

Battery Management Systems

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EMUS G1 BMS Documentation

G1 Battery Management System Manual

Version 2.12.0

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Release notes:

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1.2.1	MM	2018-11-11	Fixed some mistakes and inaccuracies in chapters 3.2.13.1, 3.2.13.2, 3.2.13.3, 4.13, and 4.14.
1.3.0	MM	2018-12-07	Updated company name and links. Updated information about new and obsolete products.
1.4.0	MD	2019-08-11	Manual information updated. Chapters 5.2, 5.13 added. Obsolete products removed from manual. New products uploaded. New mechanical drawings made.
1.6.0	HS	2020-12-08	Added new chapters (2.1.3, 2.1.4, 2.3.2, 2.3.2.1, 2.7, 4.1, 4.9, 4.11.2, 4.11.2.1, 4.11.2.2, 4.11.2.3, 4.11.2.4), added BMS battery cells arrangements configuration examples, all products technical information has been transferred to separate datasheet documents.
1.7.0	HS	2021-08-17	Added new chapters (1.12.3, 2.1.5, 3.3). Detail description of the EMUS Tesla Module (TES011C) retrofit BMS.
1.8.0	AK	2022-02-15	Added new chapters (2.5.2, 4.3, 4.4) for Cell Wire Break and LTO support. Updated Protection and Warning chapters accordingly. New M/S illustration.
2.10.0	IRR	2023-10-11	Obsolete products removed from manual and uploaded new products versions. New Clustered naming and illustration. Chapter 3.10 wiring corrected.
2.11.0	IRR	2024-08-09	Fixed figures 2.2, 2.4. Added EMUS CAN Current sensor. Added BMS Failure Output. Removed Clustered Series connection. New charging model explanation. How to configure SOC Kalman & Coulomb. Removed iOS App. Minor fixes. New format, grammar, and spelling corrections.
2.12.0	IRR	2024-08-27	Update M/S Clustered explanation. Detailed M/S Clustered functionality. Corrected I/O functions. Included DC/DC control new feature. Minor corrections.

Preface

List of Abbreviations

BMS	Battery Management System
CU	G1 Control Unit
CM	Cell Module
CGM	CAN Group Module
CCGM	Centralized CAN Group Module
CR	Carrier Return
LF	Line Feed
USB	Universal Serial Bus
CP	Control Panel
PWM	Pulse Width Modulation

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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 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. 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 G1 BMS 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, which 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 G1 BMS 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 - to help using all its capabilities and avoid common issues.



NOTE: Using EMUS G1 BMS requires at least basic knowledge in electronics and electrical engineering. The use of EMUS G1 BMS 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 G1 BMS is used improperly and reserves the right to not provide any technical support in such case.

EMUS G1 system can be used for any types of battery cells arrangements, below are provided 4 basic BMS configurations examples:

- **G1 Distributed Regular** – for simple cases, when all battery cells are connected only in series (max. 40-80 cells in series);

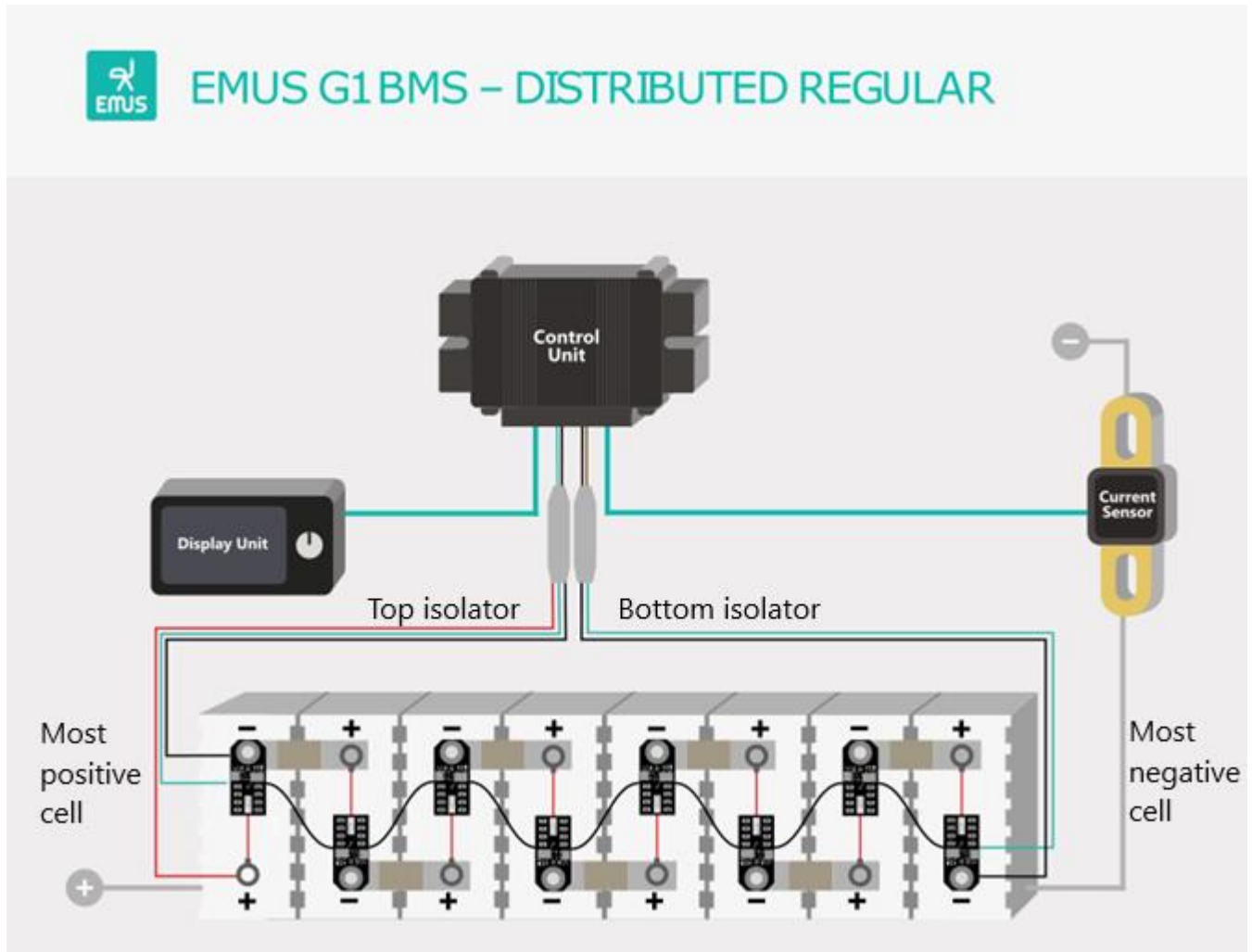


Figure 0.1 Distributed regular

- **G1 Distributed Grouped** – battery cells are grouped into packs and each pack is combined with CAN Cell Group Modules (CGM), then all (max. 24) CGMs are connected via CAN to main G1 Control Unit;

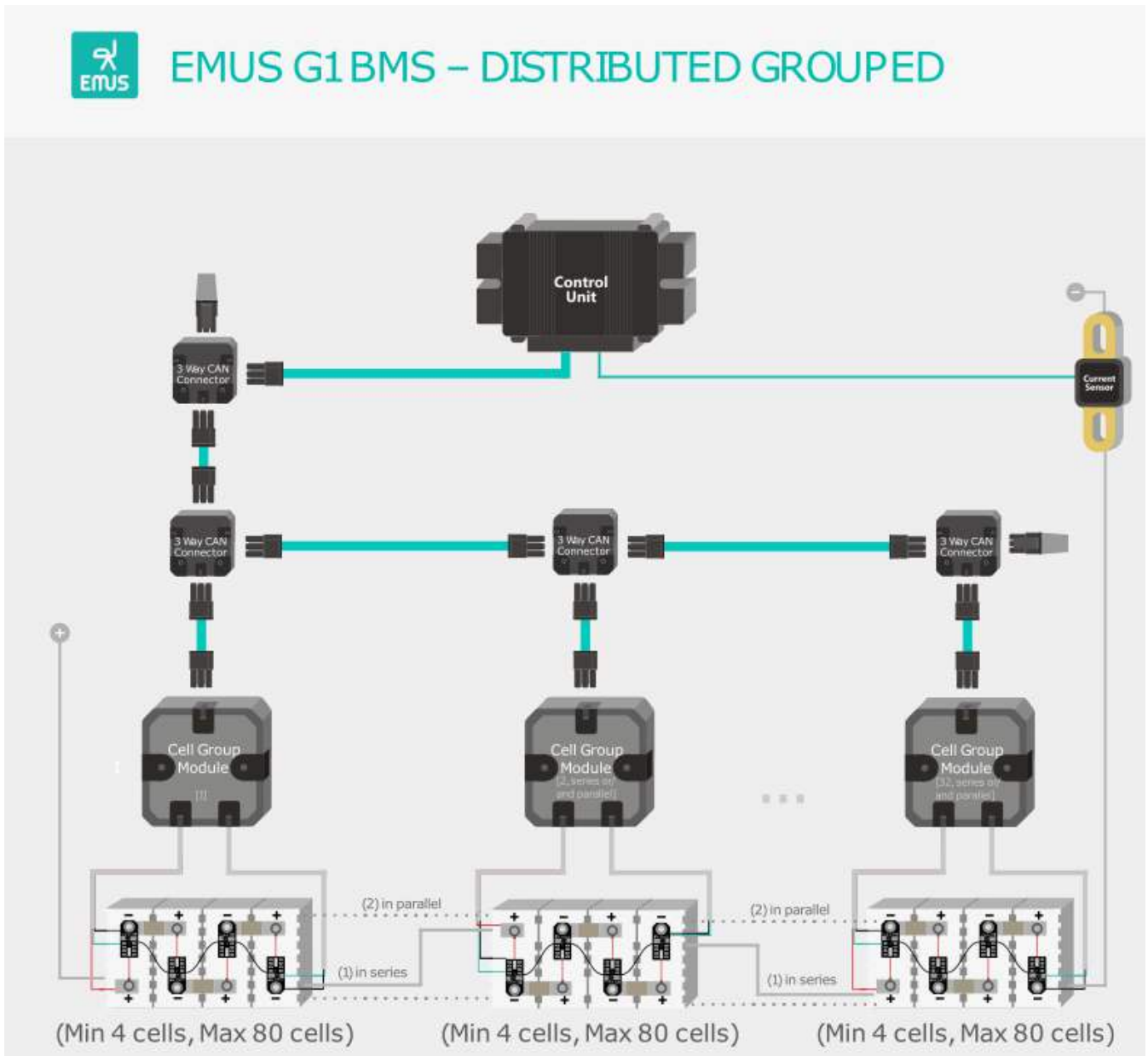


Figure 0.2 Distributed grouped

- **G1 CCGM Centralized** – for applications when batteries are split into separate blocks up to 16 cells and connected in series or/and parallel (max. 24 CCGMs for one G1 Control Unit), recommended for cells with capacities up to ~150Ah;

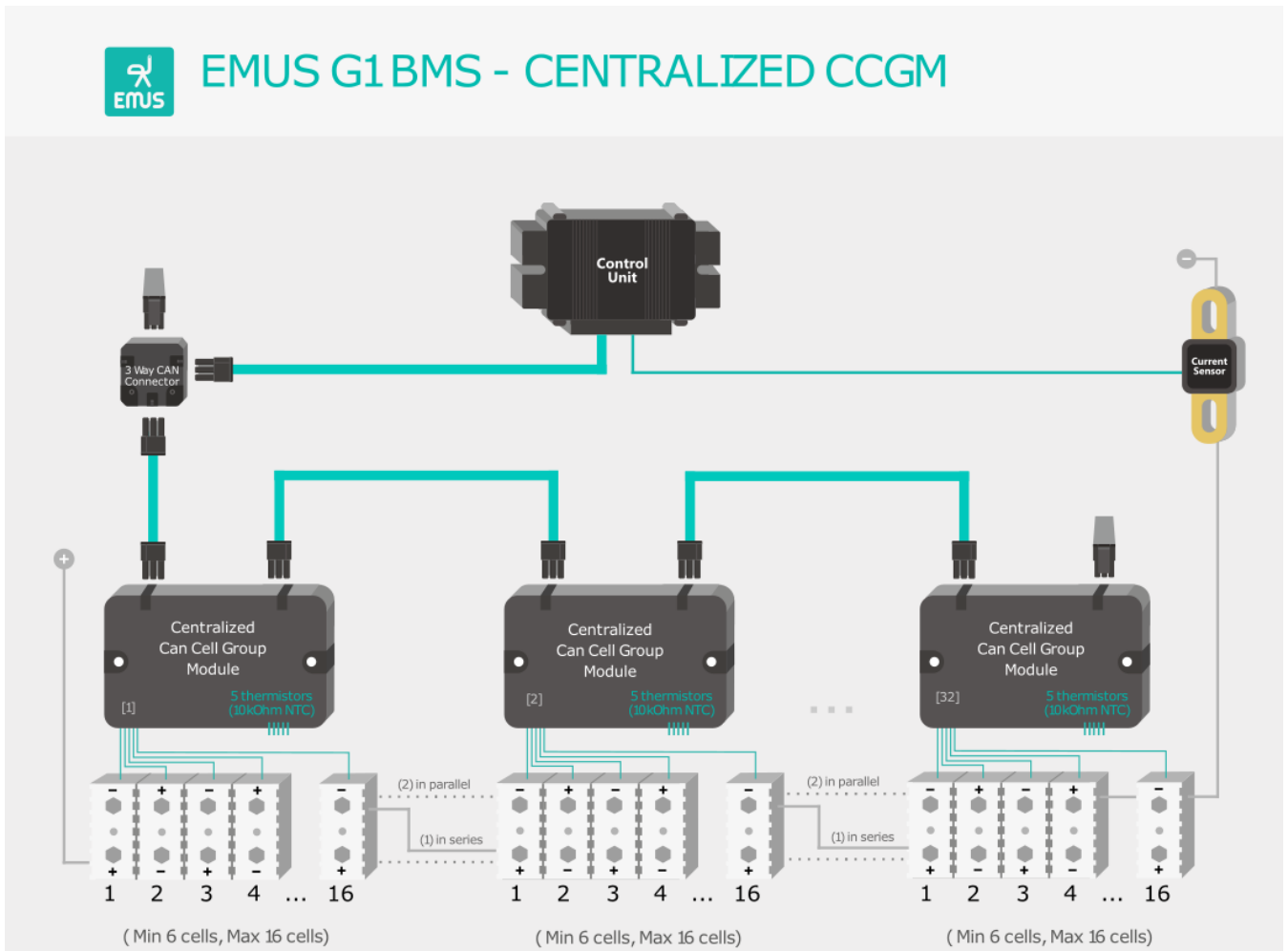


Figure 0.3 Centralized CCGM

- **G1 Distributed Clustered redundancy** –it can be combination of G1 Distributed regular and/or G1 Centralized. For applications which require high modularity, scalability, redundancy; up to 12 G1 Control Units can be combined, building modular battery system up to 6MWh;



G1 Clustered Distributed Grouped with CAN filters

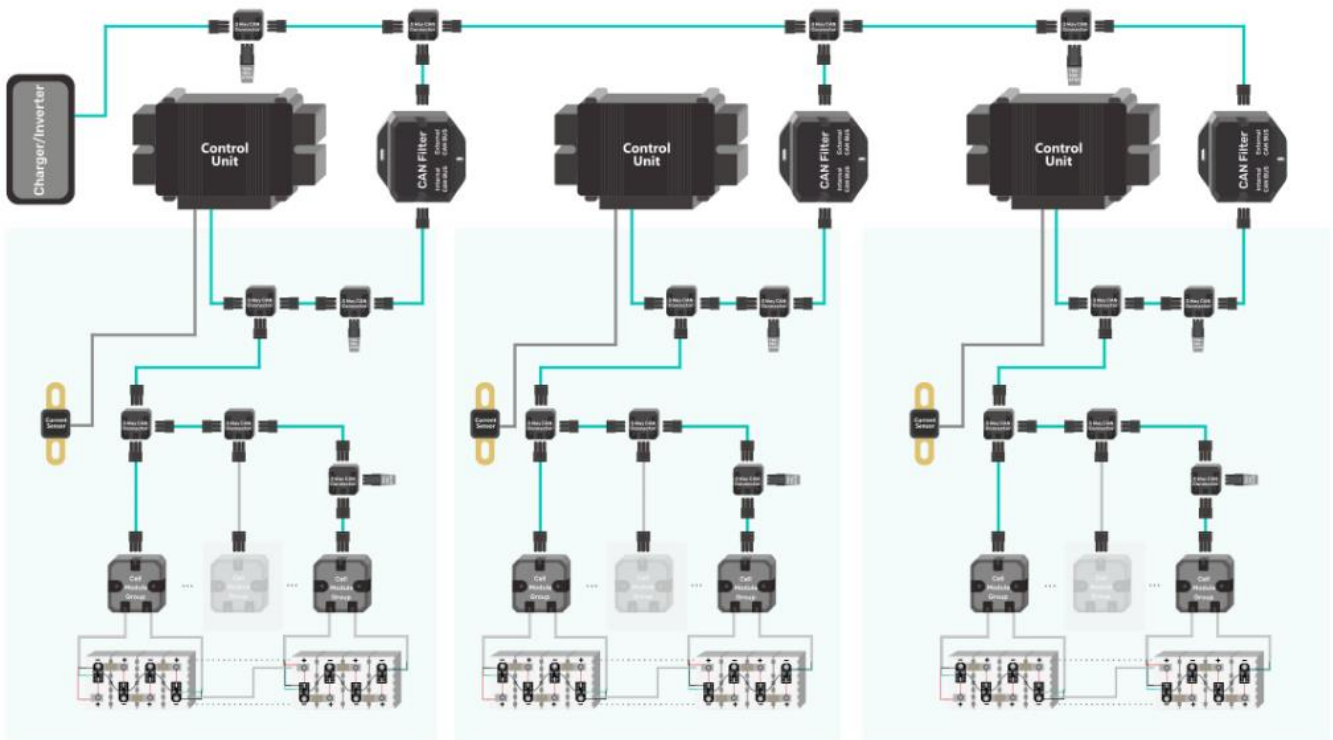


Figure 0.4 G1 Distributed Clustered redundancy



G1 Clustered Centralized CCGM with CAN filters

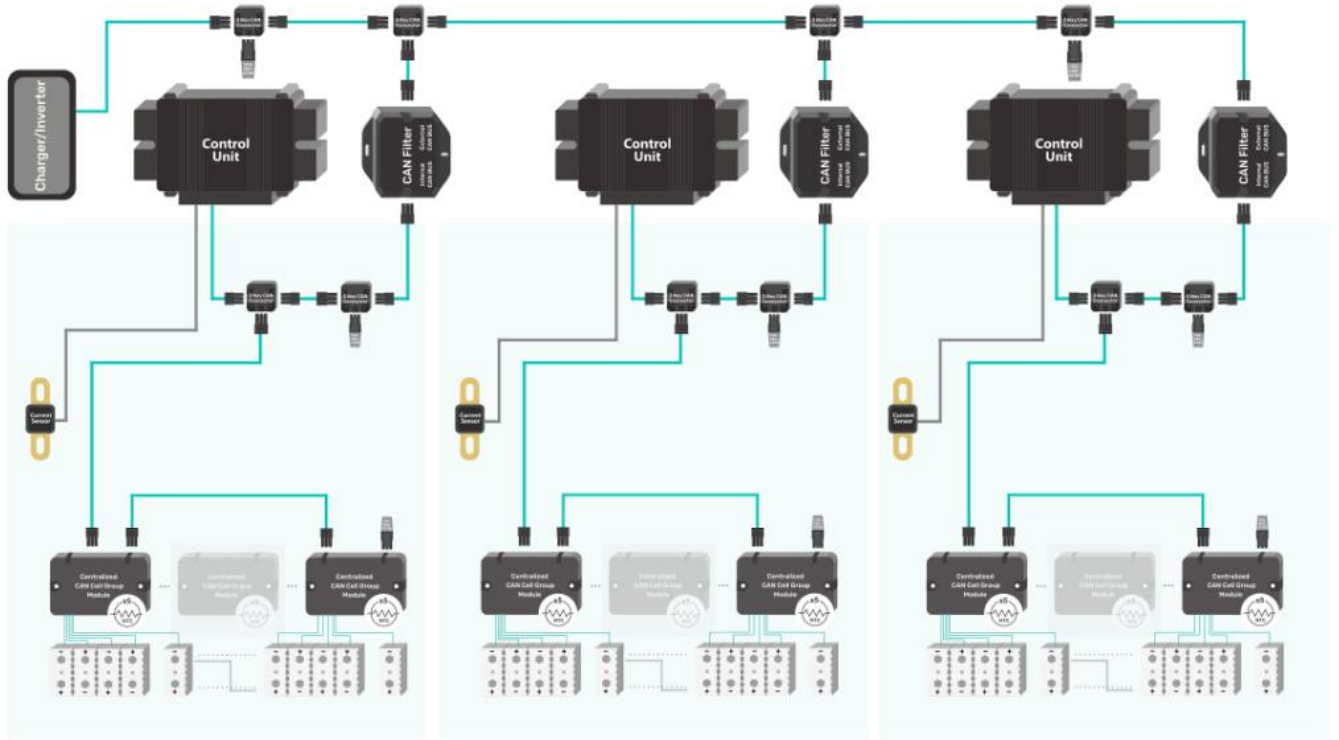


Figure 0.5 G1 Centralized Clustered redundancy

Chapter 1: System structure overview

EMUS G1 BMS is a digital, distributed topology battery management system that consists of a main controller, several cell controllers' boards (one for each individual cell), cell communication adapters, a current sensor, 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 G1 Control Unit

The G1 Control Unit is the main controller that autonomously executes all core and utility functions of battery management. It interacts with all other EMUS and third-party components in the system using various inputs, outputs and interfaces that are populated on its main 22 pin and secondary 8 pin connectors.



Figure 1.1 G1 Control Unit

Depending on their purpose, all G1 Control Unit pins can be divided into two categories: fixed and remappable. Fixed pins that are 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 that pin and cannot be mapped on others. Each of these pins is marked with its default function on the enclosure of the G1 Control Unit. More detailed information about pin functions in chapter: (4.22 - I/O Pins). In the picture below is illustrated G1 Control Unit pins, detailed information about other EMUS products can be found in their datasheet.

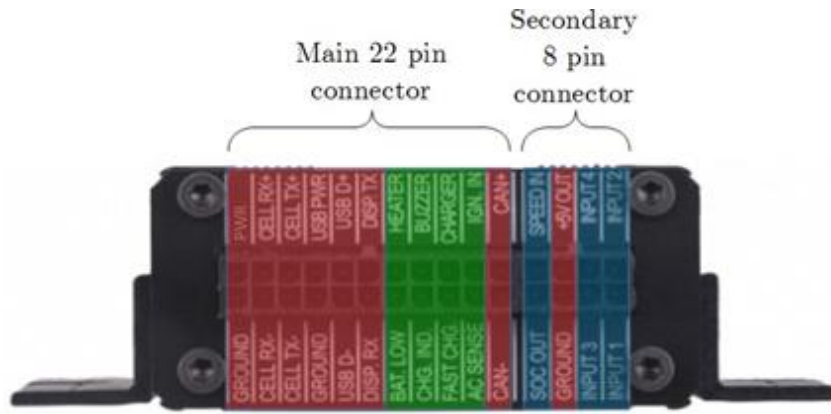


Figure 1.2 G1 Control Unit's pins - fixed red, general purpose remappable green, and special purpose remappable blue

1.2 USB data interface

The G1 Control Unit has a USB interface intended for a quick and straightforward connection to a host device (e.g., computer, tablet, smartphone) when configuration, diagnostics, or maintenance is needed. The provided USB adapter in G1 Control Unit is populated on the main 22 pin connector as the "USBPWR", "GROUND", "USB D-", and "USB D+" pins, 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 G1 Control Unit and the host application is described in an openly available document called "EMUS G1 Control Unit Serial Protocol" that can be found on [EMUS website](https://www.emusbms.com) ("Manual & Downloads" section).

1.3 RS232 data interface

The protocol used for data exchange over the G1 Control Unit's 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 "DISP. RX", "DISP.TX" and "GROUND" pins on the main 22 pin connector of the G1 Control Unit, detailed information about other EMUS products can be found in their datasheet. The protocol that defines the format of the data exchanged between the G1 Control Unit and the host application is described in an openly available document called "EMUS

G1 Control Unit Serial Protocol” that can be found on [EMUS website](#) (“Manual & Downloads” section).

1.4 CAN data interface

Because of its popularity in automotive, industrial, and many other applications, G1 Control Unit is also equipped with a non-isolated CAN 2.0A/B interface. It is populated in G1 Control Unit as the “CAN+”, “CAN-”, and “GROUND” pins on the main 22 pin connector, detailed information about other EMUS products can be found in their datasheet.

This interface is multipurpose, and enables the G1 Control Unit 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 CAN messages is described in a separate document called “EMUS G1 Control Unit CAN Protocol” that can be found on [EMUS website](#) (“Manual & Downloads” section). 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.

1.5 Serial cell communication data interface

The serial cell communication interface is dedicated for connecting a certain type of cell communication adapters and enables the G1 Control Unit to communicate with the individual cell controller boards (cell modules). It consists of pins on the main G1 Control Unit 22 pin connector of as: “CELL RX-”, “CELL RX+”, “CELL TX-” and “CELL TX+”, detailed information about other EMUS products can be found in their datasheet.

1.6 General purpose inputs and outputs

Pins that fall into the general-purpose output category are populated on the G1 Control Unit main 22 pin connector as the following: BAT.LOW, HEATER, CHG.IND, BUZZER, CHARGER. The GPO SOC OUT is explained in the following chapters as it follows different logics.

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. When driving inductive loads (e. g. relays, buzzers) it is recommended to terminate it with flyback diodes (see. Figure 3.24).

Likewise, pins that fall into the general-purpose input category are populated on the same G1 Control Unit connector as the following: FAST CHG., AC SENCE, IGN.IN, SPEED IN.

The G1 Control Unit use them to read various logic signals from third-party devices.

As mentioned already at the beginning of this subsection, general purpose inputs and outputs are remappable, and are named after their default function.

1.7 Current sensor inputs

EMUS G1 Control Unit "INPUT1", "INPUT2", "INPUT3", and "INPUT4" pins on the secondary 8 pin connector are special purpose analog input pins that are by default intended for interfacing the G1 Control Unit with a current sensor. Nevertheless, they are remappable and can also work as digital inputs in case the current sensor is not used, and current is monitored by external means. The adjacent "+5V OUT" and "GROUND" pins are intended for supplying power to the EMUS current sensor when it is connected to the G1 Control Unit.

1.8 SOC output

The "SOC OUT" pin on the secondary 8 pin connector of G1 Control Unit is a special purpose digital output pin that can generate a 0-5V pulse-width-modulated signal. Depending on which of the two special function this pin is mapped with, such signal can be used for:

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 connection diagram for a fuel sensor.

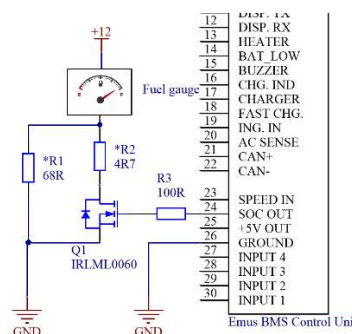


Figure 1.3 Example SOC Output connection circuit

*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 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 G1 Control Unit.

Apart from these two special functions, this pin can also be mapped to any other standard output function and generate a corresponding logic signal.

1.9 Speed sensor input

The G1 Control Unit "SPEED IN" pin on the secondary 8 pin connector is a special purpose digital input that is wired directly to a peripheral that can measure frequency of a pulsed signal. By default, it is used to measure the speed of an electric vehicle. The internal circuitry of this pin is almost identical to that of the general-purpose inputs; therefore, it can be mapped with any other digital input pin function if necessary.

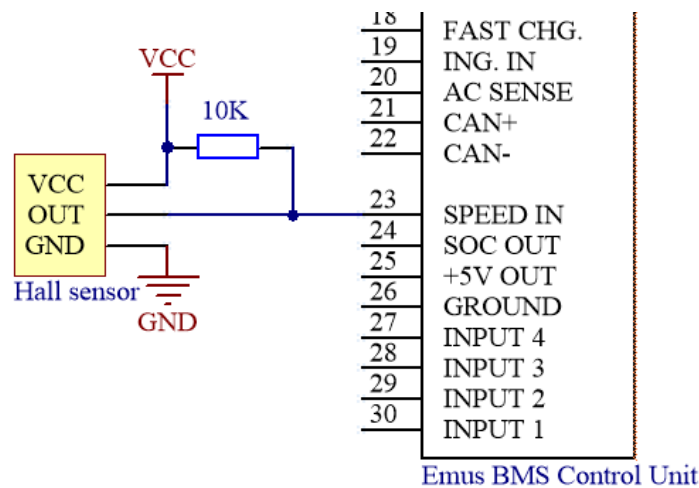


Figure 1.4 Speed IN connection diagram

1.10 Cell Modules

EMUS G1 Cell Module is a specially designed controller board that mounts directly on the terminals of a single cell and serves the purpose of a voltage probe and a balancing device. It is equipped with:

- A cell voltage measurement circuitry;
- A shunt resistor based, passive balancing sub-circuit with a red indication LED;
- An internal temperature sensor;

- Optional external temperature sensor (can be purchased separately);

A special serial communication interface with green indication LED, which allows to connect the Cell Modules into a daisy chain network using a single wire between every two adjacent Cell Modules.

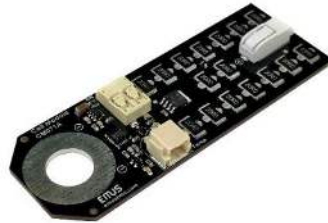


Figure 1.5 A standard 3A module Cell Module

Several models of the Cell Module are available, each of which is designed for cells with different capacity range or form factor. All cell modules can monitor from 2.00V to 4.55V.

1.10.1 Cell Module Selection Recommendations

Cell Module type from EMUS assortment is selected according to balancing current requirement. All cell modules functionally are identical; however, some newer models also have an additional external temperature sensor for measuring the temperature of the cell during operation. The maximum value of the battery capacity using some type of cell module depends on the battery pack cells quality, lifecycle, grading/sorting, temperature control, and other factors. In most of the cases the required balancing current should be equal $\sim 1\%$ of the battery cell capacity (Ah). E.g., for 50-100Ah cell is appropriate to choose 0.7A balancing current cell module Small Type (CM021A).

It is helpful to calculate the required balancing current percentage using the battery pack quality factors and coefficients described in the tables below.

Table 1 Cell Module recommendation

Cell Quality	Low	Medium	High
Coefficient	2	1	0.5

Cell Lifecycle	Second Life 70%	Second Life 80%	New
Coefficient	3	2	1

Pack Temperature Control	None	Controlled
Coefficient	1	0.7

Cell Sorting/Grading	None	Graded for the battery pack
Coefficient	1	0.9

The recommended initial estimate is equal to 1%.

Required Balancing Current % = Initial Estimate × Cell Quality Factor × Pack Temperature Control Factor × Cell Sorting/Grading Factor × Cell Lifecycle Factor

For example, battery pack constructed with medium quality, second life (SOH = ~80%), non-controlled temperature, graded for the battery pack, 100Ah capacity cells. Let's calculate the recommended balancing current using the formula:

Required Balancing Current Percentage (%) = $1\% \times 1 \times 2 \times 1 \times 0.9 = 1.8\%$

Required Balancing Current (A) = $100 \times 0.018 = 1.8A$

Recommended to select GBS Type (CM031) or CALB CAM 72Ah Type (CM060) EMUS Cell Modules.



NOTE: All battery quality factors, coefficients and the required balancing current recommendations are offered using the company's many years of experience and customer feedback.

1.11 Centralized CAN Cell Group Module

EMUS Centralized CAN Cell Group Module (also known as CCGM) is centralized cell module equipped with two CAN connectors for easy BMS system assembly and integrated proprietary EMUS software allows data transfer within 100ms frequency. CCGM monitors and controls from 6 to 16 cells. It connects directly to the G1 Control Unit via CAN bus. Communication interface that can be directly connected to 6-16 cells to monitor their voltages and temperatures along with balancing function, CCGM also has 5 external temperature sensors (can be purchased separately). Product allows to save space by reducing the need of having cell modules as each CCGM directly monitors each battery cell. No additional adapters are needed when using CCGMs with G1 Control Unit. Up to 32 Centralized CAN Cell Group can be connected to the G1 system in series or/and parallel.



Figure 1.6 Centralized

1.12 Cell Communication Adapters

Cell Communication Adapters are gateway devices that provide galvanically isolated means of communication between the G1 Control Unit and Cell Modules, thus eliminating the many safety and operation stability issues that would arise otherwise. There are two types of Cell Communication Adapters: Top and Bottom Isolators, and CAN Cell Group Modules.

1.12.1 Top and Bottom Isolators

EMUS G1 Top and Bottom Isolators are a specially designed pair of optical isolators that allow direct serial communication between the G1 Control Unit and the Cell Modules.



Figure 1.7 Top and Bottom Isolators

Such communication method is straightforward and low-cost, which makes it ideal for relatively small (in number of cells), one-piece battery packs of series-connected cells. However, this cell communication adapter type has several weaknesses when used in a large battery pack, especially if it is physically split into several sub-packs. The large cumulative wire length of the whole cell communication daisy chain and the long individual communication wires between two adjacent Cell Modules compromise the integrity of the communication channel by making

it more susceptible to electromagnetic noises. Also, because of the way the data is transferred in a daisy chain network, the energy consumption of each Cell Module, and consequently the self-discharge rate of each cell, is different. The more Cell Modules there are in a single chain, the more that difference is evident, which can be undesirable in systems that idle for a prolonged period of time. It is therefore not recommended to use Top and Bottom Isolators in such cases.

1.12.2 CAN Cell Group Modules

EMUS G1 CAN Cell Group Modules (also known as CGMs) are advanced, microprocessor equipped cell communication adapters that allow the G1 Control Unit to communicate with the Cell Modules over the CAN bus instead of directly.

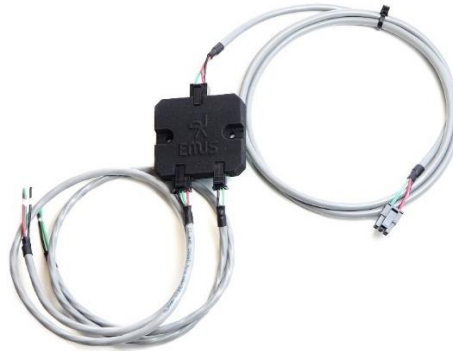


Figure 1.8 CAN Cell Group Module

A total of 24 of them can be used in a single battery pack, which allows to connect the Cell Modules into several small daisy chains instead of one long chain. This not only eliminates the drawbacks of the Top and Bottom Isolators, but also makes the EMUS G1 BMS scalable to serve a virtually unlimited number of cells. Furthermore, it enables the EMUS G1 BMS to manage battery packs that consist of several strings of cells connected in parallel.

1.12.3 Tesla Module retrofit BMS

EMUS has developed a Tesla Module (TES011C) specifically to re-use a battery pack from a Tesla Model S. The 24Vdc packs from the Tesla have a rated capacity of 5.3kWh and consist of six modules. The key is that the cells in each module may end up with different performance characteristics which is why they are no longer used in a vehicle. EMUS Tesla Module (TES011C) are advanced, microprocessor-equipped cell communication adapters that allow the G1 Control Unit to manage cells lifecycle over the CAN bus. The device has installed 6 cell modules specifically designed for continuous monitoring and managing of the Tesla Model S (24V, ~5.3kWh) battery. Up to 24 Tesla packs can be connected in series or parallel and adding G1

Control Unit and EMUS current sensor makes a full BMS system. This system is compatible with inverters from Victron, SMA inverters and numerous chargers to create a stationary power system linked to wind power or solar panels.

NOTE: EMUS Tesla Module (TES011C) specifically designed for Tesla Model S 85kWh, P/N: 1071954-00-B, S75 battery pack. Please pay attention to dimensions and mounting holes compatibility with your selected battery pack.

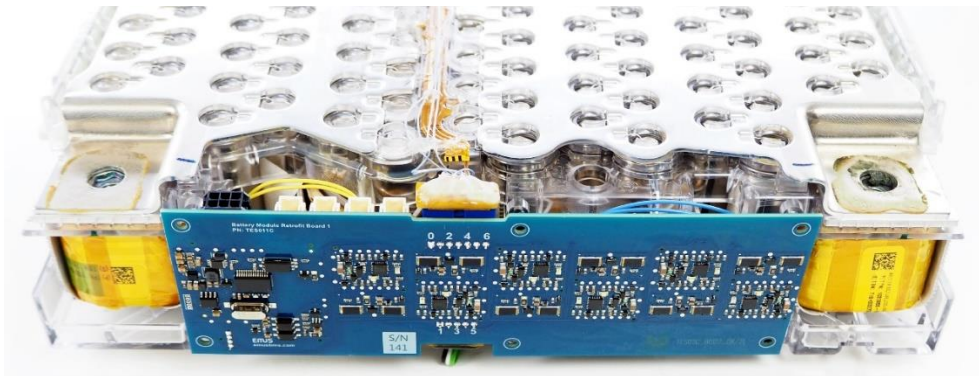


Figure 1.9 Tesla Module (TES011C) retrofit BMS

1.13 Current Sensors

The EMUS G1 Dual Range Current Sensor is an analog, hall-based current measuring device specifically designed for use as part of the EMUS G1 battery management system. Sensors have two separate measurement channels with different sensitivities, which allow accurate measurement of small currents without losing the range of measured values. The method of measuring the hall effect also provides the characteristic galvanic isolation between the sensor and the conductive part. There are two functionally identical sensors in the EMUS G1 Dual Range Current Sensor group: bus bar and closed loop.

1.13.1 Bus Bar Type

The Bus Bar type of EMUS G1 Dual Range Current Sensor is designed specifically for use in battery packs that consists of prismatic form factor cells. It doubles as an interconnecting bus bar, and due to the galvanic isolation between the sensor and the conducting part, it can be installed anywhere in the battery pack between two adjacent, series-connected cells. The current measuring range is up to 1000A.



Figure 1.10 EMUS G1 Dual Range Current Sensor: Bus Bars type

1.13.2 Closed Loop Type

The second generation, or the Closed Loop type of EMUS G1 Dual Range Current Sensor has an improved design that makes it more rugged, accurate, and less sensitive to the environment factors when compared to the Bus Bar type. It also 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 1.0 %.



Figure 1.11 EMUS G1 Dual Range Current Sensor: Closed Loop type

1.14 3rd party CAN current sensors

EMUS supports additional types of current sensors produced by 3rd parties that complement EMUS' Bus Bar and Loop sensors. These sensors are connected via CAN bus and integrated using corresponding CAN protocol. The list of supported sensors will be expanded by EMUS with new manufacturers and models. Requests for integration can be submitted to EMUS via contact

forms and will be reviewed on a case-by-case basis. List of latest available sensors will be available on G1 Control Unit product page and corresponding software release notes.

List of supported 3rd party sensors:

IVT-S series by IsabellenHütte EMUS supports additional types of current sensors produced by 3rd parties that complement EMUS' Bus Bar and Loop sensors. These sensors are connected via CAN bus and integrated using corresponding CAN protocol. The list of supported sensors will be expanded by EMUS with new manufacturers and models. Requests for integration can be submitted to EMUS via contact forms and will be reviewed on a case-by-case basis. List of latest available sensors will be available on G1 Control Unit product page and corresponding software release notes.

List of supported 3rd party sensors:

- IVT-S series by IsabellenHütte <https://www.isabellenhuette.de/>

1.15 Smartphone Connectivity Module

EMUS G1 Smartphone Connectivity Module is a wireless communication adapter that connects to the G1 Control Unit via the RS232 interface and enables external devices to connect to G1 Control Unit via BT protocol using BLE112 USB dongle. It allows users to wirelessly monitor, configuration, diagnostics, etc. The Smartphone Connectivity Module is compatible with Android and iOS EMUS applications. More details about EMUS Applications in chapter: (1.18.1 EVGUI Android).



Figure 1.12 EMUS G1 Smartphone Connectivity Module



NOTE: It is not possible to use Smartphone connectivity module with Display Unit at the same time.

1.16 Display Unit

EMUS G1 Display Unit is a device dedicated to monitor battery status and other G1 Control Unit activity data in real time. It is designed for use outdoors having glare-free, high contrast and wide viewing angle display and control knob for accessing various information. Device has RS232 and USB interfaces for connection to G1 Control Unit and Windows OS based PC respectively.

Display unit has two different interface modes: Energy storage and electric vehicle.

In storage mode possible to monitor:

- Internal and external minimum/maximum/average temperatures;
- Battery voltage minimum/maximum/average/total voltages ;
- SOC, total battery pack voltage, current;
- Charger stage, total battery pack voltage, current, stage duration.
- In vehicle mode possible to monitor:
- Distance left/trip, speed measurements;
- SOC, total battery pack voltage, current;
- Power consumption, power consumption per distance unit, temperature.



Figure 1.13 EMUS G1 Display Unit



NOTE: It is not possible to use Smartphone connectivity module with Display Unit at the same time.

1.17 CAN Filter

CAN Filter is a device that isolates/separates internal and external CAN buses, therefore minimizing CAN bus utilization (bus load) and establishing Clustered functionality (Clustered functionality requires more than 2 or more G1 Control Units connected to each other's). The device has external and internal CAN bus terminals. The internal CAN bus terminal connects to the internal BMS network, which consists of the G1 Control Unit, CGMs/CCGMs, and other CAN devices. Common CAN bus connects to other CAN Filters, 3rd party CAN devices.



Figure 1.14 EMUS G1 CAN Filter

EMUS G1 CAN Filter has 2 connectors:

- 1x Internal CAN BUS (left side)
- 1x External CAN BUS (right side)

Each G1 Control Unit must be connected to a different CAN Filter over „Internal CAN BUS“ terminal. „Common CAN BUS“ terminals are used to interconnect other EMUS G1 CAN Filters, 3rd party CAN chargers etc.

1.18 Software

1.18.1 EVGUI Android App

EMUS EVGUI (Electric Vehicle Graphical User Interface) is a freely available application for Android designed specifically for monitoring the battery status in an electric vehicle. Using this application, a smartphone or a tablet can be connected to the G1 Control Unit either via wireless BT protocol (using the EMUS G1 Smartphone Connectivity Module) or USB (using a USB-OTG cable, for Android devices only), 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 1.15 EMUS Android App (Available in AppStore)

1.18.2 Control Panel

EMUS G1 Control Panel (or simply Control Panel) is the official Windows PC software tool for configuration, maintenance, and diagnostics of the EMUS G1 BMS. It comprehensively displays all BMS activity data received from the G1 Control Unit, gives quick and effortless access to each individual configuration parameter, and allows to perform virtually easily and safely all maintenance operations. The EMUS G1 Control Panel allows users to configure more than 300 configuration parameters for the best EMUS G1 BMS user experience. The Control Panel is freely available online at <https://emusbms.com/support>.

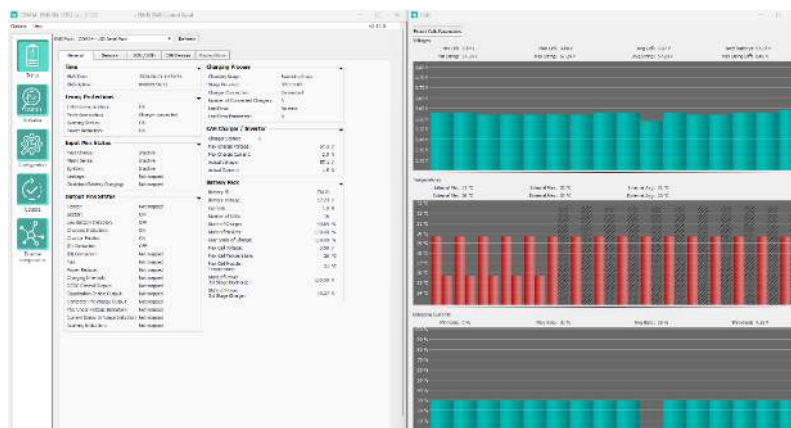


Figure 1.16 EMUS Control Panel

Chapter 2: Functionality overview

2.1 Cell Monitoring

Individual cell monitoring is fundamental and one of the most essential functions of EMUS G1 BMS. It is a complex, multi-part process in which certain roles are distributed between Cell Modules, Cell CAN Group Modules, Centralized CAN Cell Group Modules, and the G1 Control Unit.

2.1.1 Distributed Regular Cell Monitoring

Each Cell Module, once mounted on a cell, starts its work routine during which it measures the cell's voltage and its own temperature (as well as the external temperature, if applicable), and uses the measured values to regulate the balancing current 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.

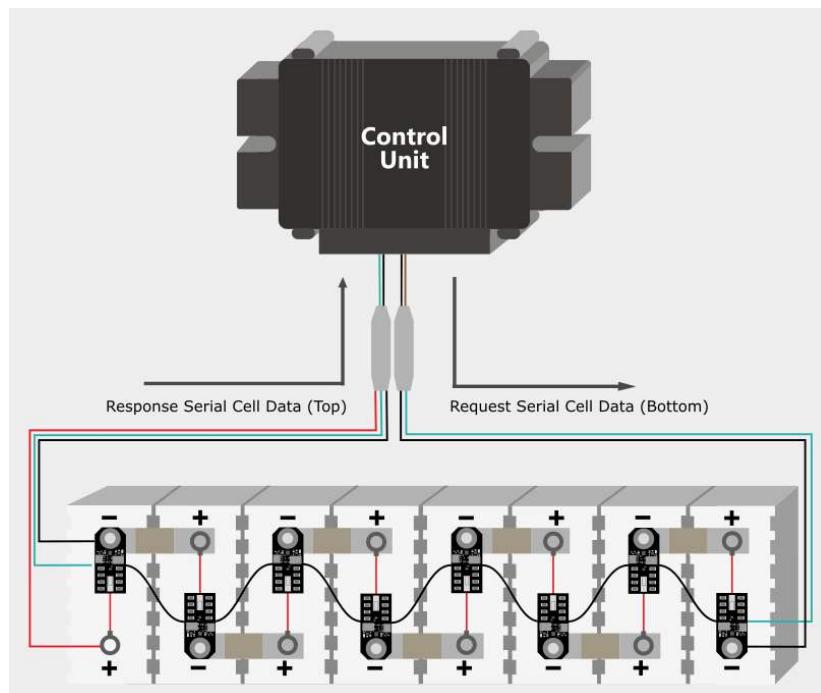


Figure 2.1 Cell communication data flow: when using Top and Bottom Isolators

The G1 Control Unit retrieves the measured voltage and temperature values, as well as the balancing rate value (which is the duty cycle of the PWM signal that is used for controlling the balancing current) from the Cell Modules by request-response" type communication with them. When using the Top and Bottom Isolators, it all begins when the G1 Control Unit sends out a

request command over the Serial Cell Communication Interface. Each Cell Module exploits the difference in electric potential between adjacent cells by echoing any logic state change at the "DN" input to the "UP" output, therefore the request command is transferred throughout the whole daisy chain network of Cell Modules. Because the echo delay is almost negligible, all Cell Modules in the network receive the command nearly simultaneously. Once the command is received, each of them save the most recent measured value of the requested parameter and then take turns to send it to the G1 Control Unit by forwarding the data through subsequent Cell Modules in the chain (as illustrated in Figure 2.1 Cell communication data flow: when using Top and Bottom Isolators).

2.1.2 Distributed Grouped Cell Monitoring

When using CAN Cell Group Modules, the G1 Control Unit sends out the request message over the CAN interface instead of the Serial Cell Communication Interface. Because of the specific properties of CAN communication all CGMs on the CAN bus receive the request message simultaneously, and from here the cell communication process is similar to when the G1 Control Unit is communicating with the Cell Modules via the Top and Bottom Isolators. Each CGM send out a request command over the special serial interface to its own daisy chain network of cell modules, and stores the data received in response. The G1 Control Unit then retrieves the data from each CGM successively by sending a special request-to-send message to it (as illustrated in Figure 2.2).

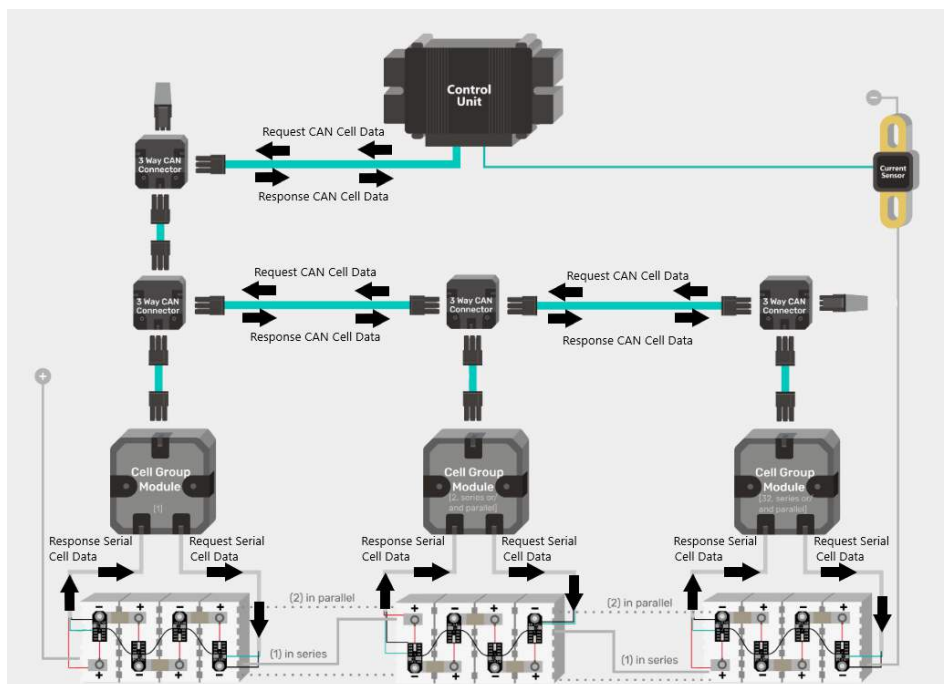


Figure 2.2 Cell communication when using CAN Cell Group Modules

The G1 Control Unit periodically performs the cell communication procedures described above

to ensure that the cell parameter values that are stored in its memory are always up-to-date and valid. Normally, each period the G1 Control Unit requests a different cell parameter according to a prioritizing scheme: highest priority is given to the cell voltages, meaning that they are requested more often than other parameters, the balancing rates come second, and both the external and internal cell module temperatures have the lowest priority. However, if an attempt to acquire any cell parameter results in an error or a timeout, that cell parameter is considered no longer valid, and the prioritizing scheme is ignored by giving exclusive priority to acquiring it in the next period. Cell parameter monitoring period depends on the number of cells in the battery pack and is most of time equal to milliseconds but is gradually increased to sever seconds if the system is idling, (i.e., charger is disconnected, ignition input is in a low state, measured current is equal to zero, and all cell parameter values are valid).

$$10ms + \frac{\text{"Total Number of Cells"}}{5}; \quad (1)$$

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

2.1.3 Centralized Cell Monitoring

EMUS Centralized CAN Cell Group Module (also known as CCGM) is a centralized cell module equipped with two CAN connectors. When using the Centralized CAN Cell Group Module, the G1 Control Unit sends out the request message over the CAN interface like CGM. CCGM performs all cell data measuring by itself, so the product allows saving space by reducing the need of having cell modules and three-way connectors also it increases speed of the cell data broadcasting. Also, the product provides for each connected battery cell balancing functionality.

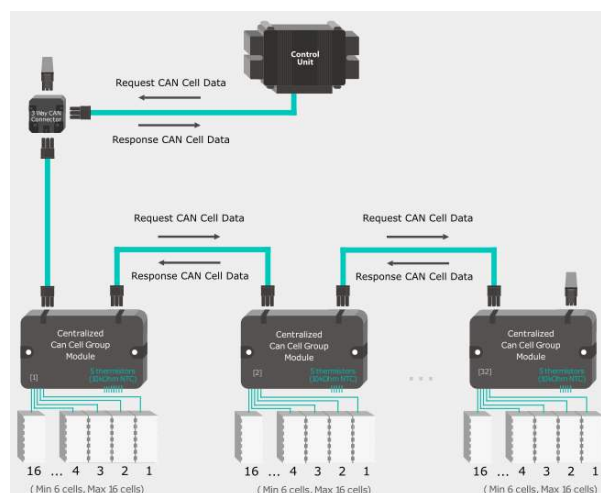


Figure 2.3 Cell communication when using Centralized CAN Cell Group Modules.

Using Centralized Cell Monitoring, G1 Control Unit has similar purpose to Distributed Grouped

Cell Monitoring. G1 Control Unit periodically performs the cell data communication procedures using internal EMUS CAN protocol. All requesting parameters have their own priority, so this functionality ensures fast and reliable data broadcast in EMUS G1 BMS.

All core G1 Control Unit functions only use the minimum, maximum, or average values rather than individual cell data, therefore only these aggregated values are normally stored during the periodic cell monitoring process. However, the individual cell data may still be useful for diagnostic purposes, therefore it can be acquired by request over USB, RS232, or CAN interfaces. Such requests are registered in a queue and are serviced during the periodic cell monitoring by temporarily saving the individual cell data of the requested parameter in a special buffer. The saved data is then sent out in chunks over the same interface from which the request came. It is also important to notice that the previously mentioned prioritizing scheme that is used during periodic monitoring is bypassed to acquire the data that is needed to service the active individual cell data request. To compensate for this, the parameter monitoring period is temporarily decreased to a minimum value in such case.

2.1.4 Temperature measurement

According to EMUS BMS distributed system communication protocol each battery cell module monitors 2 temperatures: internal – Cell Module temperature that is used for itself protection and external temperature for measurement selected point on the cells. Therefore, the Control Panel displays a pair of these temperatures for each battery cell. EMUS CCGM uses a new centralized system that allows to measure 5 external temperatures. We adapted our current parameter display view to this configuration. All 5 external temperature sensors are shown. Internal temperatures we use averaged board temperature and present it as the same temperature for all battery cells. Example chart is displayed in the following Figure 2.4 CCGM Temperature status.

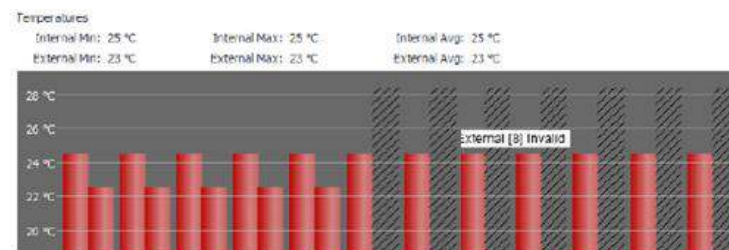


Figure 2.4 CCGM Temperature status

Using Temperature Breakout (or Extender) Boards (TBB011A) it is possible to extend up to 15 temperature sensors, but with this option, 2 temperatures, highest and lowest are shown in the Control Panel.

2.1.5 Tesla Module cell monitoring

EMUS Tesla Module (TES011C) retrofit BMS board is the device that once mounted on a battery pack measures cells voltages, board is also equipped with 2 original Tesla temperature sensors and 4 additional external temperature measurement sensors. All measured values were broadcast to the main unit. Module supports cell voltages from 2V to 4.55V with a balancing current of 0.5A and a maximum cell power (Pmax) of 2.1W. This is ten times the power supported by Tesla's original BMS board. EMUS Tesla Module performs combined Cell Modules (CMXX) and Cell Group Modules (CGM) cell monitoring algorithm which allows to reduce number of wires and increases application reliability.



NOTE: EMUS Tesla Module (TES011C) specifically designed for Tesla Model S 85kWh, P/N: 1071954-00-B, S75 battery pack. Please pay attention to dimensions and mounting holes compatibility with your selected battery pack.

2.2 Current measurement

2.2.1 EMUS current sensors

The measurement of the battery current in EMUS G1 BMS comprises of two continuous, simultaneously executed processes. During the first process, the G1 Control Unit continuously measures the analog signals given by EMUS G1 Current Sensor using a high sample rate analog-to-digital converter peripheral, and periodically stores averaged measurement results for further processing. Averaging is needed to mitigate the effects of thermal, quantization and other noises.

During the second process, the most recent results of the measurement process are taken, verified for validity, and used for calculating the momentary battery current value by subtracting the "Zero Offset" parameter value and multiplying by either "L Calibration Value" or "H Calibration Value" parameter value depending on the magnitude of the raw measured value. Before storing the result for use in higher level algorithms, the momentary current value is further processed by applying the "Dead zone" and "Reverse Direction" configuration parameters. This process runs at a steady rate of 100Hz.

2.2.2 EMUS CAN Current sensor or 3rd party CAN current sensors

In case of using EMUS CAN Current sensor or 3rd party current sensors. It is necessary to configure the G1 Control Unit to collaborate with them. By default, a new Current Sensor will require 500kbps CAN speed to be correctly discovered.

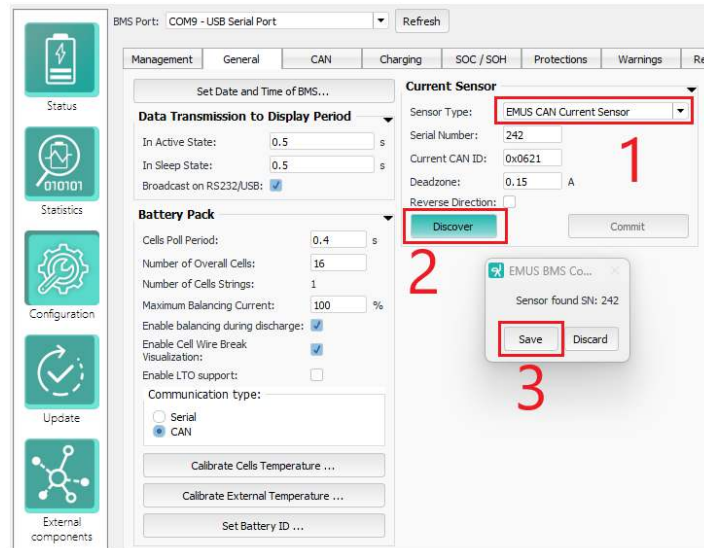


Figure 2.5 Current sensor type selection

2.3 SOC estimation

State of Charge estimation in EMUS G1 BMS could be counted by coulomb counting or advanced Kalman filter based SOC/SOH/SOP. Coulomb counting is done coordinated 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 new advanced Kalman filter-based algorithm incorporates cell degradation factors and increases SOC calculations accuracy by knowing actual battery cells capacity.

2.3.1 SOC Coulomb Counting algorithm

Coulomb Counting is a standard method of State of Charge estimation method. Yet it depends on used current sensor characteristics and setup. Coulomb Counting technique relays on the current sensor, using the current measurements to estimate the State of Charge. 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 be 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 used. When it is enabled, the battery charge value is adjusted in such a 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. Coulomb counting is recommended for battery cells which have flat voltage zones such as LiFePo4 chemistry.

2.3.2 SOC Kalman Filter algorithm

Kalman Filter algorithm is advanced predictive method which has been adapted to calculate SOC in the G1 Systems. This algorithm uses the OCV curve that describes the voltage of the cells to roughly estimate the actual state of charge. Using just the cell voltage is an inaccurate method as the voltage suffers deviations due to charge or discharge currents as well as hysteresis. To improve that method, Kalman filter predicts the following State of Charge using prior battery status and new voltage and current measurements. It uses past data to predict what will be next SOC and corrects its own prediction with voltage and current measurements collected.

Kalman filter is a dynamic algorithm based on voltage, current and previous SOC estimations. It is especially suitable for cell chemistries which present no constant voltage along the OCV. The algorithm needs to know the single cell capacity, voltage, and current measurements, OCV of the cells to accurately calculate.

There is an option to correct the SOC to 100% every time the battery is fully charged. It is recommended to clear any possible drifts that might have appeared over time. As Kalman also uses cell voltage as an information input, the drift is less significant than using Coulomb, although it is always recommended to set a new reference point when the battery is completely changed for any algorithm.

2.3.3 Integrated SOC/SOH estimator

Both "Coulomb Counting" and "Adjustment by cell voltage" methods can only estimate SOC. These methods lose accuracy over time 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 2.6). 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.

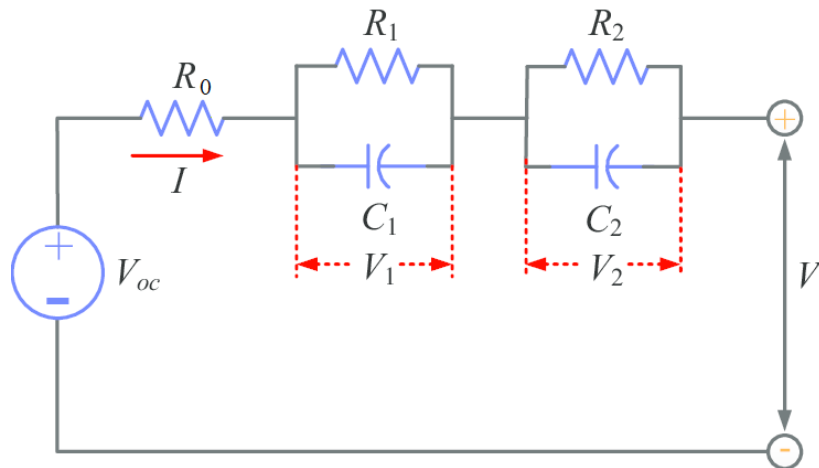


Figure 2.6 EMUS Equivalent circuit model

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 (R_0 , R_p , C_p) 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 4.16.3 SOC/SOH estimator.

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

time is needed.

2.3.4 SOH algorithm

As battery cell ages, its total capacity decreases, and internal resistance increases. To estimate and correctly evaluate these values BMS calculate cell cycles. Usually, cell manufacturers provide details about estimated cell life cycle, which would mean that after that number of cycles is reached cells would lose around 20% of their capacity (this can vary based on the manufacturer).

SOH prediction should be within range of 1-5%. But it may vary depending on manufacturer provided data.

2.3.5 SOP algorithm

The State of Power algorithm is responsible for estimating power a user can withdraw or input into cells. It is mainly based on a specific or rough estimate of SoC-OCV curve, when using coulomb counting it is a rough estimate depending on min/max voltages and chemistry type and when using Kalman filter it is based on the SoC-OCV curve that the user specified. Main principle of SOP estimation is calculating distribution of energy based on the curve, since we rely on curve for most accurate results, SoC accuracy also greatly impacts this estimator.

2.4 Charging process and charging device control

EMUS G1 Control Unit 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 and off using a switching device that is driven by a G1 Control Unit general purpose output pin mapped with "PF10 Charger Enable Output" pin function. The G1 Control Unit 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, current values and other params 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 contractor.



NOTE: For all chargers recently supported please refer to <https://emusbms.com/product/g1-bms-control-unit>



NOTE: For more information on each charger communication protocol, contact the charger manufacturer.

The G1 Control Unit 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 G1 Control Unit. Disconnection is acknowledged if the G1 Control Unit 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 "SOC OUT" pin of the G1 Control Unit, 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 G1 Control Unit's internal memory limitations G1 Control Unit can support only one charging device type or model at a time, and it is necessary to re-upload the G1 Control Unit with a different firmware in case it is desired to change the supported type or model. When several one type chargers are connected the G1 Control Unit detects each charger automatically and distribute the charging current among connected chargers.

Regardless of the charging device type, the charging process begins when the G1 Control Unit detects that a charging device has been connected. The G1 Control Unit divides system charge status into six separate stages:

"Pre-Heating" stage is entered when the minimum cell module temperature (or minimum cell 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 out that the battery is too cold to be charged safely, therefore during this stage the G1 Control Unit 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:

$$I_{Charging} = \frac{[Pre-charge Current \% configuration parameter] \times [Configured Capacity] \times [Number of Clusters]}{100\%}; \quad (2)$$

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:

$$I_{Charging} = \frac{[Pre-charge Current \% configuration parameter] \times I_{Max}}{100\%}; \quad (3)$$

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 G1 Control Unit does not have the ability to effectively reduce its output current without potentially forcing it to function outside of its normal operating conditions.

Note that pre-charging stage will not be reached if "Slow Charging" current is lower than calculated pre-charge current.

"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 to charge safely, therefore during this stage the battery is charged with the highest possible current. The actual charging current value depends on certain G1 Control Unit 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 G1 Control Unit 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).

The "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 G1 Control Unit 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 Cell Module(s) naturally start to divert the charging current through their shunt resistors 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 cells that are not full yet could "catch up". The "Balancing stage" is over if now 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 G1 Control Unit 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 cell module 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) 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 is 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 G1 Control Unit attempts to protect the battery by deactivating the general-purpose output pins mapped with "PF10 Charger Enable Output" and "PF5 Heater Enable Output" functions to disconnect it from both the charging device and the heater. Conditions that result in transition to "Charging Error stage" are the following:

Cell Communication Loss – if cell communication is lost during any stage of the charging process, G1 Control Unit 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, G1 Control Unit will not register a charging error for as long as the "Restore Duration" parameter value. During this time, G1 Control Unit 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 Cell Modules;

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 G1 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 cell module malfunction, or that G1 Control Unit is configured incorrectly;

Protection event occurred – if either the Charge Over-Current, Discharge Over-Current, Leakage 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 the most critical and are checked separately 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 to avoid blocking the charging process;

Cell or cell module temperature too high – G1 Control Unit will terminate the charging if internal cell module temperature is higher than the value of Cell Module Over-heat protection "Activate at" parameter, or external cell module 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 so in the battery;

Cell Over-voltage – G1 Control Unit 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, G1 Control Unit will not go back to "Main Charging stage" directly;

Once "Charging Finished stage" has been reached, G1 Control Unit will not go back to "Pre-Charging stage", "Main Charging stage", or "Balancing stage" directly unless the minimum 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 G1 Control Unit acknowledges that the charging device has been disconnected regardless of which charging stage G1 Control Unit 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 G1 Control Unit 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. Also, it is possible to quickly disable charging from Control Panel (more information: 4.3 Charging Disable).

2.4.1 Charging algorithm

EMUS G1 system uses an advanced charging algorithm to maximize the charging efficiency and reduce charging time. The charging process is composed of 3 different phases described below:

- Bulk Phase – Full charging power is requested. The charger is requested to provide as much current as configured in Control Panel. This phase takes place at the beginning of the charge when all the cells voltage are far away from the fully charge voltage
- Iteration Phase – As soon as one of cells reaches Fully Charge Voltage or gets close enough, the BMS will reduce the charging current. This phase has 3 main objectives:
 - Smoother approach to the end of the charge when the voltage is more sensitive to high currents.
 - Initiate an early balancing in case some cells stand out over the rest.
 - Determine the current that keeps the cells close to the end point of charge and reduce the current progressively, keeping the cells close to the end point of charge.
- Equalization Phase – When all the cells are close to fully charged voltage, the BMS equals the charging current to the balancing current. It allows to keep the most charged cells stable and the lowest charged cells to increase their voltage slowly. The algorithm, therefore, does not stop charging to balance and resumes charging after few seconds of balancing. The continuous smooth charging happens simultaneously with the balancing avoiding undesirable Balance-Charge-Balance-Charge cycles which stresses the cells at the end of the charge.

EMUS Charging algorithm can be better understood in the pictures below. The first picture shows how the battery goes through all 3 phases and how voltage and current behave. In the second picture it is detailed how during Equalization phase, the least charged cells are charged meanwhile the most charged cells show stable voltage as they are being balanced.

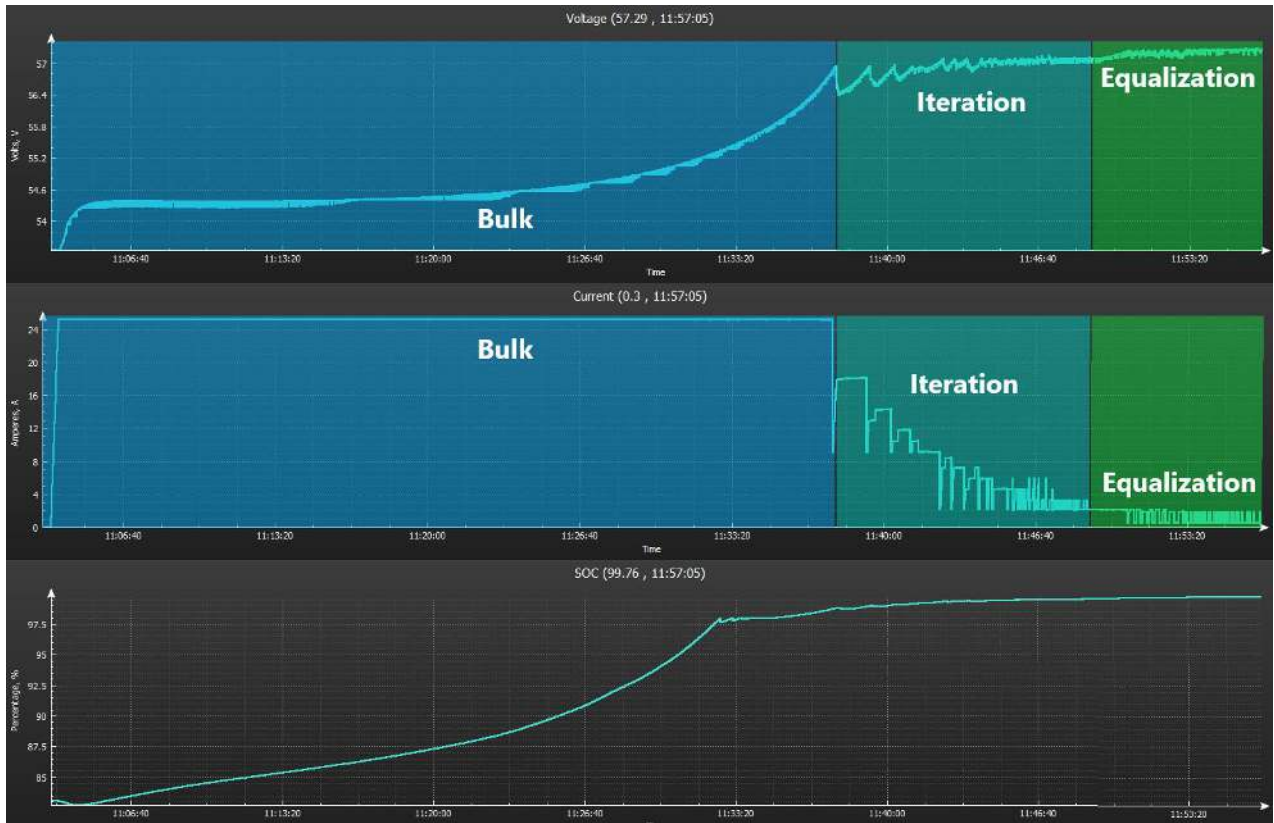


Figure 2.7 Charging algorithm phases detailed



Figure 2.8 Charging algorithm end of charge logic

New charging algorithm brings many benefits for battery cells. Those benefits include:

- Reduced charging and equalization time
- Batteries do not suffer stress at the end of the charge by fast voltage spike-drops
- "Fully Charge Voltage" cannot be exceeded
- Reduces battery temperature during Iteration and Equalization phases
- More accurate equalization of the cells after the charge

2.4.2 Charging Interlock

When one of the G1 Control Unit's 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 contractor and working with any type of charging device.

2.5 Battery protections

During discharge, EMUS G1 BMS G1 Control Unit 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. These are the protection types:

Table 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.

Protection Name	Description
Cell Module Under-Heat	Prevents the battery from being operated when the temperature measured by the internal cell module's 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.
Cell Module Over-Heat	Prevents the battery from being operated when the temperature measured by the internal cell module's 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.
Cell Communication Loss	Prevents the battery operation when G1 Control Unit is not able to monitor the cells due to a hardware malfunction or incorrect installation
Leakage 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 Leakage 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 cell modules 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 cell modules 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.
String Voltage Deviation	Prevents the battery from big differences between Strings. This protection applies to Clustered systems, each G1 Control Unit is considered one string. Activating if difference between maximum and minimum total string voltages is above the threshold set by the corresponding "Activate at" configuration parameter.
Pack Voltage Deviation	Prevents the battery from big differences between battery packs. Activating if difference between maximum and minimum total battery 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 cell modules sends invalid external temperature measurements.

Protection Name	Description
Cell Wire Break	Protection is activated if a wire break is found. "Activate at" field describes the number of broken wires at which the protection will activate. Note: if the first wire of any cell group module is broken then the protection will activate regardless of the "Activate at" value.
Voltage & Ext. Temp Validation	Protection is activated if total battery voltage measured by G1 Control Unit and the selected 2 nd source device differs more than the configured value.

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 G1 Control Unit will tolerate the activation condition for as long as the corresponding "Activation delay" parameter value before activating the protection. Likewise, the deactivation condition must 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", "Cell Module Under-Heat," "Cell Module Over-Heat", "Cell Under-Heat," "Cell Over-Heat", "Pack Under-Voltage" and "Pack Over-Voltage" protections will be activated only if the corresponding cell parameter values are valid. Also, if the "Cell Communication Loss" protection is enabled, it will be active when the G1 Control Unit is powered up by default, thus preventing 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: (4.12 Protections).

2.5.1 BMS Failure Output

The function is activated if any protection is activated. The "PF22 BMS Failure Output" can be used to warn in case a protection is activated, and the system is shut down because of an emergency. It can be connected to an LED or buzzer to make visible the emergency status. This function also allows to drive a 3rd party device that is intended to be activated when the battery cannot be used. As soon as the protection is cleared, this function will switch off. There is an option to invert the function, in that case the 3rd party device will be active only if the battery system status is ok, if it is not, the function will switch it off.

2.5.2 Cell Wire Break display

Once found cell wire break is visualized in Control Panel Status page → Cells tab voltage graph. The voltages of cells around the broken wires will have an invalid value. This functionality is a

guide to help determine and locate a possible wire break in a battery system.

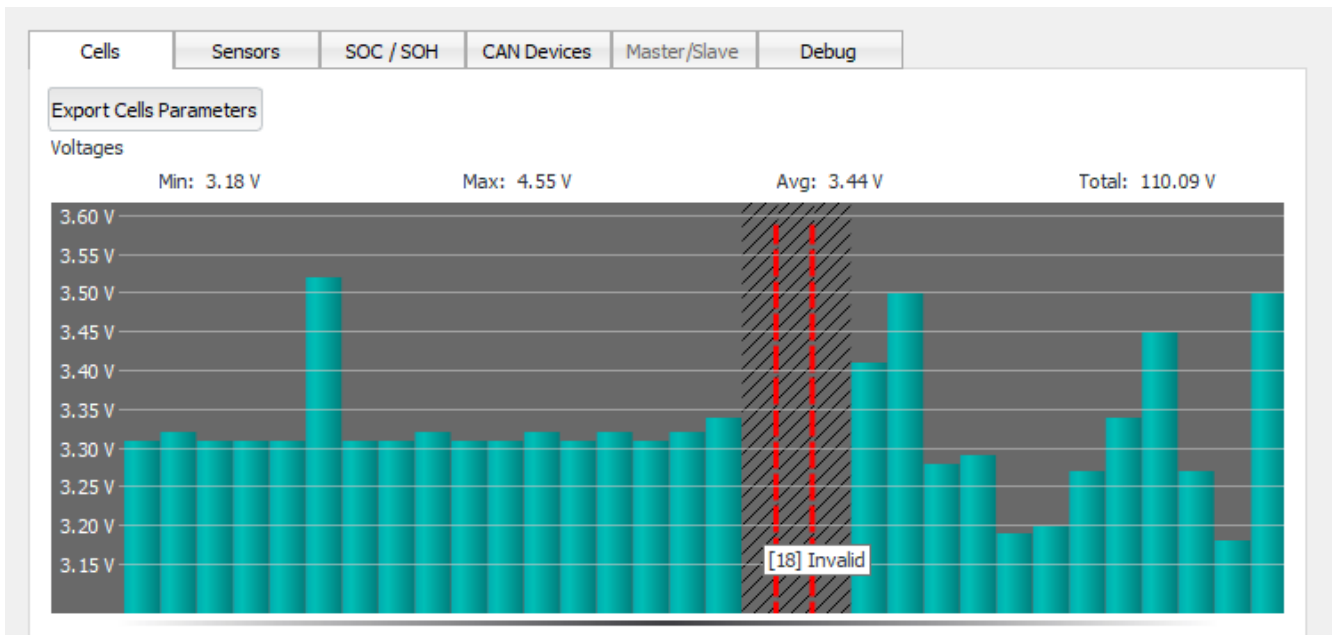


Figure 2.9: Indication of broken wires

2.5.3 Contactor pre-charge

In a lot of different applications, the battery that is managed by G1 Control Unit 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 to reduce stress to the internal components of the load device and prevent the contactor from welding. For that reason, G1 Control Unit offers a very straightforward contactor pre-charge feature (not to be confused with “Pre-Charging stage” that occurs during the charging process).

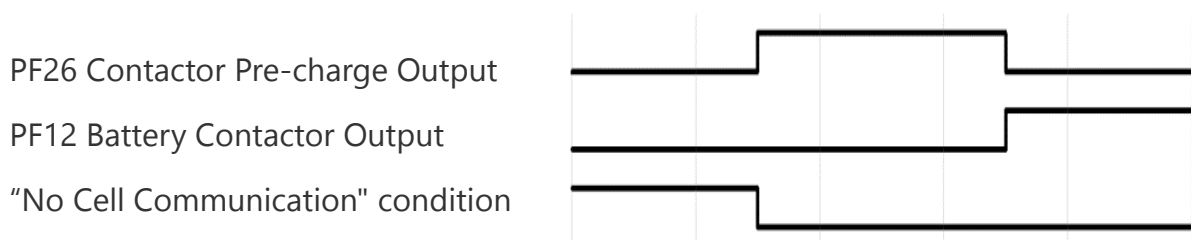


Figure 2.10 Contactor pre-charge timing diagram

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 2.10 (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.

2.5.4 External contactor deactivation

In case it is desired to allow an external system that utilizes G1 Control Unit 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 G1 Control Unit 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 the G1 Control Unit 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 a 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 contractor, G1 Control Unit 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 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 Cell Module Temperature	Is activated if the internal temperature of one of the cell modules 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 cell modules 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: (4.13 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, G1 Control Unit can also send separate warning messages to G1 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. This is a list of all warning types:

Table 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.
Cell Module Over-Heat	Warning notifies the user if the internal temperature of one of the cell modules is above the threshold set by corresponding "Activate at" configuration parameter.
Cell Over-Heat	Warning notifies the user if the external temperature of one of the cell modules 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 cell modules is below the threshold set by the corresponding "Activate at" configuration parameter.
Cell Module Under-Heat	Warning notifies the user if the internal temperature of one of the cell modules is below 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 G1 Control Unit 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.
Pack Voltage Deviation	Warning notifies the user if the difference between the maximum and minimum battery total voltages is above the threshold set by the corresponding "Activate at" configuration parameter.

Name	Description
Cell Wire Break	Warning notifies the user if a wire break has been found.
Voltage & Ext. Temp Validation	Warning notifies if total battery voltage measured by G1 Control Unit and the selected 2 nd source device differs more than the configured value.
Leakage Fault	Warning notifies 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 Leakage fault detector that is selected appropriately for the application.
No Current Sensor	Warning notifies if the Current Sensor is connected improperly or not connected at all.
Charger Connected	Warning notifies if the charging process is taking place.
External Temperature Sensor Loss	Warning notifies if unexpected temperature changes if one of the cell modules sends invalid external temperature measurements.
SoC Data Loss	Warning notifies, if necessary, data to calculate SoC is missing or partially received.

More about battery warnings configuration you can find in chapter: (4.14 Warnings).

2.8 Heater and cooling fan control

To allow safe and reliable use of lithium batteries in various climate conditions, G1 Control Unit offers several different options to control a heater and/or a cooling device. Any of the G1 Control Unit's general-purpose output pins mapped with the "PF13 Battery Fan Output" pin function will be activated whenever either the maximum cell module 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 Cell Modules 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, G1 Control Unit 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 cell 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 cell module temperature or minimum cell temperature (if both are available) falls more than 1°C below the said threshold. The 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 cell modules (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 than 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 applications where grid power is not available all the time (e.g., off-grid energy storage, electric vehicle, etc.), the main battery usually supplies power to an auxiliary 12 or 24V network through a DC/DC converter, which in turn also supplies power to G1 Control Unit. This means that if the DC/DC converter is not disconnected from the battery before leaving the system out of operation for an extended period, the BMS remains powered and can potentially drain the battery if it is not charged during that time. G1 Control Unit has a customized feature that allows disconnecting the DC/DC converter automatically to prevent such situations.

The DC / DC converter control function is active by default, does not need to be enabled in the configuration. It deactivates after the "Deactivation timeout" any general-purpose output associated with the "PF24 DC / DC Control Output" pin function if the minimum cell voltage becomes less than or equal to the value of the 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/contactors that disconnects the DC/DC converter from the battery

and is activated again if the minimum cell voltage rises above the value of the relevant threshold parameter by more than 10mV, but not sooner than "Activation timeout".

DC/DC Control Output can also be dependent on discharger current of "Zero Current DC/DC current" is enabled. This functionality is available if "PF12 Battery Contactor Output" and a current sensor are also available. In such case, the DC/DC Output Control will be disconnected after "Zero Current Timeout" if discharge current is lower than "Discharge Zero Current Margin."

2.10 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 needs to be charged. For indication PF29 Under-Voltage indication need to be mapped, the possible connection is shown in

Figure 2.11 Power supply unit voltage sense example circuit schematic. Also, the same feature can be used to control DC/DC for an automatic charge.

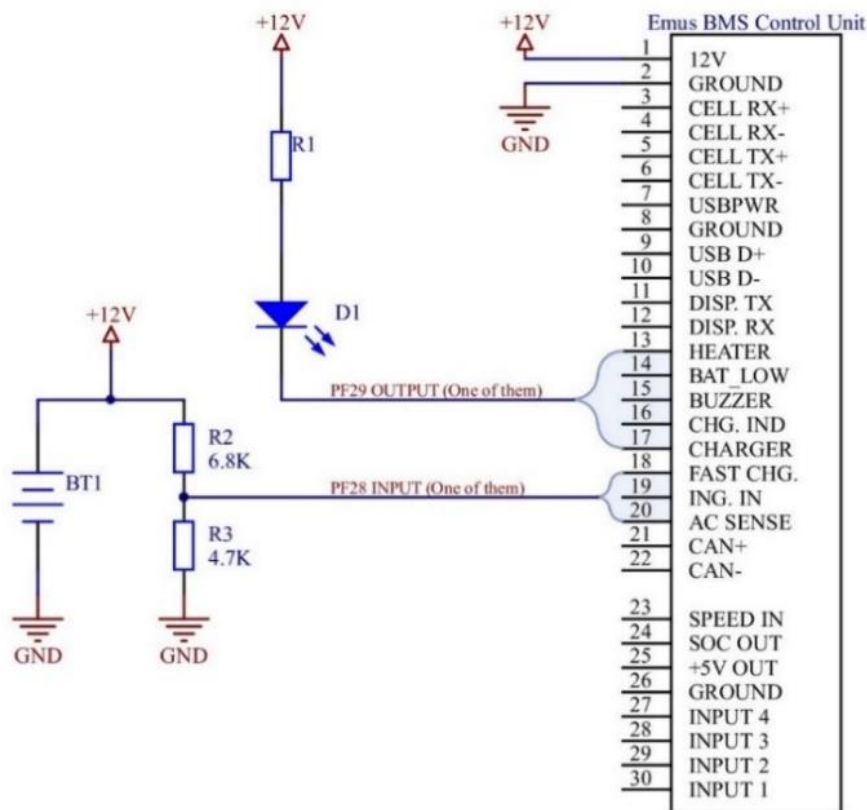


Figure 2.11 Power supply unit voltage sense example circuit schematic



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

As G1 Control Units powered from 9 to 32V and inputs can measure only from 0 to 5V, voltage divider need to be used. The value of the divider must be configured in Control Panel.as well as Activation and Deactivation thresholds.

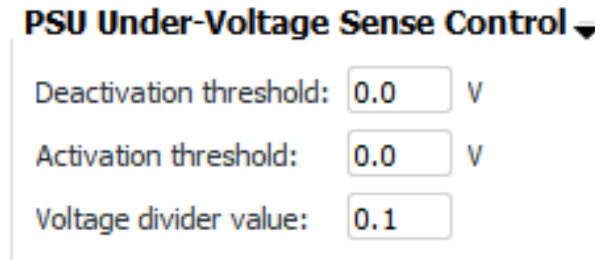


Figure 2.12 PSU under-voltage sense control

2.11 Battery contactor control by "Ignition"

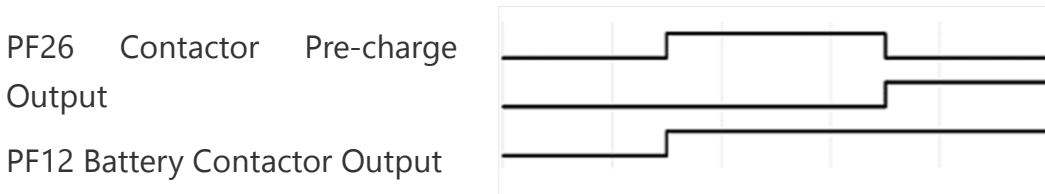


Figure 2.13 Battery contactor control by "Ignition" sequence

In applications where user must manually control battery contactor, a pin function "PF4 Ignition Key Input" can be used. This feature automatically controls the 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.

2.12 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 PF30 Optimized Battery Charging.

2.13 Statistics

For diagnostic purposes, G1 Control Unit 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 5.

Table 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 cell module temperature	The lowest recorded cell module temperature. Additionally, contains the corresponding cell ID and timestamp of when this value was recorded.
17	Max cell module temperature	The highest recorded cell module temperature. Additionally, contains the corresponding cell ID and timestamp of when this value was recorded.

ID	Statistic	Description
18	Max cell module temperature difference	The highest recorded difference between cell module temperatures. Additionally, contains the corresponding minimum and maximum cell modules temperatures, ID of the cell module with minimum temperature, and timestamp of when these values were recorded.
19	BMS start count	The number of times G1 Control Unit 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	Cell module overheat protection count	The number of times Cell Module Over-heat protection has been activated. Additionally, contains the timestamp of the last occurrence.
25	Leakage protection count	The number of times Leakage Fault protection has been activated. Additionally, contains the timestamp of the last occurrence.
26	Cell Communication Loss protection count	The number of times Cell Communication Loss 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 cell module temperature power reduction count	The number of times High Cell 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 times the "Pre-Heating" stage of the charging process has been entered.
33	Pre-charge stage count	The number of times the "Pre-Charging" stage of the charging process has been entered.
34	Main charge stage count	The number of times the "Main Charging" stage of the charging process has been entered.
35	Balancing stage count	The number of times the "Balancing" stage of the charging process has been entered.
36	Charging finished count	The number of times the "Charging Finished" stage of the charging process has been entered.

ID	Statistic	Description
37	Charging error occurred	The number of times 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 minimum cell voltage dropped below "Charger Restart Voltage" parameter value.
41	Clustered configuration error count	The number of times Clustered configuration error protection has been activated. Additionally, contains the timestamp of the last occurrence.
42	Clustered common CAN Bus failure count	The number of times Clustered common CAN Bus failure protection has been activated. Additionally, contains the timestamp of the last occurrence.
43	Clustered internal CAN Bus failure count	The number of times Clustered internal CAN Bus failure protection has been activated. Additionally, contains the timestamp of the last occurrence.
44	Clustered configuration mismatch count	The number of times Clustered configuration mismatch reduction has been activated. Additionally, contains the timestamp of the last occurrence.
45	Clustered common CAN Bus malfunction count	The number of times Clustered 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

ID	Statistic	Description
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	Cell module under-heat protection count	The number of times Cell 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.
62	Cell Wire Break protection count	The number of times Cell Wire break 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 G1 Control Unit 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 5) 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.

2.14 Events

During operation, G1 Control Unit 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 are filled, any new event replaces the oldest entry. All event types are described in the table below.

Table 6 List of events and their descriptions

ID	Event	Description
1	BMS Started	BMS Unit powered up or restarted
2	Lost communication to cells	"Cell Communication Loss" protection has been activated
3	Established communication to cells	"Cell Communication Loss" 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	Cell module temperature critically high	"Cell Module Over-Heat" protection has been activated
13	Critical high cell module temperature recovered	"Cell 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 cell module temperature-reducing power	"High Cell Module Temperature" protection has been activated
21	Power reduction due to high cell module temperature recovered	"High Cell Module Temperature" protection has been deactivated
22	Charger connected	EMUS G1 Control Unit has acknowledged charger connection
23	Charger disconnected	EMUS G1 Control Unit 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 stage has been started

ID	Event	Description
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	Clustered configuration mismatch detected	"Clustered configuration mismatch" reduction has been activated
33	Clustered configuration mismatch recovered	"Clustered configuration mismatch" reduction has been deactivated
34	Clustered configuration error	"Clustered configuration error" protection has been activated
35	Clustered configuration error recovered	"Clustered configuration error" protection has been deactivated
36	Clustered common CAN bus malfunction detected	"Clustered common CAN bus malfunction" reduction has been activated
37	Clustered common CAN bus malfunction recovered	"Clustered common CAN bus malfunction" reduction has been deactivated
38	Clustered common CAN bus failure detected	"Clustered common CAN bus failure" protection has been activated
39	Clustered common CAN bus failure recovered	"Clustered common CAN bus failure" protection has been deactivated
40	Clustered internal CAN bus failure detected	"Clustered internal CAN bus failure" protection has been activated
41	Clustered internal CAN bus failure recovered	"Clustered 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

ID	Event	Description
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	Cell module under-heat protection	"Cell Module Under-Heat" protection has been activated
60	Cell module under-heat protection recovery	"Cell 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
61	Cell Wire Break protection	"Cell Wire Break" protection has been activated
62	Cell Wire Break protection recovery	"Cell Wire Break" protection has been deactivated

2.15 Vehicle speed measurement

Using the G1 Control Unit SPEED IN input mapped with the corresponding special "PF1 Speed Sensor Input" pin function, the G1 Control Unit 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 these values can be read from the G1 Control Unit 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 separate electronics for these functions and allows to simplify the electrical system of the vehicle.

2.15.1 Energy consumption calculation

EMUS G1 Control Unit uses the measured vehicle speed or other values derived from it to calculate three distinct 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 (4)

$$\text{Momentary Consumption} = \frac{I_{\text{Momentary}} \cdot V_{\text{Pack}}}{V_{\text{Momentary}}}; \quad (4)$$

Where $I_{\text{Momentary}}$ is the momentary current value, V_{Pack} is the momentary battery pack voltage value, and $V_{\text{Momentary}}$ 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 result in the volatile memory 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 (5, 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 do not change too often and are therefore stored directly in permanent memory.

$$\text{Average Consumption} = \frac{\text{"Total discharge energy"} - \text{"Discharge energy at the end of the last charge"}}{\text{"Distance Since Charge"}}; \quad (5)$$

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 (6), 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

$$\text{Last Trip Average Consumption} = \frac{\text{"Last Discharge Energy"}}{\text{"Previous Driven Distance"}}; \quad (6)$$

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.

2.15.2 Remaining distance estimation

EMUS G1 Control Unit 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 (7), 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.

$$Distance\ Left = \frac{SOC \left(\frac{"Total\ discharge\ energy"}{"Discharge\ energy\ at\ the\ end\ of\ the\ last\ charge"} \right) \cdot (100 - "Safety\ Margin")}{100 \cdot "Consumption" \cdot (SOC\ At\ Start\ Of\ Trip - "SOC")}; \quad (7)$$

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 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.

2.16 Communication with external devices

EMUS G1 Control Unit Serial and CAN communication protocols are open source. These protocols can be integrated into external devices to provide direct communication with G1 Control Unit. Protocols are available in our website <https://emusbms.com/support>

2.17 Indication

EMUS G1 Control Unit 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.

2.17.1 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 2.14 Charging indicator timing.

- Charger Disconnected
- Pre-heating stage
- Pre-charging stage
- Main charging stage
- Balancing stage
- Charging process finished
- Charging error

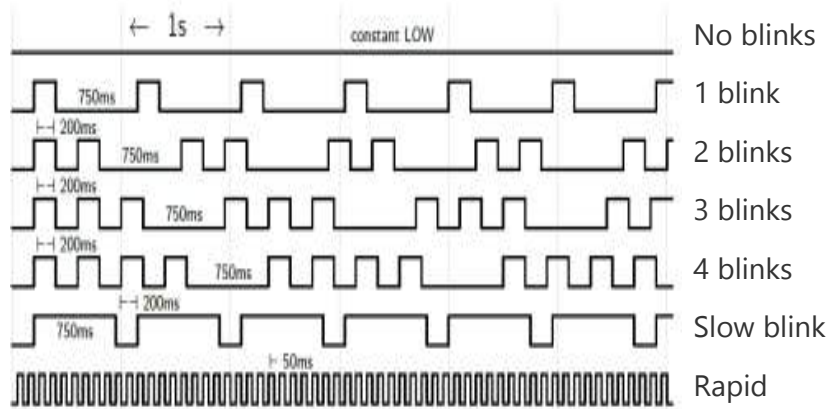


Figure 2.14 Charging indicator timing

2.17.2 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 2.15 Sound indicator timing.

- "Low Cell Voltage" Reduction
- "Charging Error occurred"

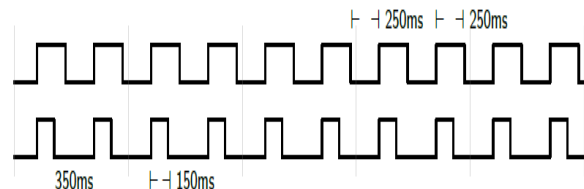


Figure 2.15 Sound indicator timing

2.17.3 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 2.16 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

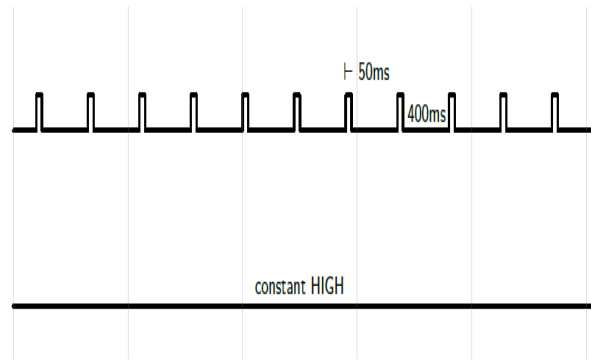


Figure 2.16 Low battery indicator timing

Chapter 3: Installation

Correct EMUS G1 BMS installation will prevent both immediate and delayed issues in the system yet requires certain knowledge to be conducted 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.) to avoid injuries, damage to the BMS components, or other unexpected harmful consequences. It should be conducted only by a qualified employee who has carefully read this whole section and thoroughly understands all the risks involved when working with lithium cells.

3.1 G1 Control Unit

EMUS G1 Control Unit should be tightly secured to a surface using screws, as shown in Figure 3.1. It is recommended to install it a small distance away from the battery (ideally in the same enclosure) to make the wiring process easy and to keep the wires between different EMUS G1 BMS components short. The wiring process should start by connecting the G1 Control Unit to its power source (several different strategies on how to provide power to EMUS G1 BMS are described in sub-chapter 3.1.1). Wires coming from the power source should be stripped, crimped with the provided crimp contacts using a suitable crimp tool, and inserted into the corresponding slots on the G1 Control Unit main 22 pin connector. Since no outputs dedicated for powering other EMUS G1 BMS or third party components are populated on any of the G1 Control Unit's connectors for space saving and simpler design purposes (except for the Current Sensor), power should be distributed using external means, as shown in the example in Figure 3.1.

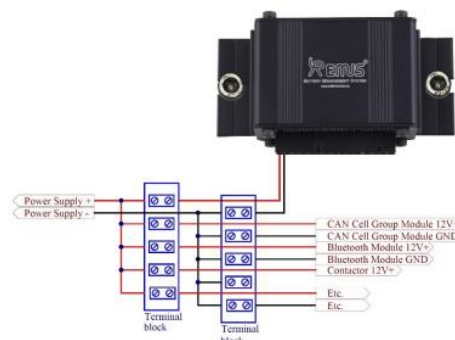


Figure 3.1 Correct installation of G1 Control Unit and distribution of power supply to other EMUS G1 BMS components

3.1.1 Choosing the power supply strategy

Depending on whether the application requires the battery to be operated continuously or with idling periods, and whether the application guarantees a constant grid power availability or not, three different strategies of supplying power to G1 Control Unit can be recommended:

In applications that guarantee constant grid power availability (i.e. domestic energy storage systems for increasing self- consumption from solar panels or wind turbines, industrial energy storage systems for peak shaving, fast charging stations, etc.), it is recommended to supply power to the G1 Control Unit and the rest of EMUS G1 BMS components from the grid using an appropriate isolated AC adapter, as shown in the example in Figure 3.2;

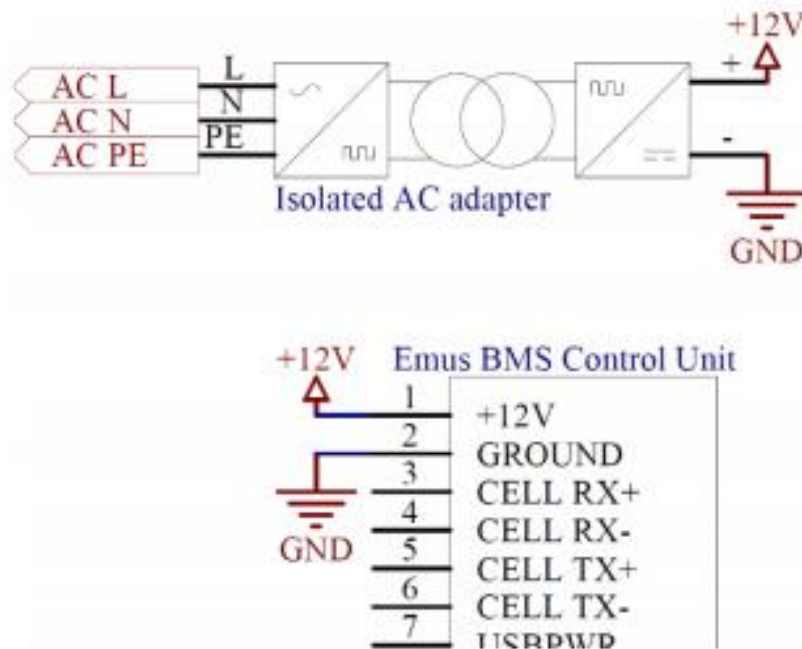


Figure 3.2 Power supply strategy 1

In applications that do not guarantee constant grid power availability, yet do not require 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 G1 Control Unit and the rest of EMUS G1 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 3.3

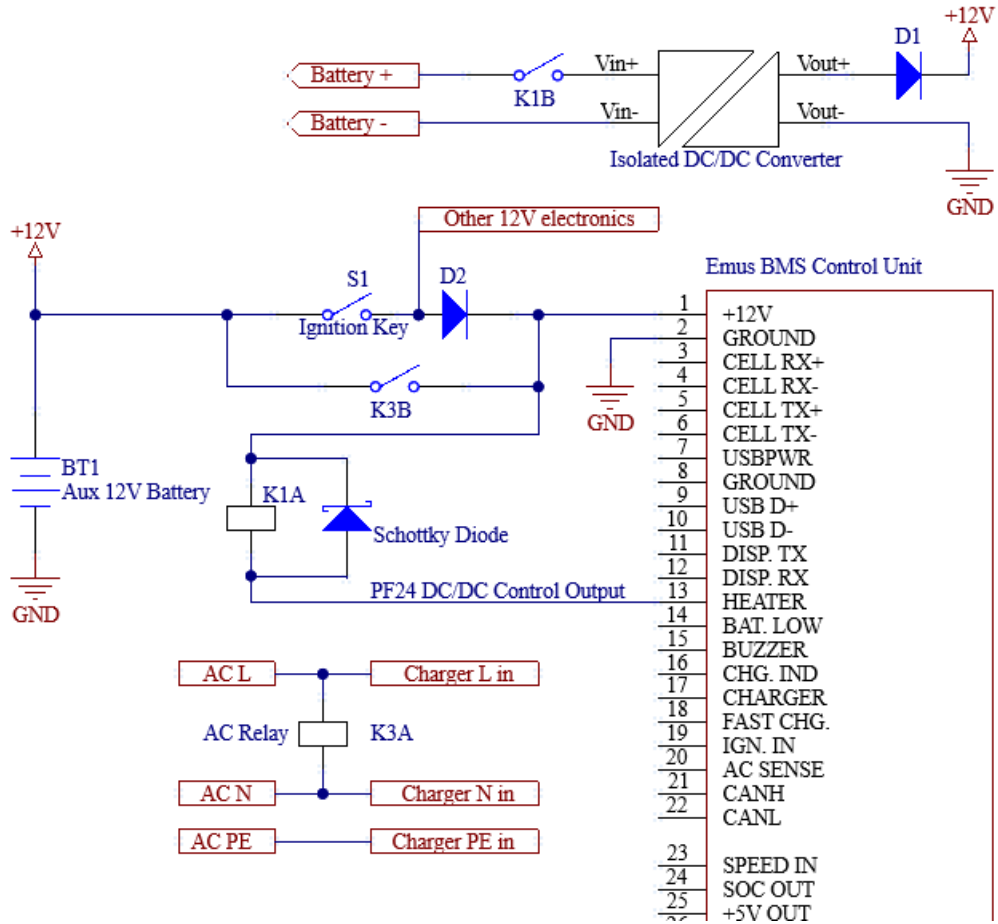


Figure 3.3 Power supply strategy 2

In this example G1 Control Unit 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 G1 Control Unit's general-purpose pins mapped with "PF24 DC/DC Control Output" function. This ensures that G1 Control Unit does not drain the auxiliary nor the main battery when the system is not in operation and 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 extended period of time. It is also important to mention that in the system given in this example the auxiliary battery and DC/DC converter most likely powers not only G1 Control Unit, but also a whole network of other devices, therefore it is recommended to use a diode (marked as D2 in this example) 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 G1 Control Unit and the rest of EMUS G1 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 G1 Control Unit 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 3.4.

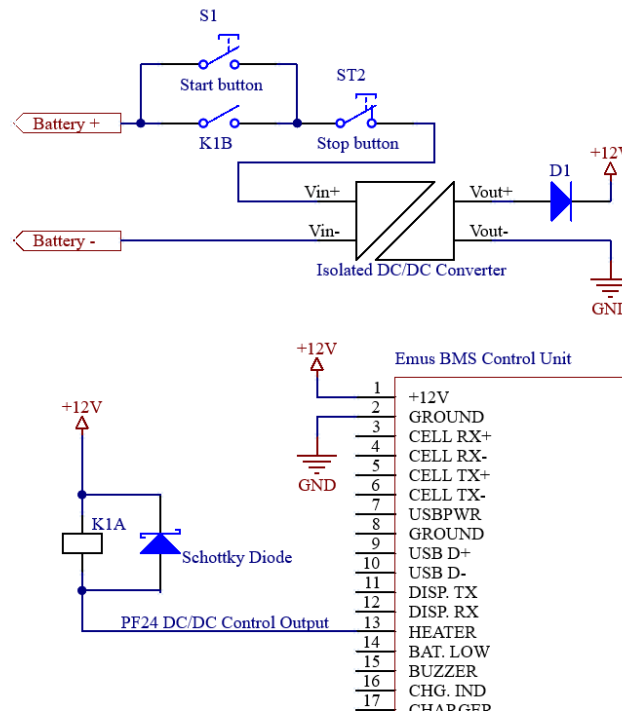


Figure 3.4 Power supply strategy 3

In this example the system is turned on manually by pressing the start button that connects the DC/DC converter to the battery and holding it until the G1 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 Cell Modules

EMUS G1 Cell Modules are designed to be mounted directly on the cell terminals together with the interconnecting bus bars and power cables, therefore they should be installed during the battery assembly process. The battery side wires of the cell communication adapters must be connected during this process as well.

Before starting the installation, it is recommended to sand the aluminum and copper contact surfaces of the cell terminals, interconnecting bus bars, and power cable terminal lugs with fine sandpaper (180 to 240 grit) to ensure good electrical contact between the cells and the Cell Modules. Once sanding is complete, it is necessary to thoroughly clean off the resulting metal

dust, as well as any remaining dirt, grease, or moisture afterwards. Also, the cell communication adapters should be prepared prior to installation by stripping the ends of the wires that will connect to the plus or minus terminal of the cell (shown in Figure 3.5), crimping them with provided the ring terminals using an appropriate crimp tool, and then isolating all battery side wires with electrical tape in order to avoid unintentional damage in case the wires are accidentally dropped across several cells.

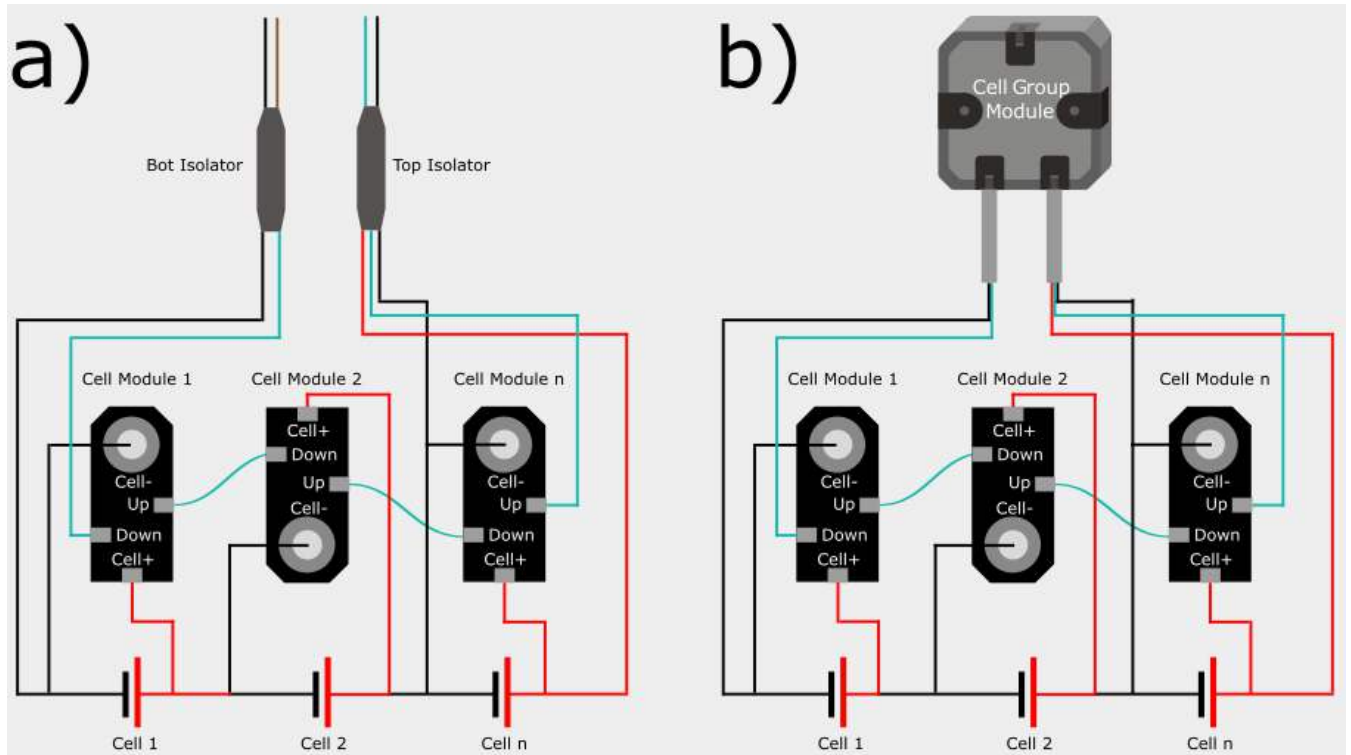


Figure 3.5 Correct way of wiring a cell communication daisy chain: (a) Top and Bottom Isolators; (b) CAN Cell Group Module.

Then, the power cables/interconnecting bus bars, Cell Modules, cell communication adapter plus and minus wires, and fixing elements should be installed on each cell in the following order:

- Interconnecting bus bar or terminal lug of the power cable;
- Cell Module;
- Cell communication adapter negative and positive wire ring terminals;
- Washer;
- Spring washer;
- Bolt.

Special attention should be paid to ensure that the Cell Module polarity matches the polarity of the cell. Connecting the Cell Module to the cell in reverse order or across more than one cell even for a brief period may permanently damage the Cell Module. To avoid over-tightening, the bolts and breaking the Cell Module, an adjustable torque wrench should be used, and the bolts

should be tightened according to the recommendations in Table 77

Table 7 Recommended cell terminal bolt

No	Terminal Bolt type	Recommended tightening torque (N)m
1	M5	10
2	M6	12
3	M8	14
4	M14	24

While tightening the bolts it should also be observed that the wrench would not touch the electrical components of the Cell Module and knock them off, or damage them in any other way.

Once the interconnecting bus bars and Cell Modules are properly installed, the cell communication daisy chain can be wired. To reduce the risk of damaging the Cell Modules in case the cell communication wires are connected incorrectly, it is strongly advised to start by connecting the green communication wire of the bottom cell communication adapter to the "DN" input of the first Cell Module. Then the wiring process should be continued by successively connecting the "UP" output of each Cell Module to the "DN" input of the next Cell Module and finished by connecting the green communication wire of the top cell communication adapter to the "UP" output of the last Cell Module. It is also important to note that for safety reasons, no load, utility, or charging device should be connected to the battery until the cell communication daisy chain(s) has been properly wired. Furthermore, no contactors, fuses, or other disconnection devices should be installed between two cells if their Cell Modules belong to a single cell communication daisy chain, since an electric circuit between the battery and any device connected to it then closes through the cell communication wire, which produces a very high risk of irreversible damage to the Cell Modules and shock hazard when working near the battery terminals. If the battery needs to be disassembled for any reason, the cell communication daisy chain should be taken apart and the Cell Modules should be removed beforehand.

In case Small or CAM72, model Cell Modules that have pre-soldered cell communication wires instead of terminal blocks are used, the recommended method for joining the cell communication wires together is using 3M™ Scotchlok™ butt connectors (a.k.a. jelly crimps) (shown in Figure 3.6), since it is a very quick, easy, and safe way to make a reliable electrical contact without using special tools.



Figure 3.6 3MTM ScotchlokTM butt connector

The reliability, however, will be achieved only when the correct connectors for used wire gauge are used, and instructions of correct use are followed:

Straighten the wire ends and trim them, if necessary, but do not strip them;

Fully insert the wires ends into the connector;

Place the connector between pliers in such way that the wires would be sticking out in the same direction as the pliers are pointing;

Firmly press down the cap of the connector with a single quick motion.

This will ensure that both wires are crimped at the same time, and that a cold weld is formed. Excessive force should not be used to avoid crushing the connector through, as this will compromise its sealing properties and might cut off the wires.

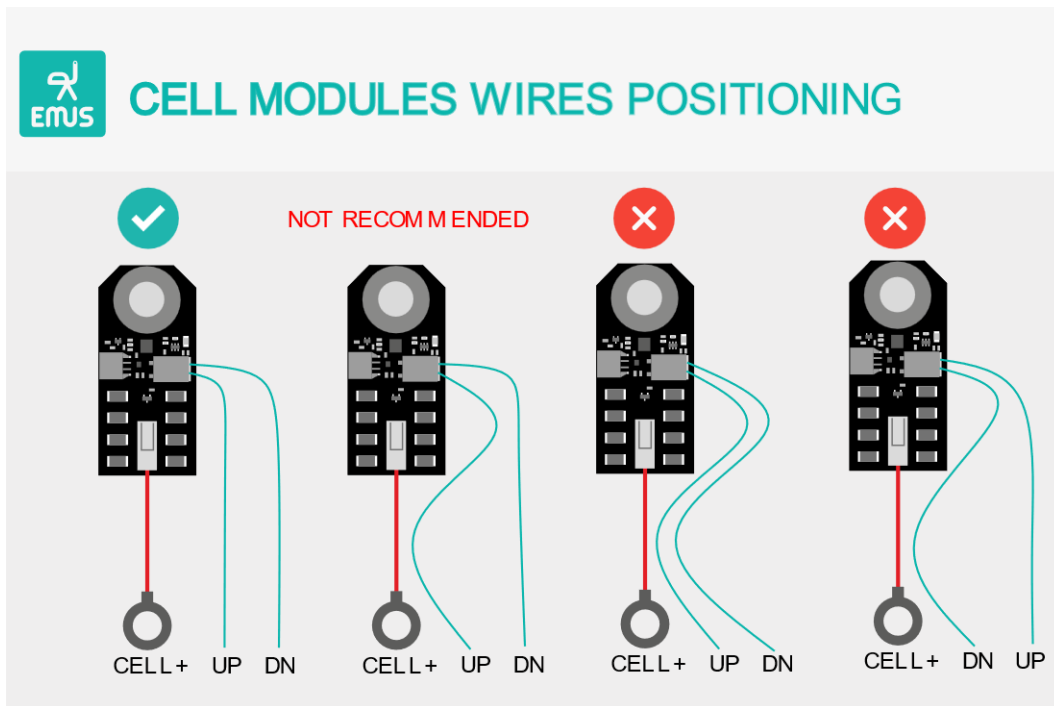


Figure 3.7 Cell Modules Wires Positioning



NOTE: Recommended cable (data and power) length between cell modules is less than 10cm. If longer cables are used, please follow these recommendations (polarity and UP/DOWN cable directions mentioned are in reference to that cell module):

- Power positive and data cables should not be routed next to each other in parallel. If this is unavoidable, the power positive and UP data cables (coming from cell module) could be routed together in one current direction; the DN cable (coming into cell module) then must be routed further away, although this is still not recommended.
- To reduce any possible noise coming from power cables shielded cables can be used for data. Only DN end of the shield must be connected to the CGM's negative terminal.

3.3 Tesla Module

EMUS Tesla Module (TES011C) retrofit BMS is designed specifically for Tesla Model S battery pack (24V, ~5.3kWh). The device must be connected using battery pack connectors during the battery assembly process. Firstly, should be connected Cell 1 (13, 14, 15, 16) battery connector, after this step need to connect Cell 2 (17, 18, 19) battery connector. Finally for proper device communication with G1 Control Unit need to connect CAN communication (1,2,3,4) connector to the EMUS G1 CAN Bus. All temperature sensors are optional and hot-swappable (the replacement or addition of temperature sensors to a system can be performed without stopping, shutting down, or rebooting the system).

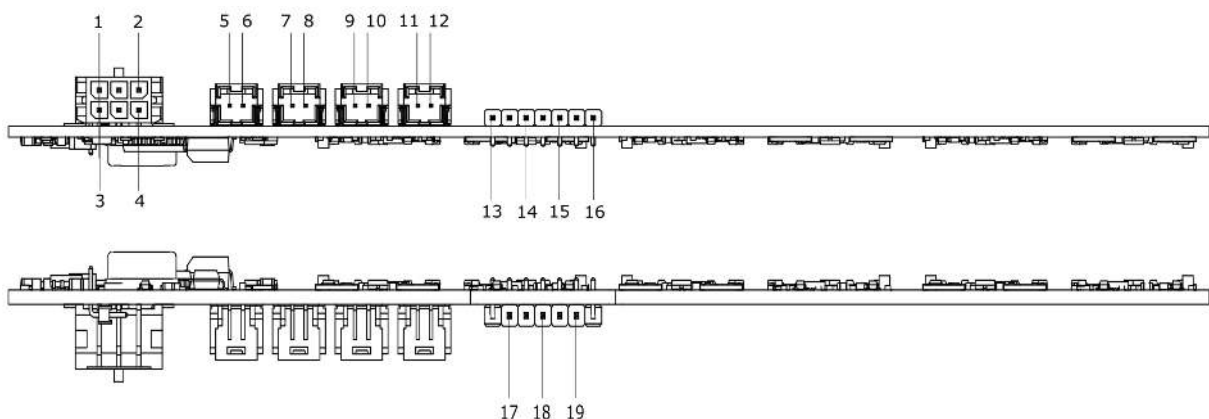


Figure 3.8 EMUS Tesla Module (TES011C) connectors

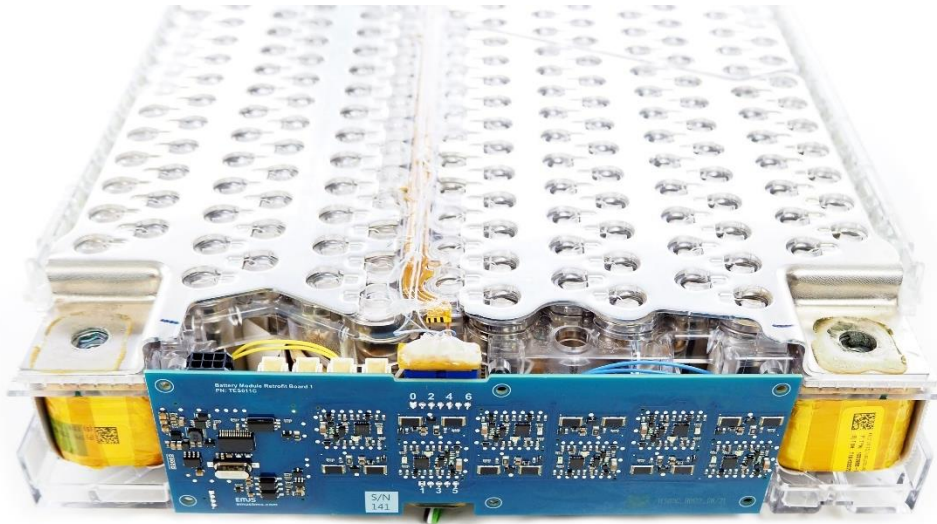


Figure 3.9 Installed EMUS Tesla Module (TES011C)



NOTE: EMUS Tesla Module (TES011C) specifically designed for Tesla Model S 85kWh, P/N: 1071954-00-B, S75 battery pack. Please pay attention to dimensions and mounting holes compatibility with your selected battery pack.

3.4 Current Sensor

3.4.1 EMUS current sensor

EMUS G1 Current Sensor, regardless of its type, should be installed in such way that all currents going in and out of the battery would flow through it (i.e., behind all load, charging, or utility devices that are connected to the battery). In Figure 3.10 is shown how the Bus Bar Current Sensor must be connected. The Closed Loop type Current sensor connects identically.

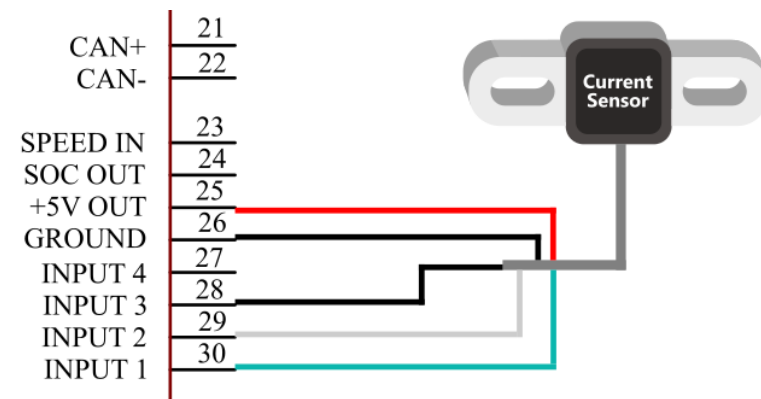


Figure 3.10 EMUS G1 Current Sensor connection diagram.

When using the Bus Bar type Current Sensor, additional care should be taken to install it away

from any sources of heat or stray magnetic fields (permanent magnets, power cables, etc.), and without bending or twisting its conductor, since all these factors may affect its calibration accuracy. Ideally it should be installed as an interconnecting bus bar between two adjacent prismatic form factor cells that are fixed and cannot move vertically relative to each other, as shown in Figure 3.11.

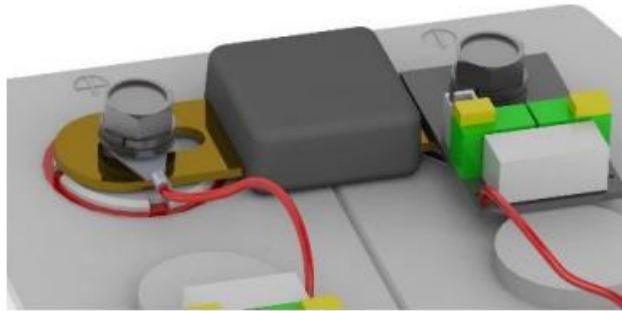


Figure 3.11 Correct EMUS G1 Bus Bar Current Sensor installation

The Closed Loop type Current Sensor is more rugged than the Bus Bar type in several ways, however it is still recommended to place it away from any sources of heat or stray magnetic fields. It should be installed by securing it to a surface and threading one of the battery power cables through it (shown in Figure 3.12).

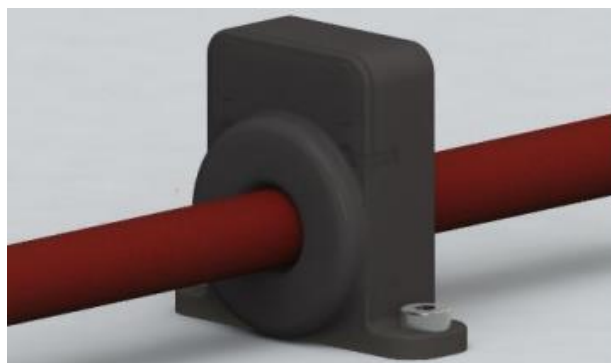


Figure 3.12 Correct EMUS G1 Closed loop type Current Sensor installation

The battery cable should then be secured to the surface in such way that it would not exert any bending force on the sensor. Once the Current Sensor is installed, it can be connected to the G1 Control Unit by plugging its cable directly into the 8-pin connector. The cable should then be secured to a surface in such way that it would not be strained and would not go alongside the power cables to avoid interference. Plastic cables ties and adhesive cable tie holders are recommended for securing it.

3.4.2 3rd Party current sensor

If a 3rd party current sensor is being used, installation depends on sensor type. EMUS provides

recommendations on how to install such current sensors, but if you need more details, you can refer to the specific sensor's datasheet.

3.4.3 CAN Current Sensor

In Figure 3.13 CAN current sensor you can see how to connect CAN current sensor. Since this type of sensor sometimes measures not only current, but also voltage. To acquire correct voltage measurements, the negative terminal of a sensor must be connected to a negative terminal of the battery pack.

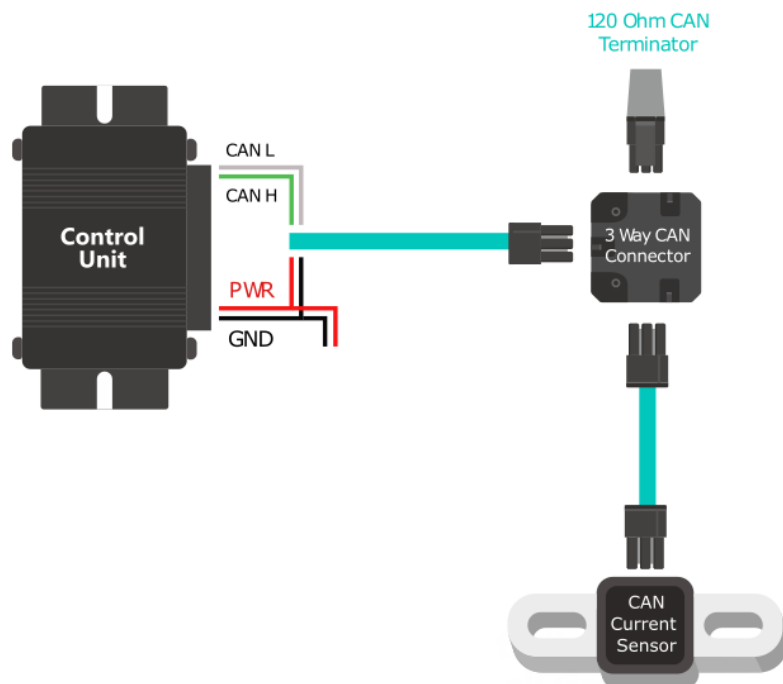


Figure 3.13 CAN current sensor

3.5 Cell Communication Adapters

EMUS G1 Top and Bottom Isolators should be connected to the G1 Control Unit as shown in Figure 3.14.

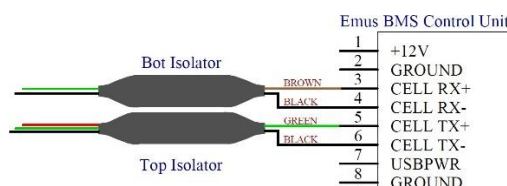


Figure 3.14 Correct way of connecting the TOP/BOT Isolator to the G1 Control Unit.

The ends of the corresponding Isolator should be stripped and crimped with the crimp contacts

that are provided with the G1 Control Unit using an appropriate crimp tool and inserted into corresponding slots on the main 22 pin connector. The battery side wires of the Top and Bottom Isolators should be installed together with the Cell Modules, therefore the instructions on how to connect them are provided in chapter 3.2. The wires on each end of the Isolators can be shortened or extended if necessary, however it is not recommended to extend them over 0.5m. Once connected, the Isolators should be secured to a surface in such way that their wires would not be strained and would not go alongside the power cables to avoid interference due to capacitive coupling. The recommended method for securing the Isolators in place is using plastic cables ties and adhesive cable tie holders.

Similarly to the Top and Bottom Isolator, instruction on how to connect the battery side cable wires of a CAN Cell Group Module are described in chapter 3.2, while connecting the CAN Cell Group Module(s) to the G1 Control Unit should be done following the general rules of correct CAN bus setup, which also apply to other CAN equipped devices in the system and are therefore abstractly described separately in chapter 3.6.

3.6 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 G1 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 3.15.

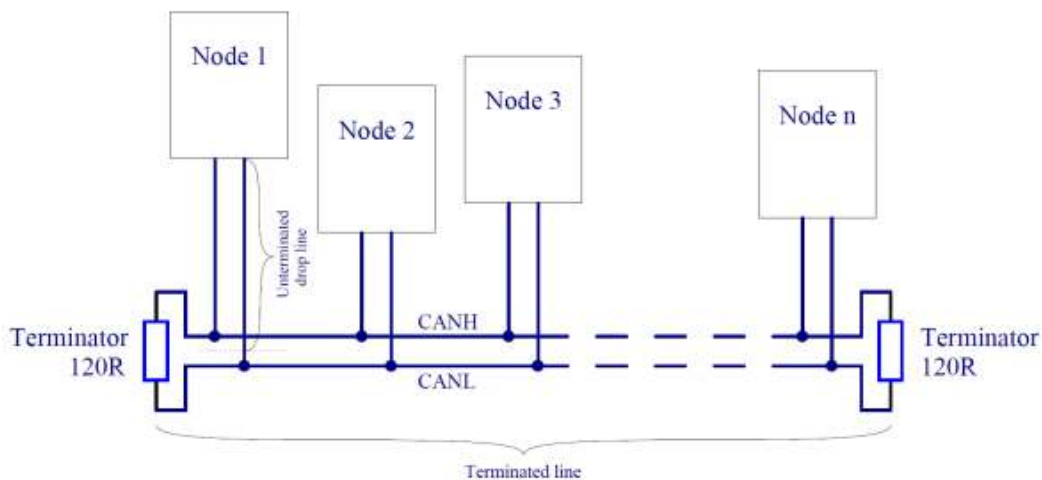


Figure 3.15 High-speed CAN network specified in ISO-11898-2 standard

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 G1 BMS components are connected are presented in the Table 8 The Maximum bus line lengths from Table 8, 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 8 Maximum bus line lengths

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

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 G1 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 8 are calculated based on the bit timing settings used in CAN-equipped EMUS G1 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 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.

The 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 G1 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 20kΩ and 120Ω 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 G1 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 to avoid ground loops.

3.7 Centralized CAN Cell Group Module

Batteries must be connected to CCGM connectors from right to left side in a sequence from lowest potential to the highest potential. **Green** lines indicate wires connecting battery cells to CCGM connector pins.



NOTE: Connection must start from the most negative cell to the most positive. In cases when cells number is less than 16, e.g., 8 cells, then free cells connection wires (dedicated for 9th-16th cells) must ALL be connected to the last 8th (most positive cell). As shown in Figure 3.16 Cells connection, with e.g., 8 cells in series.

Cells Layout: (using other amount of cells)

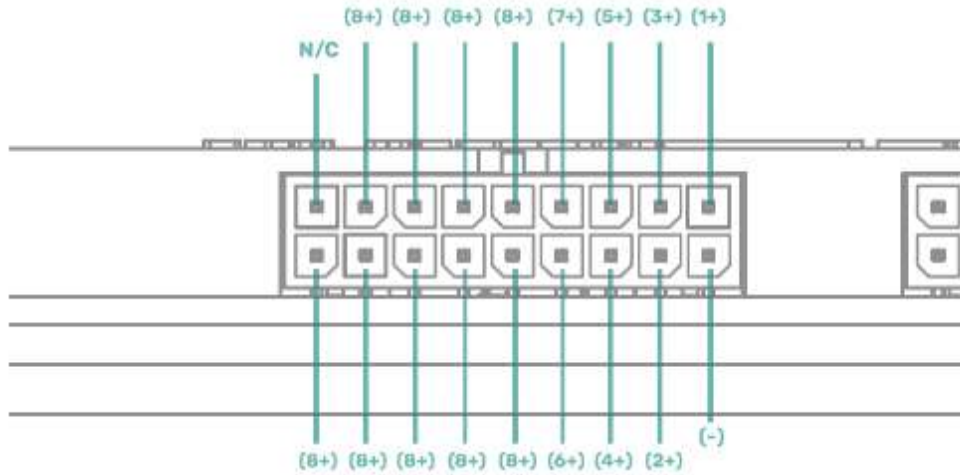


Figure 3.16 Cells connection, with e.g., 8 cells in series

To set up the 16 cells and 5 external temperature sensors please refer to figure below.

Cells Layout:

Ext. Temperature Sensors Layout:

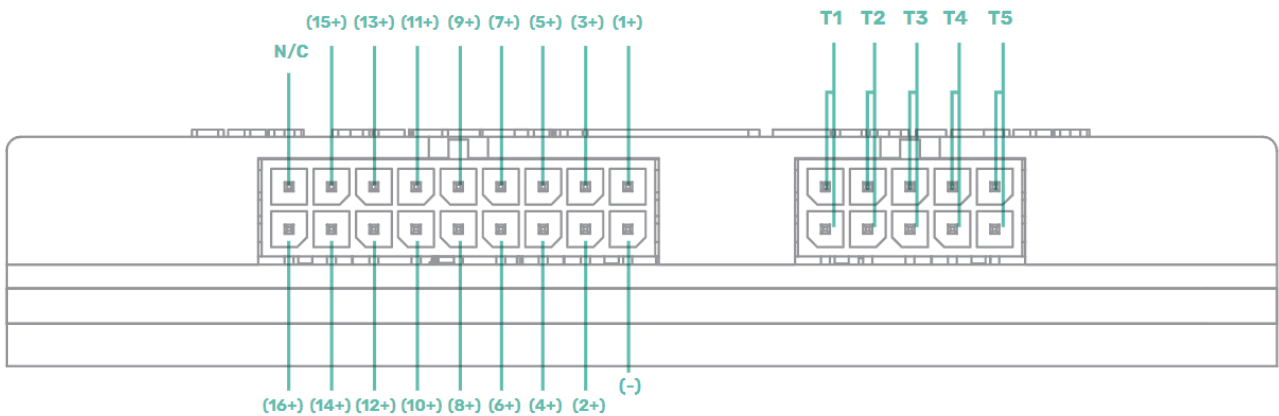


Figure 3.17 CCGM Battery, Ext. Temperature Sensors installation

To set up the CAN connector please refer to the figure below.

CAN Connection Layout:

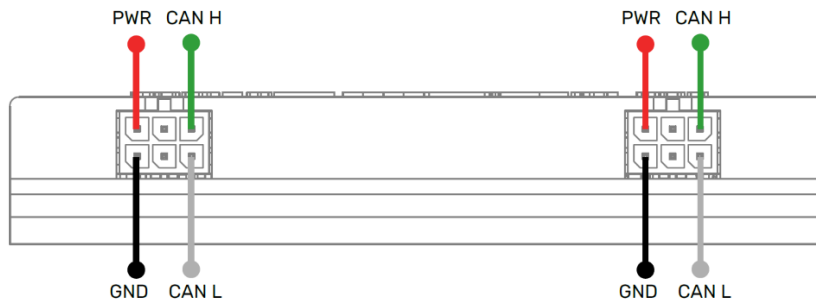


Figure 3.18 CCGM CAN port pinout

Main power supply to CCGM CAN line should be supplied from G1 Control Unit, with power supply from auxiliary battery (12-32V) or other external power source through converter. Power supply from the battery cells is required to power up BQ chip, however unless CAN line is not powered, none of CCGM will be functioning.

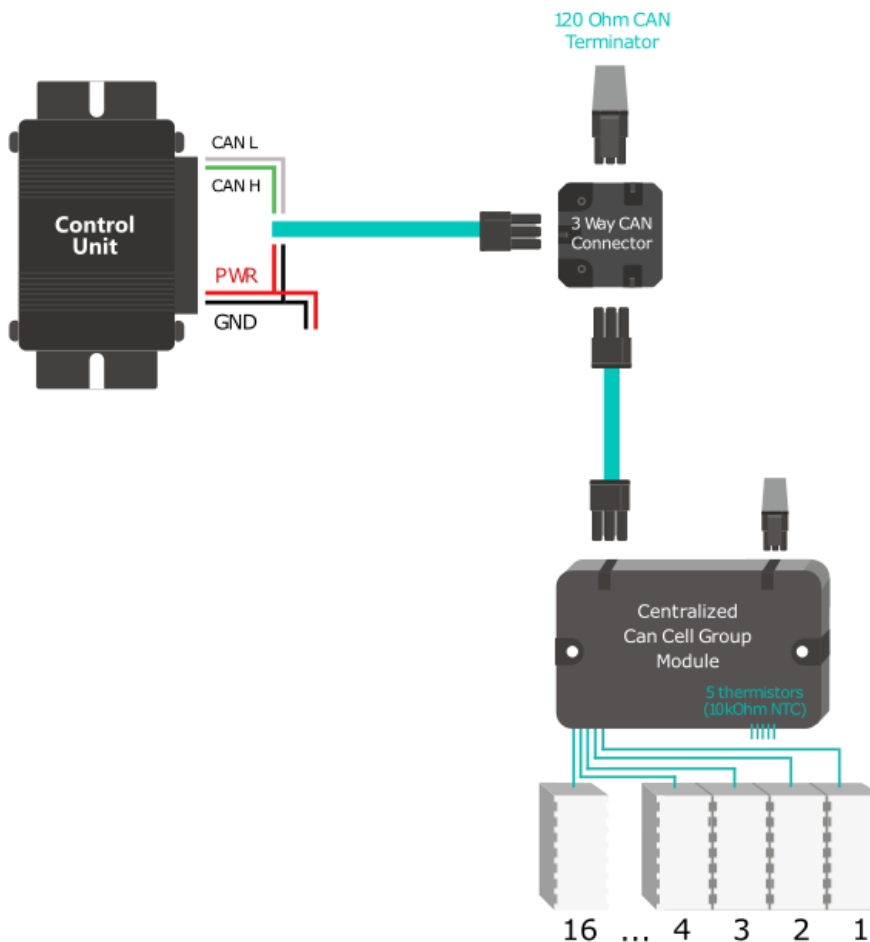


Figure 3.19 Power supply connection for CCGM

To set up the Temperature Breakout board please refer to the figure below.

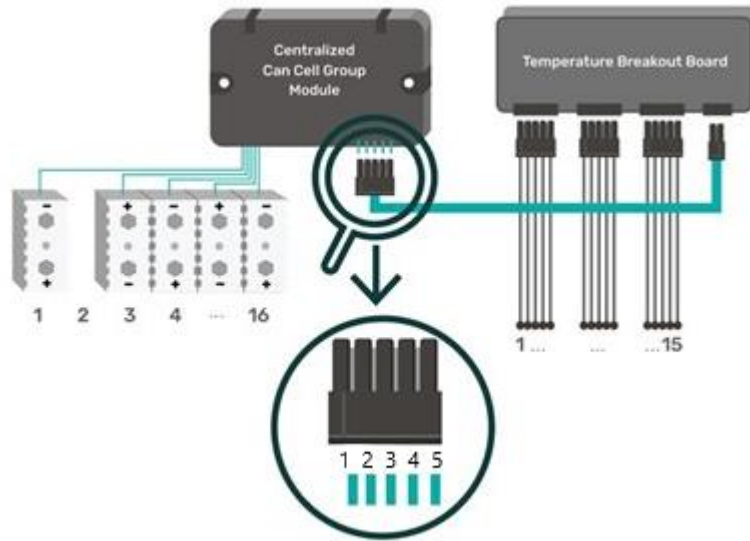


Figure 3.20 Temperature Breakout Board connection possibility to CCGM



NOTE: Temperature Breakout board is non stocked item, contact EMUS for availability.

3.8 CAN Filter

In Figure 3.21 CAN Filter connection you can see an example of how to use CAN Filter to create G1 system network.

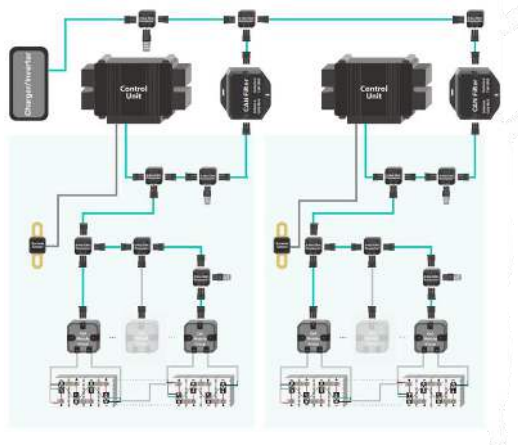


Figure 3.21 CAN Filter connection

3.9 Smartphone Connectivity Module

EMUS G1 Smartphone Connectivity Module should be installed by connecting it to the G1

Control Unit as shown in Figure 3.22.

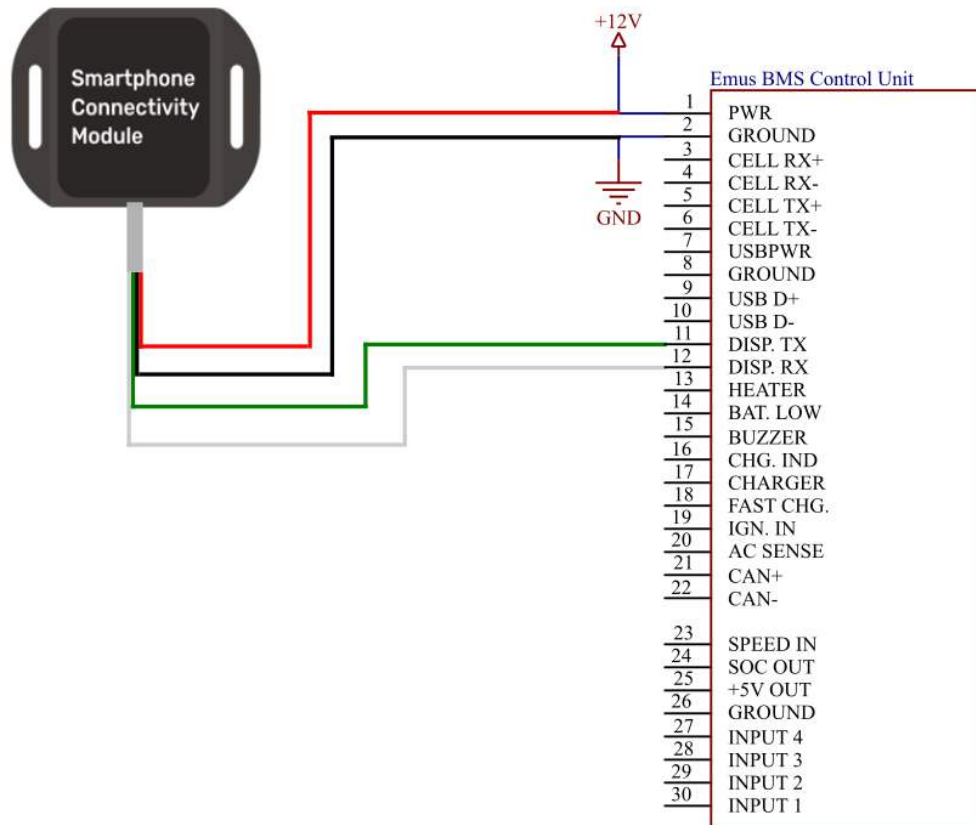


Figure 3.22 EMUS G1 Smartphone Connectivity Module connection diagram

The end of each wire of the Connectivity Module cable should be stripped and, depending on its purpose, either crimped with the crimp contacts that are provided with the G1 Control Unit using an appropriate crimp tool and inserted into corresponding slots on the main 22 pin connector, or connected to the same power supply that powers the G1 Control Unit. Once all the wires are connected, the G1 Smartphone Connectivity Module should be placed in an appropriate spot where it is not covered by any objects that could obstruct its signal (e.g., metal enclosures), and secured to a surface. It is also recommended to secure its cable to a surface using plastic cables ties and adhesive cable tie holders in such way that it would not be strained.



NOTE: It is not possible to use Smartphone connectivity module with Display Unit at the same time.

3.10 Display unit

EMUS G1 Display Unit should be connected to the G1 Control Unit as shown in figure 3-23. The end of each wire of the Display Unit cable should be stripped and depending on its purpose, either crimped with the crimp contacts that are provided with the G1 Control Unit and inserted

into corresponding slots on the main 22 pin connector or connected to the same power supply that powers the G1 Control Unit. RS-232 connector on the Display Unit consists of 4 pins. Once the wires are connected, the Display Unit should be secured to a surface in such way that its wires would not be strained, by using plastic cables, adhesive cable tie holders and screws or bolts. For correct EMUS G1 Display Unit operation G1 Control Unit USB connector must be disconnected from PC.

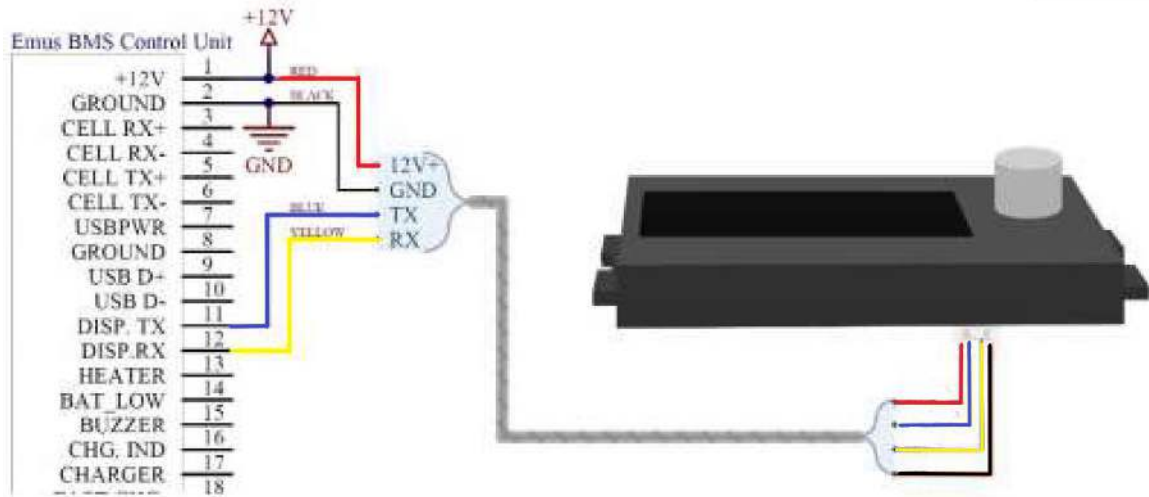


Figure 3.23 EMUS G1 Display Unit wiring



NOTE: It is not possible to use Smartphone connectivity module with Display Unit at the same time.

3.11 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 3.24 and Figure 3.25. 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.

3.12 Contactor

The main contactor should be installed behind all load devices, and its coil terminals should be connected directly between G1 Control Unit's power supply positive terminal and one of the general-purpose outputs of G1 Control Unit that is mapped with appropriate pin function, as shown in Figure 3.24.

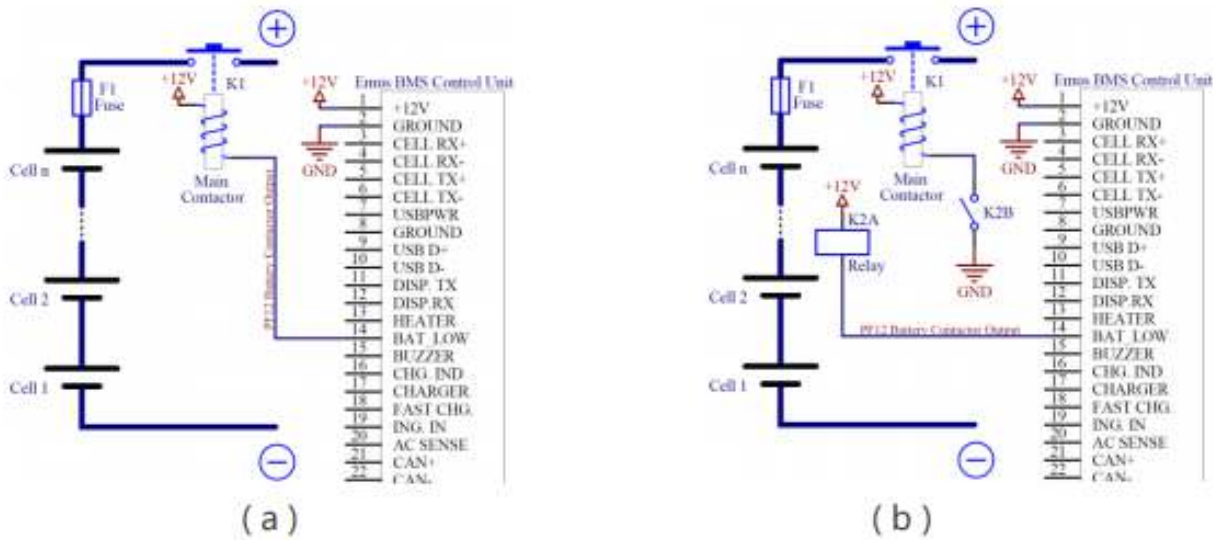


Figure 3.24 Connecting contactor to G1 Control Unit: (a) directly, when the rated current of the contactor coil is less than 0.5A; (b) through a relay, when the rated current of the contactor coil is 0.5A or more.

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.

3.13 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 G1 Control Unit's power supply and one of the general purpose outputs of the G1 Control Unit that is mapped with appropriate pin function, as shown in Figure 3.25.

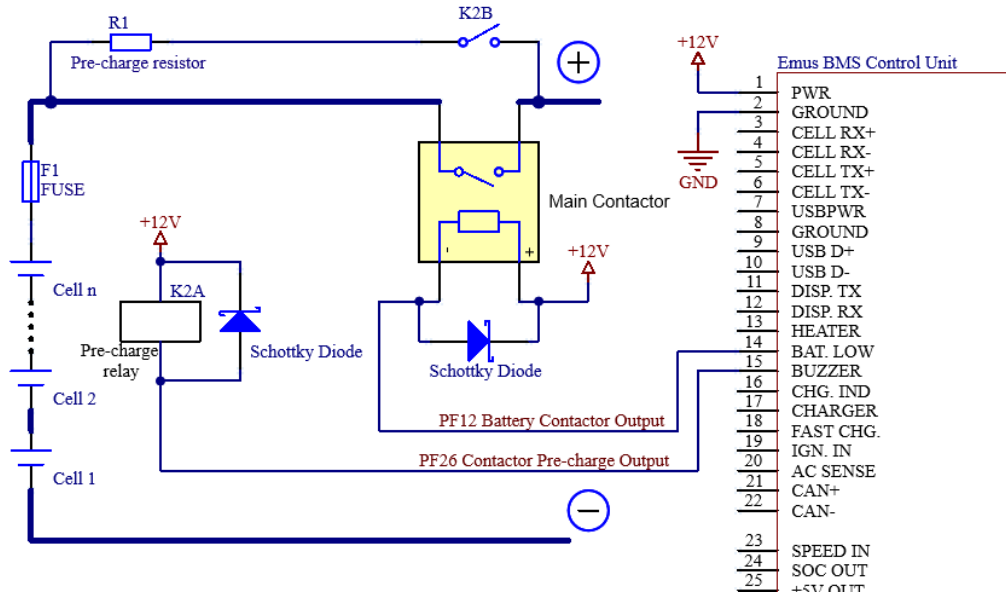


Figure 3.25 Contactor pre-charge sub-circuit connection diagram

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.

3.14 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 especially important to correctly select and connect a charging device in order allow G1 Control Unit 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 G1 Control Unit is described in the following chapters.

3.14.1 CAN-based chargers

To allow G1 Control Unit 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 G1 Control Unit's general-purpose outputs mapped with "PF10 Charger Enable" function, as shown in Figure 3.26.

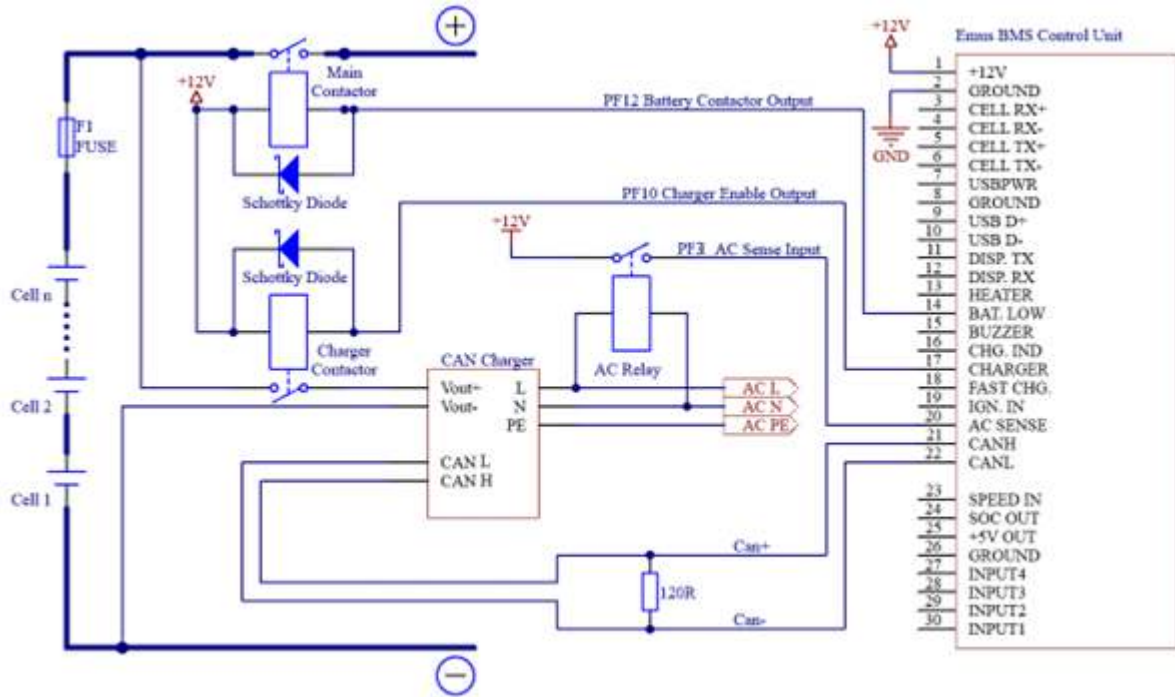


Figure 3.26 Correct CAN charger and charger contactor connection in respect of the battery, battery fuse, and main contactor

The connection between a CAN charger and G1 Control Unit is shown in Figure 3.26 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 3.6. Most CAN chargers supported by G1 Control Unit have an internally powered isolated CAN interface and should be connected to the G1 Control Unit as shown in the general example in Figure 3.26, 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.

3.14.2 CAN chargers/inverters

The connection between EMUS G1 Battery Management System and CAN Charger/Inverter is very similar to the CAN-based chargers described (3.14.1 CAN-based chargers). The difference between a charger and inverter/charger is enabled "PF10 Charger Enable" output pin when charging or discharging process controlled by charger/inverter. G1 Control Unit manages battery activity and ensures safe battery use by disconnecting "PF12 Battery Contactor Output" before hazardous situations occur. The figure below shows a visual example of the system that can use an EMUS G1 Battery Management 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.

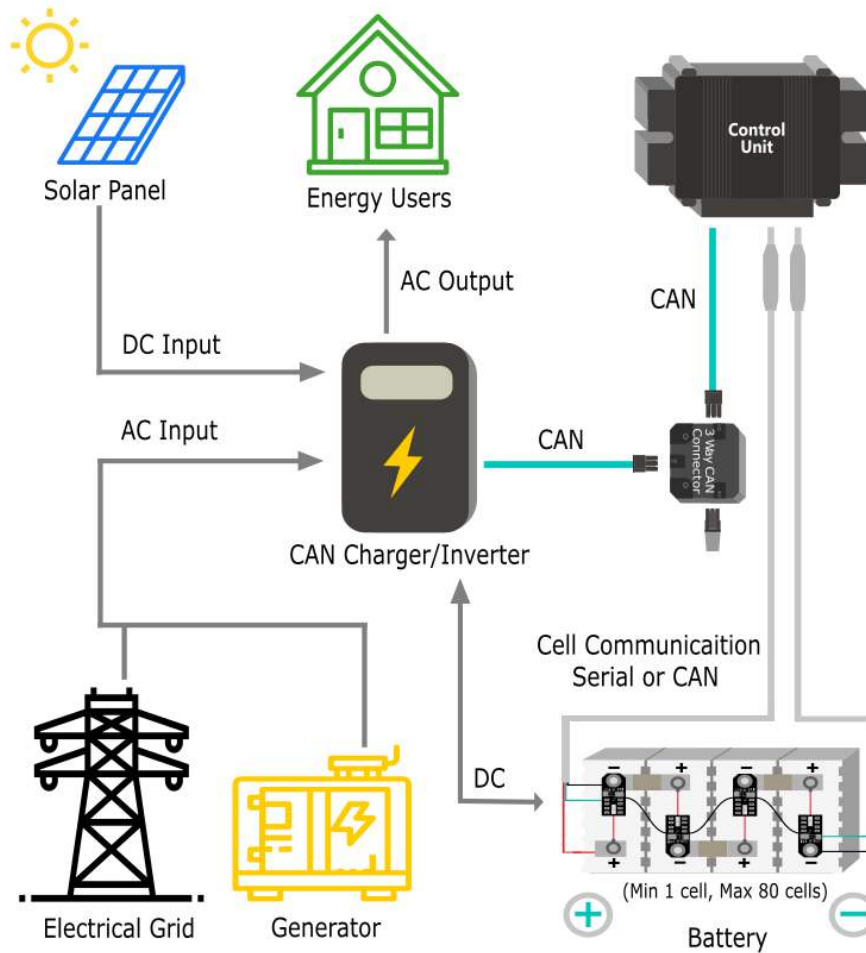


Figure 3.27 CAN Charger/Inverter system

3.14.3 Non-CAN chargers

Non-CAN charging devices should generally be connected directly to the battery and controlled using a third-party electromechanical contactor, as shown in the example in Figure 3.28. In such cases, the charger connection acknowledgment should be provided to the G1 Control Unit 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.

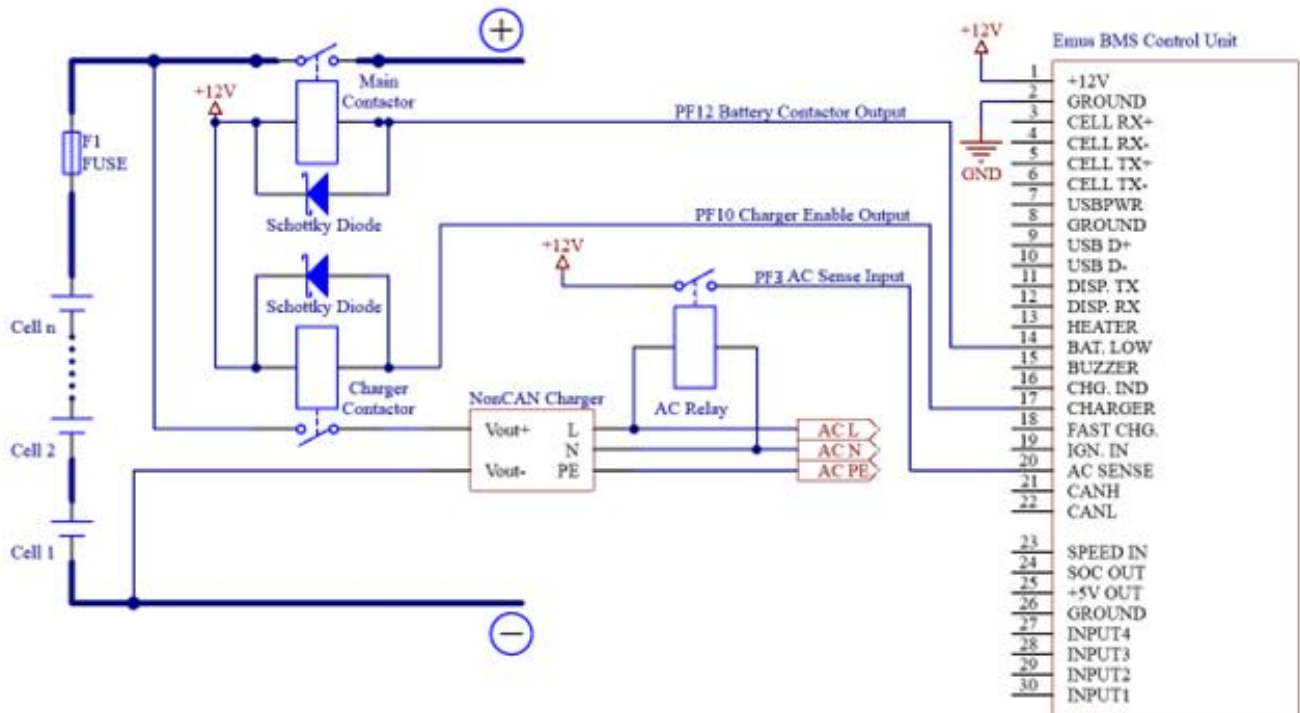


Figure 3.28 Correct connection of a non-CAN charger in respect of the battery, battery fuse, and main contactor: using a third-party electromechanical contactor.

3.14.4 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 3.29. To connect the charger to the G1 Control Unit a signal conditioning sub-circuit is usually required, such as the one shown in Figure 3.29, 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.

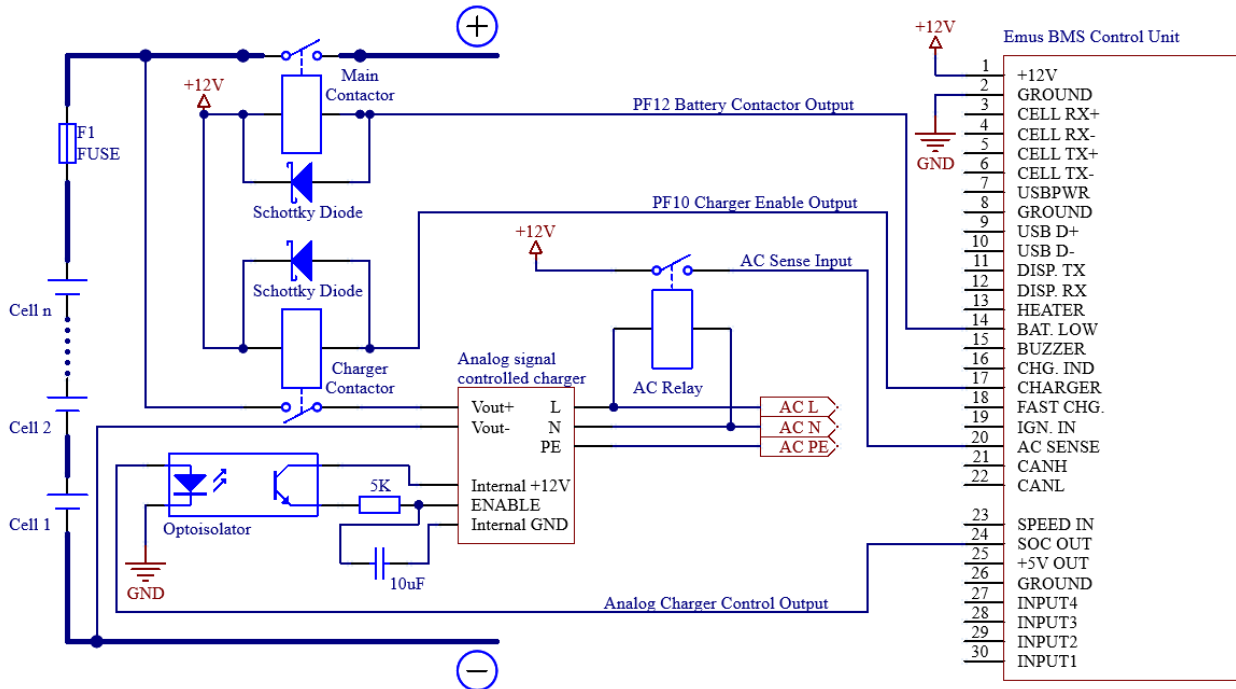


Figure 3.29 Correct analog signal-controlled charger and charger contactor connection in respect of the battery, battery fuse, and main contactor

3.15 Cooling fan

Cooling fan for cooling the Cell Modules during balancing is usually requires quite low amount of power and can be supplied from the same power supply as the G1 Control Unit and controlled using a single relay, as shown in the example in Figure 3.30. 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 Cell Modules, as well as dimensioning and selection of its components is out of the scope of this document.

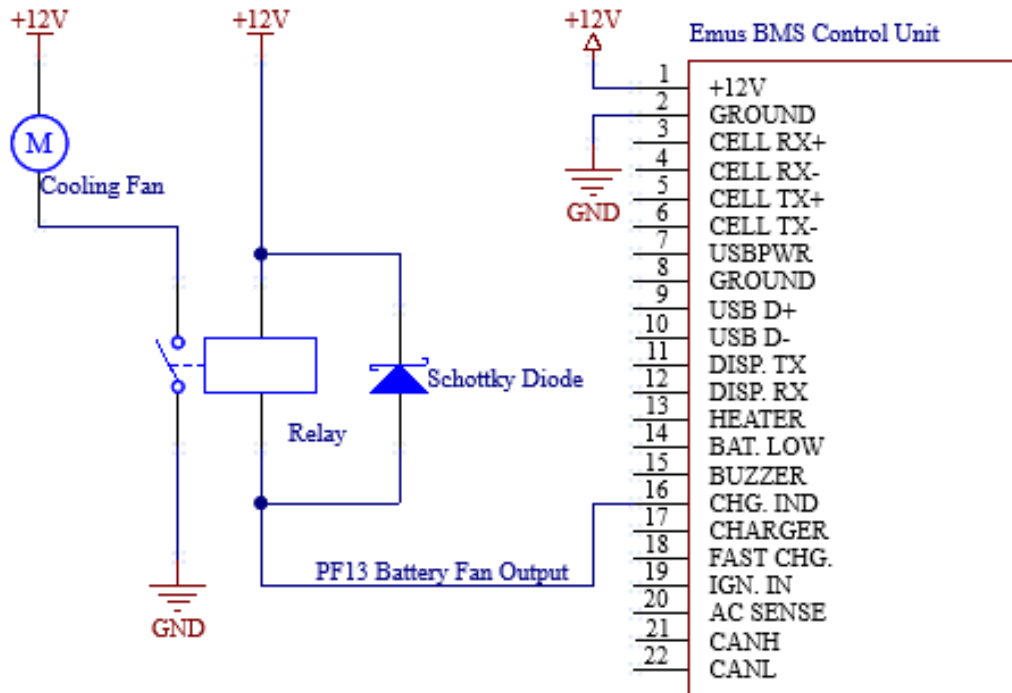


Figure 3.30 : Cooling fan connection diagram

3.16 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 G1 Control Unit, therefore it is usually connected directly to the battery, and controlled using a separate, dedicated contactor, as shown in Figure 3.31. 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).

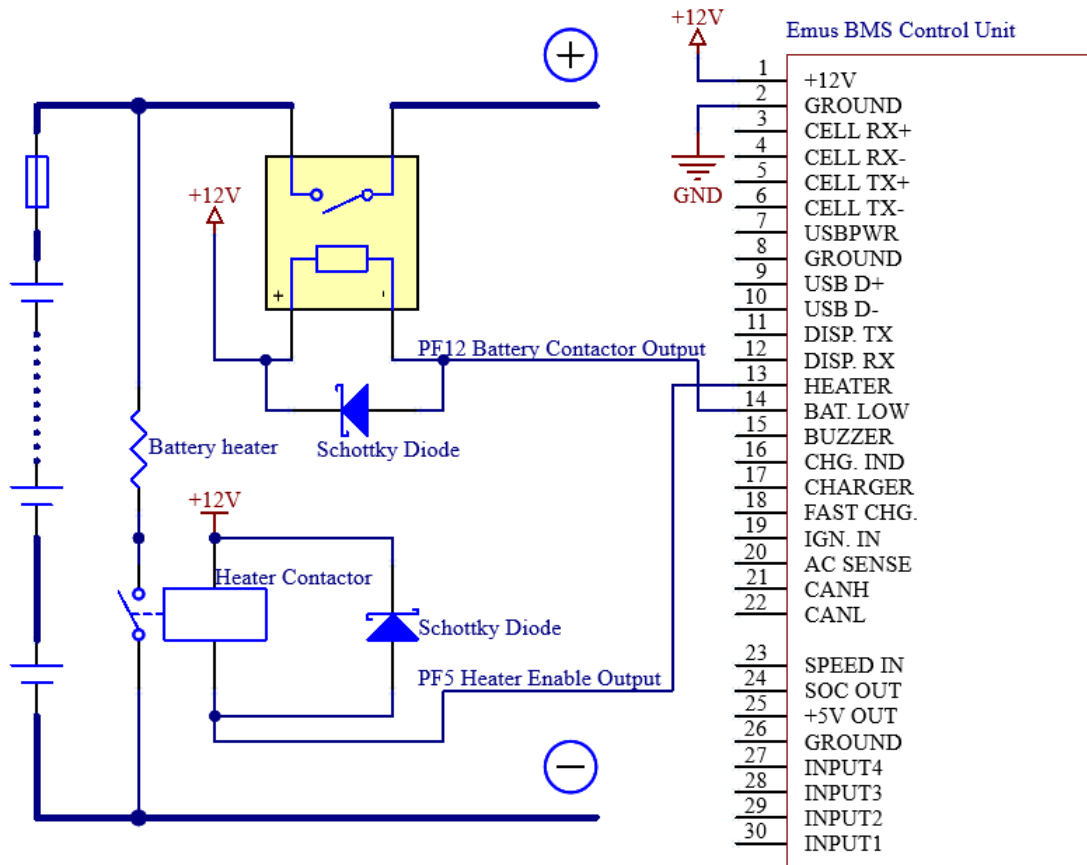


Figure 3.31 Heater connection diagram

3.17 Indicators

If they are required, discrete visual or audial indicators should be connected between the positive terminal of the G1 Control Unit's power supply and one of the G1 Control Unit's general-purpose outputs mapped with appropriate function, as shown in Figure 3.32. An LED or an indication lamp is recommended to be used for visual indication, while the audial indicator must be a self-oscillating type of 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 conducted according to the system requirements and is out of the scope of this document.

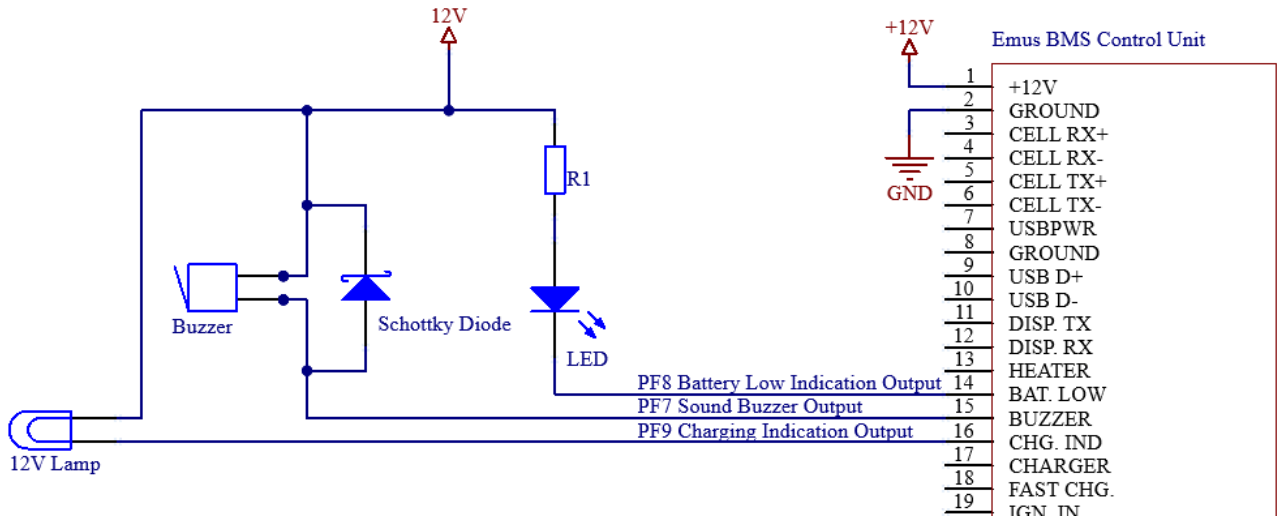


Figure 3.32 Examples of connecting visual or auidial indicators to the G1 Control Unit (left to right): an indication lamp, a self-oscillating buzzer, and an LED.

3.18 Leakage fault detector

If required by the application, leakage fault detector should be installed in the system by connecting its corresponding inputs to the battery terminals, and its output to one of the G1 Control Unit's general-purpose inputs, as shown in the example in Figure 3.33. It is important to note that the G1 Control Unit expects a logic signal with levels of 0V and 5 to 12V respectively, therefore depending on the particular models of the detector that is used, and addition signal conditioning sub-circuit may be needed.

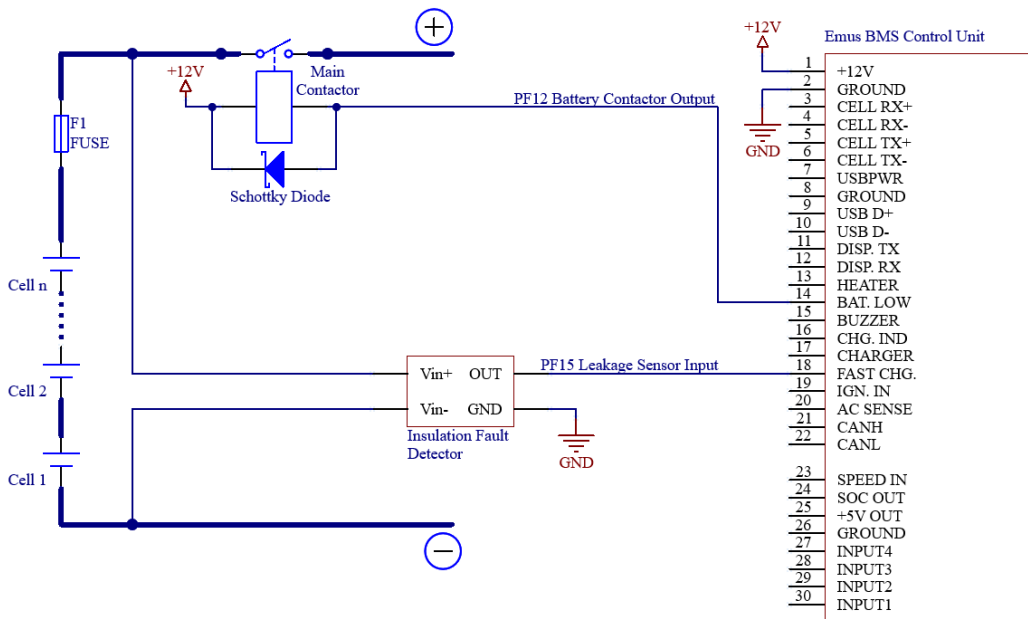


Figure 3.33 Example of connecting a third-party leakage fault detector to the G1 Control Unit.

Chapter 4: Configuration

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



NOTE: Certain configuration parameters may be inactive or invisible for certain versions used by the G1 Control Unit, 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 are shown Control Panel pages and their tabs.



Status

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



Statistics

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.



Configuration

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.

Control Unit

CAN Devices



Update

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.



External components

EMUS Control Panel External components page allows to configure, update, and monitor EMUS BMS G1 system external components: EMUS G1 Display Unit, EMUS G1 Smartphone Connectivity module.

4.2 Serial data interface

Serial communication parameters are in "Configuration" → "General" interface settings are located in "Data Transmission to Display Period" box. By checking "Broadcast on RS232/USB" checkbox, data broadcast to display over RS232/USB interface is enabled. Data transmission is divided into two states: active and sleep. Both parameters refer to a 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.

Data Transmission to Display Period	
In Active State:	0.1 s
In Sleep State:	0.1 s
Broadcast on RS232/USB:	<input checked="" type="checkbox"/>

Figure 4.1 Data Transmission to Display parameters

4.3 Cell Wire Break Detection

Cell Wire Break Detection functionality can be enabled by checking the "Enable Cell Wire Break Detection" checkbox which can be found in "Configuration" page → "General" tab → "Battery Pack" box. See Figure 4.2.

This functionality enables detecting any possible broken cell wires. If this functionality is enabled and the configured CAN devices do not support this function, there will be a warning

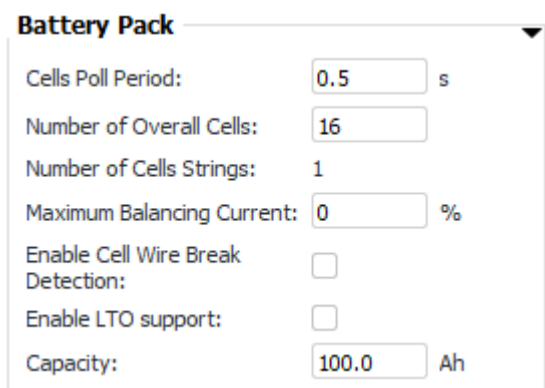
shown "Wire Break Unsupported."

4.4 LTO cell support

Support for LTO cells can be enabled by checking the "Enable LTO support" checkbox which is located in "Configuration" page → "General" tab → "Battery Pack" box.

This functionality enables the use of cells which voltage ranges between 1.01-3.54V. For this feature to work a special version of CCGM firmware must be used which can be received from EMUS support.

Note: all voltage values in the Control Panel will switch to 1.01-3.54V range once this function is enabled.



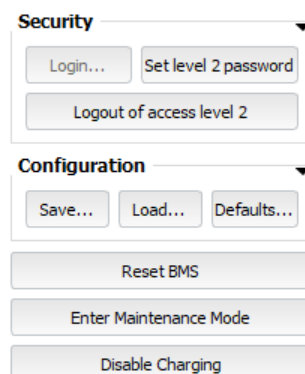
The screenshot shows a configuration panel titled "Battery Pack". It contains the following settings:

- Cells Poll Period: 0.5 s
- Number of Overall Cells: 16
- Number of Cells Strings: 1
- Maximum Balancing Current: 0 %
- Enable Cell Wire Break Detection:
- Enable LTO support:
- Capacity: 100.0 Ah

Figure 4.2: Enable Cell Wire Break Detection and LTO support parameters

4.5 Charging Disable

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



The screenshot shows two panels: "Security" and "Configuration".

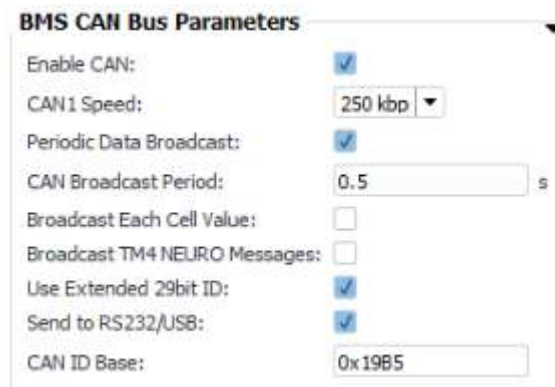
The "Security" panel contains buttons for "Login...", "Set level 2 password", and "Logout of access level 2".

The "Configuration" panel contains buttons for "Save...", "Load...", "Defaults...", "Reset BMS", "Enter Maintenance Mode", and "Disable Charging".

Figure 4.3 Disable Charging Button

4.6 CAN data interface

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



Parameter	Value
Enable CAN:	<input checked="" type="checkbox"/>
CAN 1 Speed:	250 kbp
Periodic Data Broadcast:	<input checked="" type="checkbox"/>
CAN Broadcast Period:	0,5 s
Broadcast Each Cell Value:	<input type="checkbox"/>
Broadcast TM4 NEURO Messages:	<input type="checkbox"/>
Use Extended 29bit ID:	<input checked="" type="checkbox"/>
Send to RS232/USB:	<input checked="" type="checkbox"/>
CAN ID Base:	0x19B5

Figure 4.4 CAN communication parameters

- **Enable CAN** – Check to use G1 Control Unit CAN interface for data transmission and reception. BMS reset is required for change to take effect;
- **CAN1 Speed** – G1 Control Unit 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 a fully functional CAN/Serial converter, because of BMS CAN message processing and serial interface speed limitations. It is recommended to use when there are few 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 G1 Control Unit. It allows us to use several EMUS G1 BMS systems on the same CAN bus or resolve 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 broadcast messages. For example, if this number is entered 800 then BMS will broadcast messages with standard 11-bit IDs starting from 800.
- **Device CAN ID Base** – CAN Identifier base, allocated for communication with EMUS G1 BMS internal peripherals. For extended 29-bit ID it represents upper 13 bit and for basic 11-bit ID is a base address number.

4.7 Cell communication data interface

Cell communication settings are in "Configuration" → "General" → "Battery Pack" box. There are two options for serial communication type: Serial and CAN. Serial communication is used with G1 Distributed Regular configuration, CAN communication is used with G1 Distributed Grouped and G1 CCGM Centralized configurations.

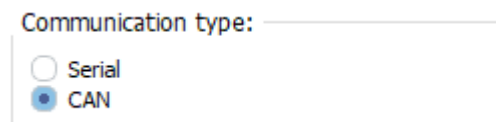


Figure 4.5 Cell communication parameters

4.8 CAN Cell Group Module configuration

CAN Cell Group Module (CGM) configuration is performed in Control Panel, Configuration page → CAN Devices tab.


Configuration is initiated by clicking on "Discover device" which discovers all available CAN Group Modules connected to G1 Control Unit CAN bus. Discovered devices appear in the Unconfigured list table (Figure 4.6) along with serial number and number of cells. When discovering CAN devices G1 Control Unit is put into configuration mode until the discovery is complete. During this mode, normal operation of the G1 Control Unit is stopped. After discovery of devices, to assign particular CGM to a cell string, simply drag entry from Unconfigured list to



Configuration (Figure 4.7) table and drop on the desired field.

Unconfigured EMUS CAN Devices

Part Number	Serial	Cell Count	ID

Figure 4.6 CAN Devices in unconfigured list

This table consists of columns that represent strings of series-connected cells that are connected in parallel and of rows that represent CAN Group Modules in a single cell string. E.g., if the battery pack consists of three strings connected in parallel, each one of them having 40 cells connected to two CAN Group Modules, then configuration table will be three columns  and two rows. After placement of CAN Group Modules in each field icon will appear. The column headers will be updated and will additionally display the total cell count of the string.

By pressing "Commit Configuration" button finished configuration will be sent to G1 Control Unit and if everything is okay,  the icons will turn  to icons, indicating that CAN Cell Group Module configuration was completed successfully.

Configuration

Parallel:







	String 0 (Cells: 40)	String 1 (Cells: 40)	String 2 (Cells: 40)
1	 CGM sn: 197, cells: 20	 CGM sn: 200, cells: 20	 CGM sn: 202, cells: 20
2	 CGM sn: 199, cells: 20	 CGM sn: 201, cells: 20	 CGM sn: 210, cells: 20
3			

Figure 4.7 CAN Devices in configuration table before commit

Configuration

Parallel:









	String 0 (Cells: 40)	String 1 (Cells: 40)	String 2 (Cells: 40)
1	 CGM sn: 197, cells: 20	 CGM sn: 200, cells: 20	 CGM sn: 202, cells: 20
2	 CGM sn: 199, cells: 20	 CGM sn: 201, cells: 20	 CGM sn: 210, cells: 20
3			

Figure 4.8 CAN Devices in configuration table after commit

If some error occurred while committing the configuration, some of the icons may turn from  to  indicating an error.

Configuration

Parallel: 3

	String 0 (Cells: 40)	String 1 (Cells: 40)	String 2 (Cells: 40)
1	✔️ CGM sn: 197, cells: 20	✔️ CGM sn: 200, cells: 20	❌ CGM sn: 202, cells: 20
2	✔️ CGM sn: 199, cells: 20	❌ CGM sn: 201, cells: 20	✔️ CGM sn: 210, cells: 20
3			

Figure 4.9 CAN Devices in configuration table after committing failed



NOTE: If the CAN Group Modules were installed following the order that is suggested in the Installation section, it is advised to set up the configuration in such way that serial numbers of the CAN Group Modules would be sorted in a downwards ascending order in every column, and also from column to column (Figure 4.8). This way cells in Status page → Cells tab will be displayed correctly. Cell of the most negative potential (the one connected to the minus terminal) in the string will be displayed as the first cell on the left, and cell with of the most positive potential (the one connected to the plus terminal) will be the first one on the right.



NOTE: The configuration of the EMUS Tesla Module (TES011C) is identical to the CAN Group Modules (CGM).

4.9 External Temperature Breakout board configuration

For a valid Temperature Breakout board configuration need to proceed to the Control Panel → Configuration page → CAN devices tab → Advanced configuration... button. In the new window it is possible to discover all external temperature breakout board features supporting EMUS system devices. To start to use the external temperature breakout board need to select devices from the "Supported Devices" and click the "Enable all" button.

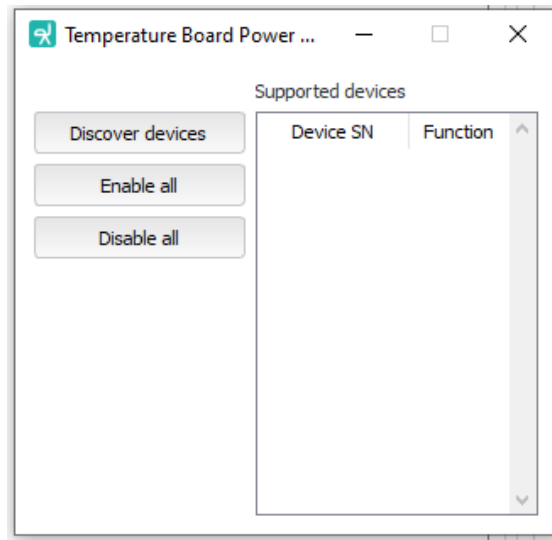


Figure 4.10 External Temperature Breakout board configuration

4.10 Maximum balancing current parameter

Regarding the "Maximum balancing current parameter," if CCGM is used instead of CGM It is only possible to set this parameter with intervals of 10% due to different approach to cells balancing (key mode used). This parameter is in EMUS Control Panel → Configuration page → General tab, under Battery Pack widget. Battery Pack widget is presented in the following Figure 4.11.

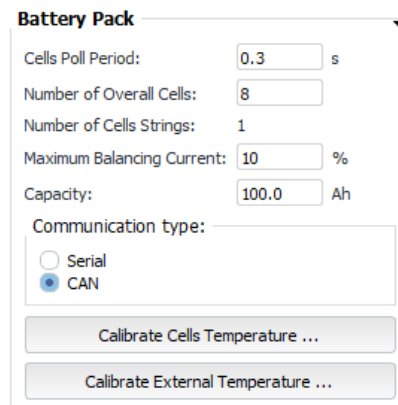


Figure 4.11 Location of "Maximum balancing current" parameter

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

If CGM or TOP/BOT isolators are used, "Maximum balancing current parameter" can be set from 0% to 100% increased by 1%.

4.11 Charging process

Configuration parameters related to the charging process are 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 G1 Control Unit 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 G1 Control Unit is uploaded with firmware that supports Eltek Valere EV Power chargers. It should be set equal to the "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 G1 Control Unit is uploaded with firmware that supports an analog signal-controlled charging device. 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 parameters 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, 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. 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.

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 defined 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, as well as the model of Cell Modules used in the battery pack. 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.

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.

To regulate some charger and inverter advanced settings, it is possible to refer to Charger/Inverter parameters. These parameters are detailed below:

- **Optimized Battery Charging Level** – State of Charge at which it is considered "Charging Finished"
- **Inverter Compensation** – Compensation voltage to use with inverters like Victron. This value is the total battery voltage measurement error between BMS and inverter.
- **Stabilization Window Size** – The value of this parameter sets battery voltage charge limit

window where the CVL (Charge Voltage Limit) value does not oscillate. Used when MPPT power generation keeps being interrupted by drops in CVL.

- **Stabilization Window Hysteresis Margin** – This parameter determines acceptable difference between newly calculated CVL and last one that is used to decide if steady CVL needs to be lowered.
- **Discharge Current Limitation** – Discharge current limitation determines maximum discharge current which is provided to an inverter.

4.11.1 CAN chargers / inverters

To set up CAN charger inverter, need to configure some of parameters which allows you 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 G1 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 G1 Control Panel "Configuration" page → "Charging" tab → "Charging Stage Duration Parameters" group-box.

Also, it is important to set EMUS G1 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 G1 battery management system.

4.12 Protections

Settings that regulate the behavior of the "PF12 Battery Contactor Output" pin function can be found in the Control Panel → Configuration page → Protections tab → Protection / Fault Settings group box and consist of ten 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).

Cell Communication Loss 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 Cell Module Over-Heat protection is around 60°C, regardless of the model of Cell Modules used. For the Cell 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 G1 Control Unit 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 Cell 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.

For Cell Wire Break protection, the "Activate at" field describes the number of broken wires at which the protection will activate. Note: if the first wire of an any cell group module is broken then the protection will activate regardless of the "Activate at" value.

The screenshot shows a software interface titled "Protection / Fault Settings". Under the "Cell Under-Voltage:" section, there is a checked checkbox. To its right, the "Activate at:" parameter is set to 2.50 V, and the "Act. delay:" parameter is set to 0.0 s. Below these, the "Deactivate at:" parameter is also set to 2.50 V, and the "Deact. delay:" parameter is set to 12 s.

Figure 4.12 Single protection example

4.13 Load power reductions

Settings that regulate the behavior of the "PF16 Power Reduction Output" pin function can be found in the Configuration page → Protections 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).

The screenshot shows a configuration window titled "Reduction". Inside, there is a section for "High Cell Module Temperature". A checkbox is checked, indicating the feature is enabled. Below the checkbox, there are four input fields: "Activate at" with a value of 50 and a unit of °C, "Act. delay" with a value of 0.0 and a unit of s, "Deactivate at" with a value of 50 and a unit of °C, and "Deact. delay" with a value of 0 and a unit of s.

Figure 4.13 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 Cell Module Temperature and High Cell Temperature power reduction both parameters can have a value from 20°C to 155°C; The possible value range for the Act. delay and Deact. The delay parameter is 0.0 to 25.5s and 0 to 255s respectively, regardless of the power reduction type.

4.14 Warnings

Settings that notify the user about various dangerous situations without any direct impact on the operation of the battery management system can be found in the Control Panel → Configuration page → Warnings tab → Warnings group box. It consists of 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.

Cell Wire Break warning also is an exception and only has the enable/disable checkbox.

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 Cell Module Over-Heat warning is around 5°C under Cell 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 G1 Control Unit 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 Cell 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.

The screenshot shows a configuration window titled "Warning" with a dropdown arrow. Inside, the "Cell Under-Voltage:" label is followed by a checked checkbox. To the right, there are four input fields: "Activate at:" with a value of "2.00" and unit "V", "Act. delay:" with a value of "0.0" and unit "s", "Deactivate at:" with a value of "2.00" and unit "V", and "Deact. delay:" with a value of "0" and unit "s".

Figure 4.14 Single warning example

4.15 Current measurement

Current measurement configuration is performed in Control Panel → Configuration page → General tab → Current sensor box. There are 7 related configuration parameters: "Sensor Type",

“L Calibration Value”, “H Calibration Value”, “Dead zone”, “Reverse Direction”, “Reset Current to 0”, “Compensate current”.

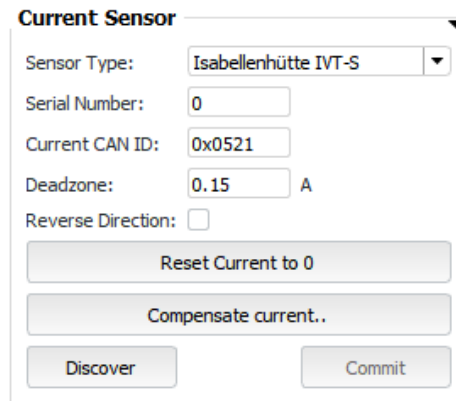
Figure 4.15 Current measurement parameters

- **L and H calibration values** are intended to be filled with calibration values which are written on the EMUS G1 Current Sensor case. L calibration value is used to adjust measurements for low currents and H calibration value is used to adjust measurements for high currents.
- **Dead zone** 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.
- **Reverse direction** option allows to reverse measurement polarity. It is required to use this option to ensure that positive current is displayed during charging and negative when discharging.
- **Reset Current to 0** sets current to 0.0 and sets a new refence.
- **Compensate current** is calibration current sensor value with provided momentary current. System will use this value and recalibrates its current sensor so that its reading would match provided one.

After installation it is recommended to check that the displayed current measurement value is equal to 0 A. If not, the current measurement should be reset. There are two ways to do it:

- When no current is flowing click on “Reset Current to 0”;
- When current is flowing click on “Compensate Current...” and enter momentary current;

This procedure determines the value of “**Measurement Zero Offset**” parameter, thus compensating any offset that occurs due to surrounding stray magnetic fields or other environment factors.



Current Sensor

Sensor Type:

Serial Number:

Current CAN ID:

Deadzone: A

Reverse Direction:

Figure 4.16 Isabellenhütte sensor configuration

Isabellenhütte sensor configuration:

- **Serial Number** – displays factory serial number of connected sensors.
- **Current CAN Id** – base CAN address for current sensor. Should be taken into consideration while assigning the address because addresses may overlap. This may lead to undefined behavior. This address is used as base address with offset 1 for U1 – voltage sensor.
- **Discover** – perform sensor discovery on sensor connection to set desired sensor for configuration.



NOTE: For more detail information about current sensors calibration please contact EMUS Support Team.

4.16 SOC estimation

4.16.1 SOC Coulomb counting algorithm configuration

To achieve a correct SOC calculation, it is mandatory to correctly configure the G1 Control Unit. In Configuration > SOC/SOH, can be found the following parameters after selecting Coulomb Counting algorithm.

Battery Estimator Parameters

Battery Estimator Type: Coulomb Counting

Cell Model Reference Settings

Cell Capacity: 100.0 Ah

Min Voltage: 2.80 V

Max Voltage: 3.65 V

Min Calibration Voltage: 2.80 V

Max Calibration Voltage: 3.65 V

Min Calibration Time: 100.00 s

Max Calibration Time: 100.00 s

Tuning Parameters

Enable SOC Correction: Estimator Diagnostics:

SoH Parameters

Cell Life Cycle: 2000

Cell SOH Endpoint: 0.8

SoP Parameters

SoP Continuous Time: 3600 s Cell Chemistry Type: LFP

SoP 2nd Time Period: 1200 s SoP 3rd Time: 120 s

Max Discharge Rate: 1 C Max Charge Rate: 1 C

Distance Parameters

Pulses per Distance Unit: 1000

Distance Unit Name:

Estimate Safety Margin: 5 %

User SOC Config Parameters

0% User SoC from Real SOC: 10.00 %

100% User SoC from Real SOC: 90.00 %

Swap User SoC/SoC

Figure 4.17 Kalman filter parameters

All parameters shown in “Cell Model Reference Settings” must be correctly configured. Here are detailed each of them:

- **Cell Capacity** – Single cell nominal capacity measured in Ah. Consult battery cell datasheet or supplier.
- **Min. Voltage** – Minimum voltage of a brand-new battery cell. Consult battery cell datasheet or supplier.
- **Max. Voltage** - Minimum voltage of a brand-new battery cell. Consult battery cell datasheet or supplier.
- **Min. Calibration Voltage** – Must correspond to the voltage at which User SOC is 0%.
- **Min. Calibration Voltage** – Must correspond to the voltage at which User SOC is 100%.
- **Min. Calibration Time** – Sets how long the cell must be lower than Min. Calibration Voltage prior to correcting the User SOC to 0%.
- **Max. Calibration Time** – Sets how long the cell must be lower than Min. Calibration Voltage prior to correcting the User SOC to 0%.

4.16.2 SOC Kalman filter algorithm configuration

To achieve a correct SOC calculation, it is mandatory to correctly configure the G1 Control Unit. In Configuration > SOC/SOH, can be found the following parameters after selecting Kalman Estimator algorithm. To make Kalman Estimator work correctly is at least necessary to set the Cell Capacity in (Ah per single cell) and the SOC-OCV Curve. All other parameters can be by

default if are unknown to the user.

Figure 4.18 Kalman filter parameters

All parameters described below are advanced details about the cells, if these values are not known, it is recommended to use default values:

Table 9 Kalman filter parameters

Parameter	Description	Value Range (LFP)	Nominal Value
R0	Internal resistance	From to 0.001	0.004
Rp1	Internal resistance of cell charge polarization	0.0001 to 0.004	0.007
Cp1	Internal capacities of cell charge polarization	3000 to 9000	3600
Curve Slope	The parameter used when cells SoC-OCV curve is linear at given parts. Used to switch between Kalman filter and counting. At the value of 20.0 Kalman filter is always on. At the value of 10.0 algorithm switches between two of them, using coulomb counting in the linear part of curve. At value of 0.0 coulomb counting only is used	0 to 20	20

Parameter	Description	Value Range (LFP)	Nominal Value
SOC Sensitivity	Controls how fast SoC reacts to voltage changes and incoming current, when value of this parameter is larger (1e-04) it will react faster to those changes, when its smaller(1e-09) there is a delay. Worth to note that faster changes are not better, since balance needs to be found. Recommend starting with the value of 1e-07	1e-04 to 1e-09	1e-09

4.16.3 SOC/SOH estimator

4.16.3.1 Tuning parameters

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

Table 10 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 Memory	Variable used to update recursive parameters, which count Cbat over the duration of algorithm
Restart Estimator	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 SOH Estimator	Reset all filters that adjust value of SOH and Cbat. Those two values are also set to default.

Parameter Name	Description
Restart SOP Estimator	Reset all filters that adjust value of SOP. Those two values are also set to default.
Estimator Diagnostics	Enables diagnostical messages that are required when diagnosing estimator operation with EMUS support team.
Enable SOC correction	If enabled, when charging stage would be finished sets SOC value according to voltage readings at that time. Works only with Kalman Filter.

Tuning Parameters

Restart Estimator

Restart SOC Estimator

Restart SOP Estimator

Restart SOH Estimator

Enable SOC correction: Estimator Diagnostics

R0 Start Sensitivity: Cbat Memory:

R0 Sensivity:

Start V Sensitivity:

Start SOC Sensitivity:

V Sensitivity:

SOC Sensitivity:

Figure 4.19 Tuning Parameters

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

4.16.3.2 Cell model reference settings

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

Table 11 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.

Parameter Name	Description
Cp1	Internal capacities of cell charge polarization used to estimate and eliminate SOC counting error. Variable calculated by creating cell model.
Cell Capacity	Internal capacity of cell. One of most important variables while calculating SOC and SOH. The first value is a reference point, with time algorithm adjusts the value. Variable calculated by creating cell model.
Curve Slope	The parameter used when cells SoC-OCV curve is linear at given parts. Used to switch between Kalman filter and coulomb counting. At the value of 20.0 Kalman filter is always on. At the value of 10.0 algorithm switches between two of them, using coulomb counting in the linear part of curve. At value of 0.0 coulomb counts only is used.

Cell Model Reference Settings

SOC-OCV Curve

Set SOC

R0: Ω Set SOH

Rp1: Ω

Cp1: F

Curve Slope:

Cell Capacity: Ah

Figure 4.20 Cell Model 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.

4.16.3.3 SOC-OCV dependency curve of cell

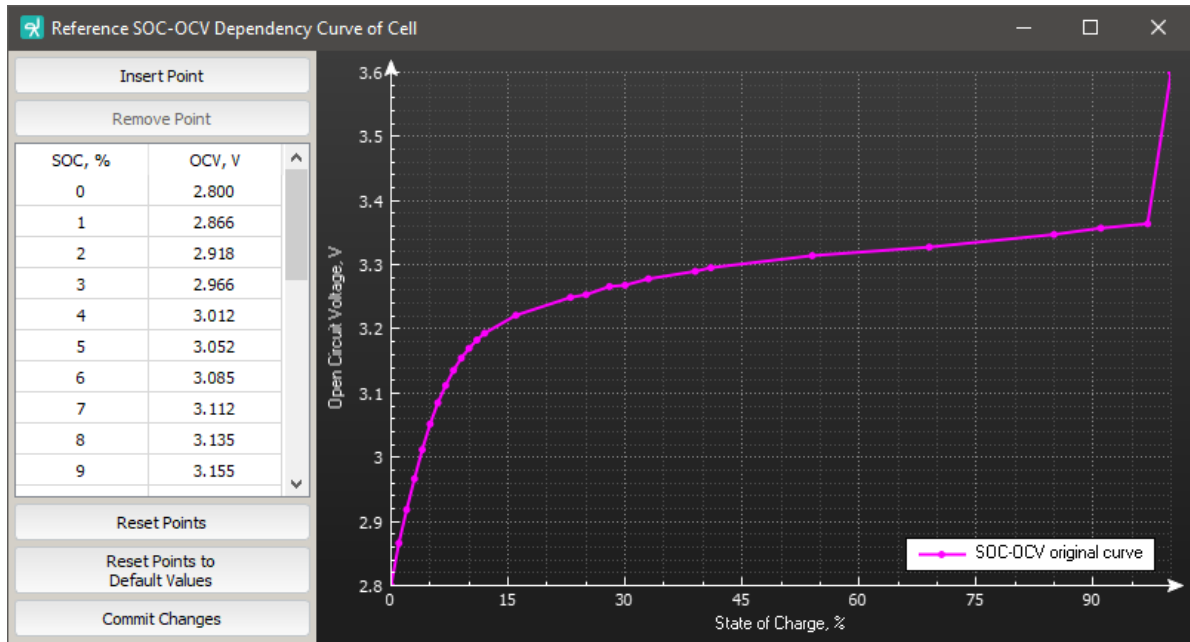


Figure 4.21 SOC-OCV dependency curve of cell

4.16.3.4 SOC dependency on temperature

The EMUS team is working on an algorithm and this feature will be available in the future G1 Control Unit versions.

4.16.3.5 SOH Parameters

SOH has two parameters. Which should be present at manufacturer datasheet. SOH parameters can be found Control Panel → Configuration page → SOC /SOH

SoH Parameters

Cell Life Cycle:

Cell SOH Endpoint:

Figure 4.22 SOH Parameters

Table 12 SOH Parameter description

Parameter Name	Description
Cell Life Cycle	Parameter that describes how many cycles cell should go through before reaching SOH Endpoint.
Cell SOH Endpoint	Parameter that describes what would be estimated SOH after given Cell Life Cycle, usually cell manufacturer estimated a value of 80%, so in this case value of this parameter should be 0.8.

4.16.3.6 SOP Parameters

SOP parameters can be found Control Panel → Configuration page → SOC /SOH

SoP Parameters

SoP Continuous time: s Cell Chemistry Type: ▼

SoP 2nd time period: s SoP 3rd time: s

Max Discharge rate: C Max Charge rate: C

Figure 4.23 SOP Parameters

Table 13 SOP Parameter description

Parameter Name	Description
SoP Continuous time	Time parameters in seconds. Which allows user to configure display of SoP and see how much power could be drawn/given to the battery for given time.
SoP 2 nd time period	Time parameter in seconds. Works like SoP Continuous time parameter.
SoP 3 rd time period	Time parameter in seconds. Works like SoP Continuous time parameter.
Cell Chemistry Type	Used when using coulomb counting estimator for rough estimate of SoC-OCV curve. Currently supports two chemistries (LFP and NMC).
Max Discharge rate	The 'Max Discharge rate' in C rating stands for Capacity. The C rating is the maximum, safe, continuous discharge rate of a pack as specified by the manufacturer.
Max Charge rate	The ' Max Charge rate in C rating stands for Capacity. The C rating is the maximum, safe, continuous charging rate of a pack as specified by the manufacturer.

4.17 Heater control

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

Heater And Fan Control

Fan On Temperature: 20 °C

Minimum Charging Temperature: 1 °C

Climate Control

Enable:

Normal Temperature: 20 °C

Charging Temperature: 25 °C

Minimum SOC: 20.00 %

Max duration when not charging: 48 h

Figure 4.24 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 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 Climate Control.

4.18 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.

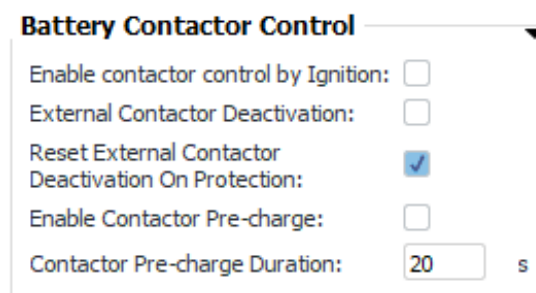
4.19 Battery contactor control

Battery contactor control settings are in Control Panel → Configuration page → Controls tab → Battery Contactor Control box. Box consists of five parameters:

- **Enable contactor control by Ignition** is used to enable battery contactor control by

Ignition.

- **External Contactor Deactivation** is used to enable battery contactor control deactivation over CAN message see "[EMUS G1 Control Unit CAN Protocol](#)"
- **Reset External Contactor Deactivation on Protection** is used to enable external contactor deactivation to be reset if a protection event occurs. Meaning that contactor will not be automatically closed after the protection clears, but instead of G1 Control Unit will wait for an external activation CAN message again.
- **Enable Contactor Pre-charge** is used to enable timeout before closing the load contactor.
- **Contactor Pre-charge Duration** is used to set contactor pre charge timeout in seconds.



Battery Contactor Control

Enable contactor control by Ignition:

External Contactor Deactivation:

Reset External Contactor Deactivation On Protection:

Enable Contactor Pre-charge:

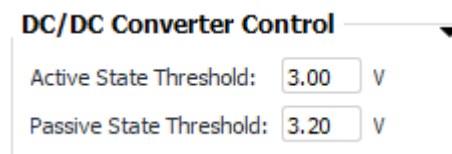
Contactor Pre-charge Duration: s

Figure 4.25 Battery Contactor Control parameters

4.20 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.



DC/DC Converter Control

Active State Threshold: V

Passive State Threshold: V

Figure 4.26 DC/DC Converter Control parameters

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

4.21 Current in Range Control

Function PF31 Current in Range Indication will be activated when the measured current is in the configured range. Otherwise, the function will be deactivated.

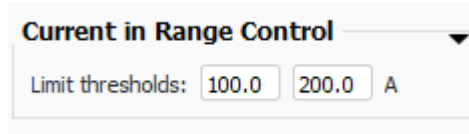


Figure 4.27 Current in Range Control parameters

4.22 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 G1 Control Unit's pin. Each group contains two parameters:

- **Assigned Pin Function** – determines the pin function of that 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 and "SOC OUT" pin 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 G1 Control Unit speed sensor input (SPEED IN), 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.

NOTE! After configuring the PF functions, it is necessary to reset the BMS to make sure the configuration changes are applied!

Table 14 Pin function names

Pin Function Name	Type	Description	Reference
PF0 No Function	Input/Output	No function mapped	-

Pin Function Name	Type	Description	Reference
PF1 Speed Sensor Input	Input	This pin function allows to use all speed, distance, remaining distance, functionalities	4.23 Distance Parameters
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 charging contactor.	2.8 Heater and cooling fan control 2.10 PSU Under-Voltage Sense Control
PF5 Heater Enable Output	Output	Using for "Pre-Heating" and "Climate Control" stages.	2.4 Charging process and charging device control, 2.8 Heater and cooling fan control
PF7 Sound Buzzer Output	Output	Provide an audial indication of some conditions	2.17.2 Buzzer
PF8 Battery Low Indication Output	Output	Provide a visual indication of some "Low Cell Voltage" reductions.	2.17.3 Low battery indication
PF9 Charging Indication Output	Output	Pin function indicates charging process.	2.17.1 Charging status indication
PF10 Charger Enable Output	Output	Using to turn on and off charging devices.	2.17.3 Low battery indication
PF11 State of Charge Output	PWM Output	Broadcasts current SOC value using a 5V PWM signal	4.22 I/O pins
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, 4.12 Protections
PF13 Battery Fan Output	Output	Using for "Climate Control" stage.	2.8 Heater and cooling fan control
PF15 Leakage Sensor Input	Input	Activates "Leakage Fault" protection.	2.5 Battery protections, 4.12 Protections
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, 4.13 Load power reductions

Pin Function Name	Type	Description	Reference
PF17 Charging Interlock	Output	Dedicated control signal that is active if the charging device is connected, regardless of any other condition.	2.4.2 Charging Interlock
PF18 Analog Charger Control Output	Output	Used to control Analog chargers by 5VDC PWM signals	4.22 I/O pins
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 G1 Control Unit 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 G1 Control Unit does not drain the battery when the system is not in operation.	2.9 DC/DC converter control, 3.12 Contactor
PF25 Eltek Smart Pack 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.	2.5.3 Contactor pre-charge

Pin Function Name	Type	Description	Reference
PF28 PSU Under Voltage Sense	Input	PSU Under-Voltage feature enable	2.10 PSU Under-Voltage Sense Control
PF29 PSU Under-Voltage Indication	Output	For indication PF29 Under-Voltage indication	2.10 PSU Under-Voltage Sense Control
PF30 Optimized Battery Charging Sense	Input	Optimized battery charging sense activation	2.12 Optimized Battery Charging
PF31 Current Sense in Range Indication	Output	Compares measured current with configured current range to activate/deactivate the function	4.21 Current Sense in Range Indication
PF50 Warning Indication Output	Output	This function will be activated in case at least one Warning is activated	-
PF51 Negative Contactor	Output	Same function as "PF12 Battery Contactor Output". This function will switch ON slightly sooner than PF12 and switch OFF slightly later than PF12.	-

Pin Name	Assigned Pin Function	Invert
INPUT 1:	PF14 Current Sensor Input	<input type="checkbox"/>
INPUT 2:	PF14 Current Sensor Input	<input type="checkbox"/>
INPUT 3:	PF14 Current Sensor Input	<input type="checkbox"/>
INPUT 4:	PF14 Current Sensor Input	<input type="checkbox"/>
AC SENSE:	PF3 Charger Mains AC Sense Input	<input type="checkbox"/>
IGN. IN:	PF4 Ignition Key Input	<input type="checkbox"/>
FAST CHG.:	PF2 Fast Charge Switch Input	<input type="checkbox"/>
CHARGER:	PF10 Charger Enable Output	<input type="checkbox"/>
HEATER:	PF5 Heater Enable Output	<input type="checkbox"/>
BAT. LOW:	PF8 Battery Low Indication Output	<input type="checkbox"/>
BUZZER:	PF7 Sound Buzzer Output	<input type="checkbox"/>
CHG. IND.:	PF9 Charging Indication Output	<input type="checkbox"/>
SPEED IN:	PF1 Speed Sensor Input	<input type="checkbox"/>
SOC OUT:	PF11 State of Charge Output	<input type="checkbox"/>

Figure 4.28 Pin mapping settings

Additional parameters that regulate the minimum and maximum duty cycle values of the PWM signal when the "SOC OUT" pin is 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 → Charger 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 G1 Control Unit is used.

4.23 Display Unit

Display Unit settings are in Control Panel, in the top menu bar, "External devices" menu → Display entry. There are four configurable parameters:

- **Contrast** – changes display contrast from 0 to 100 %;
- **Sleep after** – when specified time duration value elapses, during which no actions are

taken, devices go to sleep;

- **Temperature units** – determines whether temperature is displayed in Celsius or Fahrenheit;
- **Display mode** – allows to choose between "Electric vehicle" or "Energy storage" display modes.

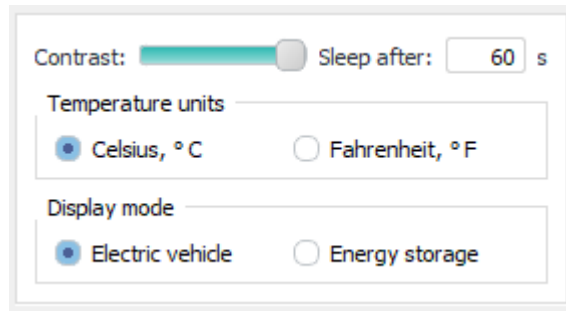


Figure 4.29 Display Unit settings in Control Panel



NOTE: Please configure 4.24 Distance Parameters for valid speed measurements.

4.24 Distance Parameters

Distance parameters located in EMUS BMS Control Panel → Configuration page → SOC/SOH → Distance Parameters. Here you can configure:

- Pulses per Distance Unit – Used to calculate speed.
- Distance Unit Name – possible to set distance unit name for information purposes.
- Estimate Safety Margin – sets the left distance estimated safety margin in % of total range of fully charged battery pack. This value is subtracted from estimated left distance. Recommended to set: 5-15%.

Distance Parameters ▾

Pulses per Distance Unit:

Distance Unit Name:

Estimate Safety Margin: %

Figure 4.30 Distance Parameters

Chapter 5: Master/Slave Clustered

Clustered functionality allows several G1 systems to be connected into one network using CAN Filter devices. It enables high modularity and high scalability, so G1 systems could be expanded and managed more easily.

The idea of such a system is that two or more battery packs (each controlled by G1 system), can be connected in parallel. Battery packs must be equivalent. Each G1 Control Unit manages its own battery pack, while only one G1 Control Unit (master) controls the charger. The master device is selected automatically according to lowest serial number, in other words, devices with lowest serial number, becomes master of the network automatically.

5.1 Master/Slave Clustered Wiring

In the Master/Slave Clustered system each G1 Control Unit is responsible for its own string. To make sure each G1 Control Unit communicates with his CCGM or CGM , it is necessary to use a CAN Filter to isolate the communication. The system will require internal and external CAN buses. In Master/Slave Clustered topology, one G1 Control Unit will automatically become a Master G1 Control Unit (lowest serial number becomes master). The Master G1 Control Unit will perform the same tasks as all other Slave G1 Control Units (those G1 CONTROL UNITS that did not become Master G1 Control Unit). In addition, the Master G1 Control Unit will collect information from all Slave G1 Control Unit from the external CAN bus and will be able to communicate with the charger over the external CAN bus

- Internal CAN bus – Isolated from the external CAN bus, it is intended to keep straight communication between the G1 Control Unit and the CCGMs or CGMs. The CAN filter will allow to pass through its specific CAN messages to/from the external CAN bus
- External CAN bus – All internal CAN buses are isolated from the external CAN bus, but some messages will be allowed by the CAN filters to report the strings status to the Master G1 Control Unit and communication with the charger (charger communication will be with Master G1 Control Unit only)

To correctly wire an M/S Clustered system must have 2 CAN Terminators to close each bus. As an example in the picture below, a total of 8 CAN terminators are required. It is important to correctly install the polarity of the CAN Filters, it must be pointing to the correct INTERNAL or EXTERNAL CAN buses. How to connect CGMs or CCGMs to the battery cells can be consulted in previous in this document.

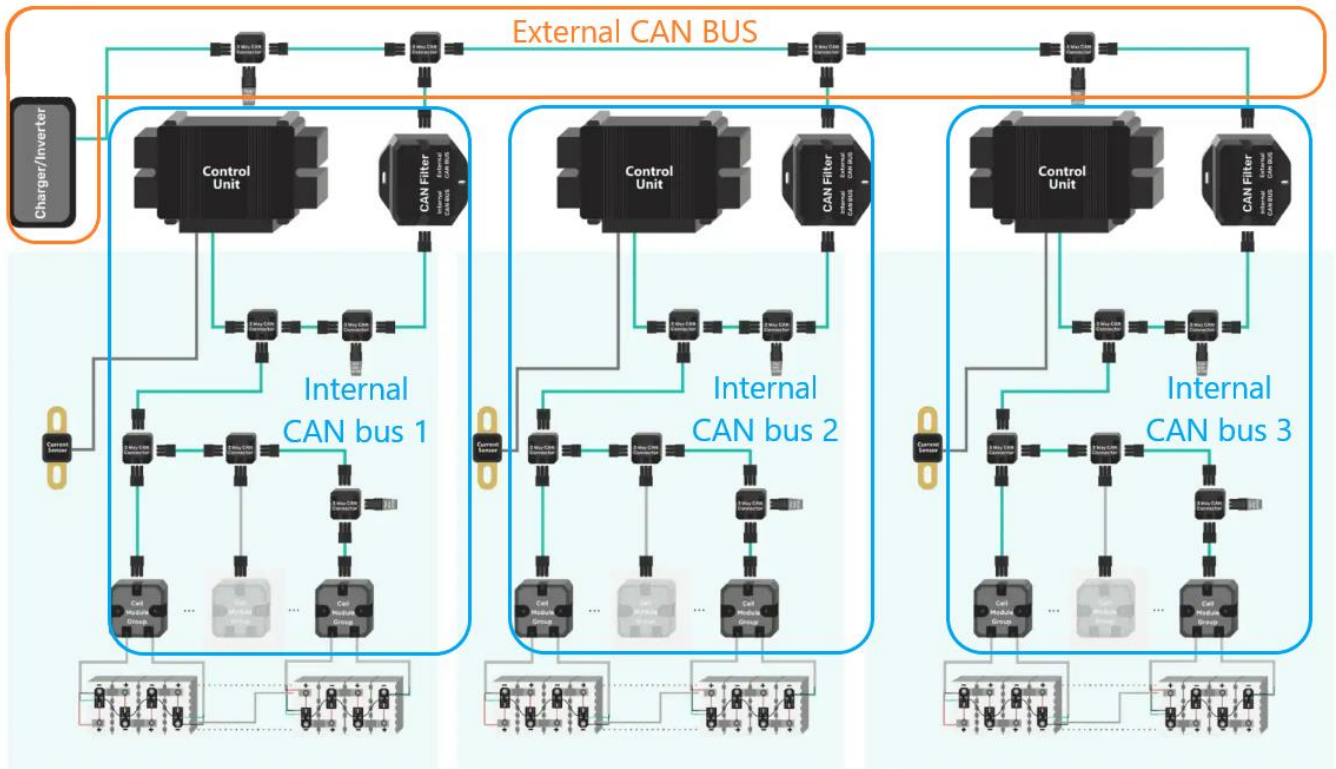


Figure 5.1 M/S Clustered CAN bus boundaries

After wiring the entire system, it must be composed of:

- Internal CAN Buses. Each internal CAN bus will require:
 - 1x G1 Control Unit
 - 1x CAN Filter
 - 1x Current Sensor
 - 1 to 24x CGMs or CCGMs
 - 2x CAN Terminators
 - 3-Way connectors and CAN cables as many as needed
- External CAN bus:
 - 2x CAN Terminators
 - 3-Way connectors and CAN cables as many as needed

The M/S Clustered system provides redundancy, which means in case one of the strings is disconnected due to a protection active, it is possible to keep the battery system working. To achieve this redundancy, each G1 Control Unit needs to be wired to a contactor driven by the function PF12 "Battery Contactor Output". That contactor must be capable of disconnecting the string managed by the G1 Control Unit in case a protection is activated.

The charging contactor is managed by the Master G1 Control Unit only using the PF function "PF10 Charger Enabled Output". Although only the Master G1 Control Unit will control charging contactor, all G1 Control Units must be wired to the same charging contactor using the same PF function. In the event of missing the Master G1 Control Unit, the next Slave G1 Control Unit with the lowest serial number will become Master G1 Control Unit. It will be necessary for the new Master G1 Control Unit to be able to control the charging contactor.



NOTE: M/S Clustered Series Configuration and Bypass Contactor feature are currently not available. For more information about these features refer to support@emusbms.com

5.2 Master/Slave Clustered Configuration

After installing the whole BMS M/S Clustered System each G1 Control Unit must be configured individually as explained below:

1. Enable Master/Slave Clustered functionality. (Configuration > CAN > Master/Slave Parameters).

Enable Master/Slave:	<input checked="" type="checkbox"/>
KeepAlive ID:	0x19B4FFFF
System Status ID 1:	0x19B4FFFE
System Status ID 2:	0x19B4FFFD
Use Extended 29bit ID:	<input checked="" type="checkbox"/>

Figure 5.2 M/S Clustered feature activation

2. Enable CAN communication and Use Extended 29bit ID. (Configuration > CAN > BMS CAN Bus Parameters).

Enable CAN:	<input checked="" type="checkbox"/>
CAN1 Speed:	250 kbp
Periodic Data Broadcast:	<input type="checkbox"/>
CAN Broadcast Period:	0.5 s
Broadcast Each Cell Value:	<input type="checkbox"/>
Broadcast TM4 NEURO Messages:	<input type="checkbox"/>
Use Extended 29bit ID:	<input checked="" type="checkbox"/>
Send to RS232/USB:	<input checked="" type="checkbox"/>
Only M/S messages	<input type="checkbox"/>
CAN ID Base:	0x19B7

Figure 5.3 M/S Clustered CAN communication

- In the same tab, configure a different CAN ID for each G1 Control Unit by default it will use 0x19B5. Note that each G1 Control Unit can use same or different Internal CAN speed (CAN1 speed) but the external bus CAN speed must be the same for all of them.

The screenshot displays four configuration panels:

- BMS CAN Bus Parameters:** Includes 'Enable CAN' (checked), 'CAN1 Speed' (250 kbp), 'Periodic Data Broadcast' (checked), 'CAN Broadcast Period' (0.5 s), 'Broadcast Each Cell Value' (unchecked), 'Broadcast TM4 NEURO Messages' (unchecked), 'Use Extended 29bit ID' (checked), 'Send to RS232/USB' (checked), 'Only M/S messages' (unchecked), and 'CAN ID Base' (0x19B5).
- EMUS CAN Modules Parameters:** 'Device CAN ID Base' is set to 0x0000.
- Master/Slave Parameters:** 'Enable Master/Slave' (checked), 'KeepAlive ID' (0x19B4FFFF), 'System Status ID 1' (0x19B4FFFE), 'System Status ID 2' (0x19B4FFFD), and 'Use Extended 29bit ID' (checked).
- CAN Filter Parameters:** 'Ext Bus Speed' is 250 kbps. A list of 16 CAN IDs (all 0x00000000) is shown, each with 'Ext Address', 'Pass To Int', and 'Pass To Ext' checkboxes.

A 'Commit CAN Filter Configuration' button is located at the bottom right of the CAN Filter Parameters panel.

Figure 5.4 M/S Clustered CAN speed example

- Select the number of G1 Control Units connected in M/S Clustered systems and enter the number of all G1 Control Units connected (Configuration > Master/Slaver > BMS List). The serial number of a G1 Control Unit can be consulted on the back of the case or connecting an USB to it, the serial number will be show on Control Panel on top left corner.

The screenshot shows the BMS control panel interface. On the left, a 'Status' icon is visible. On the right, the 'BMS List' configuration window is open, showing:

- 'Number of BMS': 3
- 'BMS 1 Serial': 10866
- 'BMS 2 Serial': 11525
- 'BMS 3 Serial': 11819

Figure 5.5 M/S Clustered BMS List & Serial Number Consultation

- Make sure the CAN Filter are discovered, and all previous steps correctly done. After that click on "Commit configuration" to automatically configure the CAN Filter (Configuration > Master/Slave > CAN Splitter Configuration).

Master/Slave Configuration

Parallel:

Enable String Voltage Equalization:

Equalization Voltage: V

Equalization Cancellation Current: A

Equalization Max Duration: min

Current Deviation

Max Current Deviation: A

Max Current Deviation Time: s

CAN Splitter Configuration

Commit configuration

Figure 5.6 M/S Clustered CAN Filter configuration

- Repeat previous steps until all G1 Control Units are correctly configured to work in M/S Clustered mode. Until all G1 Control Units are correctly wired and configured, a Master/Slave communication error will be present. After correcting wiring and configuration the error should be gone.

Errors, Protections

Cells Communication: OK

Protection status: Clustered Configuration Error Cutoff,
Clustered Common Bus Failure Cutoff,
Clustered Internal Bus Failure Cutoff

Warning Status: Reduction Active,
Clustered Common Bus Failure Cutoff,
Clustered Internal Bus Failure Cutoff,
Clustered Configuration Error Cutoff

Power Reduction: Clustered Configuration Mismatch Reduction

Errors, Protections

Cells Communication: OK

Protection status: OK

Warning Status: OK

Power Reduction: OK

Figure 5.7 M/S Clustered communication error before and after

When the M/S Clustered is correctly working, the Master G1 Control Unit will show in "Status > Master/Slave" tab detailed information about all G1 Control Units connected to the system. To access to all information about a G1 Control Unit Master or Slave, would be necessary straight USB connection. Only the Master G1 Control Unit is allowed to communicate with the charger which will show information about the charger parameters, the Slave G1 Control Units will only show the current Charging Station and measured current.

Splitter S/N 569		Status: Network OK										
BMS master												
Serial Number	Status	CAN ID Base	String	Contactor	Total Volt	Min Volt	Max Volt	Avg Volt	Min Temp	Max Temp	Avg Temp	
1	10866	Master	0x19B5	0	On	48.11 V	3.00 V	3.01 V	3.00 V	29°C	29°C	29°C

Splitter S/N 639		Status: Network OK											
BMS slave													
Serial Number	Status	CAN ID Base	String	Contactor									
1	10866	Master	0x19B5	0	On								
2	11525	Slave	0x19B6	0	On								

Figure 5.8 M/S Clustered Status summary

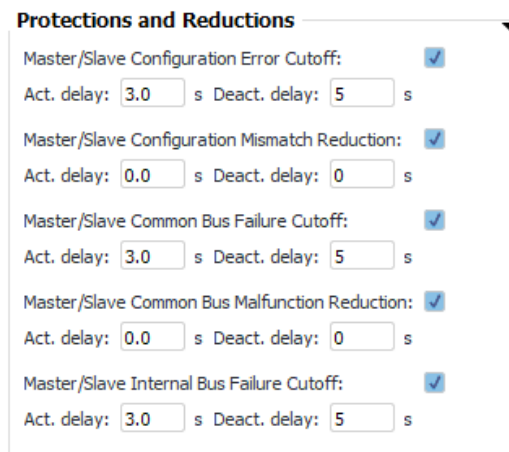
Once the system is completely set up, it is highly recommended to configure the Master G1 Control Unit as most of configuration changes made in the Master G1 Control Unit will also affect the Slave G1 Control Unit.

Protections, Reductions and Warnings contains parameter set related to communication and configuration issues. Each protection/reduction contains three of the following parameters:

Enable/Disable checkbox, which enables or disables corresponding protection/reduction;

"Act. delay" input field, which specifies time period after which protection/reduction is activated, when triggered. Possible values 0 - 25.5 s.

"Deactivation. delay" input field, which specifies time period after which protection/reduction is deactivated, when triggered. Possible values 0 - 255 s.



Protections and Reductions		
Master/Slave Configuration Error Cutoff:	<input checked="" type="checkbox"/>	
Act. delay:	<input type="text" value="3.0"/> s	Deact. delay: <input type="text" value="5"/> s
Master/Slave Configuration Mismatch Reduction:	<input checked="" type="checkbox"/>	
Act. delay:	<input type="text" value="0.0"/> s	Deact. delay: <input type="text" value="0"/> s
Master/Slave Common Bus Failure Cutoff:	<input checked="" type="checkbox"/>	
Act. delay:	<input type="text" value="3.0"/> s	Deact. delay: <input type="text" value="5"/> s
Master/Slave Common Bus Malfunction Reduction:	<input checked="" type="checkbox"/>	
Act. delay:	<input type="text" value="0.0"/> s	Deact. delay: <input type="text" value="0"/> s
Master/Slave Internal Bus Failure Cutoff:	<input checked="" type="checkbox"/>	
Act. delay:	<input type="text" value="3.0"/> s	Deact. delay: <input type="text" value="5"/> s

Figure 5.9 Clustered Protection and Reduction table

In the following list all protections/reductions are described:

Table 15 List of Clustered protections/reductions and their descriptions

Reduction Name	Description
Clustered Configuration Error Cutoff	protection will become active in case Clustered topology is incorrectly specified, not all devices specified in the Clustered configuration are detected (applies to series topology without bypass contactor), or an unspecified device is detected.
Clustered Configuration Mismatch Reduction	power reduction output pin PF16 (if assigned will be activated in case not all devices specified in the Clustered configuration are detected (applies to parallel topology or series topology with bypass contactor).
Clustered Common Bus Failure Cutoff	protection will become active in case a fault is detected on the common CAN bus (one or more CAN Filters are not

Reduction Name	Description
	transmitting/responding). Applies to parallel topology and series topology with bypass contactors only if the number of remaining active devices is less than half of the number of specified devices, or if the number of active devices is equal to half of the number of specified devices, but the initial master device is not in the active configuration (to achieve redundancy).
Clustered Common Bus Malfunction Reduction	power reduction output pin PF16 (if assigned will be activated in case a fault is detected on the common CAN bus (one or more CAN Filters are not c/responding). Applies only to parallel topology and series topology with bypass contactors, and only if the number of remaining active devices is more than half of the number of specified devices, or if the number of active devices is equal to half of the number of specified devices, but the initial master device is in the active configuration.
Clustered Internal Bus Failure Cutoff	protection will become active in case connection with CAN filter on the internal CAN bus is lost.

The M/S Clustered systems includes some functionalities in addition to a single G1 Control Unit system, these functionalities can be found in "Configuration > Master/Slave" tab.

String Voltage Equalization will equalize all string voltages before closing the string contactor. Equalization is performed by connecting the string with equalizer resistor in series using the Equalization Enable Output pin/ Do not use this feature if equalization circuitry between string does not exist. It would be necessary to configure:

- **Equalization Voltage** sets the minimum voltage difference between a string and the rest of the battery, above which equalization is performed if enabled, before closing the contactor
- **Equalization Cancellation Current** is the current value at which when is reached by any string that is connected while other are equalizing, will cancel the equalization process to avoid even deeper string voltage disbalance. This functionality can be turned off by setting this parameter to 0.0.
- **Equalization Max Duration** once it is exceeded, the contactor will be closed regardless of the voltage difference between the strings.

Current Deviation sets the maximum current difference measured by each parallel string. If the maximum current difference is exceeded longer than the configured time limit, a warning message will be sent to the CAN bus but will not have direct impact on the system.

Master/Slave Configuration

Parallel:

Enable String Voltage Equalization:

Equalization Voltage: V

Equalization Cancellation Current: A

Equalization Max Duration: min

Current Deviation

Max Current Deviation: A

Max Current Deviation Time: s

Figure 5.10 M/S Clustered additional features

Chapter 6: 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>.

6.1 Calibration of Cell Module temperature sensors

The procedure to calibrate the internal temperature sensor of Cell Modules is the following:

- Open Control Panel and navigate to Configuration → General tab → Battery Pack box;
- Click on "Calibrate Cells Temperature ..." button;
- In the opened window enter a new temperature value which should be measured by a calibrated external tool and will be used as a reference temperature.
- Click "Ok" to finish calibration.

The procedure to calibrate the external temperature sensor of Cell Modules is the following:

- First step is the same as internal temperature calibration;
- Click on "Calibrate External Temperature ..." button. A window showed in Figure 6.1 should appear;
- Before adjustments, click on "Reset" button to discard any changes. Curve in pink color is the original thermistor curve and curve in teal is modifiable one;
- Enter temperature related resistance values of selected thermistor. It is done by clicking on "Enter curve" button and filling the values in. Once done "Confirm" or "Cancel" button must be pressed. To return to default values button "Reset" should be pressed.
- Adjust position of the modified curve by Coefficient handles if necessary. By sliding β , γ and δ handles adapt teal curve to the pink one to get the best calibration results.
- Once adaptation is finished it is possible to transfer calibration values to particular Cell Module or to all of them together. Select which Cell Modules should be calibrated: to send values to one particular module a cell ID should be entered to "Module ID" field, to send values to all Cell Modules at once "Select all" checkbox should be selected.
- Lastly "Calibrate" button should be pressed, and new calibration values will be uploaded to selected Cell Modules.

It is important to note that external temperature calibration should be performed only when the type of the thermistors used is different than the type of the thermistors provided by EMUS.

Otherwise, the default calibration values are valid and there is no need for calibration.

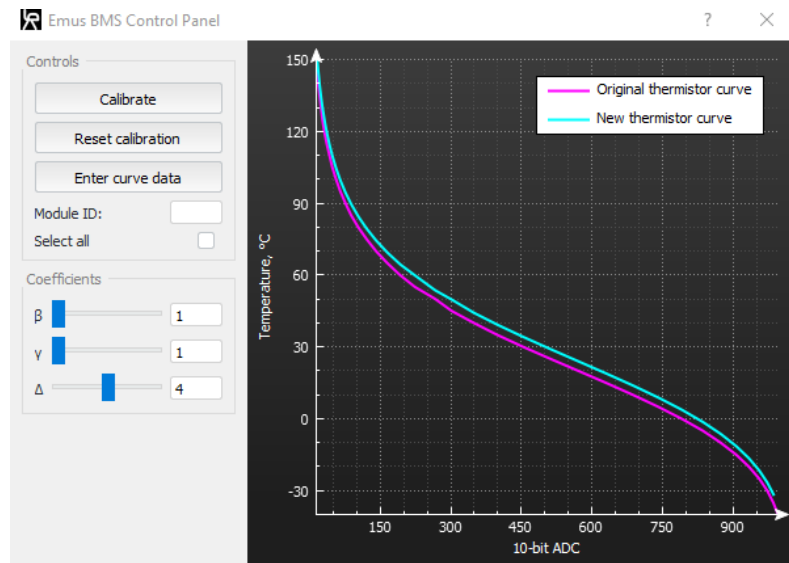


Figure 6.1 External temperature sensor calibration window

6.2 Re-calibration of current sensor

Occasionally, due to the influence of various environmental factors, EMUS G1 Current Sensor factory calibration values become invalid, and it start to measure the current inaccurately. This results in several undesired effects, most notably inaccurate SOC estimation. In such cases it is necessary to re-calibrate the current sensor by manually determining new calibration values

Calibration of current sensor is performed in Control Panel → Configuration page → General → Current sensor box. There are 2 main fields involved in sensor recalibration: L Calibration value and H calibration value. This procedure will require an external current measurement device (e.g., current clamp), and for the best results should be done without removing the current sensor from the system. The rest of it is described in the following steps:

- Write down current L and H calibration values.
- Produce a constant, stable current of 30 A to 70 A in the system (e.g., connect a charger).
- Measure the current with the external current measurement device and write it down. Also write down the value measured by G1 Control Unit - it can be found in Control Panel → Status page → General tab → Battery Pack box.
- Calculate the new value of "L Calibration Value" parameter using ; (8)equation.
- Produce a constant, stable current of 130 A and repeat steps 3 and 4 to determine the new value of "H Calibration Value" parameter.

The following equation is used to recalculate both L and H calibration values:

$$C_{new} = C_{current} \cdot \frac{I_{set}}{I_{measured}}; \quad (8)$$

where C_{new} is new calculated calibration value, $C_{current}$ – current calibration value, I_{set} – current set for power supply, $I_{measured}$ – measured current by G1 Control Unit.




NOTE: The new G1 Bus Bar Dual Range Current Sensor (CS012A) is factory calibrated and needs to be calibrated only if measurement inaccuracies are observed due to different EM.

6.3 Master Clear

Master clear can also be described as a 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 G1 Control Unit 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 G1 Control Unit to computer using USB or COM connector.
- Connect to G1 Control Unit COM port via the terminal emulator
- You can find it in the 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 G1 Control Unit to reset it. G1 Control Unit should respond with "VR1" sentence, meaning operation succeeded.
- Within 10 seconds of BMS startup you must enter "xxxxx" characters without "" and  hit enter. G1 Control Unit will again respond with "VR1" sentence, meaning master clear operation succeeded.

6.4 Setting up password

As a security feature, G1 Control Unit prevents unauthorized users from performing maintenance operation and from changing its configuration parameters by means of two separate passwords. This gives three distinct 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 G1 Control Unit, setting the SOC value, and calibrating the internal and external temperatures sensors of the cell 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 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.

6.5 Exporting and importing configuration

EMUS G1 Control Unit features configuration management that provides functionality to save and load system configuration file. All G1 Control Unit configurable parameters are stored inside this file. It is possible to save the 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. In order to save current BMS configuration click on “Save” button and proceed to following pop-

up window. The configuration file will be saved as .bcf format. To upload the configuration to the system from a previously saved G1 Control Unit configuration file and want to upload it to the system click on "Load" button. Immediately a new window will pop up with the progress bar showing uploading status.

6.6 G1 Control Unit firmware update

To ensure that G1 Control Unit has all the latest features and bug-fixes, it is recommended to periodically perform the G1 Control Unit 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 → G1 Control Unit tab;
- Click on "Open firmware" button;
- In opened dialog select desired G1 Control Unit 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 G1 Control Unit where they resided is formatted. After update configuration and statistics stored on hard drive are transferred back to G1 Control Unit. This is done to make sure that the new firmware will function flawlessly.



NOTE: During update process normal operation of control unit will be stopped.

6.7 CAN Cell Group Module firmware update

CAN Cell Group Module Firmware update procedure is like G1 Control Unit update. Latest firmware can be found on our website <https://emusbms.com/support>.

These steps will guide you through firmware upgrade process:

- Connect device to the same CAN bus to which G1 Control Unit is connected;
- Open Control Panel and select Update → CAN Devices tab;

- Click on "Discover" button to discover all available devices on CAN bus;
- In the table below select desired CAN Cell Group Module which firmware should be updated;
- Click on "Open firmware" button and select firmware file. If file is valid then File, Version and Target Device fields will be updated with corresponding information from the file;
- Press "Update" button to initialize update progress. A progress bar will appear under this button with the status field, where process information will be shown.



NOTE: During update process normal operation of control unit will be stopped



NOTE: The EMUS Tesla Module (TES011C) can be also updated with a CAN Cell Group Module firmware.

6.8 Display Unit firmware update

Latest firmware for Display Unit can be found on our website <https://emusbms.com/support>. These steps will guide you through firmware upgrade process:

- Open Control Panel, in the top menu bar, under "External devices" select Display entry;
- Click on "Upload" button;
- In the resulting dialog select EMUS G1 Display Unit firmware file with extension .img;
- Click on "Start" button to initialize update procedure.

Firmware version and Serial number fields will be updated with information from image file if it is valid.

6.9 Exporting and importing statistics

Both Export and Import options can be reached from the top menu bar "Options" option. By clicking on "Export statistics" Control Panel saves all statistics of currently connected G1 Control Unit to local hard drive. 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 G1 Control Unit and import them into another. This is useful when the G1 Control Unit needs to be replaced and data must be preserved.

Support

Please contact EMUS for BMS installation or support questions to:

support@emusbms.com

Thank you for choosing EMUS BMS!

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