EMUS BMS mini
User Manual v0.8

Contents

List of Abbreviations

BMS	Battery Management System
PWM	Pulse Width Modulation
RPM	Revolutions per minute
LIN	Local Interconnect Network
CAN	Controller Area Network
GPIO	General Purpose Input Output
PC	Personal Computer
AC	Alternating Current
NC	Normally Closed

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1 System structure overview

EMUS BMS mini is a centralized battery management system that consists of a main controller and optional components that serve different purposes or amplifies the integrated ones. All of the populated pins and tabs of the main controller are described below:

- pins dedicated to connecting battery cells
- 5 connectors for external temperature sensors
- 9 multi-purpose input/output programmable pins
- CAN Bus
- LIN Bus
- Battery power tabs
- Load/Charger power tab

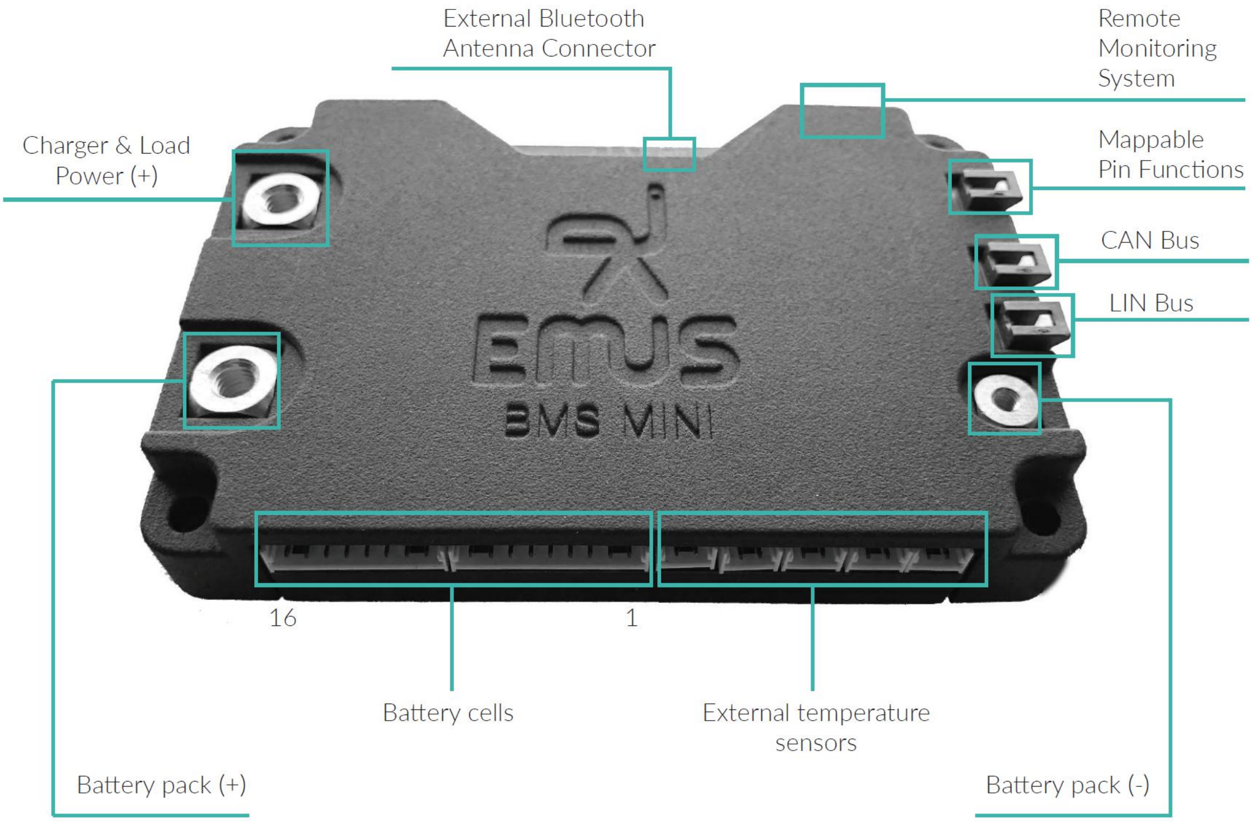

Figure 1.1: System structure

2 Setting up the BMS

2.1 Battery cells installation

There are two dedicated connectors for battery pack's power terminals and two for direct connection with batteries.

In order to safely connect batteries follow these instructions step by step. Also please refer to the wiring diagram in figure 2.1 for detailed overview of described connections.

1. Connect BMS mini "Terminal (-)" with "-" of #1 Battery;
2. Connect BMS mini "Terminal (+)" with "+" of highest battery cell in a string;
3. Connector BAT1 has 9 pins and connects first 8 batteries of a battery pack. Connector BAT2 has 8 pins and connects remaining 8 batteries. Batteries must be connected to connectors from right to left side in a sequence from lowest potential to the highest potential.

Note! When connecting less than 16 battery cells all unused wires **must** be connected to the highest battery cell in a string.

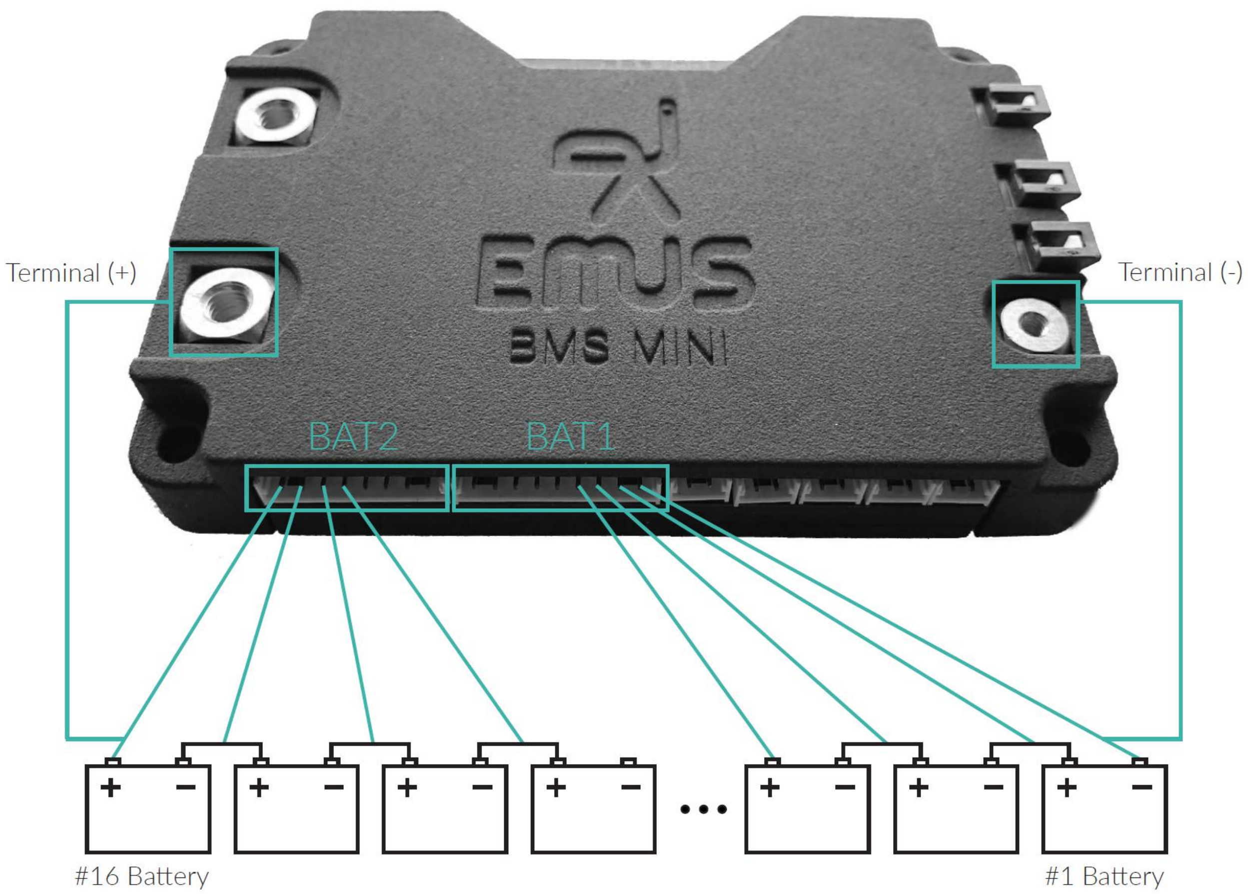

Figure 2.1: Battery connection diagram

Example 24 V system

In this example 7 Lithium Ion (Li-ion) battery cells are used to reach nominal total voltage of 25.9 V. In order to connect 7 battery cells only 8 pins of BAT1 connector is used. Remaining 9th pin and all BAT2 connector pins must be tied to positive potential of #7 Battery. Refer to figure 2.2.

Wiring steps:

1. Connect BMS mini "Terminal (-)" with "-" of #1 Battery;
2. Connect BMS mini "Terminal (+)" with "+" of #7 Battery;
3. Connect wires from BAT1 connector to battery cells in a series. From lowest (#1) to highest (#7) potential.
4. All remaining (unused) wires from BAT1 and BAT 2 connectors must be connected to positive potential of #7 Battery;

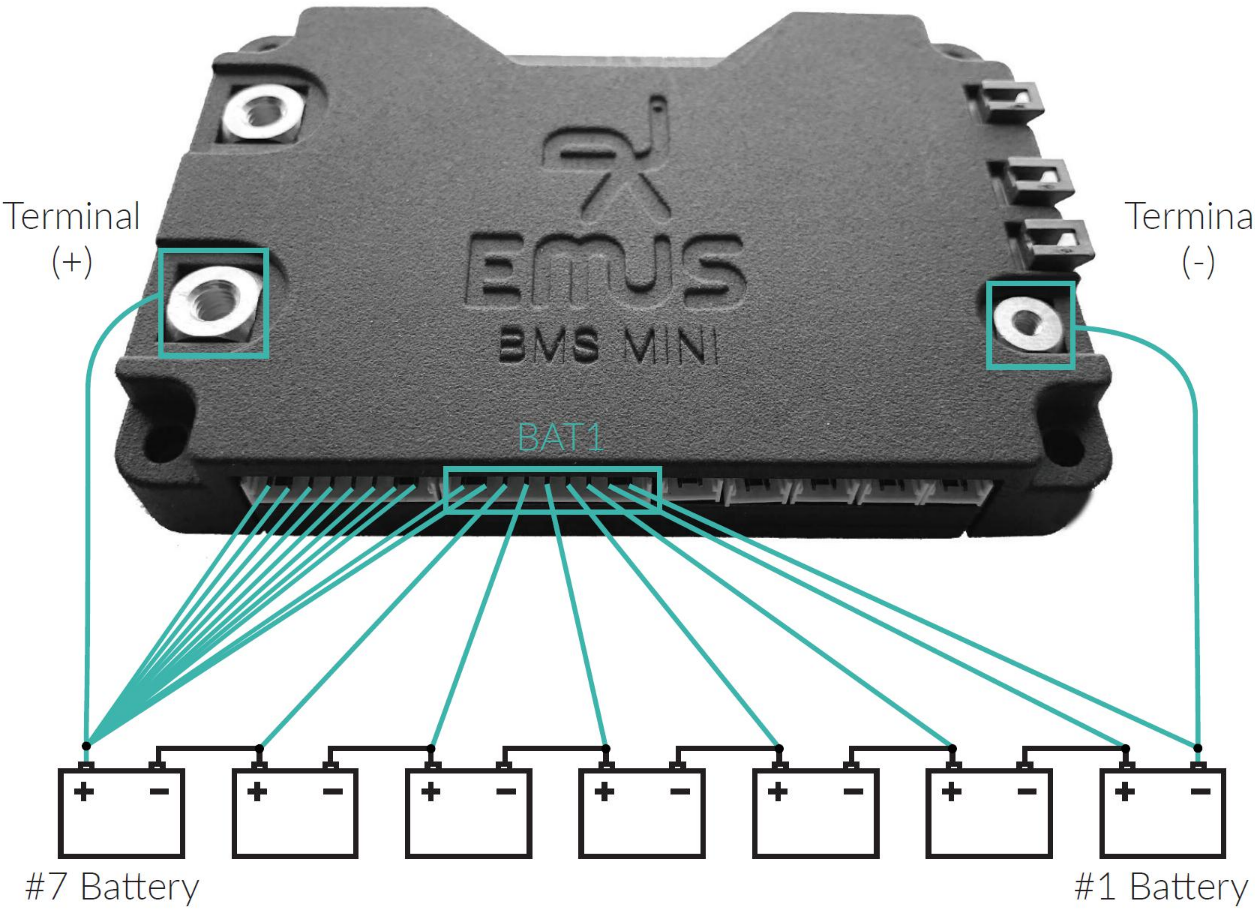

Figure 2.2: Example system 24 V (7 battery cells)

Example 36 V system

In this example 10 Lithium Ion (Li-ion) battery cells are used to reach nominal total voltage of 37.0 V. In order to connect 10 battery cells 9 pins of BAT1 connector and 2 pins of BAT2 connector must be used. Remaining 6 pins of BAT2 connector must be tied to positive potential of #10 Battery. Refer to figure 2.3.

Wiring steps"

1. Connect BMS mini "Terminal (-)" with "-" of #1 Battery;
2. Connect BMS mini "Terminal (+)" with "+" of #10 Battery;

3. Connect wires from BAT1 and BAT2 connectors to battery cells in a series. From lowest (#1) to highest (#10) potential.

4. All remaining (unused) wires from BAT2 connector must be connected to positive potential of #10 Battery;

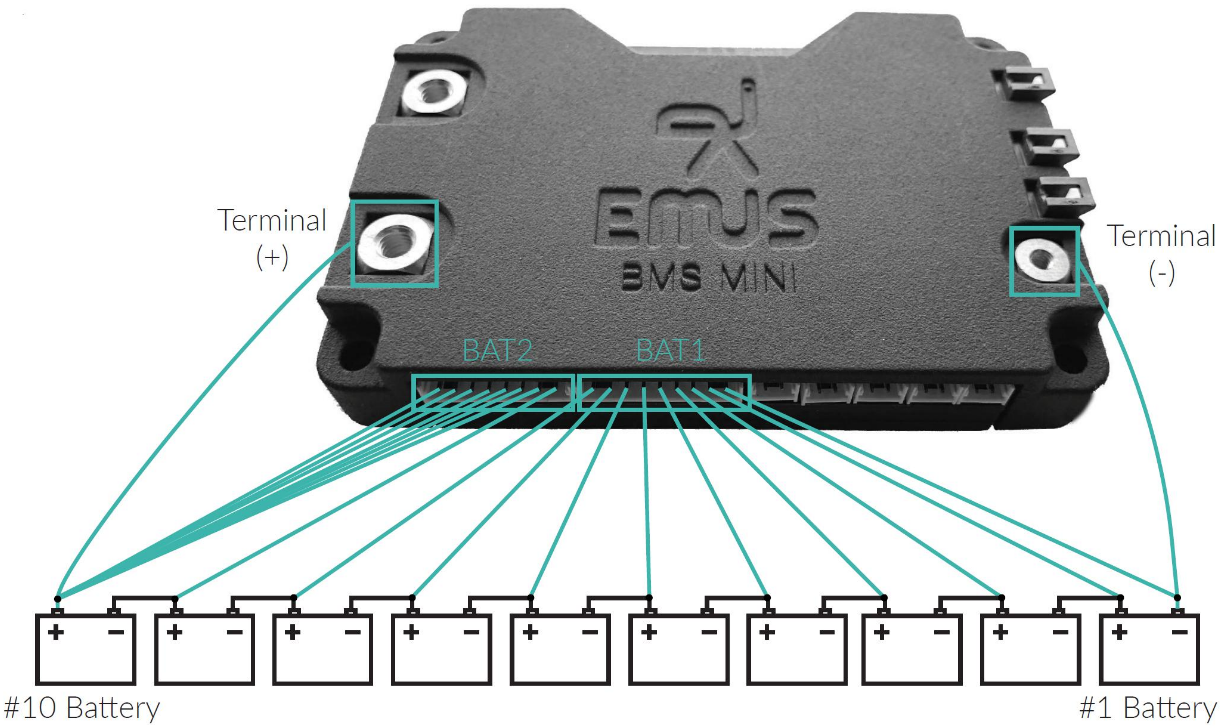

Figure 2.3: Example system 36 V (10 battery cells)

2.2 Connecting temperature sensors

On the bottom of the BMS mini (refer to figure 2.5) there are five 2-pin connectors dedicated to external temperature sensors. External temperature sensor is shown in a Figure 2.4.

Figure 2.4: External Temperature Sensor

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. In Figure 2.5 is it shown that external temperature sensors can be mounted on battery cells or between them.

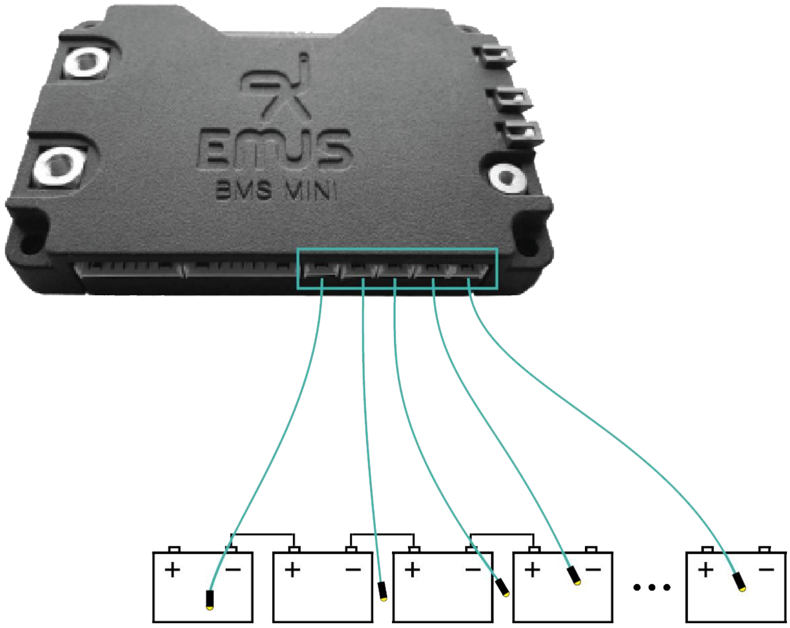

Figure 2.5: External Temperature Sensor installation diagram

2.3 Charger installation

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 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 charger's 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. The maximum charger's output current should not exceed the maximum charging current specified in the same specification sheet. Correct connection of different charging devices types supported EMUS BMS mini is described in the following chapters.

2.3.1 Non-CAN based charger

Non-CAN charger can be integrated with EMUS BMS mini in 2 different scenarios: using additional components to control the charger or without control. Main differences of these two scenarios are described below:

1. When using Non-CAN charger without control BMS cannot perform charger switching, also battery pack does not reach full potential of balanced cells.

2. When using Non-CAN charger with additional components for control, BMS can perform charger switching, and total battery cell balance is reached, but with relatively slower balancing process.

Scenario 1 (uncontrolled Non-CAN charger)

In the following figure 2.6 a system using uncontrolled Non-CAN charger is presented. In this scenario Non-CAN charger is directly connected to the battery pack. BMS has no control over charger's output voltage or current. Therefore, when the battery pack is nearly fully charged these events will happen: because this type of charging is uncontrolled, balancing is not efficient and

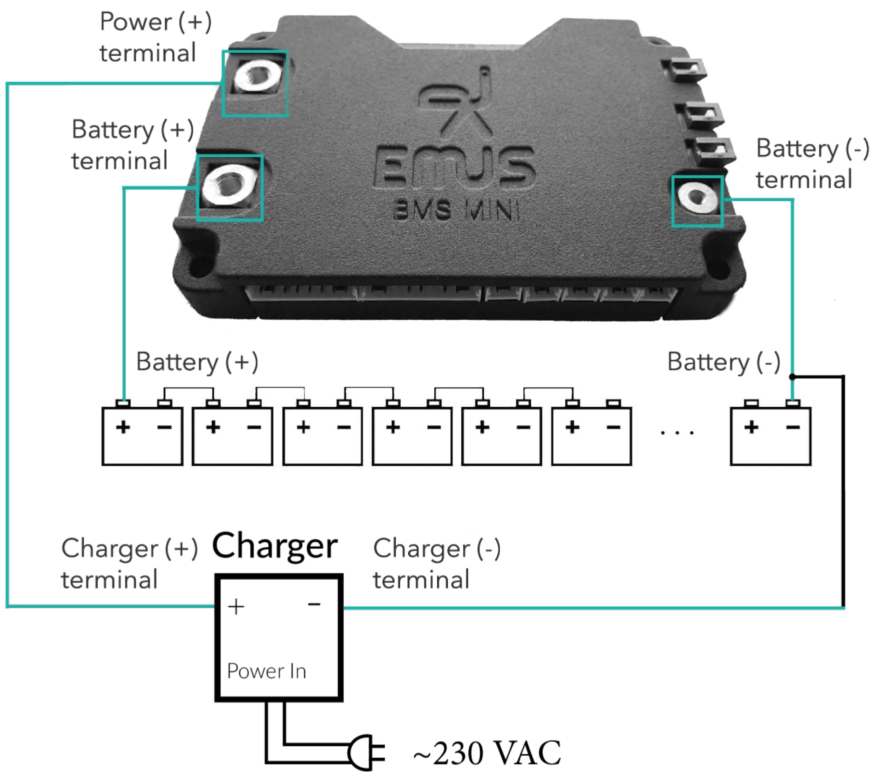

Figure 2.6: Uncontrolled Non-CAN charger installation diagram

eventually one of battery cells will be charged to its maximum voltage and when it tries to rise even more BMS will trigger 'Over-voltage' protection and internal contactor will disconnect a charger, which will finish charging process. For this set-up firstly connect battery to BMS mini: connect "Battery (-)" to "Battery (-) terminal" and "Battery (+)" to "Battery (+) terminal" using power cables. Now charger can be connected: using power cables connect "Charger (-) terminal" to "Battery (-)" and "Charger (+) terminal" to "Power (+) terminal".

Scenario 2 (controlled Non-CAN charger)

In the following figure 2.7 a system using controlled Non-CAN charger is presented. In this scenario Non-CAN charger is directly connected to the battery pack and controlled using low and high power relays. For this set-up firstly connect battery to BMS mini: connect "Battery (-)" to "Battery (-)

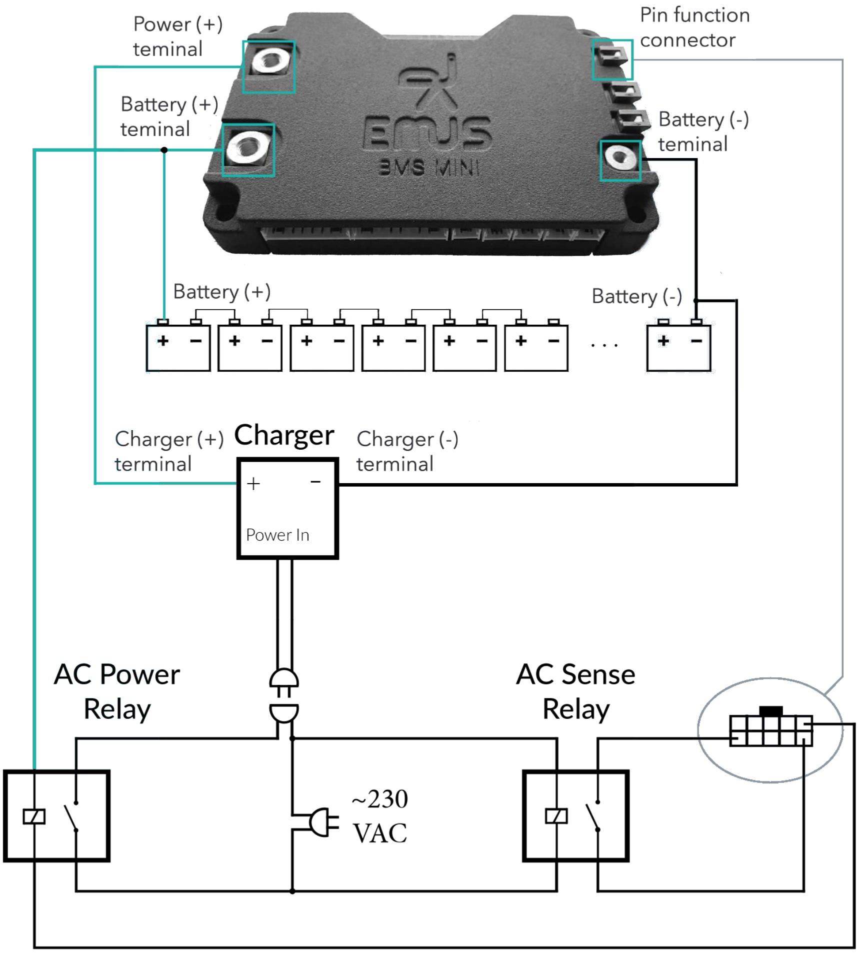

Figure 2.7: Controlled Non-CAN charger installation diagram

terminal" and "Battery (+)" to "Battery (+) terminal" using power cables. Now charger can be connected: using power cables connect "Charger (-) terminal" to "Battery (-)" and "Charger (+) terminal" to "Power (+) terminal". Now we will setup control/indication components. Low power AC Sense Relay of type NC (normally closed) should be connected in series to the AC Mains, which purpose is to signal whenever power is present. Connect one output of this relay to 'I1' pin of pin function connector, which is displayed in figure 2.8. Other output connect to '-' pin of the safe 10-pin connector. Use high power relay to connect Non-CAN charger as shown in figure 2.7. Connect one power relay input to "Battery (+) terminal" and another one to 'O1' pin of pin function connector. Wiring is completed what is left is to enable these "AC Sense" and "Enable Charger"

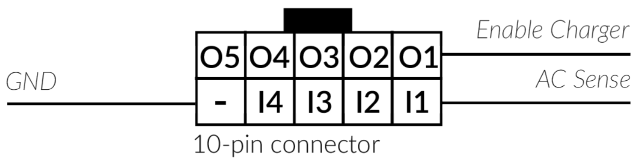

Figure 2.8: 10-pin Pin Function connector

pin functions on a mobile application. Refer to section 9.1 for how to download mobile application. Navigate to Configuration → Pin Functions and enable "AC Sense" function for pin "GPI1" and "Enable Charger" for "GPO1". 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.

Note! If voltage of the battery pack is greater than supply voltage of AC Power Relay, additional DC/DC converter should be used.

2.3.2 CAN based charger

Provided wiring connection between BMS mini and CAN Charger in figure 2.9 is only for reference, and should be done according to the general rules of correct CAN bus setup that are described in section 4.2. CAN charger is directly connected to a battery, but its control is performed over CAN Bus. Wiring diagram is shown in figure 2.9. Firstly connect battery to BMS mini: connect "Battery (-)" to "Battery (-) terminal" and "Battery (+)" to "Battery (+) terminal" using power cables. Now charger can be connected: using power cables connect "Charger (-) terminal" to "Battery (-)" and "Charger (+) terminal" to "Power (+) terminal".

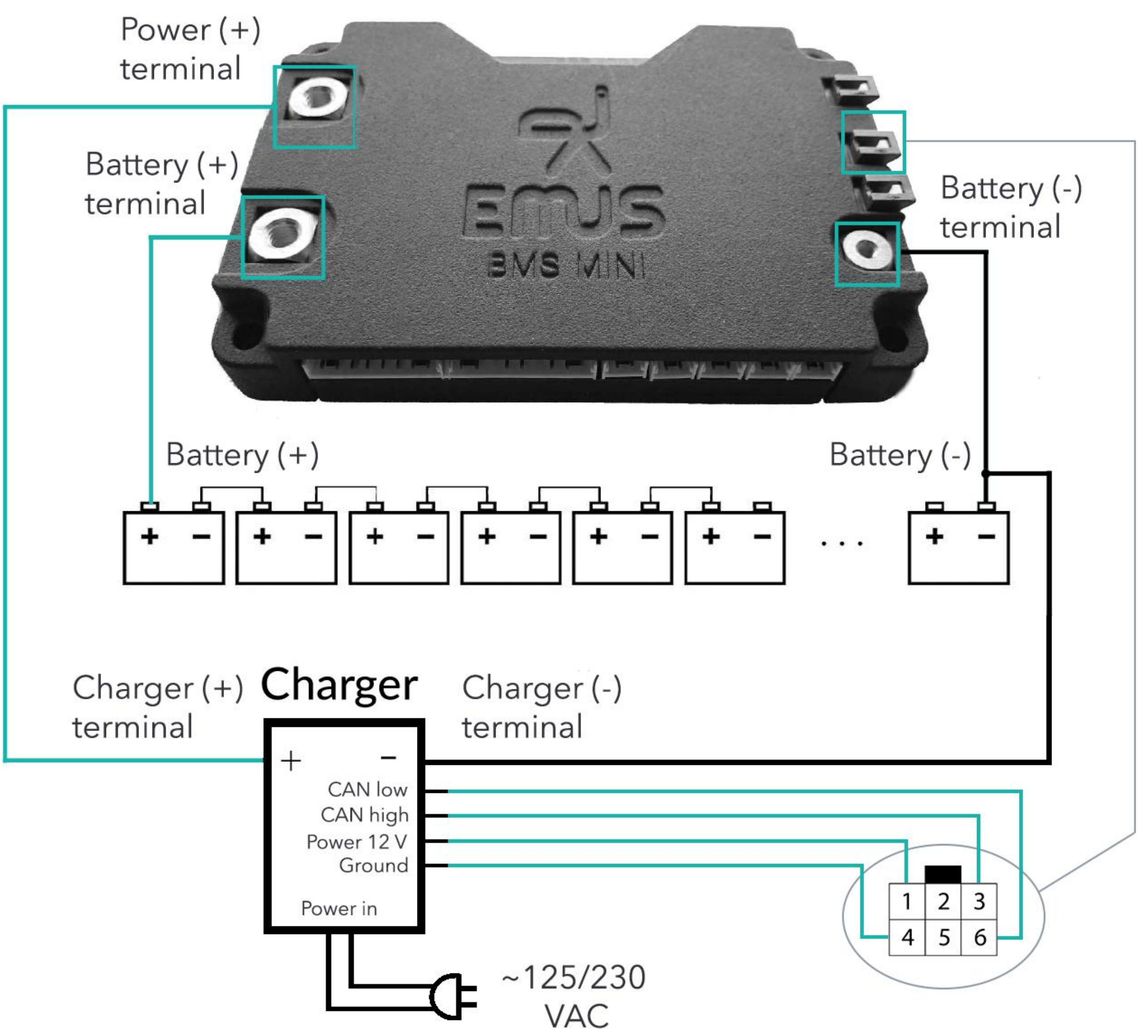

Figure 2.9: CAN charger wiring diagram

What is left is to wire CAN interface according to a CAN connection pinout shown in a figure 2.10.

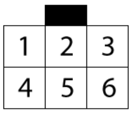

Figure 2.10: CAN connector

1. Power supply (+12 V)
2. 120 Ω terminator jumper
3. CAN high signal
4. Ground (GND)
5. 120 Ω terminator jumper
6. CAN low signal

Connect 1st pin to power supply of 12 volts, 4th pin to ground terminal (0 volts). CAN uses two dedicated wires for communication, which are called CAN high and CAN low. Connect those with your charger CAN Bus interface or with common CAN Bus communication wires. Additionally BMS mini provides integrated CAN Bus terminating resistor. In order to use it just short 2nd and 5th pins together, and 120 Ω terminating resistor would be applied to CAN Bus.

2.4 Load installation

On the left side of EMUS BMS mini (refer to figure 2.11) there are 2 power terminals: one is dedicated to connect battery and another one is for connecting load. Before connecting any device (load) you must power-up the BMS mini itself. Therefore, connect battery pack power cables to BMS mini: "Battery (-)" with "Battery (-) terminal" and "Battery (+)" with "Battery (+) terminal" and BMS should be up and running. **Make sure that device (load) will not draw current immediately connected**: power switch is turned off or in electric vehicle case throttle is released. Firstly connect "Load (-) terminal" to "Battery (-)" and then "Load (+) terminal" to "Power (+) terminal" using power cables.

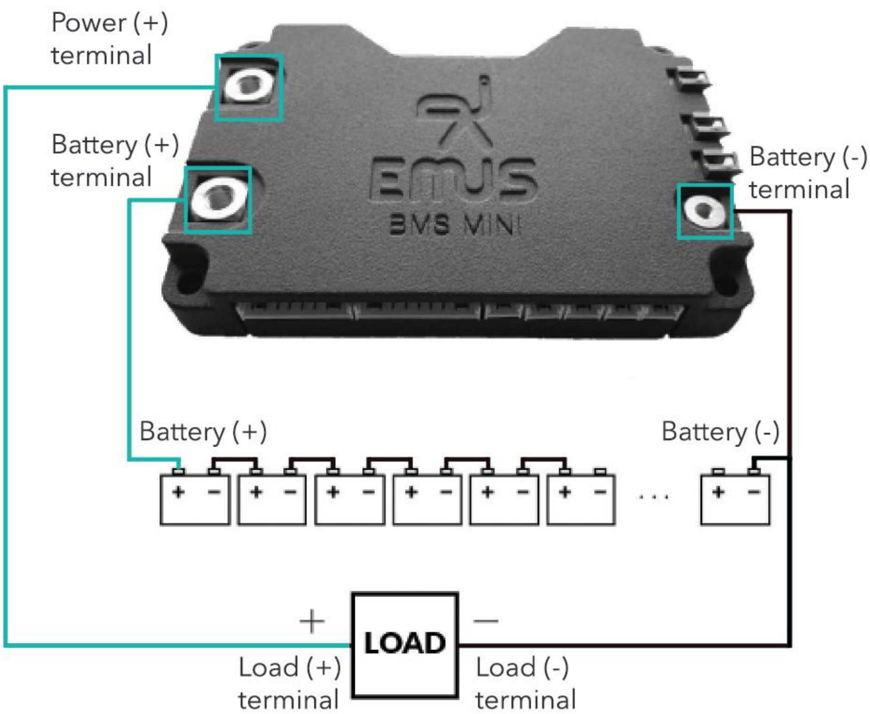

Figure 2.11: Load installation diagram

BMS mini supports "Contactor pre-charge" (refer to section 3.5), meaning BMS internal contactor will gently, without putting stress to internal components connect devices with load capacitance.

3 Core BMS functionality

3.1 Battery Monitoring

3.1.1 Voltage Monitoring

Battery cell voltage can be measured from 1.000 V to 4.500 V. Before final evaluation each battery cell is simultaneously sampled 32 times with a precision of 3 digits after decimal point in order to get the most precise and stable value. These measurements are performed at 32 Hz (31.25 ms) frequency. Settings for "Minimum Cell Voltage" and "Maximum Cell Voltage" parameter values are located in EMUS Mobile Application, Configuration page $\rightarrow$ Battery tab.

3.1.2 Current Measurement

EMUS BMS mini dual range integrated current sensor is an analog, hall-effect based current measurement device. The hall-effect measurement method also provides an inherent galvanic isolation between sensor ant the conducting part.

There are two functionally identical types of the EMUS BMS mini dual range current sensor: internal and external. Internal current sensor works in a range from $-75A$ to $+75A$ and has current update rate of 1 kHz. External current sensor parameters depend on its sub-type. Current measurements have an accuracy of 1 digit after decimal point (e.g. 15.7 A) for all types of current sensors.

Table 3.1: External current sensor operating current range

From, A	To, A
$-200A$	$+200A$
$-800A$	$+800A$

Table 3.2: External current sensor current update rate

Communication type	Update rate, Hz
CAN	100
LIN	10

Either internal or external current sensor module continuously measures the analog signals given by current sensors using a high sample rate analog-to-digital converter peripheral, and periodically stores averaged measurement results for further processing. The averaging is needed in order to mitigate the effects of thermal, quantization and other noises. The most recent results of the measurement process are taken, verified for validity, and used for calculating the momentary battery current value.

Each external Current Sensor is available with CAN or LIN communication interface. Current Sensor based on CAN communication is recommended when power consumption is not an issue and high sampling-broadcasting rate is needed. On the other hand if power consumption is an issue then Current Sensor based on LIN communication is recommended, because it requires significant lower power for operation and communication.

In order to install external current sensor connect it to LIN / CAN Bus connector. If direct connection is not possible, a LIN / CAN Bus splitter should be used in order to interconnect additional bus node.

3.1.3 Temperature measurement

External temperature sensors are able to measure temperatures from -40 °C up to 150 °C. Measurements are performed 2 times a second ($T = 0.5s$). There are also several internal temperature sensors that measure temperature of internal device components. All of them are stationary and cannot be disconnected or altered.

Real time external and internal temperature readings can be found in Status page → Battery tab. Temperature readings are split in to two separate charts. Each chart displays aggregated minimum, maximum and average values of temperature.

3.2 State of Battery

3.2.1 Charge estimation

State of Charge estimation in EMUS BMS mini is mainly based on the coulomb counting technique. 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, is accumulated as Battery Charge value (in Ah). This value is later compared to "Capacity" configuration parameter value in order to determinethe SoC expressed in percentage.

3.2.2 Health estimation

TBD

3.3 Charging process

BMS controls charging process and regulates output current of the charging device according to feedback of measured battery parameters. It ensures that the battery is charged safely and the battery cell voltages are correctly balanced after the charging process is finished. Regardless of the charging device type, charging process is divided into six stages:

1. **"Pre-Heating" stage** is entered when the minimum temperature value of all system temperature sensors is lower than the value of "Minimum Charging Temperature" parameter, meaning that the battery is too cold to be safely charged. Therefore during this stage BMS attempts to warm it up by activating "Heater" function which can be enabled using pin functions. This function is indended for switching third-party heating devices on and off.

2. **"Pre-Charging" stage** is entered then the minimum cell voltage is lower then Pre-Charge Threshold" parameter value. This condition is met only when the battery cell is deeply discharged, therefore during this stage the battery is charged with a reduced current in order to avoid heat development inside the battery cells due to their increased internal resistance.

3. **"Charging" stage** is entered if the maximum battery cell voltage is less than "Maximum Cell Voltage" parameter value and no other stage conditions are met. This indicates that no special precautions are needed in order to safely charge the battery, therefore during this stage the battery is charged with the highest possible current. Highest current depend on charging device and Maximum Charging Current" parameter value.

4. **"Balancing" stage** is entered when the maximum cell voltage is more than or equal to the "Maximum Cell Voltage" parameter value. The balancing threshold is by default equal to "Maximum Cell Voltage" parameter value as well. When balancing condition is active BMS starts to divert the charging current for each battery cell through shunt resistors in attempt to prevent the cell voltages from rising further. At the beginning of this stage the charging device is kept on until the maximum cell voltage starts to exceed the "Maximum Cell Voltage" parameter value by more than 10 mV, even though the corresponding battery cell is being balanced. Then the charging device is turned off and the balancing threshold is set to "Minimum Cell Voltage" plus the value of "Voltage Disbalance" parameter (but not higher than "Maximum Cell Voltage" parameter value) in order to dissipate the energy difference between cells as heat. At the end of this phase the difference between minimum and maximum cell voltages is lower than the "Allowed Disbalance" parameter value, then this stage is over, otherwise the charging device is turned on again and this process repeats.

5. **"Finished" stage** is entered whenever the "Balancing Stage" is completed. It indicates that the charging process is complete, therefore during this stage the charging device, regardless if its type, is disconnected from the battery pack by opening the charging contactor.

6. **"Error" stage** is entered if one of the several pre-defined critical conditions are met during he charging process.

Each charging stage persists until its entering condition is valid. The order in which charging stages take place is not strictly defined. Naturally, they follow the order as they are listed above, but it can vary depending on the situation. For safety reasons BMS does not allow to change any configuration parameters during the charging process.

3.3.1 Using Non-CAN charging device

Basic charging devices that do not have any EMUS BMS compatible interface for controlling their output current and voltage (also referred to as Non-CAN charging devices) are controlled by utilizing a special algorithm to turn them on an off using a switching device that is driven by a general purpose output pin mapped with "Charger Enable" 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 "AC Sense" function;

3.3.2 Using CAN charging device

Charging devices that are equipped with a CAN interface (or simply CAN chargers) are controlled by sending the requested output voltage and current values to them in a CAN message using a protocol that is specific to a particular charger.

Currently EMUS BMS mini officially supports the following CAN chargers:

- Elcon

BMS acknowledges that a CAN charger is connected when it receives a particular CAN message from a charger. Depending on the charger model, the charger transmits this message either by itself (periodically), or as a response to a requested CAN message from BMS. Disconnection is acknowledged if BMS does not receive any CAN message from the charger for more than 15 seconds. Consequently, the "Pin Function: AC Sense" has no meaning when using this type of charging device.

3.3.3 Configuration

All configurations for charging can be made using EMUS mobile application. These configurations are located in Configuration page → Charging tab and consists of "Voltage Settings" and "Current Settings".

Voltage Settings group has the following parameters:

- Balancing voltage threshold — battery cells voltage balancing is enabled on battery cells, which voltage is higher than this threshold and out of "Voltage disbalance" range related to other battery cells.
- Recharging voltage threshold — battery pack charging is reinitiated when "Minimum Cell Voltage" is below this threshold.
- Voltage disbalance — maximum allowed voltage difference between current minimum and maximum battery cell voltages.

Current Settings group has the following parameters:

- Maximum charging current (continuous) — maximum allowed continuous charging current.
- Maximum discharging current (continuous) — maximum allowed continuous discharging current.

3.4 Battery Protections

During charge and discharge EMUS BMS protects the battery cells from an operation beyond certain limits of its parameters: voltage, current, temperature. Description and configuration for each protection is described in the following chapters.

3.4.1 Cell Over-Voltage Protection

Cell Over-voltage protection prevents the battery cells from being overcharged during regenerative process, and is activated if the voltage of at least one of the battery cells is above the threshold set by "Maximum Cell Voltage". When protection is triggered integrated/external contactor disconnects charger from the battery pack to prevent any damage to the battery cells. When voltage of the battery cells, which triggered protection, drops below this voltage threshold parameter, contactor connects charger back and system recovers from the triggered protection.

3.4.2 Cell Under-Voltage Protection

Cell Under-voltage protection prevents the battery from being discharged further if the voltage of at least one of the battery cells is below the threshold set by the "Minimum Cell Voltage" parameter. When protection is triggered integrated/external contactor disconnects load (motor) from the battery pack to prevent deep depletion of the battery cells. When charger is connected and prepared to charge the battery pack, contactor connects load back. System recovers from this protection when voltage of battery cells, which invoked this protection rise above mentioned threshold parameter.

3.4.3 Charge Over-Current Protection

Charge Over-Current protection disconnects charger contactor or disables charger itself if pin function "Charger enable" is activated whenever the measured charge current is above the threshold set by the corresponding "Activation Threshold" parameter value, thus preventing the high currents during regenerative processes from potentially damaging the battery cells.

3.4.4 Discharge Over-Current Protection

Discharge Over-Current protection is activated if the measured discharge current is above the threshold set by the corresponding "Activation Threshold" parameter value, thus preventing the battery from being discharged at a rate that is higher than specified by the battery cell manufacturer.

3.4.5 External Over-Temperature Protection

External Over-Temperature protection prevents the battery from being operated when the temperature measured by one of the external temperature sensors is above "Activation threshold" parameter value, which may indicate an unexpected heat development somewhere in the battery.

3.4.6 External Under-Temperature Protection

External Under-Temperature protection prevents the battery from being operated when the temperature measured by one of the external temperature sensors is below "Activation threshold" parameter value, which indicates that environment is too cold for battery exploitation.

3.4.7 Internal Over-Temperature Protection

Internal Over-Temperature protection prevents the device from being operated under high temperature, which could build-up if heat dissipation is not performed well due to unexpected heat development inside device. Protection is activated when value of measured internal temperature is above "Activation Threshold" parameter value.

3.4.8 Configuration

Settings that regulate the behavior of the protections can be found in the Configuration page → Protections tab and consists of six sets of parameters for each different protection type. Each set contains five of the following parameters:

- Enable/Disable protection;
- Enable deactivation
- Activation Threshold;
- Deactivation Threshold;
- Activation Delay;
- Deactivation Delay.

All thresholds and delays are configured independently for each protection. All protections are enabled by default, but can be disabled individually if necessary."Activation Threshold" and "Deactivation Threshold" parameters, allow to create hysteresis between activation and deactivation values. BMS is forced to tolerate activation condition for as long as 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. When Enable deactivation is activated, this protection will not recover even if its recovery conditions are met, therefore protection must be reset manually.

The possible value range for the "Activation Delay" and "Deactivation Delay" parameters is from 0 to 600 s with a step of 1 millisecond.

The possible and recommended value range for the "Activation Threshold" and "Deactivation Threshold" parameters depend on the corresponding protection type:

- For "Cell Under-Voltage" and "Cell Over-Voltage" protections both parameters can have a value from 2.000 to 4.500 V. However recommended values should be set according to discharge and charge cut-off voltage values that are defined in the manufacturer provided specification sheet of the battery cells used in the battery pack;
- For "Discharge Over-Current" and "Charge Over-Current" protections the range of possible values of the "Activation Threshold" parameter is from 0.1 to 800.0 A, depending on the selected EMUS contactor model;
- For "External Over-Temperature" parameter can have a value from 20 to 155 °C. Recommended value is 60 °C.
- For "External Under-Temperature" parameter can have a value from -40 to 10 °C. Recommended value should be set according to minimum operating temperature value that is defined in the manufacturer provided specification sheet of the battery cells.

The optimal values for 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 is used, or determined experimentally.

3.5 Contactor pre-charge

In a lot of different applications the battery that is managed by EMUS BMS 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 contactor 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 offers a very straightforward contactor pre-charge feature (not to be confused with "Pre-Charging stage" that occurs during the charging process).

This feature works by constantly sampling voltage on contactor from load device side while slowly closing contactor providing small current to pass through. When voltage difference between battery and load device input capacity is less than 10%, contactor is fully closed.

4 Data interfaces

BMS mini uses CANopen protocol for communications through listed interfaces (except LIN). Device has it's object dictionary supporting various parameters viewing and configuring. Each interface caries CANopen packets and has access to all available device features. All interfaces can be accessed asynchronously and independently to each other.

4.1 Wireless smartphone connectivity

2.4 GHz integrated wireless interface is designed to connect with smart-phones and PCs supporting the same wireless technology. "EMUS BMS mini" application has to be installed in order to connect BMS mini device used for information display and configuration. Smartphone acts as a CANopen client and communicates through EMUS BMS mini object dictionary. Interface works as serial transmission channel and transfers standard CANopen packets back and forth. Wireless interface also enables features like discovering currently enabled BMS mini devices in range and displays their customizable names and serial number for easier identification. It's worth notice that only one wireless client (e.g., smart-phone) can be connected at the time. BMS mini will not be discoverable until primary device disconnects. However, other interfaces will still be available.

4.2 CAN

The CAN bus has be 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 4.1.

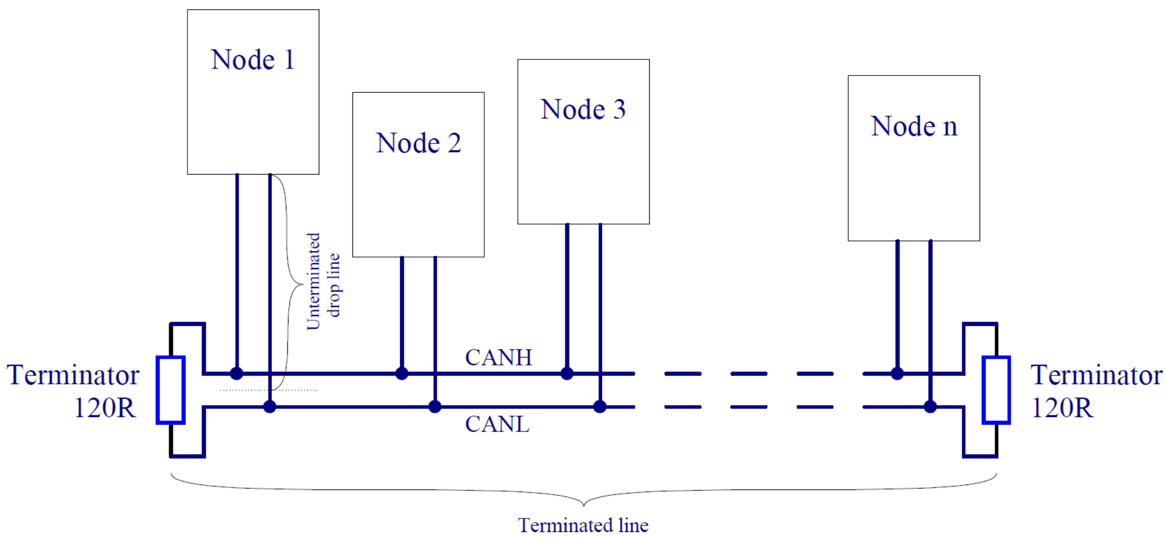

Figure 4.1: High-speed CAN network specified in ISO-11898-2 standard

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 4.1. 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.

Table 4.1: Maximum bus line lengths, 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.

Baud rate	L_U	$\sum L_U$	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

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 4.1 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 120Ω (100Ω minimum and 130Ω 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 45Ω, 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 20kΩ and 120Ω termination resistor are used.

In order 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, wire tap 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.

4.2.1 Installation

TBD

4.2.2 Configuration

Current baudrate — 250 kbps
TBD

5 Remappable GPIO Functions

5.1 Description

BMS mini supports remappable pins, which can be mapped with various different 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. Functions that fall in standard set are intended for driving relays, indicators, etc., reading or transmitting various logic signals from/to third-party devices. Functions that fall in special set are intended to control special third-party devices or read their complex signals.

There are 9 remappable pins divided into two groups: inputs (GPI1 ... GPI4) and outputs (GPO0 .. GPO5) refer to figure 5.1 for detailed overview. All functions are unique, so they can only be mapped once, meaning there can only be 1 pin mapped with particular function at a time. Tables 5.1, 5.2, 5.3 and 5.4 contains all currently supported pin functions.

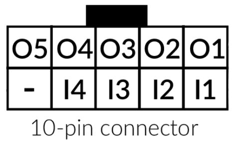

Figure 5.1: Pin function connector pinout

Table 5.1: List of standard set input functions

Pin function	Description
Ignition	Used for reading ignition state. When active BMS enables additional features and/or changes function priorities
AC Sense	Used for sensing when AC Mains is present to supply power for Non-CAN charger
Protection Reset	Used when user wants to clear all occurred protections

Table 5.2: List of special set input functions

Pin function	Description
None	-

Table 5.3: List of standard set output functions

Pin function	Description
Charging indication	Used for indicating charging process
Protection indication	Used as indication when protection occurs

Figure 5.2 shows possible ways how to configure input and output pins.Each input pin function can configure its input to accept voltage higher than 3.3 volts, meaning when high voltage is applied to input it would read high level signal, and when no voltage is supplied it would read low level signal (refer to 5.2 (a)). Input pin function can also be configured in a way that no external voltage would be needed. In this case when input is connected to ground it would read low level signal and when it is left floating input would read high level signal (refer to 5.2 (b)). All output pin functions are configured the same to use 'open-drain' technique. **Note!** $V_{max} <= 70$ V.

Table 5.4: List of special set output functions

Pin function	Description
State of Charge indication	Used to generate pulse-width-modulated signal from 0 volts to total voltage of Battery pack. When driving an analog fuel gauge the duty cycle of the generated PWM signal is directly proportional to the estimated battery state of charge

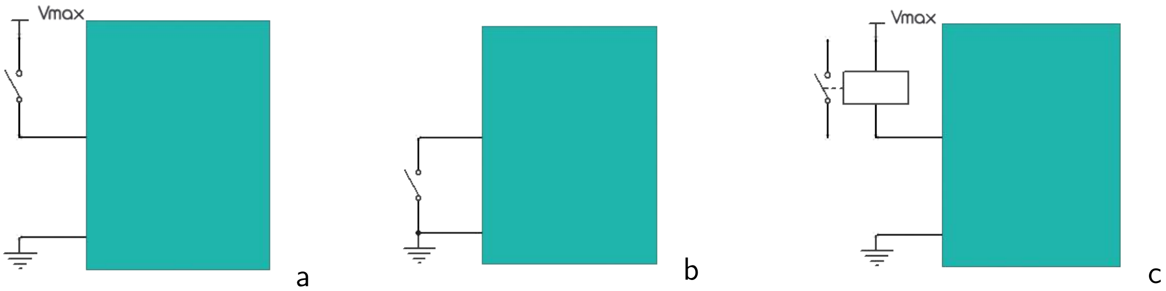

Figure 5.2: Input and output pin configuration: a) High voltage sensing input, b) Ground sensing input, c) High voltage output

5.2 Configuration

Using EMUS BMS mini mobile application each pin can be configured individually and effortless:

- In the main menu locate Configuration page → Pin Functions tab;
- There will be all available input and output pins with programmable functions. Select a pin which function you would like to change.
- In the resulting drop-down window a list of all currently available functions for this pin will be listed. Simply select new function and it will be automatically configured and enabled.
- Each pin function has additional parameters: e.g. functionality inversion, input sensing type... Therefore it can be additionally configured when needed.

Note! Pay attention to input pin function sensing type. If input function is configured with Voltage sensing it means pin is sensing high voltage, and if configured as Ground sensing - pin is sensing ground (0 V). When input pin is configured for ground sensing, and high voltage is applied it will result in damaging the interior components of this input pin.

6 Analytics

6.1 Statistics

For diagnostic purposes, system keeps track of various pre-defined battery and BMS operation statistics and stores them internally. 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 6.1.

Table 6.1: 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).
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	Min Cell Voltage	The lowest recorded cell voltage. Additionally contains the cell number and timestamp of when this value was recorded.
11	Max Cell Voltage	The highest recorded cell voltage. Additionally contains the corresponding cell ID and timestamp of when this value was recorded.
12	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 value were recorded.
13	Min Pack Voltage	The lowest recorded battery pack voltage. Additionally contains timestamp of when this value was recorded.
14	Max Pack Voltage	The highest recorded battery pack voltage. Additionally contains timestamp of when this value was recorded.
15	Min external temperature	The lowest recorded external temperature. Additionally contains the corresponding sesnor ID and timestamp of when this value was recorded.
16	Max external temperature	The highest recorded external temperature. Additionally contains the corresponding sensor ID and timestamp of when this value was recorded.
17	Max external temperature difference	The highest recorded difference between temperature of sensors. Additionally contains timestamp of when this value was recorded.
18	Under-voltage protection count	The number of times Under-Voltage protection has been activated. Additionally contains the timestamp of the last occurrence.

19	Over-voltage protection count	The number of times Over-Voltage protection has been activated. Additionally contains the timestamp of the last occurrence.
20	Discharge over-current protection count	The number of times Discharge Over-Current protection has been activated. Additionally contains the timestamp of the last occurrence.
21	Charge over-current protection count	The number of times Charge Over-Current protection has been activated. Additionally contains the timestamp of the last occurrence.
22	Cell Over-Temperature protection count	The number of times Over-Temperature protection has been activated. Additionally contains the timestamp of the last occurrence.
25	Pre-heat stage count	The number of time the "Pre-Heating" stage of the charging process has been entered.
26	Pre-charge stage count	The number of time the "Pre-Charging" stage of the charging process has been entered.
27	Charging stage count	The number of time the "Charging" stage of the charging process has been entered.
28	Balancing stage count	The number of time the "Balancing" stage of the charging process has been entered.
29	Charging finished count	The number of time the "Charging Finished" stage of the charging process has been entered.
30	Charging error occurred	The number of time the "Charging Error" stage of the charging process has been entered.
32	Charge restarts count	The number of times the charging process automatically restarted when maximum cell voltage dropped below "Recharge Voltage" parameter value.
33	Over-Temperature protection count	The number of times Over-Temperature protection has been activated. Additionally contains the timestamp of the last occurrence.
34	Min Internal Temperature	The lowest recorded internal temperature. Additionally contains timestamp of when this value was recorded.
35	Max Internal Temperature	The highest recorded internal temperature. Additionally contains timestamp of when this value was recorded.

6.2 Events

During operation, BMS keeps a log of the most recent events internally. It consists of 128 entries, each of which stores an event type identifier and occurrence timestamp. Once all 128 entries a filled, any new event replaces the oldest entry. All event types are described in the Table 6.2.

Table 6.2: List of events and their descriptions

ID	Event	Description
1	Cells voltage critically high	"Cell Over-Voltage" protection has been activated
2	Critical high voltage recovered	"Cell Over-Voltage" protection has been deactivated
3	Cells voltage critically low	"Cell Under-Voltage" protection has been activated
4	Critical low voltage recovered	"Cell Under-Voltage" protection has been deactivated
5	Charge current critically high	"Charge Over-Current" protection has been activated
6	Charge critical high current recovered	"Charge Over-Current" protection has been deactivated
7	Discharge current critically high	"Discharge Over-Current" protection has been activated
8	Discharge critical high current recovered	"Discharge Over-Current" protection has been deactivated
9	External temperature critically high	"External Over-Temperature" protection has been activated
10	External temperature recovered	"External Over-Temperature" protection has been deactivated
11	External temperature critically low	"External Under-Temperature" protection has been activated
12	External temperature recovered	"External Under-Temperature" protection has been deactivated
13	Internal temperature critically high	"Internal Over-Temperature" protection has been activated
14	Internal temperature recovered	"Internal Over-Temperature" protection has been deactivated
15	Internal temperature critically low	"Internal Under-Temperature" protection has been activated
16	Internal temperature recovered	"Internal Under-Temperature" protection has been deactivated
17	User Connected	"User has connected to the BMS"
18	User Disconnected	"User has disconnected from the BMS"
19	Firmware Updated	BMS firmware has been updated
20	Power up	BMS was powered-up
21	Contactor Emergency Cut-off	Contactor cut-off due to incorrect pre-charging conditions
22	Contactor Soft-start timeout	Contactor pre-charging was taken too long time
23	Charging finished	Charging process has been finished
24	Charging started	Charging process has started
25	Charging error	Charging process has stopped due to an error
26	Cells Count Mismatch	"Cells Count Mismatch" protection has been activated
27	Cells Count Mismatch Recovered	"Cells Count Mismatch" protection has been deactivated
28	Forced protection deactivation	All protections have been cleared manually

7 Status Parameters

Main BMS monitoring statuses and states are grouped into 4 groups. Each of the groups are described in the following lists.

Battery group:

- State of Charge — indicates remaining charge in the battery pack. Measured in %.
- Energy Left — remaining energy in the battery pack. Measured in Wh.
- Total Energy — total energy of the battery pack. Measured in Wh.
- Cells voltage — voltage of all available battery cells. Measured in V.
- Min. Cell voltage — minimum battery cell voltage. Displayed in V.
- Max. Cell voltage — maximum battery cell voltage. Displayed in V.
- Average cell voltage — average voltage of all battery cells. Displayed in V.
- Total cell voltage — total voltage of all battery cells. Displayed in V.
- External Temperature – temperature of all available external temperature sensors. Displayed in °C.
- Min. External temperature — minimum temperature of external temperature sensors. Displayed in °C.
- Max. External temperature — maximum temperature of external temperature sensors. Displayed in °C.
- Average external temperature — average temperature of all external temperature sensors. Displayed in °C.
- Internal temperature — internal temperature of device itself. Displayed in °C.

Charging group:

- Charging stage — current battery pack charging stage.
- Charging duration — current duration of charging.
- Last charging error — last error occurred during charging.
- Charging voltage — voltage supplied by charging device. Measured in V.
- Charging current — current supplied by charging device. Measured in A.
- Longest charging duration — longest charging duration of all charging times. Displayed as time format (HH:MM:SS).
- Shortest charging duration — shortest charging duration of all charging times. Displayed as time format (HH:MM:SS).
- Total charging duration — sum of charging duration of all charging times. Displayed as time format (HH:MM:SS).

- Charging cycle count — count of charging times.
- Max. Charging current — Maximum registered charging current supplied by charging device.
- CAN charger connection state — presence of CAN charging device.
- Connected CAN charger model — CAN charging device model.
- CAN charger set voltage — voltage set for CAN charging device. Displayed as V.
- CAN charger set current — current set for CAN charging device. Displayed in A.
- CAN charger error — last CAN charging device charging error.

Protections group consist of: Under-voltage, Over-voltage, Charging over-current, Discharging over-current, Ext. over-temperature, Ext. under-temperature, Int. over-temperature, Int. under-temperature. Each entry shows whether protection is active or not.

8 Maintenance

8.1 Firmware Update

Device supports firmware updating, released by the manufacturer. All process is performed in Android application, allowing user to update to the latest firmware automatically, or manually to the previous firmware version.

All update process is performed over wireless connection. During procedure, BMS device will not be available and whole process could take up to 2 minutes in average. It is recommended to stay close to a device for maximum signal strength and transfer speed. Also, update process is secure. Connection loss or other situations will not brick a device. In case of failure, you will be able to restart the update process.

"Device Firmware Section" and "Latest Firmware Section" contains current and latest firmware versions respectively and also firmware release version.

Application periodically checks for latest device firmware. If a new one is available a Download button will appear. After pressing it, firmware package will be started to download and stored inside Android device internal memory. When a package is downloaded, you can start update process any time, by clicking a button Start device update. Also, each firmware package has it's release notes. You can view it by clicking "View release notes" button.

Device firmware can only be updated using user with administrative privileges. Follow these steps in order to update to the last available firmware version:

1. In EMUS mobile application navigate to Menu → Update page.
2. Press Download button and wait until latest firmware file is downloaded.
3. Press Install button and wait until device firmware is updated.

It is recommended to always use the latest firmware version, but if you have other version of firmware, you can manually update BMS device by following these steps:

1. Click on Load firmware image button.
2. Browse for a firmware file stored inside Android device memory. File is identified by it's name. E.g. "EMUS_BMS_mini_v1.6.4.zip".
3. After selecting a file, click on Start firmware update button and updating process will be started.

8.2 Password protection

This device is equipped with protection from unauthorized access. The request to input password will be prompted during connection to a device. Without authorization application will not be able to access certain information or functions. By default this feature is disabled. The entered password is encrypted with one way hashing algorithm and stored inside device memory. Plain password will not be visible to any user type. In case of lost password, hard reset of device must be performed. For better security, use longer password with special symbols.

8.2.1 User types

The following supported types of users in the system which differ in control access level are described below:

Administrator — has the highest control access level. Administrator is able to view and edit all parameters including other Non-Administrator users. Password protected login for this user is required.

Guest — has the lowest control access level. Guest is only able to view certain parameter, no modifications to system is allowed. Password protection login for this user is optional and is not required.

8.2.2 Enabling password protection

Follow these steps in order to enable password protection:

1. Connect to a device as Administrator.
2. Go to Menu → Profile.
3. In Authorization section mark "Enable authorization" check-box to enable authentication.
4. Type in Administrator's password.
5. Mark "Allow Administrator Auto-Login" check-box in order to remember Administrator's password on each login. Otherwise, it will be requester every time. (optional)
6. Mark "Enable Guest User" check-box to enable Guest user. (optional)
7. Mark "Password protected" check-box to protect Guest user with a password. (optional)
8. Type in Guest User password.

After selecting required authentication configuration, click Submit button to apply changes. On next connection, device authentication will behave differently, according to chosen configuration.

8.2.3 Logging in

If password authorization is enabled, device could request Guest's or Administrator's password in order to connect. Follow these steps to authorization connection:

1. Click on selected device to connect.
2. Select which user type will be used. (Guest User is showed only if enabled).
3. Type in a password. (Required if password protection is set).
4. Click "Login" button.

8.3 Time and Date

BMS mini system has it's own time and date clock used to track exact occurrences of events and statistic values update. The time is displayed inside application menus or alongside related records. The main time details and configuration can be found in Profile menu -> Time window. This windows consist of these fields:

1. System Time
2. System Uptime
3. Date view
4. Set BMS time

Item 1: displays current date and time that is known to BMS device. If "Time not set" or incorrect time is shown, it's needed to be adjusted by pressing Set BMS time button (refer to Item 4).
Item 2: displays uptime counter in seconds, started from device power up or restart. This indicates how long system is stable and correctly running.
Item 3: a setting to choose between 2 types of date display in whole application (mainly in statistics and events):

- Full date - Displays exact date and time of a record (e.g., 2018-10-10 10:00:00).
- Time ago - Displays when record happened counting from current time (e.g., event occurred 2 hours ago). This type of format is more readable and easier to distinguish.

Item 4: a button to set current time to BMS. A correct time will be provided by smartphone's services and sent to a device. After this process, all already occurred records will be set to correct time in the past and their track won't be lost.

Each time after device is powered on or firmware update it's required to manually set a correct time. In case of software restarts or internal device malfunction, correct time won't be lost.

If device is operating without time and date set it will still track exact occurrences of records but only available information will be seconds passed after device start. Accordingly, date will be displayed in seconds passed format (e.g. 2 hours after start), meaning amount of time passed between device start and record occur.

If device will be powered off without setting a date and time, there may be left some records without correct time track. In this case, these particular events or statistics time will be displayed in yellow colour and "after start" format. Resolving exact date and time of these records will not be possible when setting correct time.

9 Software

9.1 Mobile application

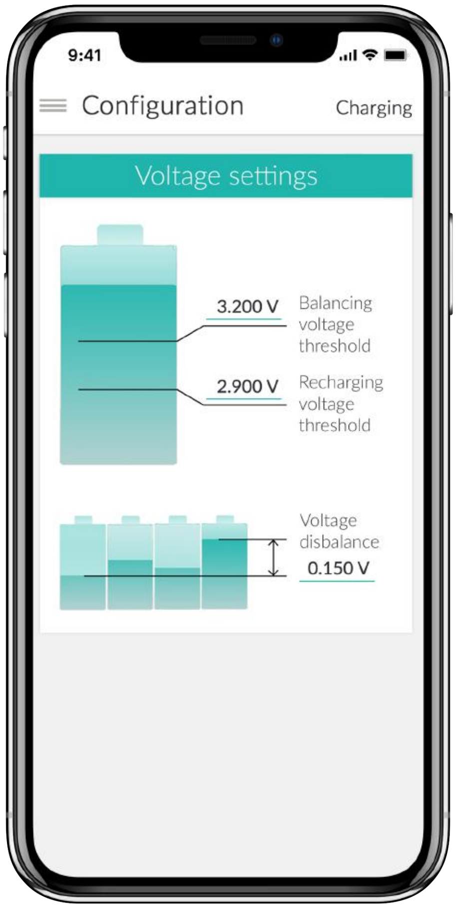

Figure 9.1: EMUS BMS mini mobile application

EMUS BMS mini is a freely available application for Android and in near future iOS devices, designed specifically for monitoring the battery status in an electric vehicle or energy storage application. Using this application, any smartphone or tablet can be connected to the device via Smartphone wireless connectivity eliminating the need for a dedicated display. Emus BMS mini application displays the most relevant statuses, such as battery cells voltages, state of charge, estimated remaining distance, power consumption, provides configuration for every parameter, performs firmware updates etc. More detailed diagnostic information can be found in separate menus.

Mobile application can be downloaded directly from Google Store for Android smartphones. We are planning to release an iOS application in the near future.

GET IT ON Google Play

10 Technical information

10.1 BMS mini

10.1.1 Mechanical specifications

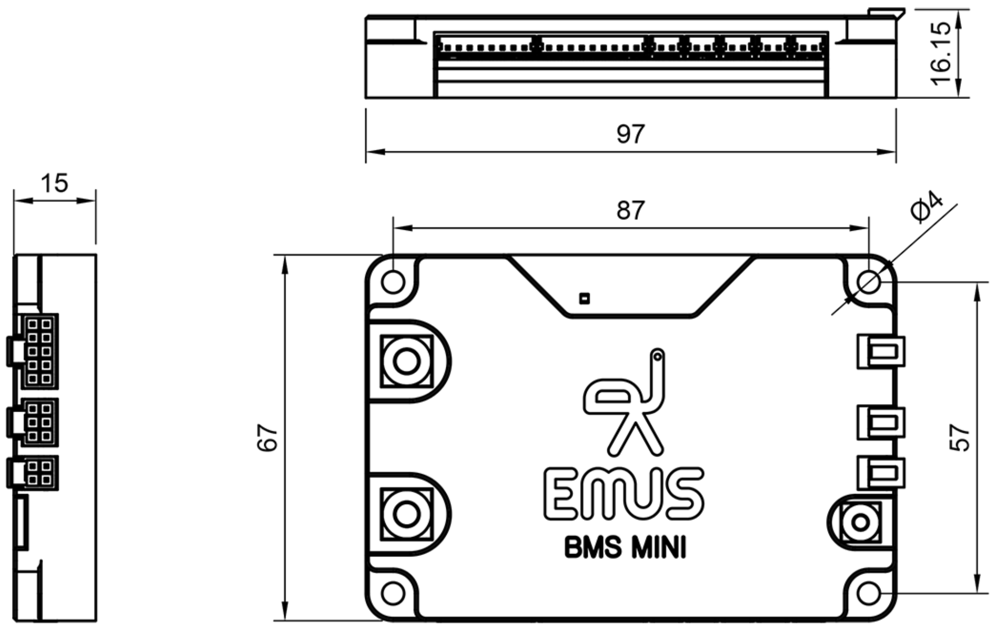

Figure 10.1: BMS mini mechanical drawing

Table 10.1: Fastening screws

Fastening screw location	Screw diameter
Positive potential tabs	M5
Negative potential tab	M3
Mounting holes	M4

10.1.2 Electrical specifications

Table 10.2: BMS mini Electric Specifications

Item	Value
Number of cells	6 - 16
Battery cell voltage	1.000 V ... 4.950 V
Battery pack voltage	12.0 V ... 67.2 V
Operating temperature	-40°C ... +80°C
Supply power (active)	50 mW
Supply power (sleep)	0.5 mW
Balancing current	200 mA
Maximum inner contactor current	75 A

10.1.3 Other specifications

Table 10.3: BMS mini Physical Specifications

Item	Value
Dimensions	97 $\times$ 67 $\times$ 15 mm
Weight	125 g