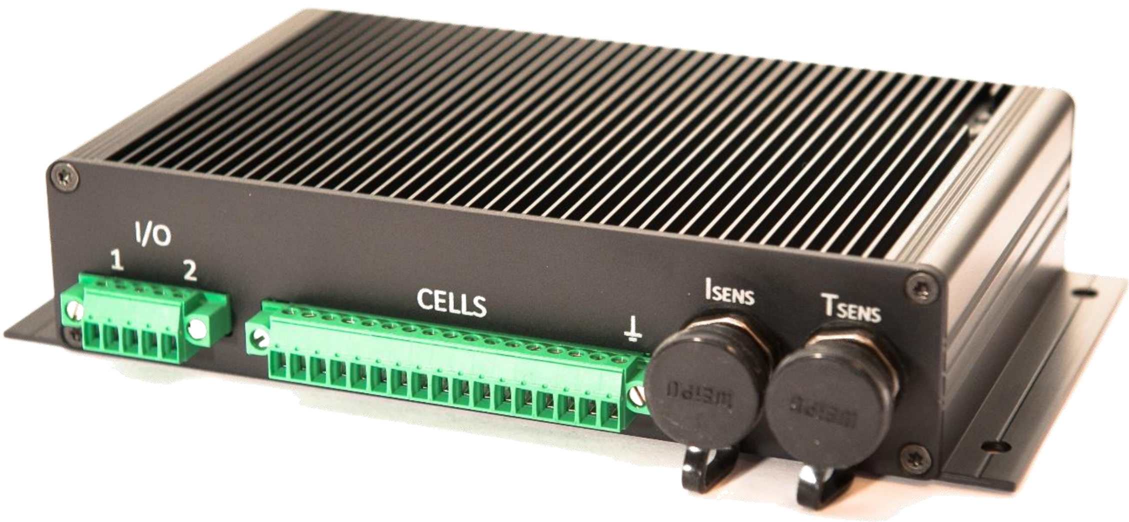
VICTRON GX-SUPPORTED BATTERY MANAGEMENT SYSTEM WITH MPPT REMOTE ENABLE REC Q BMS



REC
Control your power!

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Features:

- robust and small design
- 5-16 cells connections (14 – 68 V system)
- up to 3 digital temperature sensors DS18B20
- single cell voltage measurement (0.1 – 5.0 V, resolution 1 mV)
- single cell - under/over voltage protection
- single cell internal resistance measurement
- SOC and SOH calculation
- over temperature protection
- under temperature charging protection
- 3.9 Ω passive cell balancing
- shunt current measurement (resolution 19.5 mA @ ± 500 A)
- galvanically isolated user defined multi-purpose digital output
- internal relay output (normally open or normally closed)
- galvanically isolated RS-485 communication protocol
- CAN communication (Victron compatible)
- error LED + buzzer indicator
- PC user interface/WiFi for changing the settings and data-logging (optional accessory)
- hibernate switch
- ISO16315, ISO10133, EN61558-1, EN61558-2 and EN50498 compliant
- supports GX firmware 2.60

INDEX:

General Description of the BMS Unit:

The Battery Management System (BMS) monitors and controls each cell in the battery pack by measuring its parameters. The capacity of the battery pack differs from one cell to another and this increases with number of charging/discharging cycles. The Li-poly batteries are fully charged at typical cell voltage 4.16 - 4.20 V or 3.5 – 3.7 V for LiFePO4. Due to the different capacity this voltage is not reached at the same time for all cells in the pack. The lower the cell's capacity the sooner this voltage is reached. When charging series connected cells with a single charger, voltage on some cells might be higher than the maximum allowed voltage. Overcharging the cell additionally lowers its capacity and number of charging cycles. The BMS equalizes cell's voltage by diverting some of the charging current from higher voltage cells to power resistors – passive balancing. The device's temperature is measured to protect the circuit from over-heating due to unexpected failure. Battery pack's temperature is monitored by Dallas DS18B20 digital temperature sensor/s. Maximum 3 temperature sensors per unit may be used. Current is measured by a low-side shunt resistor. Battery pack current, temperature and cell's voltage determine state of charge (SOC). State of health (SOH) is determined by comparing cell's current parameters with the parameters of a new battery pack. The BMS default HW parameters are listed in Table 1.

Hardware Parameters:

Table 1: BMS hardware parameters.

PARAMETER	VALUE	UNIT
BMS maximum pack voltage	68.0	V
BMS minimum pack voltage	13.1	V
BMS minimum pack voltage (HW UVP)*	-	V
BMS maximum cell voltage	5.0	V
Shunt common mode input voltage interval (Shunt+, Shunt -) to the Cell 1 negative	-0.3 to 3.0	V
Shunt sensor max differential input voltage interval (Shunt+ to Shunt -)	-0.25 to 0.25	V
Cell voltage accuracy	+/-3	mV
Pack voltage accuracy	+/-6	mV
DC current accuracy	+/- 1	LSB
Temperature measuring accuracy	+/-0.5	°C
DC Current sample rate	3	Hz
Cell voltage sample rate	1	Hz
Cell balancing resistors	3.9	Ω
Maximum operating temperature	70	°C
Minimum operating temperature	-20	°C
Maximum storage temperature	30	°C
Minimum storage temperature	0	°C
Maximum humidity	75	%
Max continuouse DC current relay @ 60 V DC	0.7	A
Max continuouse AC current relay @ 230 V AC	2	A
Max DC current @ optocoupler	15	mA
Max DC voltage@ optocoupler	62.5	V
BMS unit disable power supply @ 48 V	< 1	mW
BMS unit stand-by power supply @ 48 V	< 80	mW
BMS unit cell balance fuse rating	3 slow	A
Internal relay fuse	3.15 slow	A
Dimensions (w × l × h)	190 x 104 x 38	mm
IP protection	IP32	
HW version	3.2	n.a.

*installed on request

Default Software Parameters:

Table 2: Default BMS parameter settings*.

PARMETER	VALUE	UNIT
Chemistry	3 ($LiFePO_4$)	n.a.
Capacity	640	Ah
Balance start voltage	3.45	V
Balance end voltage	3.58	V
Cell over-voltage switch-off per cell	3.85	V
Over-voltage switch-off hysteresis per cell	0.25	V
Cell end of charge voltage	3.58	V
End of charge hysteresis per cell	0.25	V
SOC end of charge hysteresis	5	%
Maximum cell float voltage coefficient	0.8	n.a.
Cell-under voltage protection switch-off	2.80	V
Under voltage protection switch-off hysteresis per cell	0.10	V
Cell under voltage discharge protection	2.90	V
Battery pack under voltage protection switch-off timer	4	s
Cells max difference	0.25	V
SOC discharge hysteresis	5	%
BMS over-temperature switch-off	55	°C
BMS over-temperature switch-off hysteresis	5	°C
Cell over temperature switch-off	55	°C
Cell over temperature switch-off hysteresis	2	°C
Under temperature charging disable	-10	°C
Under temperature charging disable hysteresis	2	°C
Voltage to current coefficient	0.01953125	A/bit
Current measurement zero offset	0.0	A
Maximum charging/discharging current per inverter device	70/100	A
Number of inverter/charger devices	1	n.a.
Charge coefficient	0.6	1/h
Discharge coefficient	1.5	1/h
CAN communication frequency	500	kbit/s
SW version	2.8	n.a.

*all parameters' values may be changed with PC Software BMS Master Control user interface/WiFi module.

System Overview:

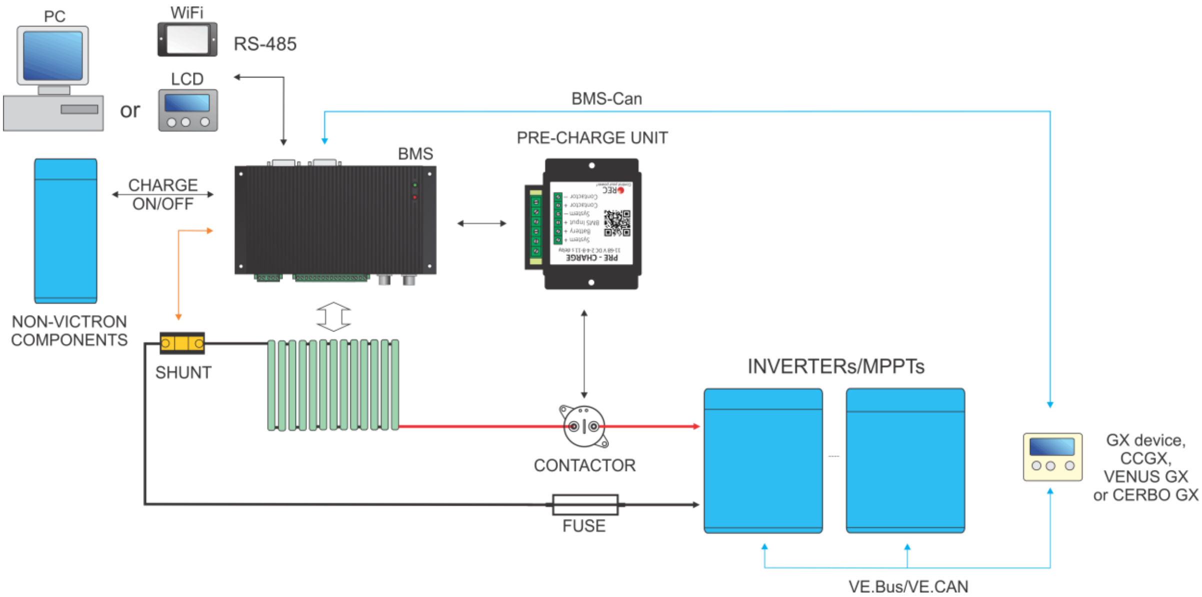

Figure 1: System overview.

BMS Unit Connections:

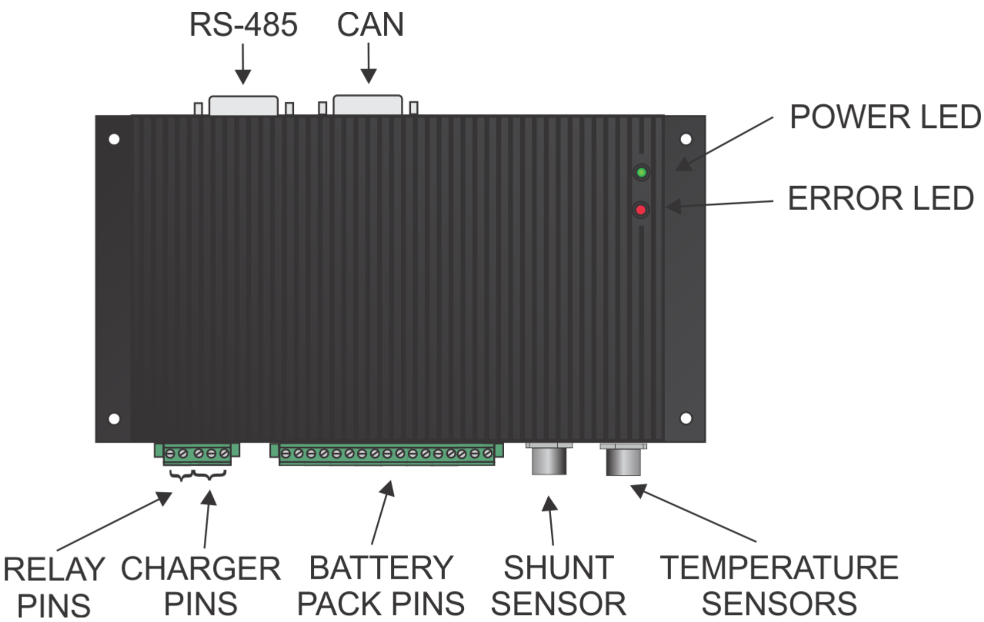

Figure 2: BMS unit function overview.

Table 3: BMS unit connections.

CONNECTION	DESCRIPTION	
Temperature sensor connector pins	DALLAS DS18B20 temp. sensor pins (pin 1)	+ 5 V
	DALLAS DS18B20 temp. sensor pins (pin 2)	GND + shield
	DALLAS DS18B20 temp. sensor pins (pin 3)	1-wire digital signal
Current sensor Connector pins	+ Shunt (pin 1)	Analog signal
	Shield (pin 2)	Analog signal
	- Shunt (pin 3)	Analog signal
Cells connector pins		
1	Cell 1 negative (⊥)	Analog signal
2	Cell 1 positive	Analog signal
3	Cell 2 positive	Analog signal
4	Cell 3 positive	Analog signal
5	Cell 4 positive	Analog signal
6	Cell 5 positive	Analog signal
7	Cell 6 positive	Analog signal
8	Cell 7 positive	Analog signal
9	Cell 8 positive	Analog signal
10	Cell 9 positive	Analog signal
11	Cell 10 positive	Analog signal
12	Cell 11 positive	Analog signal
13	Cell 12 positive	Analog signal
14	Cell 13 positive	Analog signal
15	Cell 14 positive	Analog signal
16	Cell 15 positive	Analog signal
17	Cell 16 positive	Analog signal
I/O pins		
1	Charge/MPPT remote ENABLE open collector	-
2	Charge/MPPT remote ENABLE open emitter	-
3	-	-
4	Internal Relay – pre-charge control	-
5	Internal Relay – pre-charge control	-

Setting Number of Cells and the RS-485 Address:

Before powering the device, the end user must set the correct number of cells that will connect to the unit and **if multiple BMS units are used it is also required to set a unique address for each unit to avoid data collision on the RS–485 communication bus.**

The number of cells connected to the BMS unit is selected via the **CELLS** DIP Switch pins at the back of the unit. Binary addressing is used to enable setting up to 16 cells with 4 DIP Switches. The numbering on the switch casing denotes the bit position i.e. MSB = 4, LSB = 1.

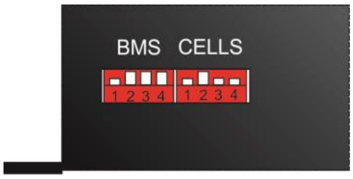

Figure 3: BMS address and cell selection DIP Switches.

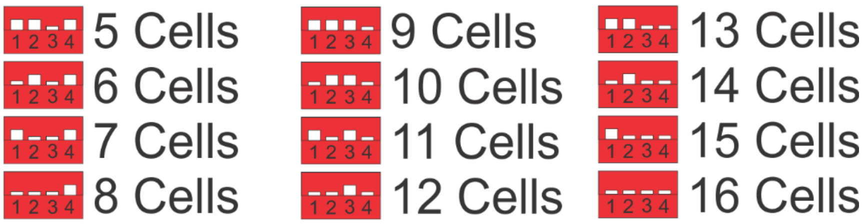

Figure 4: Number of CELLS selection description.

The BMS unit address is selected via the **BMS** DIP Switch pins at the back of the unit. Binary addressing is used to enable setting up to 15 addresses with 4 DIP Switches. **If a single BMS unit is used, the BMS DIP switch position is set to Address 1 by default. Address 0 is invalid.**

Figure 5: BMS unit address selection description.

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BMS Cell Connector:

Connect each cell to the BMS cell connector plug. We recommend to using silicon wires with a cross section of 0.5 – 1 mm^2.

! Before inserting the cell connector check the voltage level and polarity of each connection!

! When working on cells/connections – the BMS' cells connector must be unplugged, otherwise the BMS will be damaged!

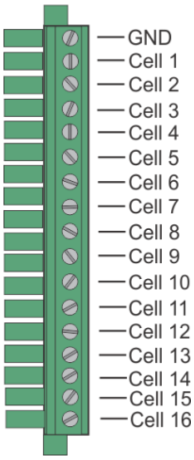

Figure 6: Battery pack to BMS connection.

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BMS Unit Power Supply:

BMS unit is always powered from the 16-th cell connection pin (pin 17).

! When less than 16 cells are used in the battery pack, an additional connection from the battery pack voltage (Pack +) to the 16-th cell connection pin should be made, as shown in Fig. 7 !

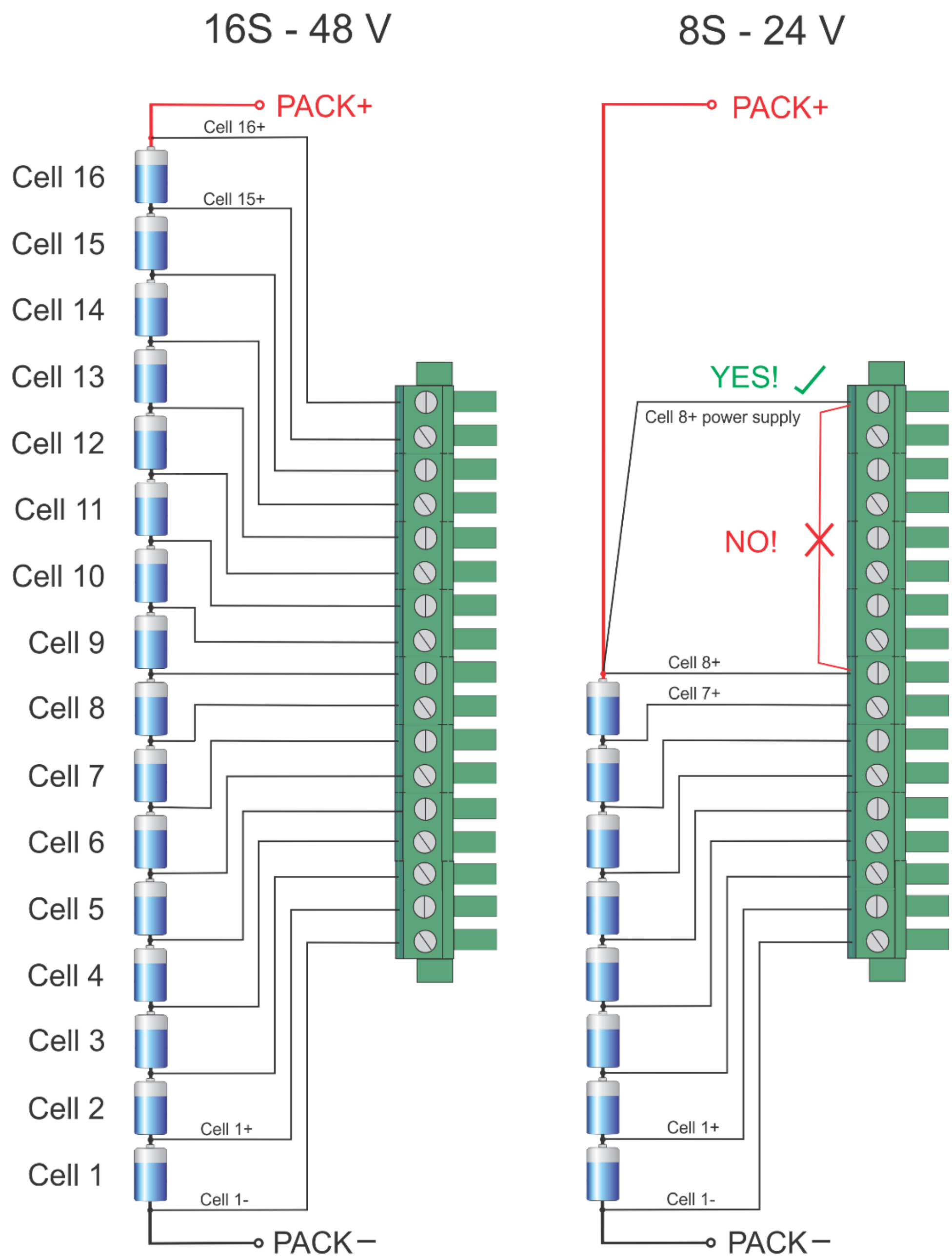

Figure 7: BMS unit power supply.

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Parallel Cell Connection:

Battery pack capacity may be increased in two ways. By adding a parallel string with the same cells using BMS Master unit and multiple 1Q BMS in Slave configuration or paralleling on the cell connection level. Master-Slave configuration makes system more redundant, but also more expensive and bulkier. Connecting cells in parallel as a sub-pack that are later connected in series have to be designed properly to enable same current distribution amongst all the parallel cells in the sub-pack. Lithium cells have very low DC impedance, sub 1 mOhm. Connecting the sub-pack with 1 mOhm cell connection difference causes the cells with the lowest connection to double the current in/out of the cell. A result is a cell with higher temperature that self-discharges faster and aging faster than the rest of the cells in the sub-pack.

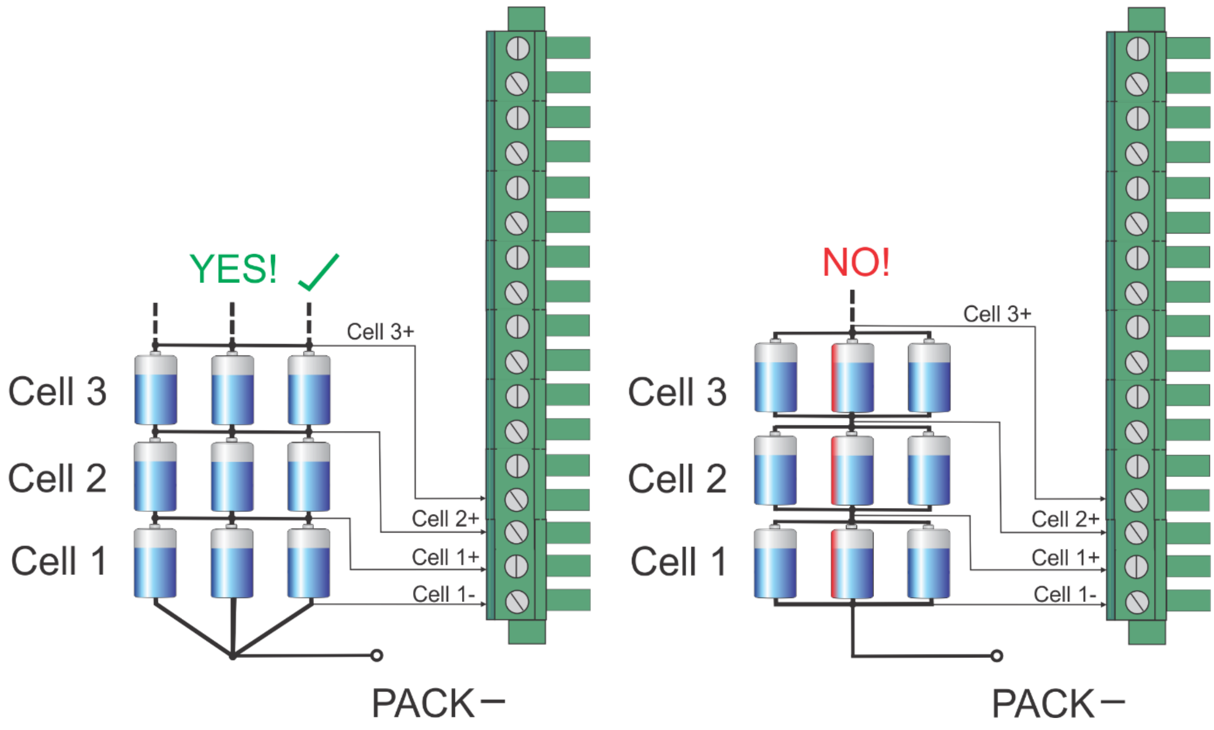

Figure 8: Parallel cell connection.

BMS Unit Connection Instructions:

Connect the BMS unit to the system by the following order described in Fig. 9. It is important to disable all the BMS functions by turning enable switch OFF before plugging any connectors. **All cells should be connected last and simultaneously**. When all the system components are plugged in, the enable switch can be turned ON and the BMS starts the test procedure.

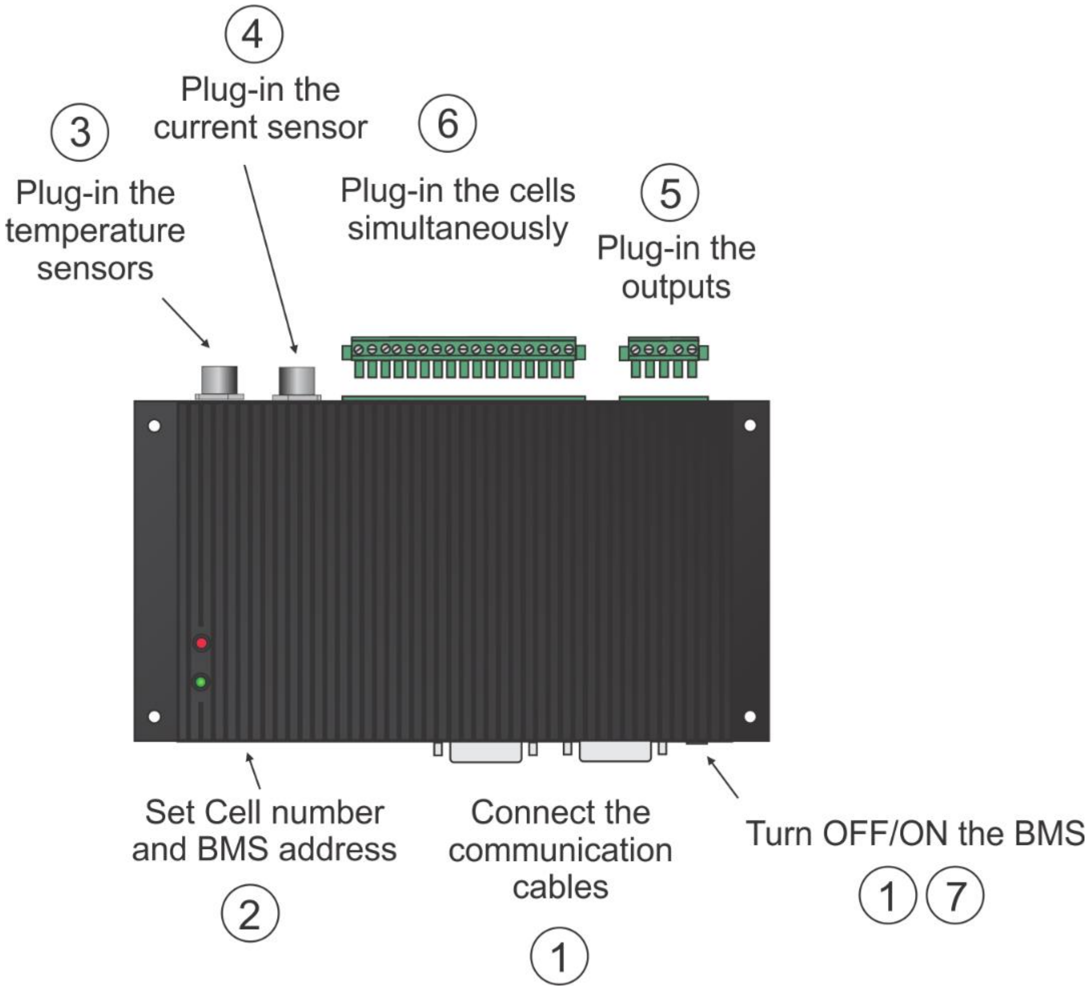

Figure 9: BMS connection order.

When disconnecting the unit from the battery pack, the procedure should be followed in reverse order.

RS-485 Communication Protocol:

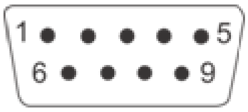

Figure 10: RS-485 DB9 connector front view.

Table 4: RS-485 DB9 connector pin designator.

PIN	DESIGNATOR
1	-
2	AGND
3	B
4	A
5	-
6	+5V to AGND
7	-
8	-
9	-

Galvanically isolated RS-485 (EN 61558-1, EN 61558-2) serves for logging and changing BMS parameters. Dedicated PC Software BMS Master Control, REC Wi-Fi module, REC LCD touch display or another RS-485 device may be used for the communication. Default RS-485 address is 1.
Unlock password: Serial without the first minus e.g. 1Q-XXXX.

Messages are comprised as follows:
STX, DA, SA, N, INSTRUCTION- 4 bytes, 16-bit CRC, ETX

- STX start transmission <0x55> (always)
- DA - destination address <0x01> to <0x10> (set as 6)
- SA - sender address <0x00> (always 0)
- N – number of sent bytes
- INSTRUCTION 4 bytes for example.: LCD1? - (combined from 4 ASCII characters, followed by '?', if we would like to receive the current parameter value or ' ','xx.xx' value in case we want to set a new value
- 16-bit CRC - big endian, for the whole message except STX in ETX - https://www.lammertbies.nl/comm/info/crc-calculation.html
- ETX - end transmission <0xAA> (always)

Dataflow:

- Bit rate: 56k
- Data bits: 8
- Stop bits: 1
- Parity: None
- Mode: Asynchronous
- Little endian format when an array is sent

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Table 5: RS-485 instruction set.

INSTRUCTION	DESCRIPTION	BMS ANSWER	SETTING INTERVAL
*IDN?	Identification	Answer "REC BMS 1Q VICTRON"	Read only
GENERAL ARRAYS INSTRUCTIONS			
LCD1?	Main data	First answer is 28 – how many byte data will be sent and then data message follows as 7 float values: LCD1 [0] = min cell voltage, LCD1 [1] = max cell voltage, LCD1 [2] = current, LCD1 [3] = max temperature, LCD1 [4] = pack voltage, LCD1 [5] = SOC (state of charge) interval 0-1-> 1=100% and LCD1 [6] = SOH (state of health) interval 0-1-> 1=100%	Read only
LCD3?	Main data	First answer is 8 – how many byte data will be sent and then data message follows as 8 byte values: LCD3 [0] = min cell BMS address, LCD3 [1] = min cell number, LCD3 [2] = max cell BMS address, LCD3 [3] = max cell number, LCD3 [4] = max temp. sens. BMS address, LCD3 [5] = max temp. sens. number, LCD3 [6] = Ah MSB, LCD3 [7] = Ah LSB	Read only
CELL?	Cell voltages	BMS first responds with how many BMS units are connected, then it sends the values of the cells in float format	Read only
PTEM?	Cell temperatures	BMS first responds with how many BMS units are connected then it sends the values of the temperature sensors in float format	Read only
RINT?	Cells internal DC resistance	BMS first responds with how many BMS units are connected then it sends the values in float format	Read only
BTEM?	BMS temperature	BMS first responds with value 1, then it sends the values of the BMS temperature sensor in float format	Read only

ERRO?	Error number description array	First answer is 4 – how many byte data will be sent and then data message follows as 4 byte values: ERRO [0] = 0 – no error, 1 – error ERRO [1] = BMS unit ERRO [2] = error number (1-16) and ERRO [3] = number of the cell, temp. sensor where the error occurred	Read only
VOLTAGE SETTINGS INSTRUCTIONS			
BVOL? or BVOL x.xx	Balance end voltage	Returns float voltage [V]	2.5 to 4.30 V
BMIN? or BMIN x.xxx	Balancing start voltage	Returns float voltage [V]	2.5 to 4.30 V
CMAX? or CMAX x.xx	Cell over-voltage switch-off	Returns float voltage [V]	2.0 to 4.30 V
MAXH? or MAXH x.xx	Cell over-voltage switch-off hysteresis per cell	Returns float voltage [V]	0.005 to 2.0 V
CMIN? or CMIN x.xxx	Cell under-voltage protection switch-off	Returns float voltage [V]	1.8 to 4.00 V
MINH? or MINH x.xxx	Cell under-voltage switch-off hysteresis per cell	Returns float voltage [V]	0.005 to 2.0 V
CHAR? Or CHAR x.xxx	Cell End of charging voltage	Returns float voltage [V]	2.0 to 4.30 V
CHIS? Or CHIS x.xxx	End of charging voltage hysteresis per cell	Returns float voltage [V]	0.005 to 2.0 V
CFVC? Or CFVC x.xxx	Maximum cell float voltage coefficient	Returns float value	0.1 to 1.0
RAZL? or RAZL x.xx	Cells max difference	Returns float voltage [V]	0.005 to 1.0 V
TEMPERATURE SETTINGS INSTRUCTIONS			
TMAX? or TMAX x.xxx	cell over temperature switch-off	Returns float temperature [°C]	-20 to 65 °C
TMIN? or TMIN x.xxx	Under-temperature charging disable	Returns float temperature [°C]	-30 to 65 °C
TBAL? or TBAL x.xxx	BMS over-temperature switch-off	Returns float temperature [°C]	-20 to 65 °C
BMTH? or BMTH x.xxx	BMS over temperature switch-off hysteresis	Returns float temperature [°C]	1 to 30 °C
CURRENT SETTINGS INSTRUCTIONS			
IOFF? or IOFF x.xxx	Current measurement zero offset	Returns float current [A]	-2.0 to 2.0 A
IOJA? Or IOJA x.xxx	Voltage to current coefficient	Returns float value	0.0005 to 0.5
BATTERY PACK SETTINGS INSTRUCTIONS			
CYCL? or CYCL xx	Current number of full battery pack cycles	Returns integer value	0 to 8000
CAPA? or CAPA x.xxx	Battery pack capacity	Returns float capacity [Ah]	1.0 to 5000.0 Ah
CHEM? or CHEM xx	Cell chemistry	Returns unsigned char value	1 to 7

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SOC SETTINGS INSTRUCTIONS			
SOCH? or SOCH x.xxx	SOC end of charge hysteresis	Returns float value 0 – 1.0	0.005 to 0.99
SOCS? or SOCS x.xx	SOC manual re-set	Returns float value 0 – 1.0	0.01 to 1.00
VICTRON COMMUNICATION SETTINGS INSTRUCTIONS			
CHAC? or CHAC x.xxx	Charge coefficient (0-3C)	Returns float value 0-3.0 (default 0.6)	0.01 to 3.0
DCHC? or DCHC x.xxx	Discharge coefficient (0-3C)	Returns float value 0-3.0 (default 1.5)	0.01 to 3.0
SISN? or SISN xx	Number of inverter devices on the bus	Returns unsigned char value (default 1)	1 to 6
MAXC? or MAXC x.xxx	Maximum charge current per inverter device	Returns float current [A]	5.0 to 345.0 A
MAXD? or MAXD x.xxx	Maximum discharge current per inverter device	Returns float current [A]	5.0 to 345.0 A
CLOW? or CLOW x.xxx	cell under-voltage discharge protection	Returns float voltage [V]	1.8 to 4.20 V
CANF? or CANF xx	CAN Frequency	Returns unsigned char value of 1 or 2	If CANF=1, CAN =250 kb/s If CANF=2 CAN =500 kb/s
ERROR LOG INSTRUCTIONS			
VMAX? or VMAX xx	Number of exceeded values of CMAX	Returns integer value	0 to 8000
VMIN? or VMIN xx	Number of exceeded values of CMIN	Returns integer value	0 to 8000
BMS SETTINGS INSTRUCTIONS			
SWVR?	BMS software version	Returns string “2.8”	Read only
HWVR?	BMS hardware version	Returns string “3.2”	Read only
EAVC? or EAVC xx	Even cells calibration value	Returns float voltage [V]	(+/-0.0003 typ.)
ODDC? or ODDC xx	Odd cells calibration value	Returns float voltage [V]	(+/-0.0003 typ.)
REFC?	ADC reference voltage 5.000 V +/- 3 mV	Returns float voltage [V]	Read only

Parameter accepted and changed value is responded with 'SET' answer.
Example: proper byte message for 'LCD1?' instruction for BMS address 2 is:

<0x55><0x01><0x00><0x05><0x4C><0x43><0x44><0x31><0x3F><0x46><0xD0><0xAA>

RS-485 message is executed when the microprocessor is not in interrupt routine so a timeout of 350 ms should be set for the answer to arrive. If the timeout occurs the message should be sent again. Little endian format is used for all sent float or integer values. In case of single data is sent ASCII characters are used e.g. -1.2351e2
Custom made instructions can be added to the list to log or set the parameters that control the BMS algorithm or its outputs.

Video instruction link for settings change: REC Changing Settings - YouTube
Video instruction link for firmware update: REC Firmware Update Procedure - YouTube
and REC Wi-Fi Module Update and REC BMS Firmware Update Using REC Wi-Fi Module - YouTube

CAN Communication:

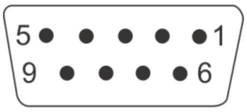

Figure 11: CAN female DB9 connector front view.

Table 6: CAN DB9 connector pin designator.

PIN	DESIGNATOR
1	-
2	CANL + TERMINATION*
3	GND
4	-
5	-
6	-
7	CANH + TERMINATION*
8	-
9	-

* **Terminate pins 2 and 7 with 120 Ohm resistor or short pins 1 and 2 to prevent BMS to reset.** REC CAN cables are already terminated using 120 Ohm resistors between CANH and CANL inside the DB9 connector. Additional RJ45 connector with 120 Ohms across CANL and CANH should be used for the end device on the CAN bus for end termination.
11-bit TX identifiers: 0x351, 0x355, 0x356, 0x35A, 0x35E, 0x35F, 0x372, 0x373, 0x374, 0x375, 0x376, 0x377, 0x379, 0x380 and 0x381.
11-bit RX heart-beat 0x305 message from GX unit is neglected.
CAN messages are sent every 170 ms.

When the CAN frequency is changed via RS-485 instruction CANF, BMS has to be reset to enable the new setting.

GX device settings:

Update GX device to 2.60 or higher.
Connect BMS and GX device with CAN cable. Use BMS-Can port with Cerbo GX or VE-Can port with other GX devices.
Open Settings menu and select Services. Set CAN-bus profile to CAN-bus BMS (500kbit/s) for Cerbo GX or VE.Can & CAN-bus BMS (250kbit/s) for other GX devices.
Then in Settings menu select System setup. Change:
- Battery monitor to REC BMS in CAN-bus.

In menu DVCC:
- DVCC→ON
- SVS→ON
- STS → ON

GX device settings are automatically saved when you change it.

IMPORTANT: Always keep CAN communication connected to BMS when resetting inverters and chargers.

BMS Unit Start Procedure:

When the BMS is turned ON it commences the test procedure. BMS checks if the user tries to upload a new firmware by turning on the Power LED. After the timeout the Red error LED turns on to signal the system's test procedure. The procedure starts by testing the balancing switches, the BMS address and cells number, temperature sensor/s detection, self-calibration and EEPROM memory parameters. The test completes in 7 seconds. In case of no Errors the red LED turns off and the BMS unit starts working in normal mode.
If an error is detected a sound alarm/blinking red LED signal will notify the user. Each error is coded to a number. The most common errors at system startup are listed below.

- Error 6 = improper DIP switch setting.
  In case of Address=0 or cell number <4, error 6 informs the user to properly set the DIP switches. BMS has to be turned off before the pins are changed.
- Error 8 = temperature sensor not detected.
- Error 10 = reference failure
- Error 15 = balancing transistor failure
- Error 16 = TWI communication failure

An overview of all possible system errors is presented in the System Error Indication Section.

Voltage/Temperature Hysteresis:

Most of the BMS setting thresholds also have a dedicated hysteresis parameter. This way the BMS prevents ringing due to the oscillation of the controlled parameter above and under the set threshold. If the threshold limits the top value of the parameter like Maximum cell voltage CMAX or temperature TMAX, the value of hysteresis should be negative to prevent the ringing. If the threshold limits the bottom value of the parameter like Minimum cell voltage CMIN or temperature TMIN the value of hysteresis should be positive to prevent the ringing. For a simplicity, all the BMS settings are set without the sign and the BMS firmware takes care for proper sign value.

BMS Unit LED Indication:

Power LED (green) signals the state of the battery pack. Low SOC is signaled by a single ON blink. Normal mode is signaled by 2 consecutive ON blinks while the balancing mode is indicated by 3 consecutive ON blinks before the longer pause. When the battery pack is fully charged and *SOC/End of Charge Hysteresis* are set POWER LED is turned 100% on.

Error LED (red) is turned on in case of system error and signals the error number with 50 % duty cycle. Between repeated error number 1 s timeout is introduced.

Cell Voltage Measurement:

Cell voltages are measured every second. The cell measurement performs 4 ms cell measurement by Sigma Delta ADC. Each cell voltage is measured after the balancing fuse, in case the fuse blows, BMS signals error 10 to notify the user.

BMS Cell Balancing:

Cells are balanced passively by discharging each cell through a 3.9 Ω power resistor. Since the balancing resistors dissipate heat an additional temperature measurement inside the enclosure of the BMS unit is performed to prevent overheating the integrated circuits. If the BMS temperature rises above the set threshold, balancing is stopped. BMS error 5 is indicated until the temperature drops under the set hysteresis value.

Balancing START Voltage (BMIN):

If errors 2, 4, 5, 8, 10, 12 are not present, the charging current is above 0.2 A and at least one cell's voltage rises above the balancing start voltage threshold the BMS initiates the balancing algorithm. The algorithm calculates a weighted cell voltage average which takes into account the internal dc resistance of each cell. On the basis of the calculated average the BMS determines which cell will be balanced.

Balancing END Voltage (BVOL):

If errors 2, 4, 5, 8, 10, 12 are not present, any cell above balance END voltage is balanced regardless of the battery pack current.

Cell Internal DC Resistance Measurement:

Cell internal DC resistance is measured as a ratio of a voltage change and current change in two sequential measurement cycles. If the absolute current change is above 15 A, cells internal resistance is calculated. Moving average is used to filter out voltage spikes errors.

Battery Pack Temperature Measurement:

Battery pack temperatures are measured by Dallas DS18B20 digital temperature sensor/s. Up to three sensors can be used in parallel connected directly to the wiring. Up to 8 sensors may be used with a junction box and a custom firmware. BMS should be turned off and main connector disconnected before adding sensors. Temperature sensor/s use shielded 3-wire cable. Cable length should be as short as possible. Placing temperature cable near the power connection should be avoided. Route temperature sensor 90° to the power cable to avoid EMI that may cause communication error no. 8.

BMS Current Measurement:

Low-side **only** precision shunt resistor for current measurement is used. Connect the shunt as close as possible to the battery negative power connection (cell 1-). Fuses or manual DC switch should be placed to the system side of the shunt. System fuse may be also placed in the system positive – after the contactor.

A 4-wire Kelvin connection is used to measure voltage drop on the resistor. As short as possible **shielded cable** should be used to connect the power shunt and BMS. The average battery pack current is calculated in every measurement cycle. A high precision Sigma-Delta ADC is used to filter out the current spikes. The first current measurement is timed at the beginning of the cell measurement procedure for a proper internal DC resistance calculation. Three more 300 ms measurements are performed through the whole BMS measurement interval Shunt connection is shown in Fig. 12. If the BMS measures charging/discharging current that is higher than the double value of the rated shunt for more than 2 consecutive cycles error 12 is triggered. This serves for shunt, contactor and fuse protection in case of short circuit.

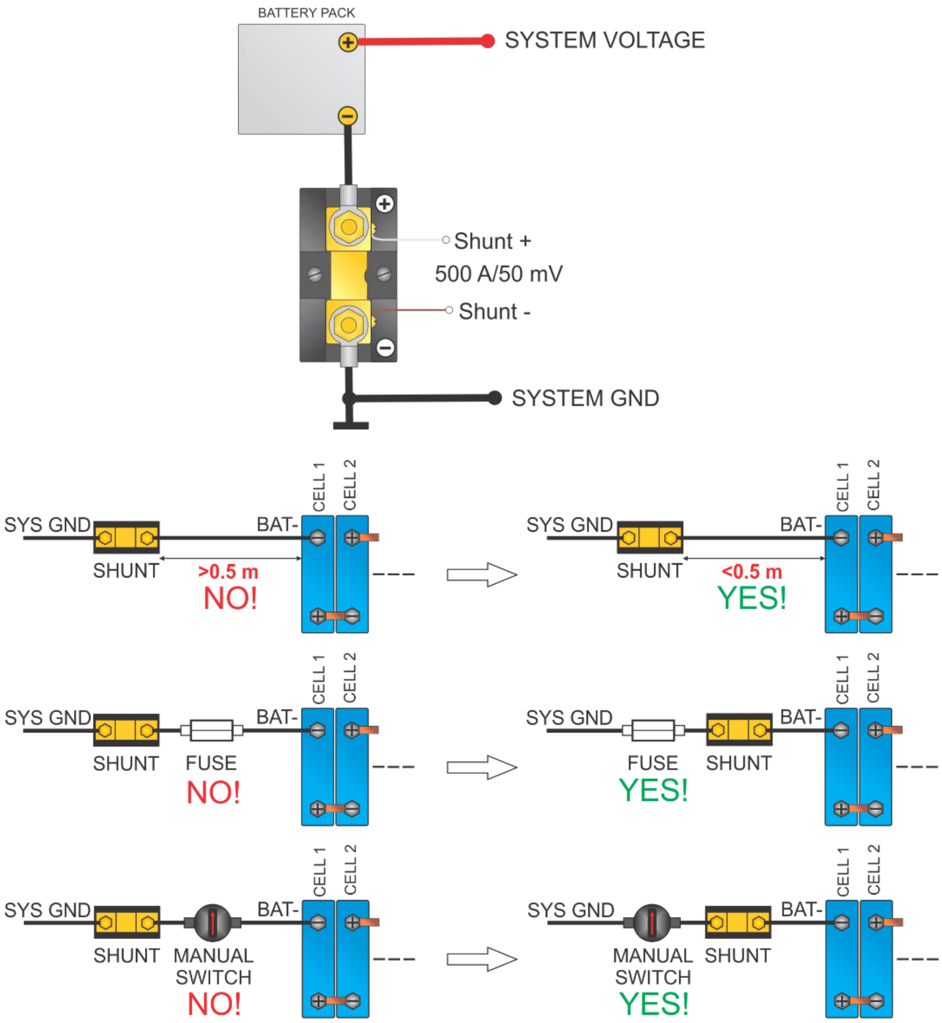

Figure 12: Shunt resistor connection.

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Different size and resistance shunts can be used, since the voltage-to-current coefficient can be changed in the BMS Control software as IOJA x.xxxx or selected from the drop menu in the REC WiFi module Settings tab. Offset may be corrected using IOFF x.xx instruction. Non-listed shunts coefficients should be entered manually. Current is calculated by the voltage drop at the shunt resistor. 1 LSB of the 18-bit ADC represents different current values according to the shunt resistance. The LSB coefficient can be calculated as:

$$k_{LSB} = 0.01171875 \cdot \frac{0.05\ \mathrm{V}}{300\ \mathrm{A}} \cdot \frac{I_{\mathrm{currentx}}}{V_{\mathrm{dropx}}}$$

where the V_{dropx} represents the voltage drop on shunt resistor at current I_{currentx}.

Table 7: Voltage-to-current coefficients for typical shunt resistors.

SHUNT RESISTOR	VOLTAGE-TO-CURRENT COEFFICIENT SETTING
100 A/50 mV	0.00390625
200 A/50 mV	0.0078125
300 A/50 mV	0.01171875
500 A/50 mV	0.01953125

Battery Pack SOC/SOH Determination:

SOC is determined by integrating the charge in or out of the battery pack. Different Li-ion chemistries may be selected:

Table 8: Li-ion chemistry designators.

NUMBER	TYPE
1	Li-Po Kokam High power
2	Li-Po Kokam High capacity
3	Winston/Thunder-Sky/GWL $LiFePO_4$
4	A123
5	Li-ion NMC/ $LiMn_2O_4$
6	LTO
7	Li-ideal

Temperature and power correction coefficient are taken into consideration at the SOC calculation. Li-Po chemistry algorithms have an additional voltage to SOC regulation loop inside the algorithm. BMS calculates battery self-discharge upon selected chemistry, SOC and temperature. *State of health* (SOH) is calculated as number of cycles compared to battery end of life cycles and compensated with SOH and temperature. Operational capacity is recalculated by the number of the charging cycles as pointed out in the manufacturer's datasheet.

When BMS is connected to the battery pack for the first time, SOC is set to 50 %. SOC is reset to 100 % at the end of charging. Charging cycle is added if the coulomb counter had reached the *Battery Pack's Capacity* CAPA.

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Battery Pack's Charging Algorithm:

The communication between the REC BMS and the Victron GX device is established through the CAN bus. All the parameters that control the charging/discharging behavior are calculated by the BMS and transmitted to the GX device in every measurement cycle.

The charging current is controlled by the Maximum charging current parameter sent to the GX device. It's calculated as *Charge Coefficient* CHAC x *Battery capacity* CAPA. The parameter has an upper limit which is defined as *Maximum Charging Current per Device* MAXC x *Number of Inverter/Charger Devices* SISN. Lowest value is selected:

Table 9: Maximum charging current calculation.

SETTING	VALUE	UNIT
Battery Capacity (CAPA)	100	Ah
Charge Coefficient (CHAC)	0.6	1/h
Maximum Charging Current per Device (MAXC)	75	A
Number of Inverter/Charger Devices (SISN)	2	n.a.

Charge Coefficient CHAC x *Battery Capacity* CAPA = 0.6 1/h x 100Ah = 60 A
Maximum Charging current per device MAXC x *Number of Inverter/Charger devices* SISN = 75 A x 2 = 150 A

Maximum charging current is set to **60 A** due to lower value of the *Charge Coefficient* CHAC x *Battery Capacity* CAPA.

When the highest cell reaches the *End of charge* CHAR voltage setting, charging current starts to ramp down to 1.1 A x *Number of Inverter/Charger Devices* SISN until the last cell rises near the *End of Charge Voltage* CHAR (CC/CV). At that point the Maximum charging voltage allowed is set to Number of cells x (*End of Charge Voltage per cell* CHAR– *Maximum Cell Float Voltage Coefficient* CFVC x *End of charge hysteresis per cell*). *End of Charge SOC hysteresis* SOCH and *End of charge cell voltage hysteresis* CHIS is set to prevent unwanted switching. SOC is calibrated to 100 % and Power LED lights ON 100 % Charge optocoupler is turned off. Maximum allowed charging current is set to 50% to allow supplying DC loads from charging devices like MPPTs. Charging current is limited to 30 % of the maximum charging current, but more than 5 A near both ends of temperature (*Max cell temperature* TMAX and *Min temperature for charging TMIN)* and when the battery is empty (Max discharging current is set to zero).

Charging is stopped in case of systems errors (See System Errors indication chapter). SOC is calibrated to 96 % when the maximum open circuit cell voltage rises above the 0.502 x (*Balance start voltage* BMIN + *End of charge voltage* CHAR), minimum open circuit voltage above balance start voltage and system is in charge regime.

In case BMS is not able to control the MPPT/Non-Victron charging sources directly (MPPT should be set to charge when the remote is in short), a small signal relay can be used to amplify the signal. MPPT should be programmed with its own charging curve set as End of charge voltage x number of cells. Digital output may be programmed with another task on request e.g. heater, under-voltage alarm, …

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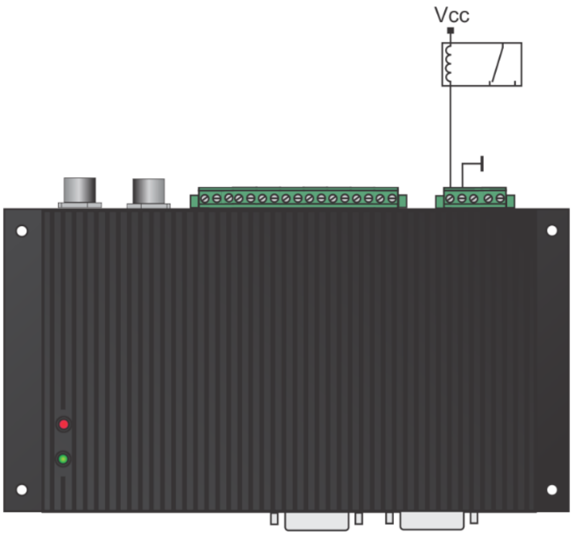

Figure 13: External signal relay with Vcc rated coil connection schematics.

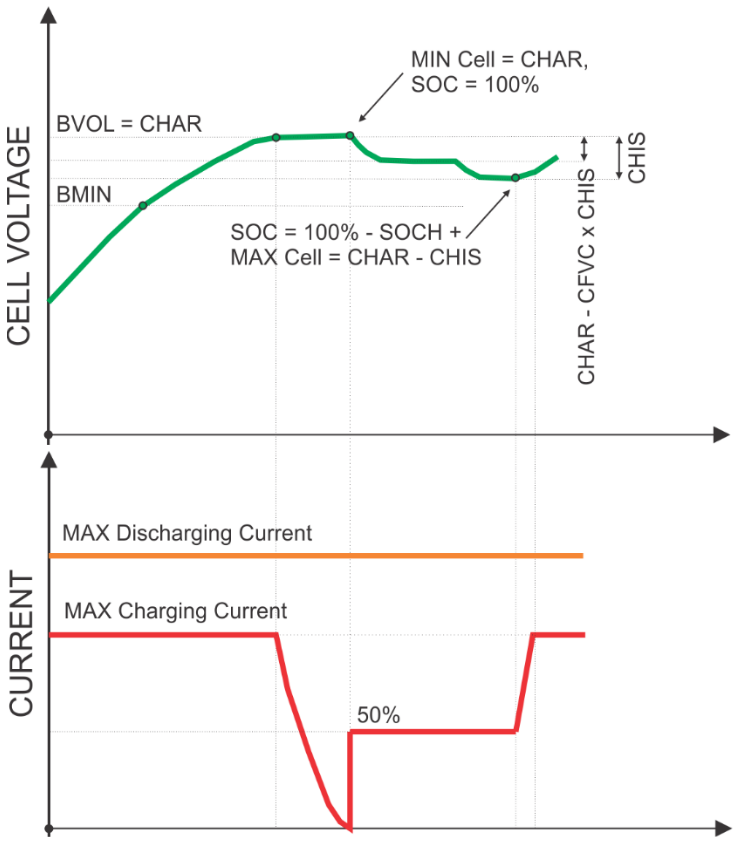

Figure 14: Charging diagram.

Maximum Cell Float Voltage Coefficient (CFVC):

Maximum Cell Float Voltage Coefficient CFVC has been introduced into the charging algorithm to enable cell float voltage change after the full charge. It may be set from 0.1 to 1.0 of the *End of Charge Hysteresis* CHIS. When *End of Charge Hysteresis* CHIS and *End of Charge SOC hysteresis* SOCH have been met, full charge is enabled again. @ CFVC 50 % of maximum charging current is allowed to supply DC loads from MPPTs directly without discharging the battery pack below *End of Charge Hysteresis* CHIS and *End of Charge SOC hysteresis* SOCH.

Battery Pack's Discharging Algorithm:

Calculated maximum discharging current is sent to the GX device by CAN communication in every measurement cycle. When the BMS starts/recovers from the error or from Discharging SOC hysteresis, maximum allowed discharging current is set. It is calculated as *Discharge Coefficient* DCHC x *Battery Capacity* CAPA. If this value is higher than *Maximum Discharging Current per device* MAXD x *Number of Inverter/Charger Devices* SISN, maximum discharging current is decreased to this value.

Table 10: Maximum discharging current calculation.

SETTING	VALUE	UNIT
Battery Capacity (CAPA)	100	Ah
Discharge Coefficient (DCHC)	1.5	1/h
Maximum Discharging Current per Device (MAXC)	100	A
Number of Inverter/Charger Devices (SISN)	2	n.a.

Discharge Coefficient DCHC x *Battery Capacity* CAPA = 1.5 1/h x 100Ah = 150 A
Maximum Discharging Current per device MAXC x *Number of Inverter/Charger devices* SISN = 100 A x 2 = 200 A
Maximum discharging current is set to **150 A**.

When the lowest cell open circuit voltage is discharged bellow the set threshold CLOW maximum discharging current starts to decrease down to 0.02 C (2 % of Capacity CAPA in A). After decreasing down, maximum allowed discharging current is set to 0 A. SOC is reset to 3 % and Discharging SOC hysteresis is set to 5 %. If the cell discharges below *Minimum Cell voltage* CMIN, BMS signals Error 2 and SOC is reset to 1 % and internal relay switches off. If the Charger/inverter is connected to the grid maximum allowed discharge current is drawn from the grid. Otherwise, 100 % load current is drawn from the battery until maximum allowed discharging current is set to 0 A. Discharging current is also limited near both ends of temperature (*Max cell temperature* TMAX and *Min temperature for charging* TMIN) to 30%, but more than 5 A. If the minimum cell discharges under the *Cell-under voltage protection switch-off* CMIN x 0.95 for more than 30 s BMS goes to deep sleep mode to protect the cells from over-discharging. OFF-ON switch sequence wakes the BMS from this state.

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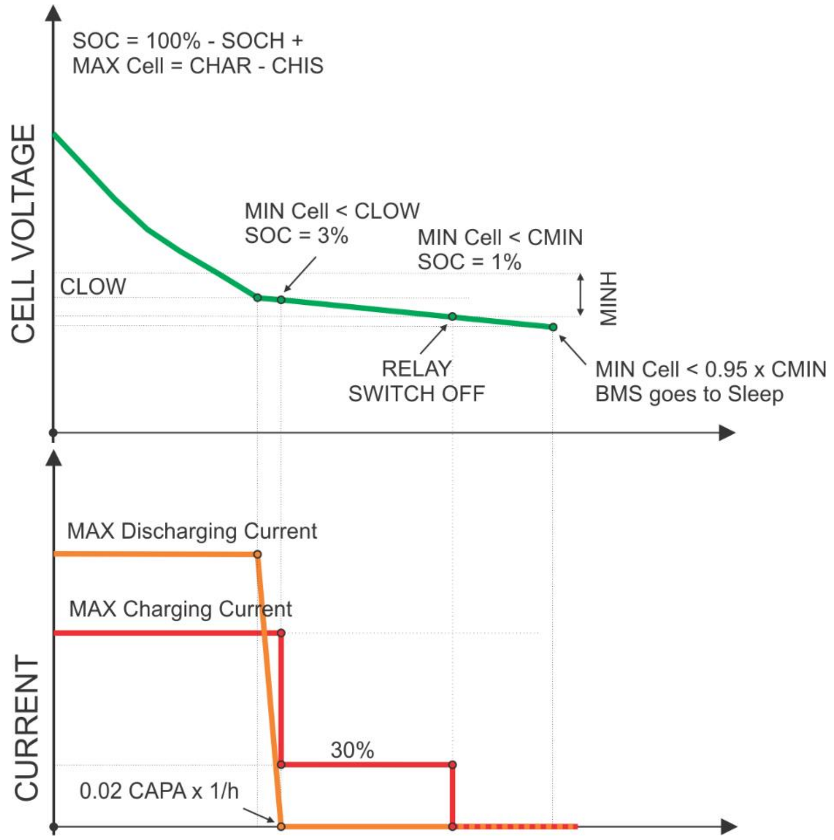

Figure 15: Discharging diagram.

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Pre-charge Connection:

Pre-charge circuit is used to charge the input capacitors of inverters. When the BMS turns the internal relay, battery voltage starts to charge the capacitors via 66-Ohm power resistors inside the pre-charge circuit. After 2-11 s (pre-charge setting), the contactor is turned ON. When the BMS encounters an error and the contactor should be turned OFF, it sends an Alarm message via CAN bus so the inverters can start the Stand-by or Turn-off procedure prior of contactor turning OFF. Figure 16 below shows how to connect the pre-charge circuit in the system.
User should test the pre-charge unit effectiveness by measuring the system voltage without the contactor. System voltage should rise @ least to the inverter/charger minimum operational voltage.

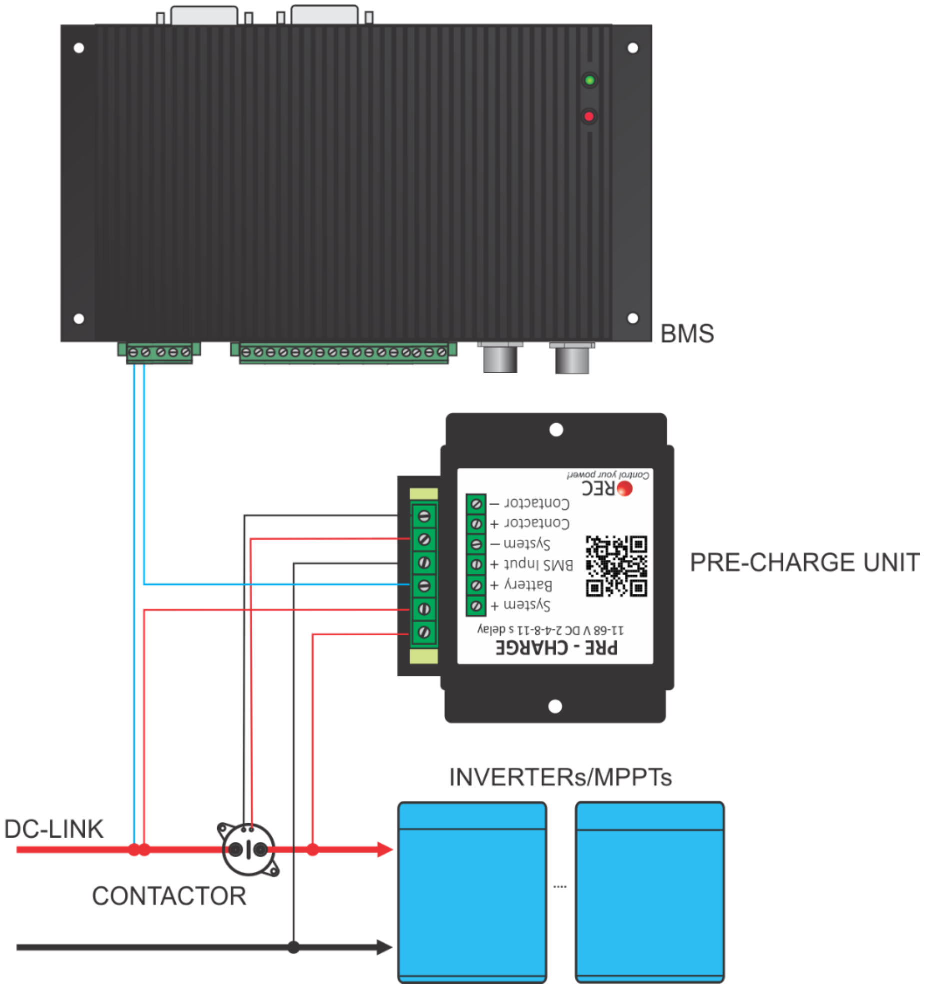

Figure 16: Pre-charge circuit connection schematics.

System Error Indication:

System errors are indicated with red error LED by the number of ON blinks, followed by a longer OFF state. Each and every error number trigger algorithm has a normal delay time of 3 measuring cycles with sensed/measured error – 3 x 1.25 s before the error is triggered.
Errors 2 and 10 are set to trigger @ the first measured error when the BMS is turned ON. If the two errors are not present normal delay timer is set.

Table 11: BMS error states.

NUMBER OF ON BLINKS	ERROR	BMS	OWNER
1	Single or multiple cell voltage is too high (cell over voltage switch-off per cell CMAX - cell over-voltage switch-off hysteresis per cell MAXH).	BMS will try to balance down the problematic cell/cells to safe voltage level (2.5 s error hysteresis + single cell voltage hysteresis is applied). Charging is disabled, discharging is enabled. Internal relay is disconnected. Charge optocoupler is disabled.	• Wait until the BMS does its job.
2	Single or multiple cell voltage is too low (cell under voltage protection switch-off per cell CMIN + under voltage protection switch-off hysteresis per cell MINH).	BMS will try to charge the battery (2.5 s error hysteresis + single cell voltage hysteresis is applied). SOC is reset to 1 % Charging is enabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is enabled.	• Plug in the charging sources. Lower MIN VCell setting CMIN for enabling the internal relay.
3	Cell voltages differs more than set (cells max difference RAZL – 20 mV hysteresis)	BMS will try to balance the cells if balancing is enabled (20 mV voltage difference hysteresis). Charging is enabled, discharging is enabled. Internal relay is connected. Charge optocoupler is enabled.	• Wait until the BMS does its job. If the BMS is not able to balance the difference in a few hours, contact the service.
4	Cell temperature is too high (cell over temperature switch-off TMAX + cell over temperature switch-off hysteresis –> 2°C).	Cells temperature or cell inter-connecting cable temperature in the battery pack is/are too high. (2.5 s error hysteresis 2°C hysteresis). Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is disabled.	• Wait until the pack cools down.

5	BMS temperature is too high –internal error (BMS over temperature switch-off TBAL - BMS over-temperature switch-off hysteresis BMTH).	Due to extensive cell balancing/hardware error the BMS temperature rose over the upper limit (2.5 s error hysteresis - 5 °C temperature hysteresis). Charging is enabled, discharging is enabled. Internal relay is connected. Charge optocoupler is enabled. Balancing is disabled.	• Wait until the BMS cools down.
6	Number of cells, address is not set properly.	Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is enabled.	• Set proper BMS address
7	The temperature is too low for charging (under-temperature charging disable TMIN + under temperature charging disable hysteresis of 2°C).	If cells are charged at temperatures lower than operating temperature range, cells are aging much faster than they normally would, so charging is disabled (2 °C temperature hysteresis). Charging is disabled, discharging is enabled. Internal relay is connected. Charge optocoupler is disabled.	• Wait until the battery's temperature rises to usable range.
8	Temperature sensor error.	Temperature sensor is un-plugged or not working properly (2.5 s error hysteresis). Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is disabled.	• Turn-off BMS unit and try to re-plug the temp. sensor. If the BMS still signals error 8, contact the service. The temperature sensors should be replaced.
9	Communication error.	RS-485 Master-Slave communication only.	
10	Cell in short circuit or BMS measurement error (Max cell voltage > 4.5 V or Min cell voltage < 0.8 V).	Single or multiple cell voltage is close to zero or out of range, indicating a blown fuse, short circuit or measuring failure (15 s error hysteresis + 10 mV voltage difference hysteresis). Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is disabled.	• Turn-off the BMS and check the cells connection to the BMS and fuses. Restart the BMS. • If the same error starts to signal again contact the service.

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11	Main relay is in short circuit.	If the main relay should be opened and current is not zero or positive, the BMS signals error 11. Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is disabled.	• Restart the BMS unit. If the same error starts to signal again contact the service.
12	Current measurement disabled or charging/discharging current >2 x shunt max current	BMS is not able to measure current or current is too high (short circuit). Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is disabled. 15 s pause is introduced before the new connection is established.	• Check the system settings/HW configuration. If the BMS still signals error 12, contact the service or change the BMS settings.
13	Wrong cell chemistry CHEM selected.	In some application the chemistry pre-set is compulsory. Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is disabled.	• Use PC Control Software to set proper cell chemistry.
14	EEPROM data corruption	During start-up or shut-down EEPROM read/write was interrupted. The corrupted setting/settings was/were set to a default value. If the setting/settings was/were changed after the first installation it/they should be corrected. Charging is enabled, discharging is enabled. Internal relay is connected. Charge optocoupler is enabled.	• Use PC Control Software to set proper settings
15	Cell balancing/measurement failure	During the start-up a burned fuse or cell balancing failure was detected. Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is disabled.	• Restart the BMS unit. If the same error starts to signal again contact the service.
16	BMS internal communication failure	I2C or SPI communication failure. BMS signals error 16 and does not start normal procedure Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is disabled.	• Restart the BMS unit. If the same error starts to signal again contact the service.

17	Charging/discharging current > 1.2 x current charging/discharging max limit	Battery current is out over the set limit. Maximum allowed charging/discharging current sent to GX unit is reduced. Internal relay is connected. Charge optocoupler is enabled.	• Wait until the BMS reduces the battery current.

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BMS Unit Dimensions:

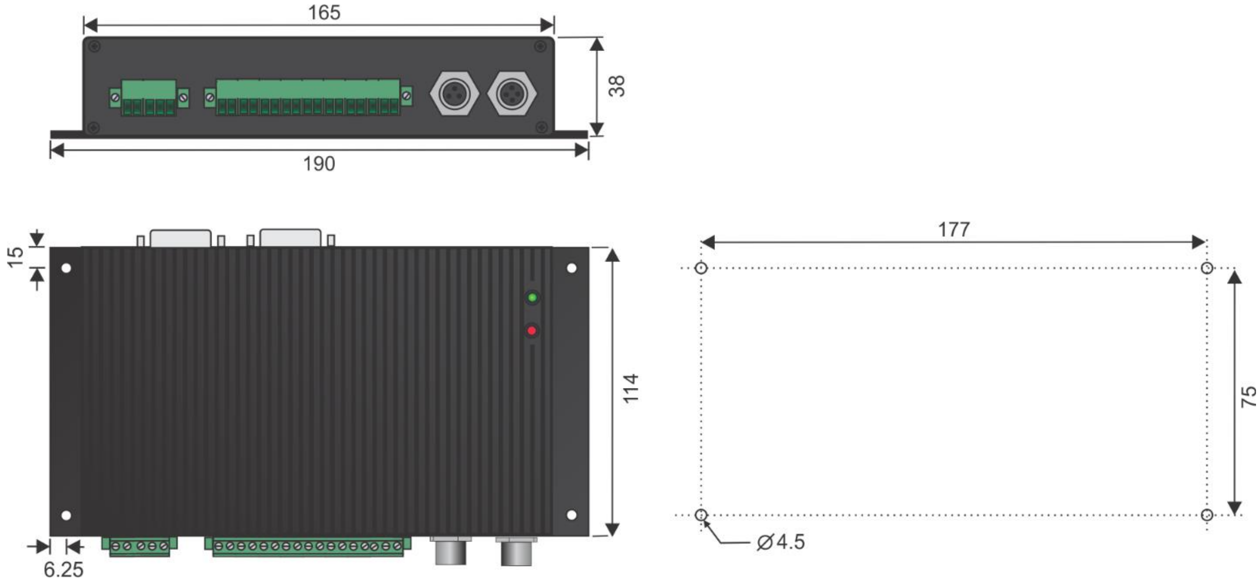

Figure 17: BMS dimensions.