMS Mini 3 installation will prevent both immediate and delayed issues in the system yet requires certain knowledge to be carried out as intended, therefore it is necessary to strictly follow the instructions described in the following chapters during the process. Also, because some parts of the installation process require working near exposed energized parts, it is extremely important to undertake all necessary safety precautions (like wearing insulating gloves, using insulated tools, etc.) in order to avoid injuries, damage to the BMS components, or other unexpected harmful consequences. It should be carried out only by a qualified employee who has carefully read through this whole section and thoroughly understands all the risks involved when working with lithium cells.

## 3.1 BMS Mini 3

It is recommended to install EMUS BMS Mini 3 small distance away from the battery (ideally in the same enclosure) to make the wiring process easy. Since EMUS BMS Mini 3 is powered from battery cells the wiring process should start by connecting cell's wires from the most negative cell to the most positive, and after making sure it is made as shown in examples, only then plug connector to EMUS BMS Mini 3. Since no outputs dedicated to powering other EMUS BMS components or third-party components are populated on any of the EMUS BMS Mini 3 connectors for space-saving and simpler design purposes, power should be distributed using external means.

### 3.1.1 Battery cells (power supply)

EMUS BMS Mini 3 is powered from battery cells. The minimum power supply for the unit must be 12V (e.g. 6 battery cells of 2V).  Every EMUS BMS Mini 3 can monitor from minimum 6 up to 16 cells. Need to pay attention how to connect all 16 cells or if you have less e.g. 8 cells in series. In both cases connection must be start from the most negative cell to the most positive.

⚠️ **NOTE:** It is strongly recommended to start with connection of wires and cells firstly and after making sure it is made as shown in examples, only then to plug connector to EMUS

## 3.1.1.1 Less than 16 cells installation
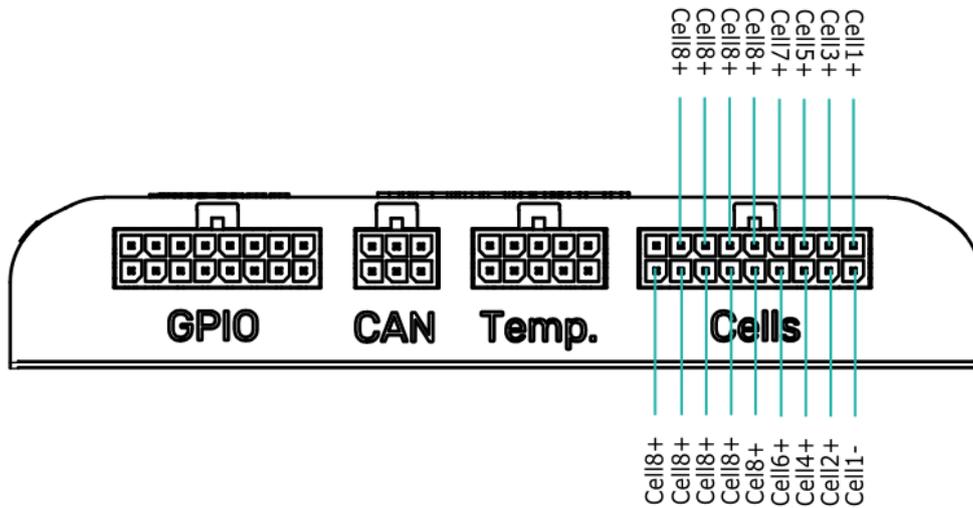


Figure 3-1 8 Cells installation example (MNC034)
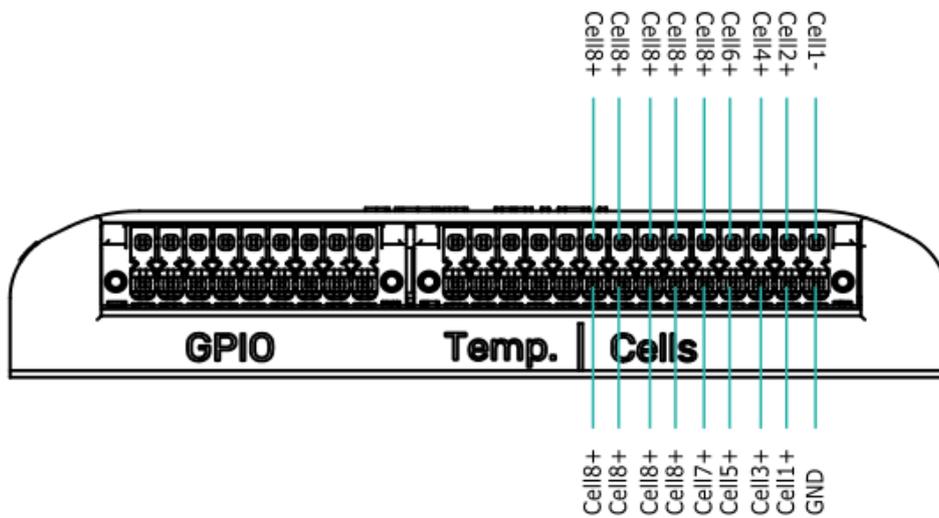


Figure 3-2 Cells installation example (MNC033)

## 3.1.1.2 16 cells installation
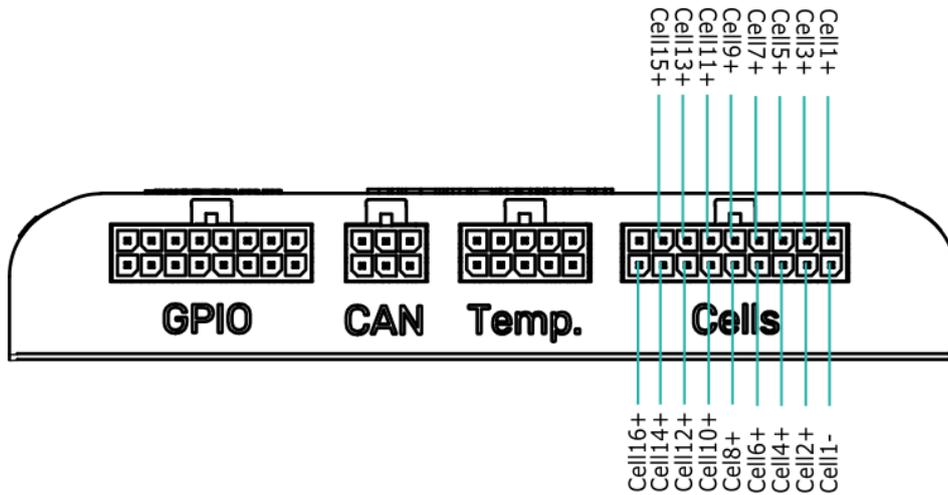


Figure 3-3 8 cells installation example (MNC034)
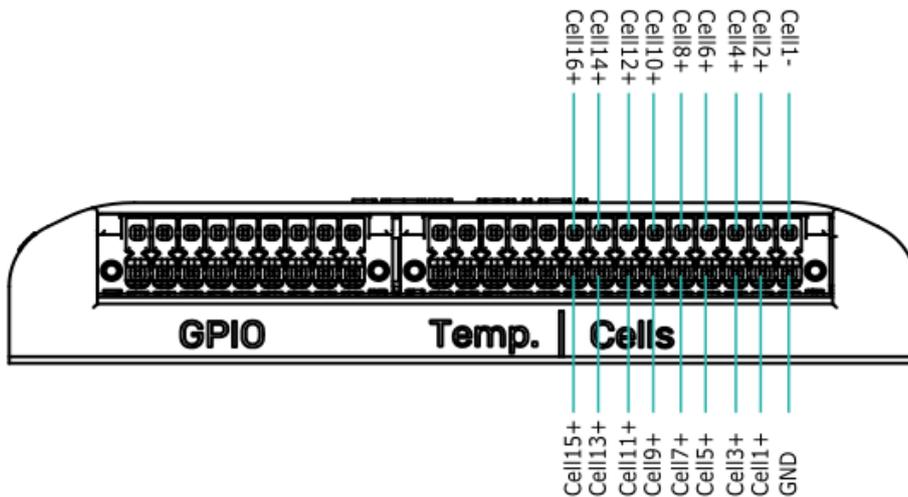


Figure 3-4 8 cells installation example (MNC033)

## 3.1.2 Choosing the power supply strategy

In applications that do not guarantee constant grid power availability, yet do not re- quire the battery to be in operation constantly either (i.e. various electric vehicles and other mobile application), it is recommended to supply power to the some EMUS BMS Mini 3 peripherals and the rest of BMS components from an auxiliary 12V battery that is charged from the main battery through an isolated DC/DC converter, as shown in the example in Figure 3-5 Power Supply Strategy 1
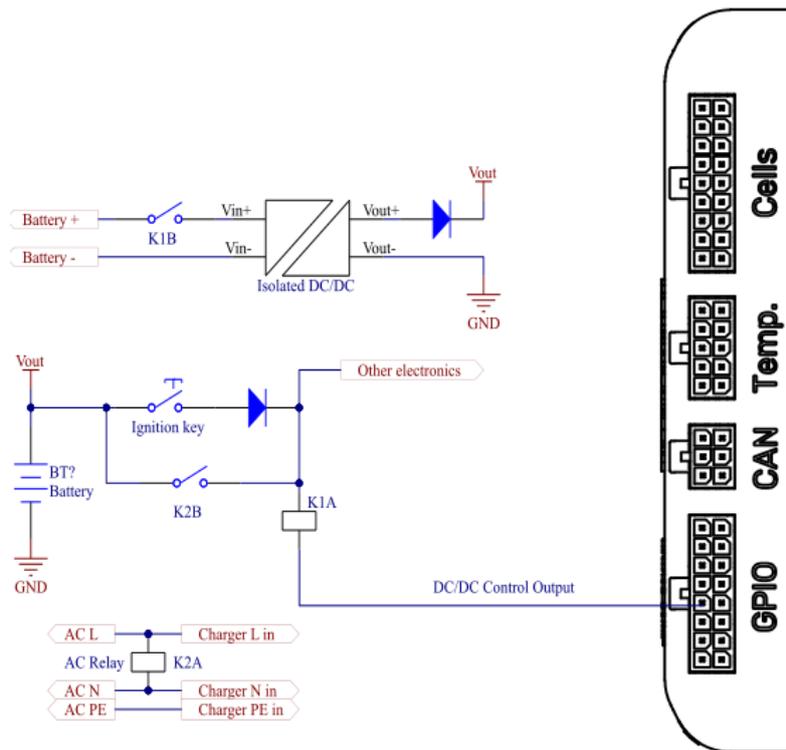
Figure 3-5 Power Supply Strategy 1

In this example EMUS BMS Mini 3 is connected to the auxiliary battery either when the ignition key is turned on or when an on-board charger is connected to the grid and controls the relay that disconnects the DC/DC converter from the main battery with one of the EMUS BMS Mini 3 general purpose pins mapped with "PF24 DC/DC Control Output" function. This ensures that BMS some peripherals does not drain the auxiliary nor the main battery when the system is not in operation, and also protects the main battery from damage due to depletion in case the operator forgets to turn off the ignition key and leaves the system to idle for an ex- tended period of time. It is also important to mention that in the system given in this example the auxiliary battery and DC/DC converter do not power the EMUS BMS Mini 3, but power the entire network of other devices, so it is recommended to use a diode that prevents bypassing of the ignition key when the on-board charger is connected to the grid.

In applications that do not guarantee constant grid power but require the battery to be constantly in operation (i.e. off-grid energy storage systems, various backup energy systems, etc.), it is recommended to supply power to the EMUS BMS Mini 3 and the rest of BMS components from the same battery that it manages directly through an isolated DC/DC converter. In this case the DC/DC converter is most likely dedicated to powering only BMS Mini 3 and draws very low current from the battery, therefore it can be connected to it or disconnected from it without using an auxiliary battery, as shown in the example in Figure 3-6 Power Supply Strategy 2
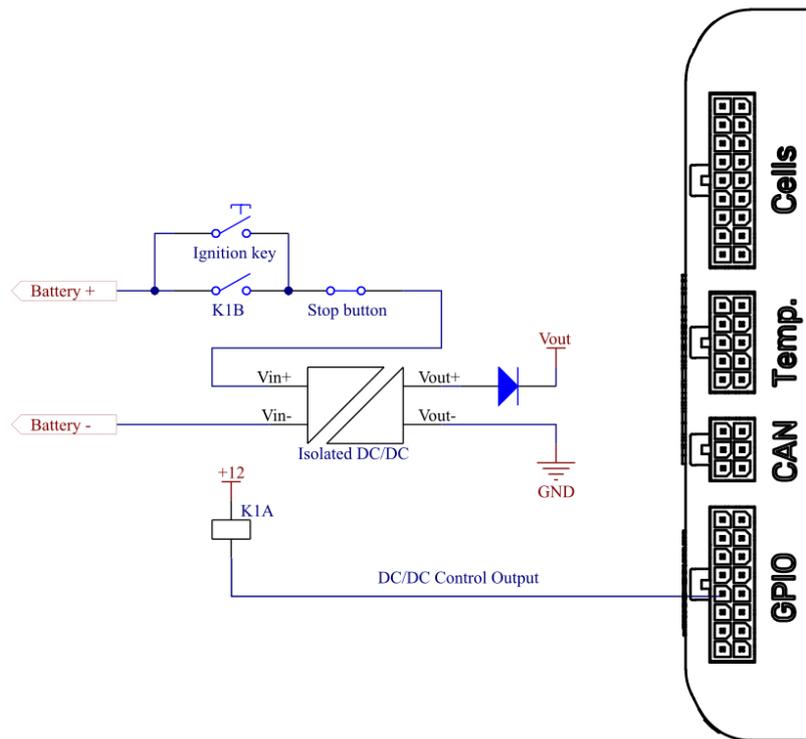
Figure 3-6 Power Supply Strategy 2

In this example the system is turned on manually by pressing the ignition key button that connects the DC/DC converter to the battery and holding it until the Control Unit activates the general-purpose output mapped with "PF24 DC/DC Control Output" function. It is turned off either manually by pressing the stop button, or automatically if the BMS detects that cell voltages have fallen below the corresponding configurable threshold.

Regardless of the chosen strategy, the dimensioning and selection of the components for the power supply sub-circuit depends on various aspects of the system in which the battery is used and is out of the scope of this document.

## 3.2 Current Sensor

## 3.2.1 EMUS Mini Power board current sensors

EMUS BMS Mini 3 has his own two current measuring sensors, which gives the battery management system great flexibility. One sensor measures the current in the charger line and another measures current between battery pack and load.
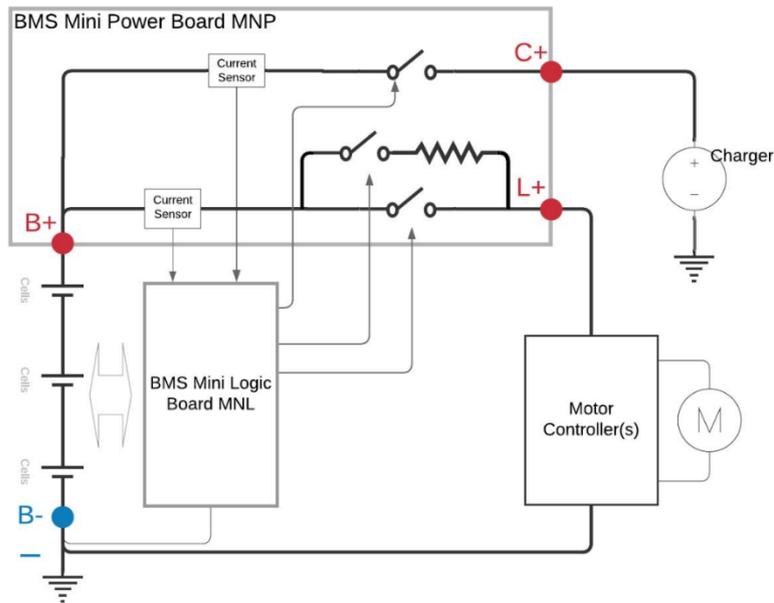
Figure 3-7 EMUS Mini Power board current sensors

## 3.3 CAN Bus

The CAN bus has been widely adopted in industrial, automotive, and instrumentation applications due to the inherent strengths of its communication mechanisms, however its reliability will be compromised if it is not set up correctly. CAN-equipped EMUS BMS components are designed to be used in high-speed CAN networks, such as the one specified by the ISO 11898-2 standard. This standard defines a single line structure network topology in which the bus lines are terminated at their furthest ends by a single termination resistor, as shown in Figure 3-87.
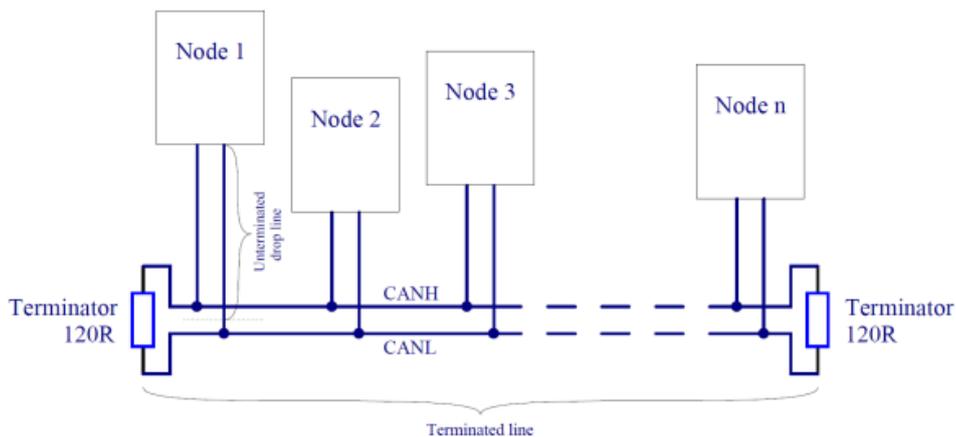


Figure 3-8 High-speed CAN network specified in ISO-11898-2 standard

The maximum total bus length and maximum lengths of a single unterminated drop line and all unterminated drop lines together of a CAN network to which EMUS BMS components are connected are presented in the Table 3-1 The Maximum bus line lengths from Table 3-1, calculated based on the used CAN bit timing setting, considering that a twisted-pair cable with a typical

propagation delay of 5 ns/m is used. $L_U$ – maximum length of a single unterminated drop line, $\sum L_U$ – maximum length of all unterminated drop lines together.

Table 3-1 Maximum bus line lengths

| Baud rate | LU | $\sum LU$ | Max total bus length |
|---|---|---|---|
| 1 Mbit/s | 2 m | 10 m | 20 m |
| 800 kbit/s | 3 m | 15 m | 32 m |
| 500 kbit/s | 3 m | 15 m | 45 m |
| 250 kbit/s | 6 m | 30 m | 120 m |
| 125 kbit/s | 12 m | 60 m | 270 m |
| 50 kbit/s | 32 m | 160 m | 770 m |

Maximum total bus length is essentially limited by propagation delays of the used CAN transceiver and transmission line, and CAN bit timing settings used in CAN-equipped EMUS BMS components. In practice however, lengths with which CAN communication is reliable may be lower due to use of low-grade cables or a high number of connected nodes, therefore it is recommended to choose the length with the maximum possible reserve when designing the CAN network. It is also important to note that unterminated drop lines contribute to the total bus length and thus limit the maximum length of the terminated line.

Ideally the topology of the actual CAN network should be as close as possible to a single line structure, since unterminated drop lines cause signal reflections to occur on the bus, and the longer they are, the more likely it is for the reflections to continue long enough to cause the node receivers to misread the signal levels. In practice however, the network is often designed to slightly deviate from ideal topology for easier installation, yet the both the length of a single drop line and the cumulative length of all drop lines on the bus should not exceed certain limits, otherwise the reflections may cause communication errors even though the line is properly terminated. The maximum values of these lengths in Table 3-1 are calculated based on the bit timing settings used in CAN-quipped EMUS BMS Components, which were chosen according to the recommendations in CiA (CAN in Automation) 301 standard, and are optimal when nodes from different manufacturers are connected to the same CAN network.

According to high-speed transmission specification in ISO11898-2 standard, both ends of the CAN bus must be terminated in order to minimize reflections and ensure that both lines are correctly returned to a recessive state, because any node on the bus may transmit data. The termination resistors should match the characteristic impedance of the cable, although the recommended value is nominally 120Ohm (100Ohm minimum and 130Ohm maximum). There should not be more than two terminating resistors in the network, regardless of how many nodes are connected, because additional terminations place extra load on the drivers. ISO-11898-2 standard also recommends not integrating a terminating resistor into a node but rather using standalone termination resistors. This concept helps to avoid a loss of a termination resistor if a node containing that resistor is disconnected, and prevents connecting more than two of them to the

bus or locating them at other points in the bus rather than at the furthest ends.

Maximum number of nodes in a CAN network is limited by their finite differential input resistance that loads the line and decreases the signal amplitude, therefore it depends on the driving capability of the used CAN transceiver. The manufacturer of the transceivers used in CAN-equipped EMUS BMS components specifies that it will drive a minimum load of 45W, allowing a maximum of 112 nodes to be connected, given that the differential input resistance of each node on the bus is not less than 20kO and 120W termination resistor are used.

To ensure the robustness and reliability of the CAN network regardless of the conditions in which it will be used, it is recommended to use a shielded twisted pair cable to implement it. Due to space saving reasons the CAN interface is populated only on a single connector in all CAN- equipped EMUS BMS components, therefore they should be connected to the bus either at its ends, or by branching the bus cable somewhere in the middle. When using the latter method, each wire of the branch cable, including the shield, should be connected to corresponding wire of the main bus cable by using a T connector, wiretap splices, or in the worst case, by soldering the wires together and covering them in heat-shrink tube. The shield should be grounded at a single point only, ideally as close as possible the output of the power supply that powers the nodes connected to the CAN network in order to avoid ground loops.

## 3.4 Battery fuse

In order to protect the battery and the system in which it is used from unpredictable, potentially destructive consequences of contactor failure (e.g. welding), load or charging device failure, short circuit, or other similar cases, it is necessary to install a battery fuse behind the main contactor as shown in Figure 3-9 and Figure 3-10. The dimensioning of the fuse depends on various aspects of the system in which the battery is used. This is out of the scope of this document.

## 3.5 Contactor

The main contactor should be installed behind all load devices, and its coil terminals should be connected directly between BMS power supply positive terminal and one of the general-purpose outputs of EMUS BMS Mini 3 that is mapped with appropriate pin function, as shown in Figure 3-9.
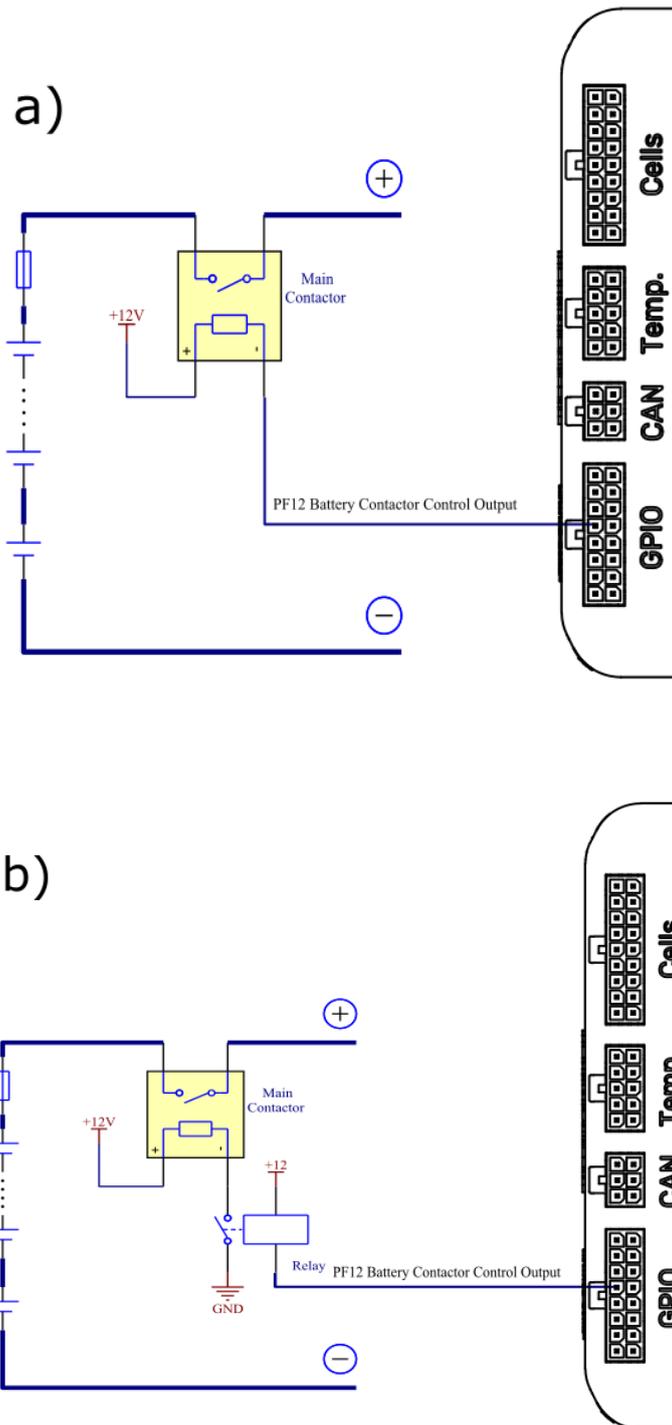
Figure 3-9 Connecting contactor to EMUS BMS Mini 3: (a) directly, when the rated current of the contactor coil is less than 0.5A; (b) through a relay, when the rated current of the contactor coil is 0.5A or more.

If the rated current of the contactor coil is 0.5A or more, additional signal relay should be used to drive the contactor. The dimensioning of the contactor depends on various aspects of the system in which the battery is used and is out of the scope of this document.

⚠ NOTE: EMUS BMS Mini 3 (MNC034) is a two-port battery management system, load (L+) and charge (C+) contactors cannot be interconnected.

## 3.6 Pre-charge sub-circuit

The contactor pre-charge sub-circuit should consist of a relay in series with a pre-charge resistor (or another current limiting device) and should be connected in such way that it would bypass the contactor. The terminals of the contactor pre-charge relay coil should be connected directly between the positive terminal of BMS power supply and one of the general purpose outputs of the BMS that is mapped with appropriate pin function, as shown in Figure 3-10Figure 3-10
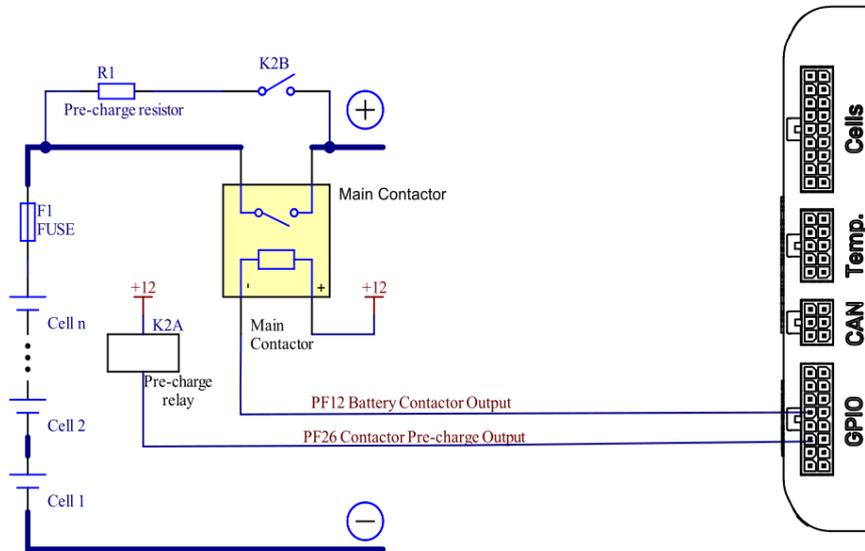


Figure 3-10 Contactor pre-charge sub-circuit connection diagram

The dimensioning of the pre-charge resistor and the pre-charge relay, as well as calculation of the actual pre-charge process duration depends on various aspects of the application and is out of the scope of this document.

## 3.7 Charger

Charging process control is one of the most important tasks that a battery management system must perform to ensure safe lithium battery operation, therefore it is very important to correctly select and connect a charging device in order allow EMUS BMS Mini 3 to control it. The selection of a particular charging device should be done considering various aspects of the application, yet its output parameters are the most important from the battery management system's point of view. The maximum output voltage should be slightly higher than the cell charge voltage specified in the cell specification sheet multiplied by the number of cells connected in series, while the maximum output current should not exceed the maximum charging current specified in the same specification sheet. Correct connection of different charging device types supported by EMUS BMS Mini 3 is described in the following chapters.

# 3.7.1 CAN-based chargers

To allow EMUS BMS Mini 3 to protect the battery in case a charging error occurs, a CAN charger should be connected to the battery through a separate dedicated contactor that is controlled by one of EMUS BMS Mini 3 general purpose outputs mapped with "PF10 Charger Enable" function, as shown in Figure 3-1113.
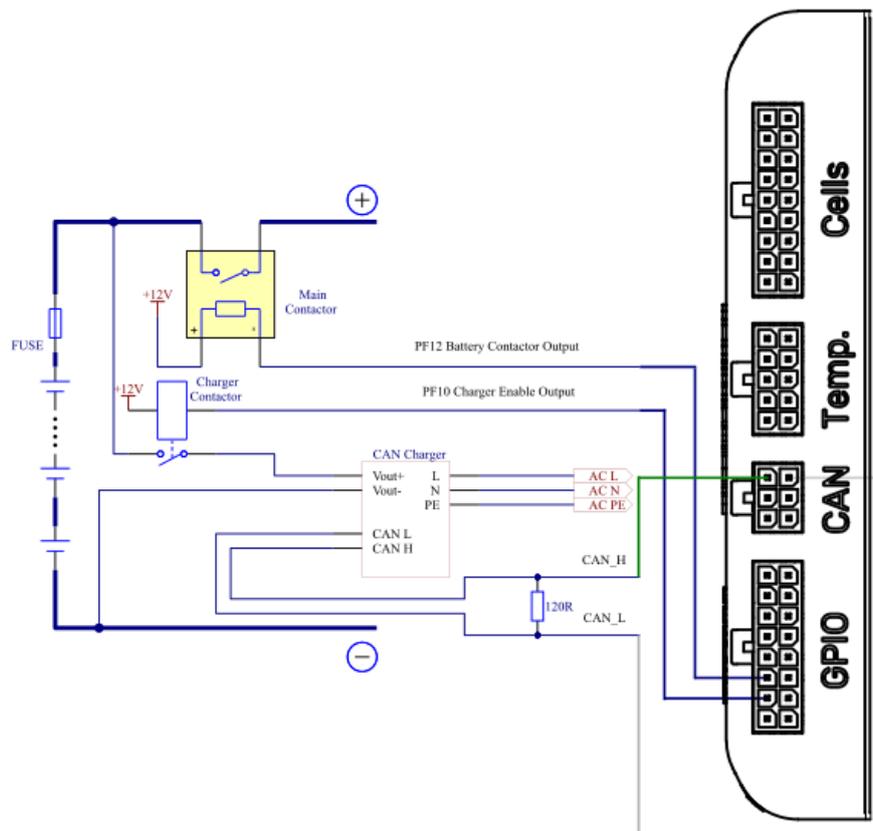


Figure 3-11 Correct CAN charger and charger contactor connection in respect of the battery, battery fuse, and main contactor

The connection between a CAN charger and BMS is shown in Figure 3-1113 as well, but only for reference, and should be done according to the general rules of correct CAN bus setup that are described in chapter 3.33. Most CAN chargers supported by EMUS BMS Mini 3 have an internally powered isolated CAN interface and should be connected to the BMS as shown in the general example in Figure 3-1113, however in some models (e.g. Zivan chargers) the CAN interface can optionally be powered from external power supply. Correct connection depends on various aspects of the system in which the battery is used in such cases and is out of the scope of this document. The dimensioning and selection of a charger contactor depends on the output parameters of the charger that is used and is out of the scope of this document as well.

## 3.7.2 Non-CAN chargers

Non-CAN charger connection acknowledgment should be provided to the BMS automatically using an appropriate signal relay, or manually using a latching pushbutton or a tumbler. Dimensioning and selection of the electromechanical contactor and other necessary components should be done according to the requirements of the particular system and is out of the scope of this document.
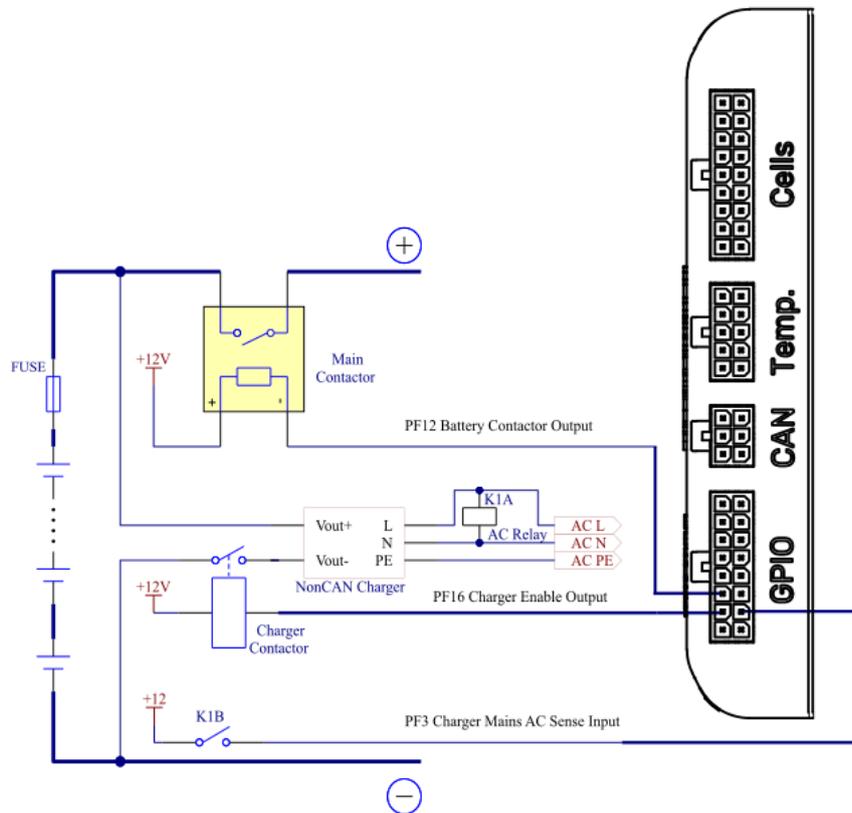


Figure 3-12 Correct connection of a non-CAN charger in respect of the battery, battery fuse, and main contactor using a third-party electromechanical contactor.

## 3.7.3 Analog signal-controlled chargers

Similarly to a CAN charger, analog signal controlled charger should be connected to the battery through a separate, dedicated contactor, as shown in the example in Figure 3-1315. In order to connect the charger to the BMS a signal conditioning sub-circuit is usually required, such as the one shown in Figure 3-1315, which is designed according to the TC/Elcon charger control interface connection documentation. If another charger model is used, the signal conditioning sub-circuit may differ and should be designed according to the control signal requirements of that particular charger.
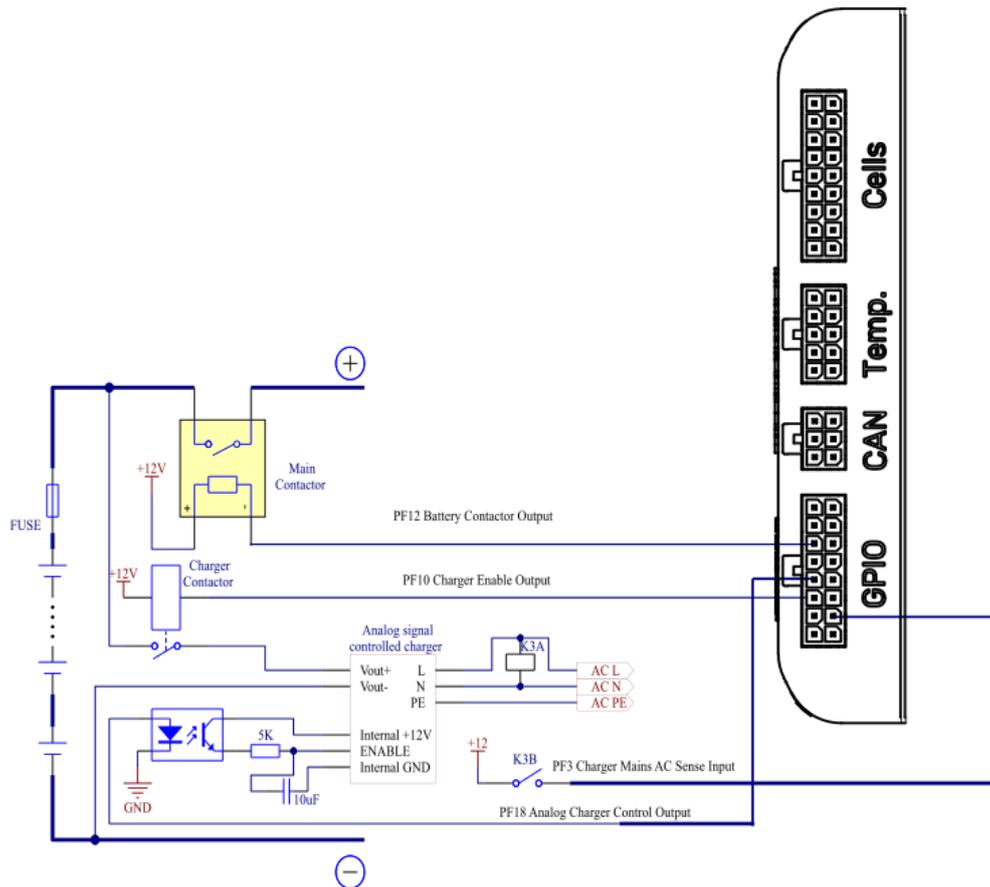


Figure 3-13 Correct analog signal-controlled charger and charger contactor connection in respect of the battery, battery fuse, and main contactor

# 3.7.4 CAN chargers/inverters

The connection between EMUS BMS Mini 3 and CAN Charger/Inverter is very similar to the CAN-based chargers described (3.7.1 CAN-based chargers). EMUS BMS Mini 3 manages battery activity and ensures safe battery using by disconnecting battery load or charge contactor outputs before hazardous situations occur. The figure below shows a visual example of the system that can use an EMUS BMS Mini 3 system and CAN charger/inverter. Correct connection depends on various aspects of the system in which the battery is used in such cases it is out of the scope of this document.
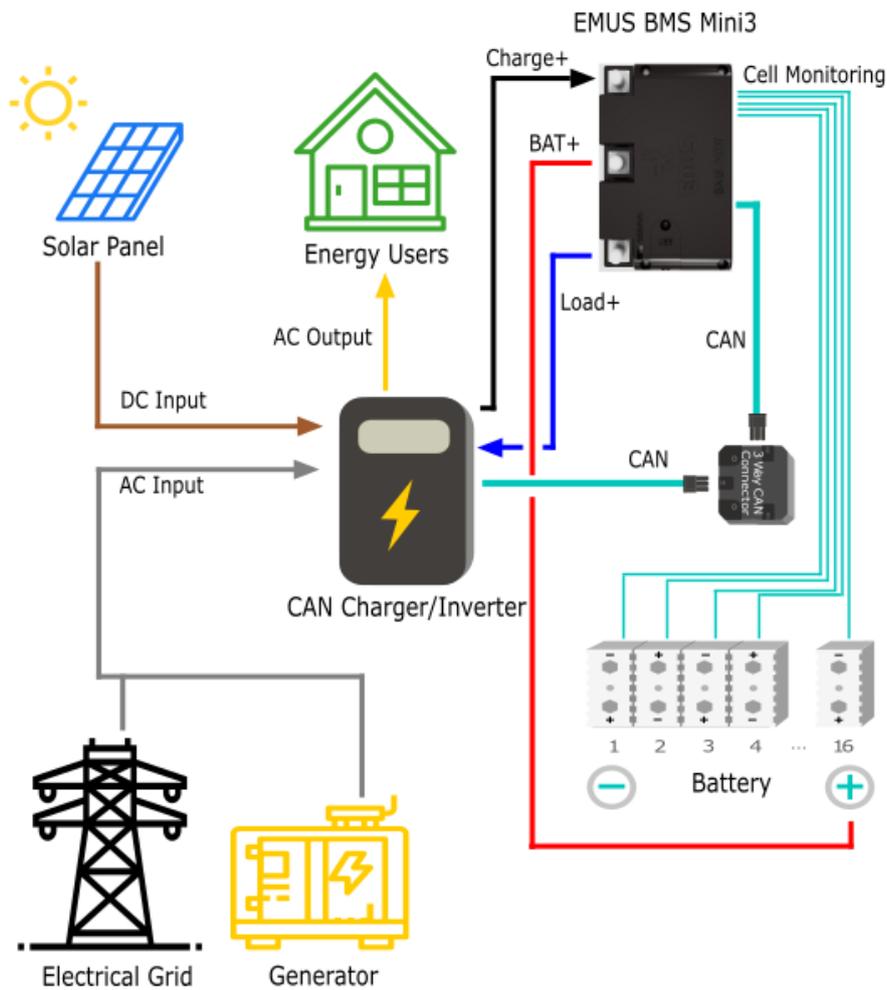


Figure 3-14 CAN Charger/Inverter system

# 3.8 Cooling fan

Cooling fan for cooling the EMUS BMS Mini 3 during balancing is usually requires quite low amount of power, and can be supplied from the same power supply as the BMS and controlled using a single relay, as shown in the example in Figure 3-1516. Coolant pumps of liquid battery cooling systems are usually relatively low power as well, can be connected and controlled in an identical manner. Designing a cooling system for the battery or the EMUS BMS Mini 3, as well as dimensioning and selection of its components is out of the scope of this document.
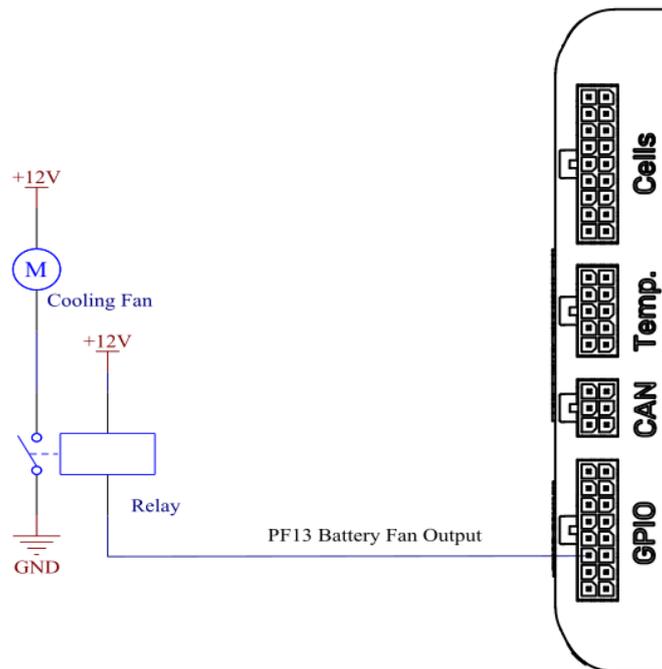


Figure 3-15 : Cooling fan connection diagram

## 3.9 Heater

In contrast to the cooling fan, battery heater usually requires a lot of power, and due to the resulting high current it is unpractical to supply power to it from the same source as the BMS, therefore it is usually connected directly to the battery, and controlled using a separate, dedicated contactor, as shown in Figure 3-1617. Due to the heater's nature to draw constant current the contactor is at a higher risk failing by welding, therefore it is extremely important to correctly dimension the contactor, since the battery can be potentially damaged due to overheat or over-discharge in case the heater contactor welds. A solid-state relay may be used instead of an electromechanical contactor to eliminate such risk (not to be confused with EMUS G1 Solid State Relay used for controlling non-CAN charger).
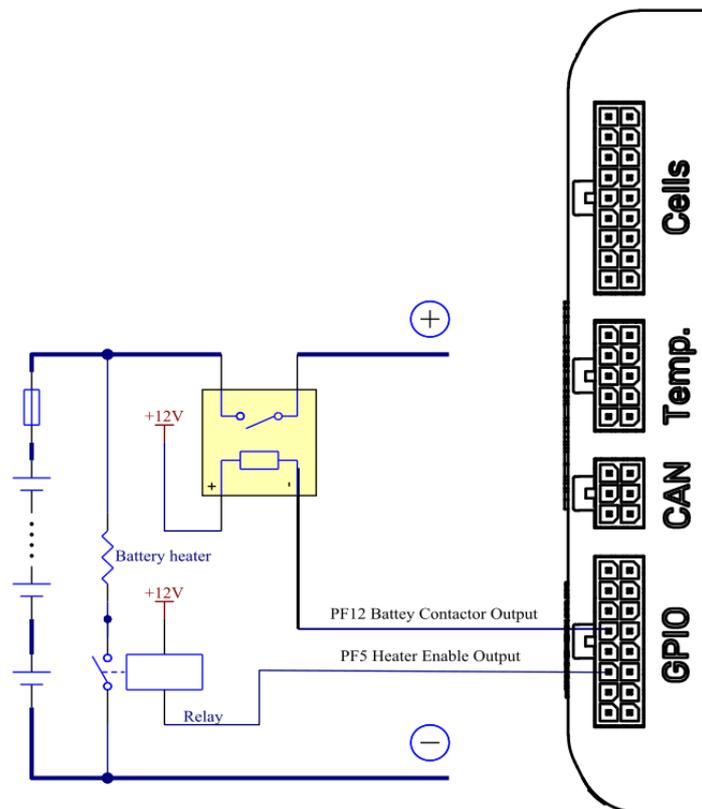


Figure 3-16 Heater connection diagram

## 3.10 Indicators

If they are required, discrete visual or audial indicators should be connected between the positive terminal of the EMUS BMS Mini 3 power supply and one of the BMS general purpose outputs mapped with appropriate function, as shown in Figure 3-1718. An LED or an indication lamp is recommended to be used for visual indication, while the audial indicator has to be a self-oscillating type buzzer that automatically emits sound of a warning frequency when powered. The selection of a particular indicator and dimensioning of any related components should be carried out according to the system requirements and is out of the scope of this document.
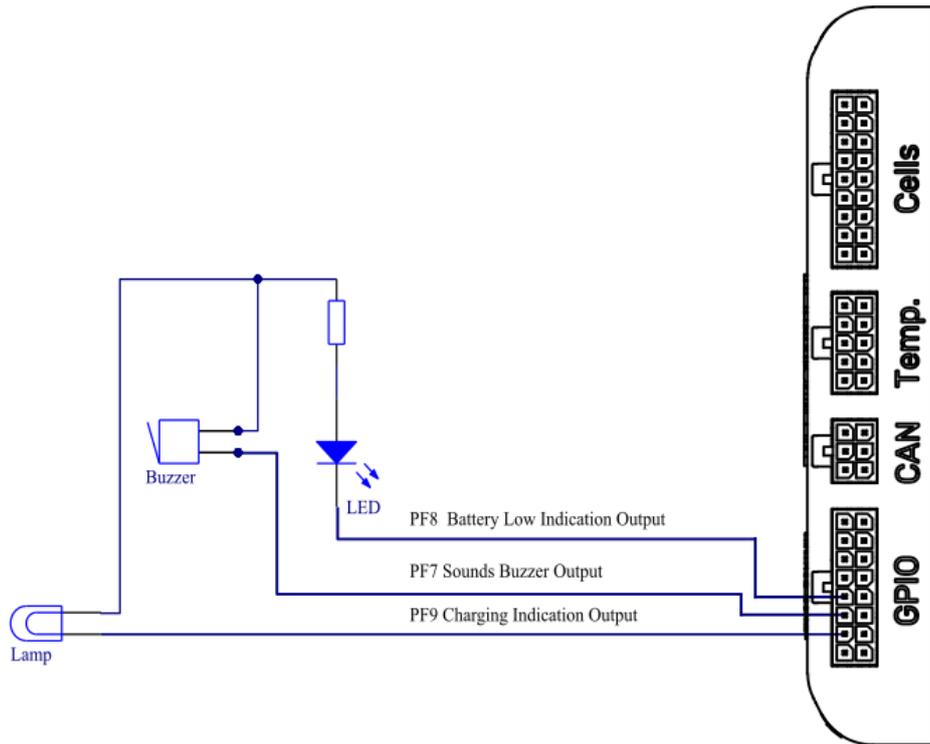


Figure 3-17 Examples of connecting visual or audial indicators to the Control Unit (left to right): an indication lamp, a self-oscillating buzzer, and an LED.

## 3.11 Insulation fault detector

If required by the application, insulation fault detector should be installed in the system by connecting its corresponding inputs to the battery terminals, and its output to one of the EMUS BMS Mini 3 general purpose inputs, as shown in the example in Figure 3-1819. It is important to note that BMS expects a logic signal with levels of 0V and 5 to 72.8V respectively, therefore depending on the models of the detector that is used, and addition signal conditioning sub-circuit may be needed.
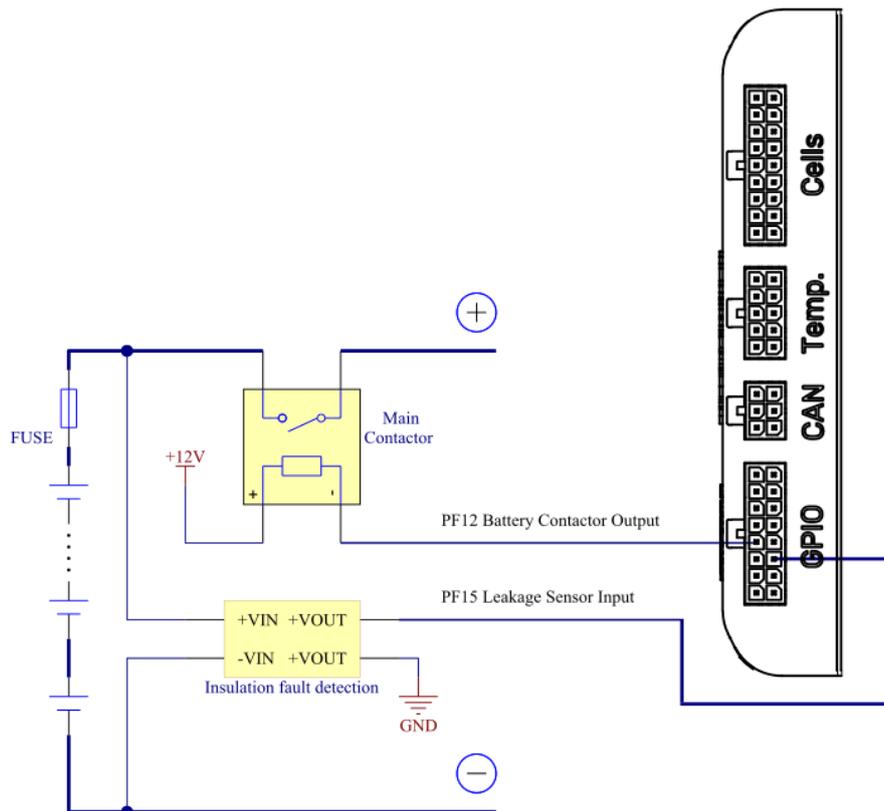


Figure 3-18 Example of connecting a third-party insulation fault detector to the Control Unit.

## 3.12 PSU Under-Voltage Sense Control

In applications where the main controller is powered by an auxiliary battery with PF28 PSU Under-Voltage Sense feature, it is possible to detect when the battery is needed to be charged. The possible connection is shown in Figure 3-19 PSU-Under Voltage Sense Control. Also, the same feature can be used to control DC/DC for an automatic charge.
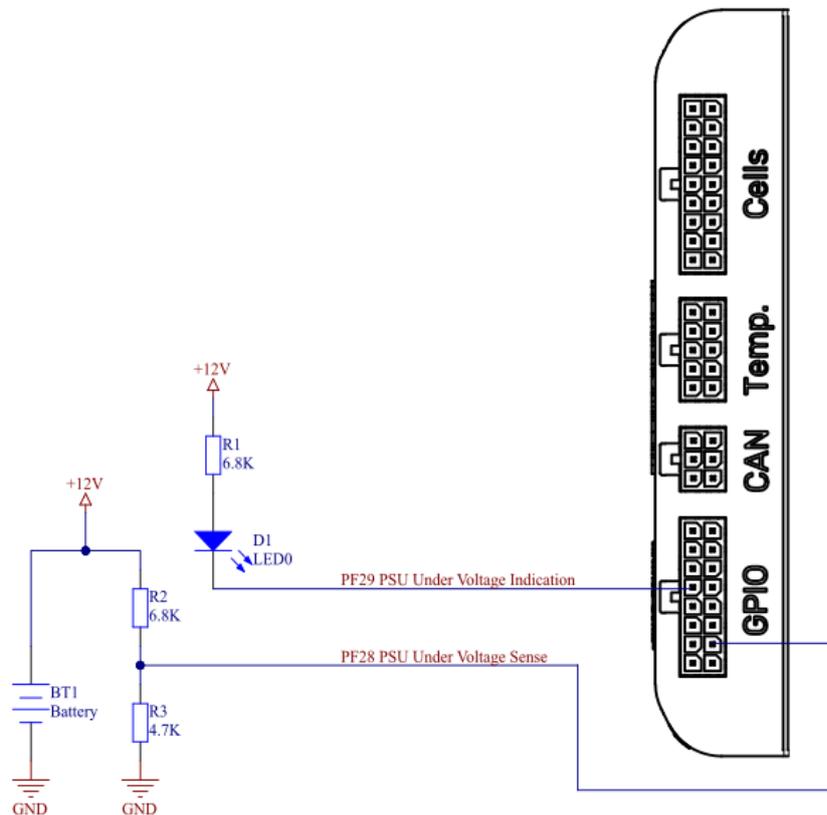


Figure 3-19 PSU-Under Voltage Sense Control

> **NOTE**: For valid calculation of input voltage divider need to include input resistance (10k).

## 3.13 Auxiliary battery sensing

Auxiliary battery sensing feature allows to detect when the battery is needed to be charged. The possible connection is shown in Figure 3-20 Auxiliary battery sensing.
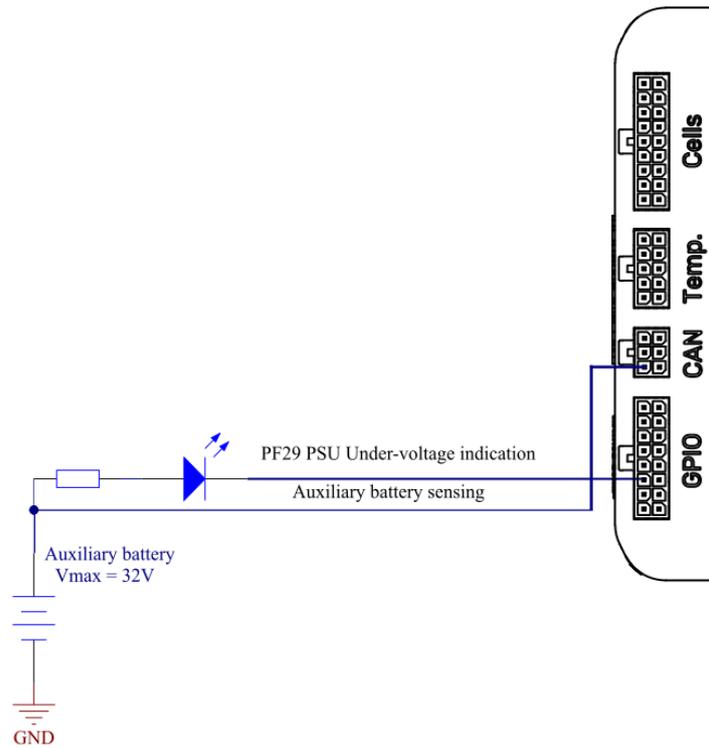
Figure 3-20 Auxiliary battery sensing

⚠️ **NOTE**:  This functionality is not available in current EMUS BMS Mini 3 version. Functionality will be available in future EMUS product firmware versions. For more detailed information please contact EMUS Support Team.

# Chapter 4: Configuration

Settings for data interfaces are located in Control Panel, Configuration page → General tab.

> ⚠ **NOTE**: Certain configuration parameters may be inactive or invisible for certain versions used by the EMUS BMS Mini 3, please contact the EMUS Support team if you need to use parameters that are not available to you

## 4.1 EMUS BMS Control Panel

EMUS Control Panel allows users to configure and monitor more than 300 parameters, also the application used to configure the various types of chargers, update EMUS G1 BMS components, and a lot more. Below shown Control Panel pages and their tabs.

| General | Cells | Sensors | SOC / SOH |
|---------|-------|---------|-----------|

EMUS Control Panel Status page allows users to monitor all EMUS BMS G1 system measurements and statuses.

| Statistics | Events |
|------------|--------|

EMUS Control Panel Statistics page allows users to monitor all EMUS BMS G1 system statistics and events of most parameters and functions of the BMS.

| Management | General | CAN | Charging | SOC / SOH | Protections | Warnings | Controls | I/O Pins | Calibration |
|------------|---------|-----|----------|-----------|-------------|----------|----------|----------|-------------|

EMUS Control Panel Configuration page allows users to configure all EMUS BMS G1 system configuration parameters e.g. Charging Parameters, Battery Protections, I/O pins, and more.

EMUS Control Panel Update page allows to users update and discover EMUS BMS G1 components. Also, on this page, you can check your product firmware version and serial number.

## 4.2 Serial data interface

Serial communication parameters are located in "Configuration" → "General" interface settings are located in "Data Transmission to Display Period" box. By checking "Broadcast on RS232/USB" checkbox, data broad- cast to display over RS232/USB interface is enabled. Data transmission is divided into two states: active and sleep. Both parameters refer to display update period which defines the frequency of broadcasting the parameters via RS232/USB interface and/or CAN bus. Active and sleep states parameters accept ranges of values from 0.1 – 25.0 s and from 0.1 – 5000.0 s respectively.



Figure 4-1 Data Transmission to Display parameters

## 4.3 Charging Disable

Charging disabling button is located in Control Panel → "Configuration" page → "Management" tab → "Disable Charging" button.



Figure 4-2 Disable Charging Button

## 4.4 CAN data interface

CAN communication parameters are located in "Configuration" → "CAN" → "BMS CAN Bus Parameters" and "CAN Group Module Parameters" boxes.



Figure 4-3 CAN communication parameters

- **Enable CAN** – Check to use EMUS BMS Mini 3 CAN interface for data transmission and reception. BMS reset is required for change to take effect;

- **CAN1 Speed**– EMUS BMS Mini 3 CAN interface speed. Available speed values: 50, 125, 250, 500, 800, 1000 kbps. BMS reset is required for change to take effect;
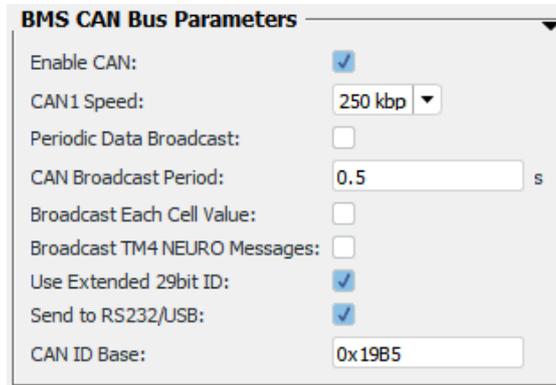
- **Periodic Data Broadcast** – Check to enable periodic BMS status data broadcast over CAN bus. This broadcast uses data transmission to display periods;

- **CAN Broadcast Period** – CAN messages period when broadcast of BMS status data over CAN bus.

- **Broadcast Each Cell Value** – Check to enable periodic broadcast of each cell values over CAN bus. This broadcast uses data transmission to display periods;

- **Broadcast TM4 NEURO messages** – Check to enable periodic broadcast of Battery status messages for TM4 NEURO series vehicle and motor controllers produced by Dana TM4 https://www.danatm4.com/. These messages include information about SOC, DOD, minimum discharge voltage, maximum discharge current, maximum charge/recuperation voltage and current, charging stages and BMS status. Please refer to TM4 documentation for more details.

- **Use Extended 29bit ID** – Check to use extended 29-bit instead of basic 11-bit length CAN IDs. This setting does not affect format of charger CAN messages;

- **Send to RS232/USB** – Check to enable the transmission of received CAN messages to the corresponding serial interface as "CN1..." sentences. This function is not intended to be fully functional CAN/Serial converter, because of BMS CAN message processing and serial interface speed limitations. It is recommended to use when there are not many messages on the CAN network;

- **CAN ID base** – CAN ID Base address which allows to set an arbitrary base address for periodic broadcast of CAN messages generated by EMUS BMS Mini 3. It allows to use several EMUS G1 BMS systems on the same CAN bus or resolve the possible addressing

conflicts with other devices. For extended 29-bit ID it represents upper 13-bits. For example, the default extended ID 6581 is 19B5h in hexadecimal and BMS broadcast the messages starting from 19B50000h and so on. For basic 11-bit ID this is a base address number which must be added to the IDs of broadcasted messages. For example, if this number is entered 800 then BMS will broadcast messages with standard 11-bit IDs starting from 800.

## 4.5 Maximum balancing current parameter

Regarding the "Maximum balancing current parameter", possible to set this parameter with intervals of 10% due to different approach to cells balancing (key mode used). This parameter is located in EMUS Control Panel → Configuration page → General tab, under Battery Pack widget. Battery Pack widget is presented in the following Figure 4-43.
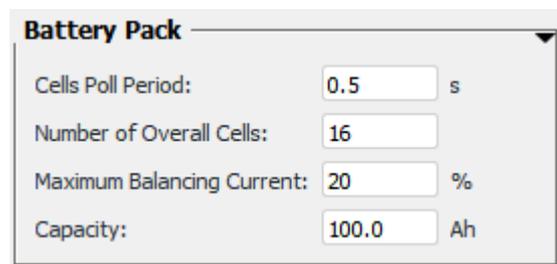


Figure 4-4 Location of "Maximum balancing current" parameter

E. g. all values below 10% are treated as 0%, all values between 10 % and 19 % are treated as 10 % and so on.

## 4.6 Charging process

Configuration parameters related to the charging process are located in the Control Panel → Configuration page → Charging tab. Depending on their purpose, they are divided into "Cell Charging Parameters", "Charger Parameters", "Charging Stage Duration Parameters" and "Charging Tuning Parameters", "Charging parameters", "Discharging Parameters" group boxes. "Charger Parameters" are the following: "Number of Chargers", "CAN Base ID", "Min PWM Output", "Max PWM Output".

"Number of Chargers" parameter appears only when the EMUS BMS Mini 3 is uploaded with a firmware that supports parallel CAN charger connection and should be set to a value that is equal to the actual number of parallel-connected chargers used in the system (possible values range from 1 to 16). Similarly, the CAN Base ID parameter will appear only when the EMUS BMS Mini 3 is uploaded with a firmware that supports Eltek Valere EV Power chargers. It should be set equal to "CAN base identifier" setting in the configuration of the charger itself, thus its possible values range from 0x0000 to 0x07FF. The Min PWM Output and Max PWM Output parameters will appear only when the EMUS BMS Mini 3 is uploaded with a firmware that supports an analog signal-controlled charging devices. Min PWM Output parameter should be set in such way that when the

control signal level is equal to it, the output current of the charging device would be 0A; Likewise, Max PWM Output should be set in such way that the charging device would output the desired maximum current when the control signal is equal to it. The possible values of these two parameters range from 0.0V to 5.0V Parameters in the "Charging Stage Duration Parameters" group box are the following:

- Max Pre-charge Stage Duration;
- Max Main Charge Stage Duration;
- Max Balancing Stage Duration.

The duration of any charging stage usually varies depending on the cell capacity, charging current, and many other aspects of system in which the battery is operated, therefore these parameter are recommended to be set in such way that their values would be about 1.5 times higher than the average duration of the corresponding charging stage, which should be determined experimentally. Alternatively, if actual the duration of the corresponding charging stages may expand indefinitely due to limited availability of power (e.g. in solar energy storage applications), these parameters can be set to 0 to turn off the corresponding charging stage duration checking. The possible values of these parameters range from 0 to 65 000 minutes. The column of cell voltage related settings on the left side of the "Cell Charging Parameters" group box consists of the following parameters:

- Fully Charged Voltage;
- Allowed Disbalance;
- Early Balancing Threshold;
- Charge restart voltage;
- Pre-charge Threshold.

The value of Pre-charge Threshold parameter is recommended to be set to discharge cut-off voltage value that is defined in the manufacturer provided specification sheet of the cells used in the battery pack (usually around 2.5V for LiFePO4 chemistry cells). The optimal values of Charge Restart Voltage, Early Balancing Threshold, and Allowed Disbalance parameters will vary depending on the way the battery is operated application and are best to be determined experimentally, however there are certain guidelines that should be followed:

The Allowed Disbalance parameter is recommended to be set to approximately 0.03V for a good compromise between the balancing accuracy and the duration of the Balancing stage.

In order to avoid trickle charging the battery, which can potentially decrease its lifetime, it is not recommended to set the Charge Restart Voltage parameter value above the nominal cell voltage that is define in the cell specification sheet.

The early balancing algorithm will have the biggest effect on reduction of charging time if the value of Early Balancing Threshold parameter is set below the nominal cell voltage that is defined

in the cell specification sheet, since in such case it will take place both before the cell voltages reach the flat region of the charge curve, and after they rise above it.

The value of the Fully Charged Voltage parameter should be set to the charge voltage value that is defined in the cell specification sheet (not to be confused with charge cut-off voltage, which usually specifies the threshold above which the operation is not safe). Usually this value is around 3.65V for LiFePo4 chemistry cells. The range of possible values is from 2.00V to 4.55V for all these parameters except the Allowed Disbalance – possible values for this parameter ranges from 0.00V to 0.20V. The charging current related settings on the right side of the "Cell Charging Parameter" group box consist of the following parameters:

- Fast Charging Current;
- Slow Charging Current;
- Pre-charge Current;
- Charging Finished Current.

Fast Charging Current parameter can be set to any desired value as long as it does not exceed the manufacturer specified maximum output current of the used CAN charger. The Slow Charging Current parameter allows to charge with reduced charging current in case the available grid power is limited and should therefore be set accordingly lower than the Fast Charging Current parameter. The possible values of these two parameters range from 0.1A to 1000A. Pre-charge Current and Charge Finished Current parameters are expressed as percentage either from 1C current for a CAN charger or maximum charging current for an analog signal controlled charging device. The resulting absolute value will therefore depend on the Capacity parameter or charging device's output current when the control signal level is equal to Max PWM Output parameter accordingly. Pre-charge Current is recommended to be set in such way that the resulting absolute value would be approximately $\frac{1}{10}$ of the current during Main Charging Stage. Charging Finished Current is recommended to be set below maximum balancing current, which depends on the Maximum Balancing Rate parameter. The range of possible values for these two parameters is from 0.1% to 25.5%.

The value of the Charging Parameters → "Optimized Battery Charging Level" field should be set to SOC value which indicates the charging finished stage.

The value of the Discharging Parameters → "Discharge Current Limitation" field determines maximum allowed discharge current which is provided to Victron Inverter.

Charging Tuning Parameters determines charging increment/decrement step size in different battery cell voltage levels.

- Safety Margin Current - Safety margin of charging current which limits the requested charging current above actual current.
- Current Increment Small Step - Small step size to increase charging current intensity when

voltage is close to fully charged voltage.

- Current Increment Medium Step - Medium step size to increase charging current intensity when voltage is below fully charged voltage.

- Current Increment Large Step - Large step size to increase charging current intensity when voltage is below fully charged voltage.

- Current Decrement Small Step - Small step size to decrease charging current intensity when voltage is below fully charged voltage.

- Current Decrement Medium Step - Medium step size to decrease charging current intensity when voltage is above fully charged voltage.

- Current Decrement Large Step - Large step size to decrease charging current intensity when voltage is above maximum allowed voltage.

## 4.6.1 CAN chargers/inverters

To setup CAN charger inverter, need to configure some of parameters which allows to safely use your battery management system. Below described some tips for setting some parameters which are in most cases configured when using CAN charger/inverter systems:

The value of the EMUS Control Panel "Configuration" page → "Charging" tab → "Discharging Parameters" group-box → "Discharge Current Limitation" field determines maximum allowed discharge current which is provided to Victron Inverter. Allowed value is from 0 A to 6553.5 A.

The actual duration of the corresponding charging stages may expand indefinitely due to limited availability of power (e.g. in solar energy storage applications), these parameters can be set to 0 to turn off the corresponding charging stage duration checking. It possible to set in EMUS Control Panel "Configuration" page → "Charging" tab → "Charging Stage Duration Parameters" group-box.

Also, important to set EMUS Control Panel "Configuration" page → "Charging" tab → "Charging Tuning Parameters" group box parameters. All parameters determine the charging increment/decrement step size in different battery cell voltage levels. "Safety Margin Current" parameter value limits the requested charging current above the actual charging current. All these section parameters ensure a stable battery charging current level in the EMUS battery management system.

## 4.7 Protections

Settings that regulate the behavior of the "PF12 Battery Contactor Output" pin function can be found in the Configuration page Protections tab Protection/Fault Settings group box, and consist of eighteen sets of parameters for each different protection type. Each set contains up to five of the following parameters:

- Enable/disable checkbox (with the corresponding protection type label next to it);
- "Activate at" threshold (if applicable to corresponding protection type);
- "Deactivate at" threshold (if applicable to corresponding protection type);
- Act. delay (activation delay);
- Deact. delay (deactivation delay).

No Cell Communication protection is an exception and has the Cell Comm Restore enable/disable checkbox and Restore duration parameter in its set as well. The "Activate at" thresholds of the Cell Under- Voltage and Cell Over-Voltage protections are recommended to be set respectively to discharge cut-off voltage and charge cut-off voltage values that are defined in the manufacturer provided specification sheet of the cells used in the battery pack. The optimal value for the same parameter of the Electronics Module Over-Heat protection is around 60°C. For the Electronics Module Under-Heat protection optimal value is around 0°C. The optimal values of the rest of these parameters, as well as the necessity of each type of protection should be assessed according to the design and requirements of the system in which EMUS BMS Mini 3 is used or determined experimentally.

Similarly, to the power reductions, the possible value range for the "Activate at" and "Deactivate at" threshold parameters depend on the corresponding protection type:

For Cell Under-Voltage and Cell Over-Voltage protections both parameters can have a value from 2.00V to 4.55V;

For Discharge Over-Current and Charge Over-Current protection the range of possible values of the "Activate at" threshold parameter is from 0.1A to 1600.0A;

For Electronics Module Over-Heat and Cell Over-Hear protections both parameters can have a value from 20°C to 155°C.

The possible value range for the Act. delay and Deact. delay parameters are 0.0 to 25.5s and 0 to 255s respectively, regardless of the protection type.

## 4.8 Load power reductions

Settings that regulate the behavior of the "PF16 Power Reduction Output" pin function can be found in the Configuration page → Warnings tab → Reduction group box and consist of four sets of parameters for each different power reduction type. Each set contains up to five of the following parameters:

- Enable/disable checkbox (with the corresponding power reduction type label next to it);
- "Activate at" threshold;
- "Deactivate at" threshold (if applicable to power reduction type);
- Act. delay (activation delay);

- Deact. delay (deactivation delay).



Figure 4-5 Single reduction example

The "PF16 Power Reduction Output" pin function can be used for various purposes and the optimal values of these parameters will vary accordingly, therefore they are best to be determined experimentally. The possible value range for the "Activate at" and "Deactivate at" threshold parameters depend on the corresponding power reduction type:

For Low Cell Voltage power reduction both parameters can have a value from 2.00V to 4.55V;

For High Discharge Current power reduction, the range of possible values of the "Activate at" threshold parameter is from 0.1A to 1600.0 A;

For High Electronics Module Temperature and High Cell Temperature power reduction the both parameters can have a value from 20°C to 155°C; The possible value range for the Act. delay and Deact. delay parameter is 0.0 to 25.5s and 0 to 255s respectively, regardless of the power reduction type.

## 4.9 Warnings

Settings that notifies user about various dangerous situations without any direct impact on the operation of the battery management system can be found in the Configuration page Warnings tab Warning group box, and consist of fourteen sets of parameters for each different warning type. Each set contains up to five of the following parameters:

- Enable/disable checkbox (with the corresponding warning type label next to it);
- "Activate at" threshold (if applicable to corresponding warning type);
- "Deactivate at" threshold (if applicable to corresponding warning type);
- Act. delay (activation delay);
- Deact. delay (deactivation delay).

Cell Communication Loss and Reduction Active warnings is an exception and has the enable/disable checkbox and Restore duration parameter in its set as well.

It is recommended to set the thresholds of the "Activate at" warnings according to the set same type protection so that the warnings notify about the future activation of the protection. The optimal value for the same parameter of the Electronics Module Over-Heat warning is around 5°C under Electronics Module Over-Heat protection. The optimal values of the rest of these parameters,

as well as the necessity of each type of warning should be assessed according to the design and requirements of the system in which EMUS BMS Mini 3 is used or determined experimentally.

Similarly, to the protections and power reductions, the possible value range for the "Activate at" and "Deactivate at" threshold parameters depend on the corresponding protection type:

For Cell Under-Voltage and Cell Over-Voltage protections both parameters can have a value from 2.00V to 4.55V;

For Discharge Over-Current and Charge Over-Current protection the range of possible values of the "Activate at" threshold parameter is from 0.1A to 1600.0A;

For Electronics Module Over-Heat and Cell Over-Hear protections both parameters can have a value from 20°C to 155°C.

The possible value range for the Act. delay and Deact. delay parameters are 0.0 to 25.5s and 0 to 255s respectively, regardless of the protection type.

## 4.10 Current measurement

## 4.10.1 On-board current sensors

Current measurement configuration is performed in Control Panel → Configuration page → Calibration tab. There are located 2 group-boxes ("Load+ High-Res Current Sensor", "Charge+ High-Res Current Sensor"). Each group box has 8 related configuration parameters: "Offset", "Coefficient", "Neg. Coefficient", "Temperature Coefficient", "Lower Boundary", "Upper Boundary", "Deadzone", "Standard Deviation".

| Load+ High-Res Current Sensor ▼ | | | Charger+ High-Res Current Sensor ▼ | | |
| --- | --- | --- | --- | --- | --- |
| Offset: | 0 | | Offset: | 0 | |
| Coefficient: | 0.012401 | | Coefficient: | 0.003103 | |
| Neg. Coefficient: | 0.012401 | | Neg. Coefficient: | 0.003103 | |
| Temperature Coef.: | 0.000000 | 1/deg | Temperature Coef.: | 0.000000 | 1/deg |
| Lower Boundary: | -300.0 | A | Lower Boundary: | -150.0 | A |
| Upper Boundary: | 300.0 | A | Upper Boundary: | 150.0 | A |
| Deadzone: | 0.040 | A | Deadzone: | 0.020 | A |
| Standard Deviation: | 0.020 | A | Standard Deviation: | 0.010 | A |

Figure 4-6 EMUS BMS Mini 3 On-board current sensors configuration

- **Offset** – Sensor reading offset value.
- **Coefficient** – Sensor positive readings coefficient value.
- **Neg. Coefficient** – Sensor negative readings coefficient value.
- **Temperature Coefficient** – Temperature compensation coefficient.

- **Lower Boundary –** Lower boundary limit of sensor reading valid values.

- **Upper Boundary –** Upper boundary limit of sensor reading valid values.

- **Deadzone –** field is used to improve zero value stability, meaning that current values that are within set range both negative and positive are all treated as 0.

- **Standard Deviation –** Standard deviation of sensor.

⚠ **NOTE**: The temperature compensation coefficient value at the current firmware version is disabled. This functionality will be available in future versions of the product. Please contact the EMUS Support team for more detailed information.

## 4.11 SOC estimation

### 4.11.1 SOC legacy adjustment algorithm
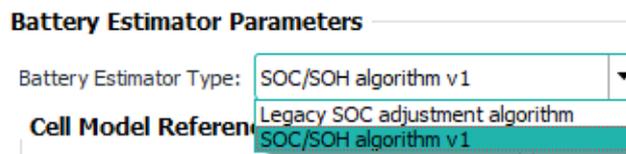


Figure 4-7 State of Charge estimation type

SOC estimation can be chosen from two types (Figure 4-77). SOC-SOH type available only when precision current sensor is currently selected (**Error! Reference source not found.**5).

Apart from being dependent on current measurement parameters, State of Charge estimation is also related to the following parameters:

"Capacity", which can be found in the Control Panel → Configuration page → General tab → Battery Pack Box;

"Reduce SOC at Under-Voltage" and "SOC at Low Volt. Warn.", can be found in the Control Panel → Configuration page → SOC/SOH tab → Battery Estimator Parameters → SOC Adjustment By Voltage Settings;

The "Capacity" parameter value is used as a reference in SOC estimation, and should be set to nominal capacity of a single cell specified by the manufacturer, unless EMUS BMS Mini 3 is configured to use different than nominal capacity during the discharge  cycle, e.g. 80% or 110% of the nominal capacity. In such case the value of the "Capacity" parameter should also be set to 80% or 110% respectively, so that the State of Charge value at the end of a discharge cycle would be 0%. The range of possible "Capacity" parameter values is from 0.1Ah to 6553,5Ah.
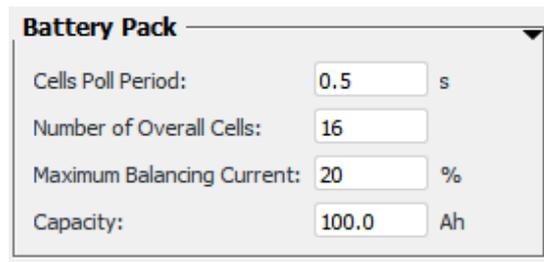
Figure 4-8 "Capacity" parameter box

If it is necessary to use the "Reduce SOC at Under-Voltage" feature the corresponding checkbox should be checked, and "SOC at Low Volt. Warn." value should be set to whatever State of Charge value the Low Voltage Reduction "Activate at" parameter value corresponds to. This can be determined from the 0.5C discharge curve in the manufacturer provided cell specification sheet. The range of possible "SOC at Low Volt. Warn." parameter values is from 0% to 100%.



Figure 4-9 SOC at low voltage warning

Figure 4-10 State of charge parameters

## 4.11.2 SOC/SOH estimator (gen1 algorithm)

### 4.11.2.1 Tuning parameters

In this chapter we will disclose variables used in control panel in tuning parameters section.

Table 4-1 Tuning parameters

| Parameter Name | Description |
|---|---|
| R0 Start Sensitivity | One of the variables that help correctly adjust reference point of R0. Controls at which rate R0 is adjusted, with time greatly decreases, directly impacts R0 tuning sensitivity and its future adjustments. |
| R0 Sensitivity | Variable that controls at what rate R0 value is being adjusted over the course of variable adjusting algorithm. |
| Start V Sensitivity | Variable that is used to help correctly calculate SOC, at specific cell voltage at the start of the algorithm. |
| Start SOC Sensitivity | Variable that is used to help correctly calculate SOC, at specific cell voltage at the start of the algorithm. |
| V Sensitivity | Variable used to calculate and modify the value of SOC over the whole duration of algorithm. Over the time of SOC counting process the value is tuned. |

| | |
|---|---|
| SOC Sensitivity | Variable used to calculate and modify the value of SOC over the whole duration of algorithm. Over the time of SOC counting process the value is tuned. |
| Cbat Start Sensitivity | Variable used to calculate internal capacity of cell at the start of algorithm. |
| Cbat S Sensitivity | Variable used to calculate and modify the value of Cbat over the whole duration of algorithm. |
| Cbat C Sensitivity | Variable used to calculate and modify the value of Cbat over the whole duration of algorithm. |
| Cbat Memory | Variable used to update recursive parameters, that count Cbat over the duration of algorithm |
| Restart Estimator button | Resets all tuning variables and counted variables to default values. |
| Restart SOC Estimator | Resets all filters that adjust value of SOC to default. SOC is also set to default value. |
| Restart Cbat Estimator | Reset all filters that adjust value of SOH and Cbat. Those two values are also set to default. |
| Estimator Diagnostics | Enables diagnostical messages that are required when diagnosing estimator operation with EMUS support team. |
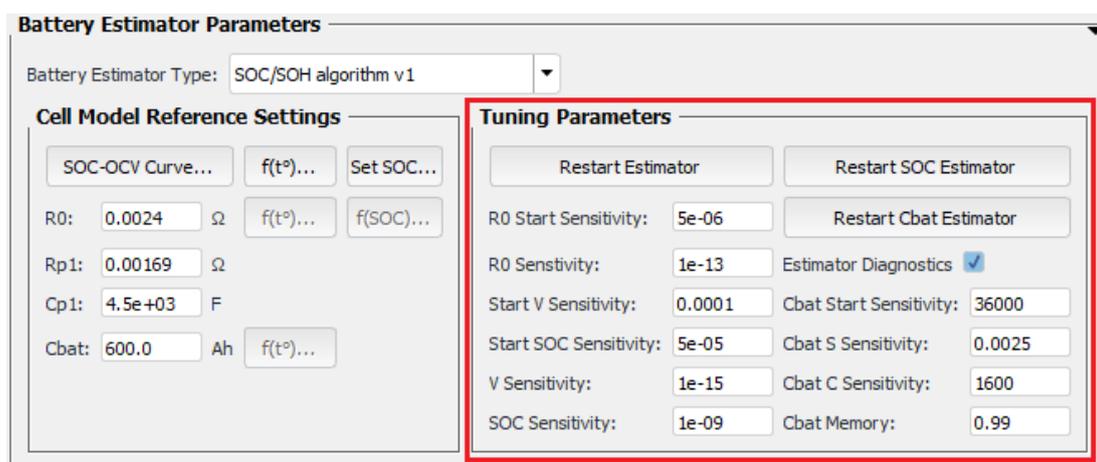


Figure 4-11 Tuning parameters

All parameters are used at the start and during the whole process of algorithm, they help accurately calculate SOC and Cbat. Some of these parameters' values are continuously adjusted over the time of algorithm, ensuring most precise values. The values should be kept default or should be put in and managed with our assistance, at the start of using BMS.

## 4.11.2.2 Cell model reference settings

In this chapter we will disclose variables used in control panel in cell model reference settings section.

Table 4-2 Cell model reference settings

| Parameter Name | Description |
|---|---|
| R0 | Internal resistance, one of the variables calculated by cell model, first value is a reference point, with time algorithm adjusts the value. It has a direct impact on accuracy of SOC. |
| Rp1 | Internal capacities of cell charge polarization used to estimate and eliminate SOC counting error. Variable calculated by creating cell model. |
| Cp1 | Internal capacities of cell charge polarization used to estimate and eliminate SOC counting error. Variable calculated by creating cell model. |
| Cbat | Internal capacity of cell. One of most important variables while calculating SOC and SOH. First value is a reference point, with time algorithm adjusts the value. Variable calculated by creating cell model. |
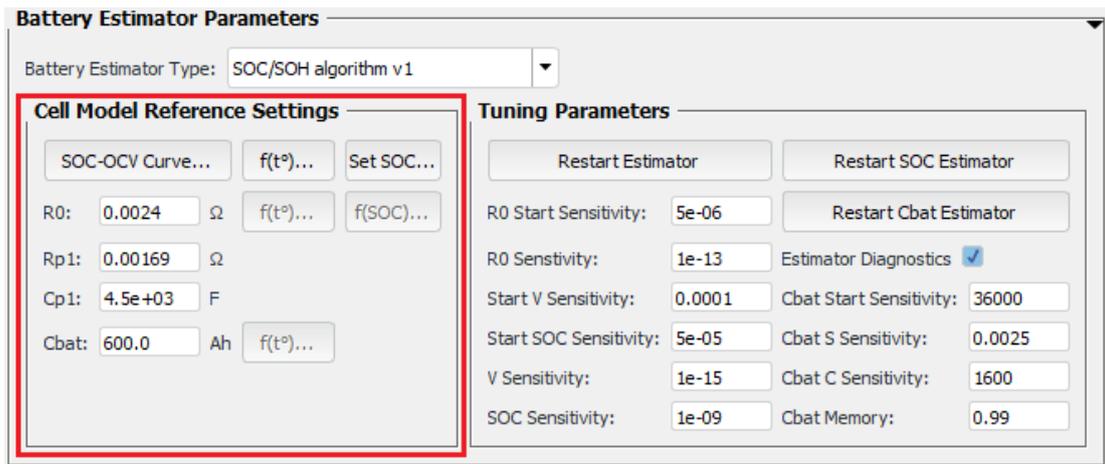


Figure 4-12 Cell mode Reference Settings

As mentioned before these values can sometimes be found in cells manufacturers datasheet, which, depending on the manufacturer, can be obtained by signing a Non-disclosure agreement.

## 4.11.2.3 SOC-OCV dependency curve of cell
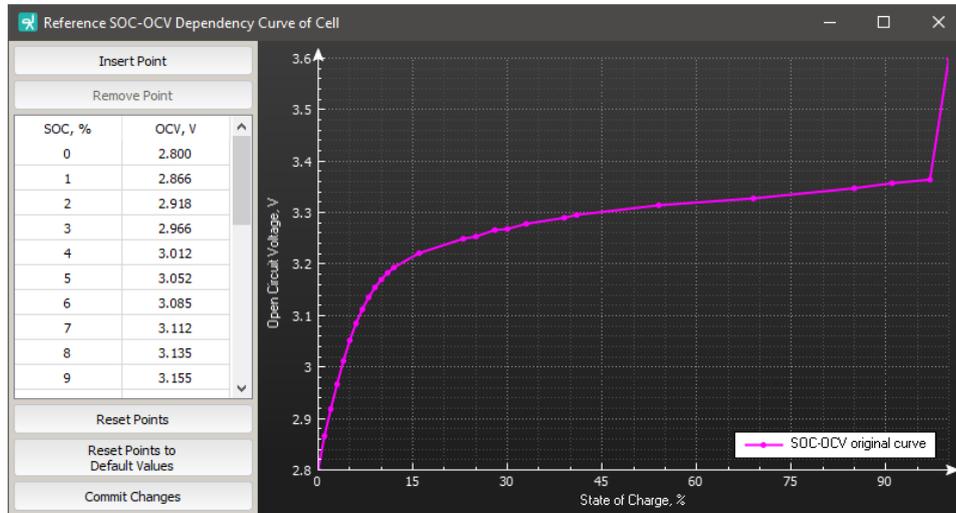


Figure 4-13 SOC-OCV dependency curve of cell

## 4.12 Heater control

Settings for heater can be found in the Control Panel → Configuration page → Controls → Heater And Fan Control.
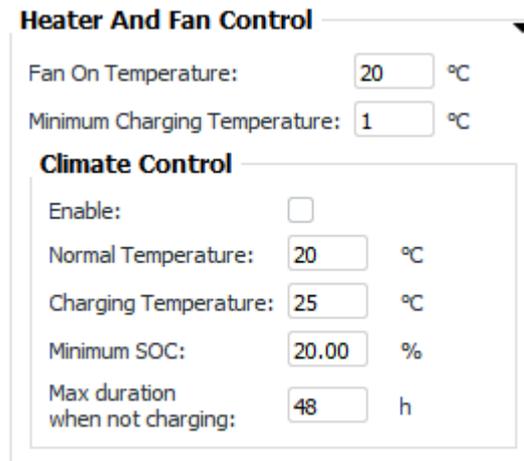


Figure 4-14 Heater and Fan parameters

- **Minimum Charging Temperature** parameter is used in pre-heating charging stage, it determines temperature threshold below which heater is activated until this value is reached. It can be disabled by entering value of −100.

- **Normal Temperature** parameter is used when Climate Control is enabled, and charger is disconnected. External heater is activated until temperature of cell batteries reaches this value.

- **Charging Temperature** parameter is used when Climate Control is enabled, and charger is connected. External heater is activated until temperature of cell batteries reaches this

value.

- **Minimum SOC** parameter determines SoC threshold below which Climate Control is disabled in order to prevent deep discharge.

- **Max duration when not charging** parameter refers to time duration after which Climate Control is disabled when charger is not connected. Setting this parameter to zero will turn off the corresponding safety mechanism that disables the Climate Control.

## 4.13 Cooling fan control

Settings for cooling fan can be found in the Control Panel → Configuration page → Controls → Heater And Fan Control. "Fan On Temperature" parameter determines temperature threshold when Fan is activated.

## 4.14 DC/DC converter control

DC/DC Converter control settings are in the Control Panel → Configuration page → Controls → DC/DC Converter Control box and consists of two parameters:

- **Active State Threshold** is used when ignition input is in logic high state or when charger is connected.

- **Passive State Threshold** is used when ignition input is in logic low state and charger is not connected.



Figure 4-15 DC/DC Converted Control parameters

Each threshold field accepts values from 2.00 V to 4.54 V.

## 4.15 PSU Under-Voltage Sense Control

For indication "PF29 Under-Voltage indication" need to be mapped. EMUS BMS Mini 3 powered from 12 to 72.8V and inputs can measure from 5 to 72.8V, voltage divider can be used. Value of the divider can be configured in Control Panel as well as Activation and Deactivation thresholds.
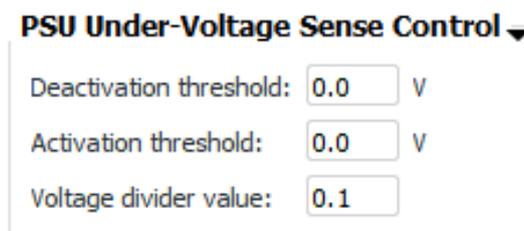
Figure 4-16 PSU under-voltage sense control

## 4.16 I/O Pins

Pin mapping settings are in "Control Panel" → "Configuration" → "I/O Pins" tab and consist of a list of parameter groups for each re-mappable BMS pin. Each group contains two parameters:

- **Assigned Pin Function** – determines the pin function of that particular pin;
- **Invert** – has different meaning depending on the pin function and whether the pin is general or special purpose.

The set of possible "Assigned Pin Function" parameter values for each pin can be seen by clicking on the corresponding drop-down menu. It differs depending on whether the pin is input or output, also whether it is a general or special purpose pin. The default function of a particular pin is always a top entry in the drop-down list.

The meaning of the "Invert" parameter for general purpose inputs, outputs is self-explanatory – it determines which logic level corresponds to the active state of the signal. There are some exceptions for special purpose inputs:

For EMUS BMS Mini 3 current sensor inputs , if they are mapped with their default pin function, the "Invert" parameter has no effect. Otherwise the meaning is the same as for general purpose inputs;

For EMUS BMS Mini 3 frequency measuring pins, if it is mapped with its default pin function, the "Invert" parameter changes which edge is used to count the pulses of the speed signal – if not inverted on rising edge, if inverted on falling edge. Otherwise the meaning is the same as for general purpose inputs.

Table 4-3 Pin function names

| Pin Function Name | Type | Description | Reference |
|---|---|---|---|
| PF0 No Function | Input/Output | No function mapped | - |
| PF2 Fast Charge Switch Input | Input | This pin function allows to switch between low charging current and fast charging current. | 2.4 Charging process and charging device control |

| PF3 Charger Mains AC Sense Input | Input | Acknowledges the connection and disconnection of non-CAN charging devices. | 2.4 Charging process and charging device control |
|---|---|---|---|
| PF4 Ignition Key Input | Input | Allows to user manually control Pre-Charge or Load/Discharge contactor. | More about battery warnings configuration you can find in chapter: (4.9 Warnings).<br><br>3.12 PSU Under-Voltage Sense Control |
| PF15 Leakage Sensor Input | Input | Activates "Insulation Fault" protection. | 2.5Battery protections, 4.75Protections |
| PF28 PSU Under Voltage Sense | Input | PSU Under-Voltage feature enable | 3.12 PSU Under-Voltage Sense Control |
| PF30 Optimized Battery Charging Sense | Input | Optimized battery charging sense activation | 2.111 Optimized Battery Charging |
| PF9 Charging Indication Output | Output | Pin function indicates charging process. | 2.16.1 Charging status indication |
| PF5 Heater Enable Output | Output | Using for "Pre-Heating" and "Climate Control" stages. | 2.4 Charging process and charging device control, More about battery warnings configuration you can find in chapter: (4.9 Warnings). |
| PF7 Sound Buzzer Output | Output | Provide an audial indication of some conditions | 2.16.2 Buzzer |
| PF8 Battery Low Indication Output | Output | Provide a visual indication of some "Low Cell Voltage" reductions. | 2.16.3 Low battery indication |
| PF10 Charger Enable Output | Output | Using to turn on and off charging devices. | 2.16.3 Low battery indication |
| PF12 Battery Contactor Output | Output | This pin function is intended for driving the main contactor that disconnects the battery from the load. | 2.5 Battery protections, 4.7 Protections |

| | | | |
|---|---|---|---|
| PF13 Battery Fan Output | Output | Using for "Climate Control" stage. | More about battery warnings configuration you can find in chapter: (4.9 Warnings). |
| PF16 Power Reduction Output | Output | Pin function used both for disconnecting non-essential loads or activating a power reduction mode on the load device. | 2.6 Power reductions 4.8 Load power reductions |
| PF17 Charging Interlock | Output | Dedicated control signal that is active if the charging device is connected, regardless of any other condition. | 2.4.1 Charging Interlock |
| PF19 ZVU Boost Charge Output | Output | Using for ZVU charger boost charging mode activation. | - |
| PF20 ZVU Slow Charge Output | Output | Using for ZVU charger slow charging mode activation | - |
| PF21 ZVU Buffer Mode Output | Output | Using for ZVU charger zero charging current activation. | - |
| PF22 BMS Failure Output | Output | Indicates EMUS BMS Mini 3 failure. | - |
| PF23 Equalization Enable Output | Output | Using for connecting equalization resistor in series to perform string voltage equalization | - |
| PF24 DC/DC Control Output | Output | Pin function ensures that EMUS BMS Mini 3 does not drain the battery when the system is not in operation. | 2.9 DC/DC converter control, 3.58 Contactor |

| PF25 Eltek SmartPack Rectifier Limit | Output | Using for Eltek charger functionality | - |
|---|---|---|---|
| PF26 Contactor Pre-Charge Output | Output | Pin function drive a current limiting pre-charge sub-circuit that bypasses the contactor. | 2.5.1 Contactor pre-charge |
| PF29 PSU Under-Voltage Indication | Output | For indication PF29 Under-Voltage indication | 3.12 PSU Under-Voltage Sense Control |
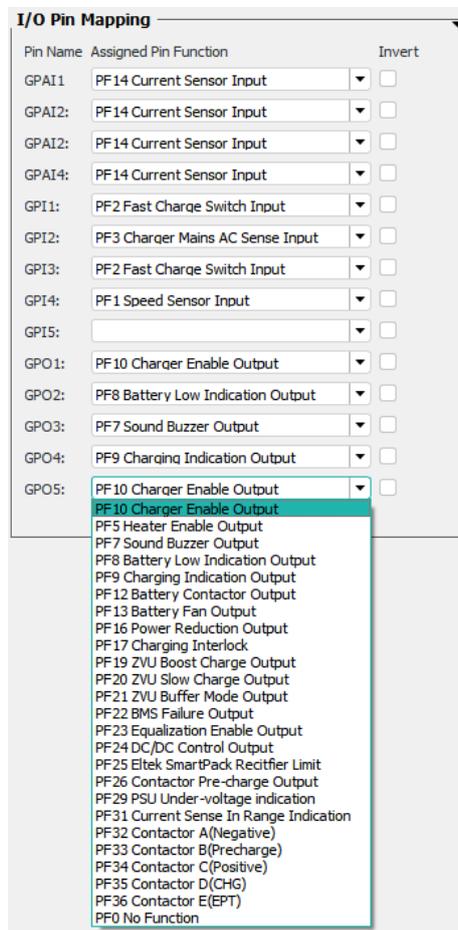


Figure 4-17  Pin mapping settings

Additional parameters that regulate the minimum and maximum duty cycle values of the PWM signal when the PWM output pins are mapped with "PF11 State of Charge Output" function can be found in SOC OUT Signal Parameters box.

Likewise, similar parameters related to the "PF18 Analog Charger Control Output" function can be found in Configuration page → Charging tab → Analog Charger Parameter box. The necessity of

each pin function, as well as the values of the corresponding "Invert" and addition parameters should be assessed and determined according to the design and requirements of the system in which EMUS BMS Mini 3 is used.

# Chapter 5: Maintenance

This section contains information and step-by-step guides on how to perform certain EMUS G1 BMS maintenance operations. These operations cover measurement calibration, firmware updates, security routines, etc. Most of them need to be performed only once.

All maintenance procedures are performed mainly using EMUS G1 Control Panel which can be downloaded from our website https://emusbms.com/support.

## 5.1 Master Clear

Master clear can also be described as factory reset feature. It is used when there is a need to reset the BMS configuration to default values and clear the statistics, events and password. This excludes "Master clear count" statistic.

Master clear procedure can be done using either RS232 or USB interface to connect the EMUS BMS Mini 3 to a computer. Before performing this procedure, it is recommended to disable the Broadcast on RS232/USB" feature in the Control Panel, Configuration page General tab. This way the periodically broadcasted data will not hinder the procedure progress observation. The mentioned feature can be re-enabled after the procedure is done. The procedure itself comprises the following steps:

- Acquire a third-party terminal emulator software that is capable of connecting to COM ports (e.g. RealTerm, TeraTerm, PuTTy, etc.)
- Connect EMUS BMS Mini 3 to computer using USB or COM connector.
- Connect to EMUS BMS Mini 3 COM port via the terminal emulator
- You can find it in Device Manager window under Ports (COM & LPT) option. Name of this COM port should be "USB Serial Port (COMx)", where x is the number, which digit count can be more than 1.
- Toggle power supply to BMS in order to reset it. EMUS BMS Mini 3 should respond with "VR1" sentence, meaning operation succeeded.
- Within 10 seconds of BMS startup you must enter "xxxxx" characters without "" and hit ⏎ enter. EMUS BMS Mini 3 will again respond with "VR1" sentence, meaning master clear operation succeeded.

## 5.2 Setting up password

As a security feature, EMUS BMS Mini 3 prevents unauthorized users from performing maintenance operation and from changing its configuration parameters by means of two separate passwords. This gives three different levels of access:

- Level 2 access allows to change individual configuration parameters and perform all maintenance operations;

- Level 1 access allows most maintenance operations, such as firmware updates, loading configuration from a file, resetting configuration to defaults, clearing the events log and statistics, resetting current measurement to 0, resetting the BMS, setting the SOC value, and calibrating the internal and external temperatures sensors of the Electronics Modules, but does not allow changing individual configuration parameters;

- Level 0 access only allows BMS activity monitoring and saving configuration to a file, but no maintenance other operations or changes to the configuration.

The procedure to set the passwords is the following:

- Open Control Panel and select Configuration → Management tab;

- Click "Set level 2" inside Security box, and type in a matching string of 4 to 8 "ASCII" symbols into the two resulting dialog windows to set the level 2 password;

- Press "Logout of access" to logout into level 1 access;

- Click "Set level 1" button to set level 1 password.

- Pressing "Logout of access" button will log the system out of current level into a lower access level. If there is a need to remove a password, it can be done by performing the following steps:

- Log into a desired access level by clicking on "Login on access" button and entering the corresponding password;

- Click "Set level" password button and press "Ok" twice, leaving password field empty to clear the password.

It is important to note that entering a password incorrectly for 10 times in a row will disable login access for 10 minutes to prevent brute force attacks. When users log in to the system, a 10-minute timer is set, after which the user again is returned to Level 0.   Also, it should be noted that when saving the password into a file together with the configuration it is stored as plain text.

## 5.3 Exporting and importing configuration

EMUS BMS Mini 3 features configuration management that provides functionality to save and load system configuration file. All EMUS BMS Mini 3 configurable parameters are stored inside this file. It is possible to save system password in the same file too, but it will be saved without encryption.

Management options are located in Control Panel → Configuration page → Configuration box. To save current BMS configuration click on "Save" button and proceed to following pop-up window. Configuration file will be saved as .bcf format. To upload the configuration to the system from a previously saved EMUS BMS Mini 3 configuration file and want to upload it to the system click on "Load" button. Immediately new window will pop-up with progress bar showing uploading status.

## 5.4 EMUS BMS Mini 3 firmware update

To ensure that EMUS BMS Mini 3 would have all the latest features and bug-fixes, it is recommended to periodically perform BMS Mini 3 firmware update procedure. The latest firmware images can be found online at https://emusbms.com/support, however this procedure also to revert to an older firmware if necessary.

> ⚠️ **NOTE**: Beware, there are few firmware images with the same version, but they differ in supported charger type.

These steps will guide you through firmware upgrade process:

- Open Control Panel and select Update → Control Unit tab;
- Click on "Open firmware" button;
- In opened dialog select desired EMUS BMS Mini 3 firmware file with extension .img;
- Click on "Start" button to initialize update procedure.
- File, Version and SN fields will be updated with information from image file if it is valid.
- After pressing the "Start" button all configuration parameters and statistics values are temporarily saved in local hard drive and memory of the EMUS BMS Mini 3 where they resided is formatted. After update configuration and statistics stored on hard drive are transferred back to BMS. This is done in order to make sure that new firmware would function flawlessly.

## 5.5 Exporting and importing statistics

Both Export and Import options can be reached from top menu bar "Options" option. By clicking on "Export statistics" Control Panel saves all statistics of currently connected BMS to local hard drive. In order to import them, "Import statistics" should be selected. There is no need to specify path to save them, because Control Panel does it by itself. These actions with statistics can only be done when logged-in and no charging or firmware update operation is taking place.

It is possible to export statistics from one EMUS BMS Mini 3 and import them into another. This is useful when BMS needs to be replaced and data must be preserved.

<p align="center">***</p>

Support

Please contact EMUS for BMS installation or support questions to:

support@emusbms.com

Thank you for choosing EMUS BMS products!