BATTERY MANAGEMENT SYSTEM WITH CHARGER ENABLE REC Q BMS

REC
Control your power!

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Features:

- robust and small design
- 5 to 16 cells connections
- up to 3 temperature sensors
- 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
- 4.1 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 (125 kbit, 250 kbit and 500 kbit)
- error LED + buzzer indicator
- PC user interface for changing settings and data-logging (optional accessory PC Software BMS Master Control)
- hibernate switch
- BMS shutdown @ 0.98 x minimum cell disconnect threshold
- ISO16315, ISO10133, EN61558-1, EN61558-2 and EN50498 compliant

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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 $LiFePO_4$. 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.

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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	0.7	Hz
Cell balancing resistors	4.1	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 DC current relay @ 60 V DC	0.7	A
Max 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	3.5 slow	A
Internal relay fuse	3.15 slow	A
Dimensions (w × l × h)	190 x 104 x 38	mm
IP protection	IP32	
HW version	3.0	n.a.

*installed by request

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Default Software Parameters:

Table 2: Default BMS parameter settings*.

Parameter	Value	Unit
Chemistry	3 ($LiFePO_4$)	n.a.
Capacity	100	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	%
Under voltage protection switch-off per cell	2.8	V
Under voltage protection switch-off hysteresis per cell	0.1	V
Cell under voltage discharge protection	2.9	V
Battery pack under voltage protection switch-off timer	4	s
Cells max difference	0.25	V
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 offset	0.0	A
Maximum charging/discharging current per source/sink device	140/200	A
Charge coefficient	0.6	n.a.
Discharge coefficient	1.5	n.a.
CAN communication frequency	125	kbit/s
SW version	3.1	n.a.

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

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System Overview:

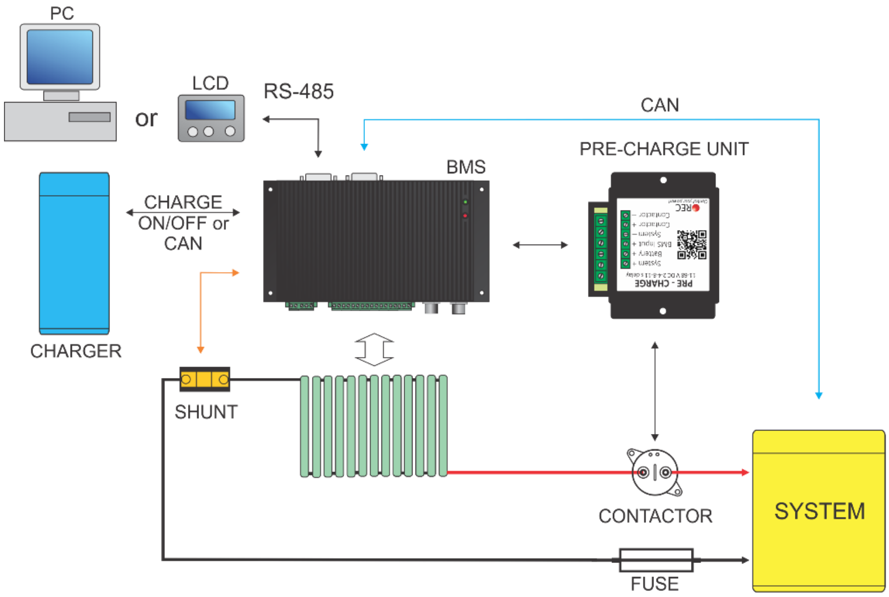

Figure 1: System overview.

BMS Unit Connections:

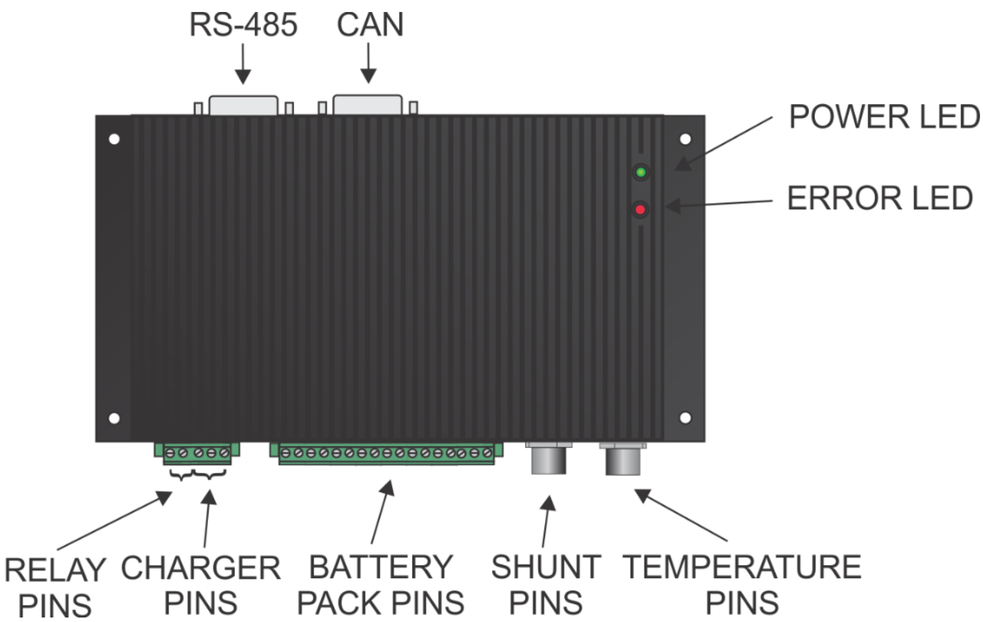

Figure 2: BMS unit function overview.

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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 ground (⊥)	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	Charger ENABLE/charge open collector	-
2	Charger ENABLE/charge 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 must be selected via **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.

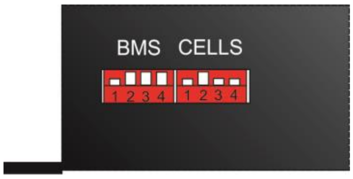

Figure 3: BMS address and cell selection DIP Switches.

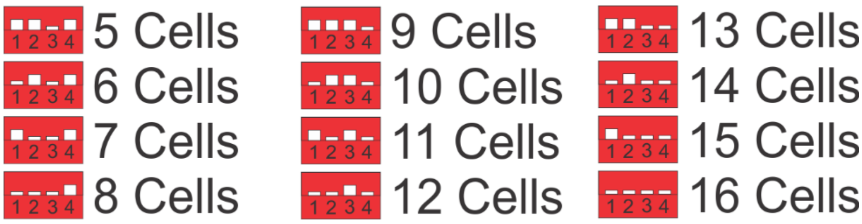

Figure 4: Number of CELLS selection description.

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 address selection description.

BMS Cell Connector:

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

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

! When working on cells connections – the BMS' cells connector should be unplugged, otherwise the BMS may be damaged!

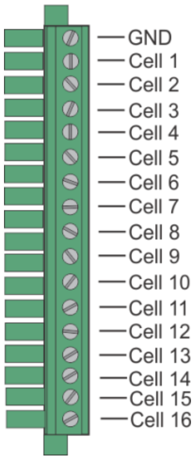

Figure 6: Battery pack to BMS connection.

BMS Unit Power Supply:

BMS unit is always supplied from the 16-th cell connection pin.

! 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 !

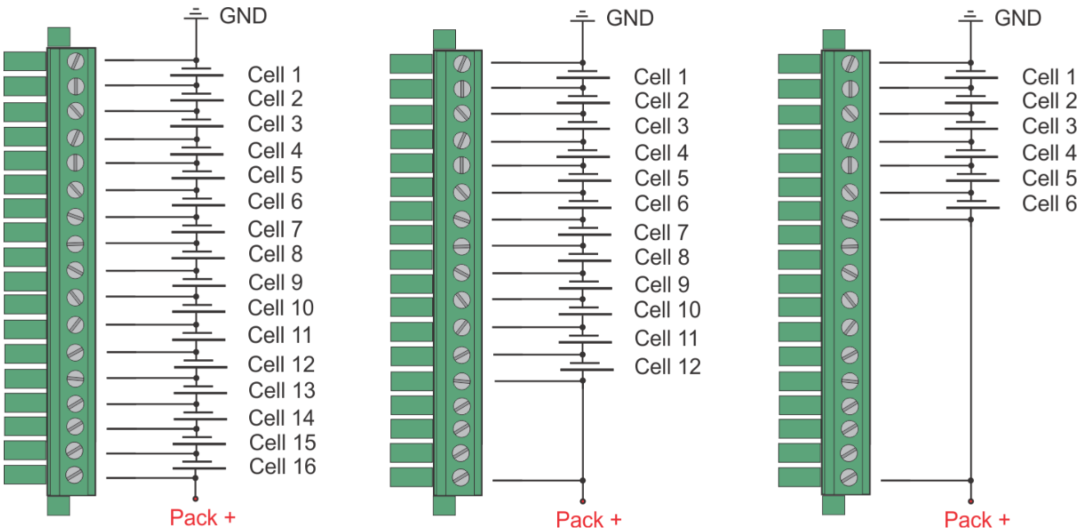

Figure 7: BMS unit power supply.

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BMS Unit Connection Instructions:

Connect the BMS unit to the system by the following order described in Fig. 8. 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.

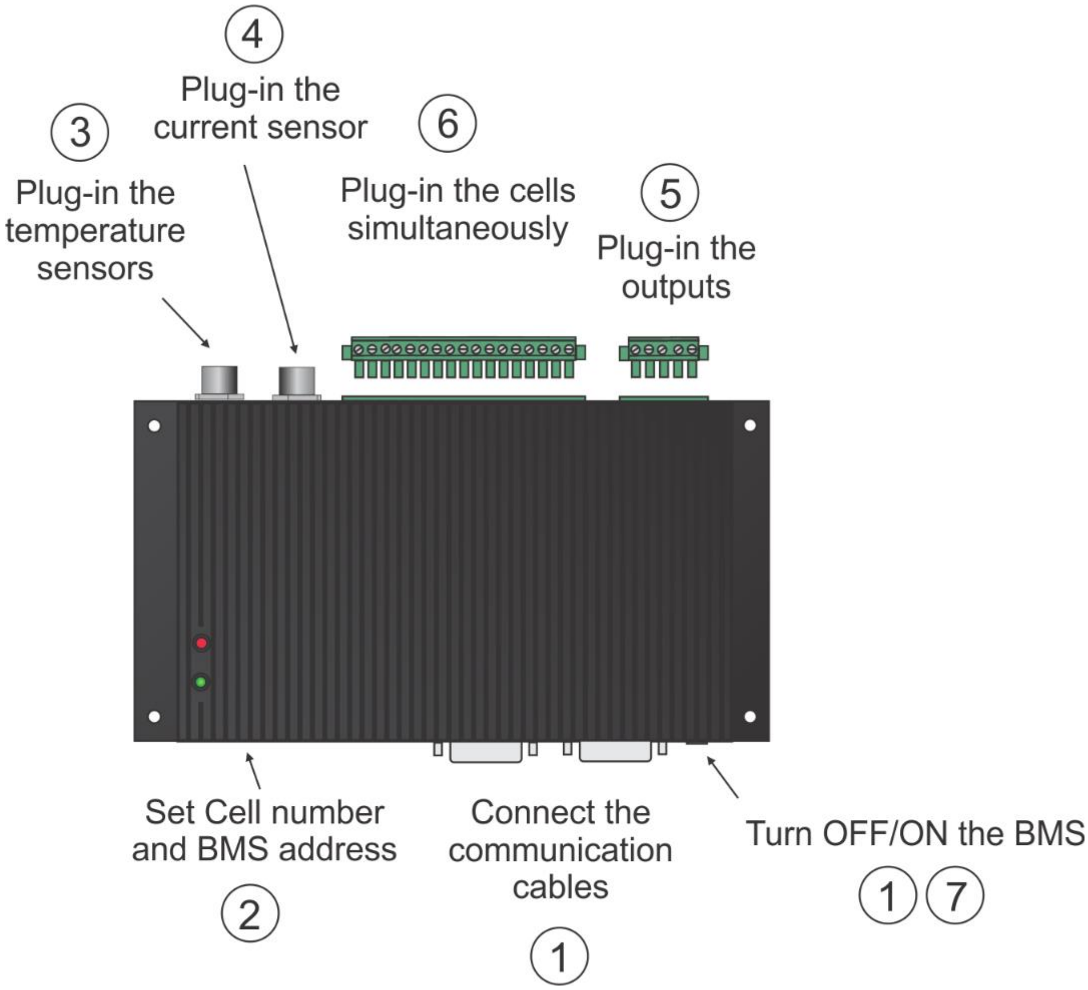

Figure 8: BMS connection order.

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

RS-485 Communication Protocol:

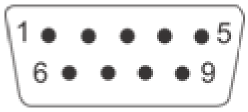

Figure 9: RS-485 DB9 connector front view.

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 (EN61558-1, EN61558-2) serves for logging and changing BMS parameters. Dedicated PC Software BMS Master Control or another RS-485 device may be used for the communication. Default RS-485 address is 1.

Unlock password: Serial number 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.: 'L','C','D','1','?', - (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

Table 5: RS-485 instruction set.

INSTRUCTION	DESCRIPTION	BMS ANSWER	SETTING INTERVAL
*IDN?	Identification	Answer "REC BMS 1Q"	Read only
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

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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 or temp. sensor where the error occurred - 1	Read only
CELL 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	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 MIN x.xxx	Over- 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
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	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	Li-ion chemistry	Returns unsigned char value	1 to 5

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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
SYSTEM COMMUNICATION SETTINGS INSTRUCTIONS			
CHAC? or CHAC x.xxx	Charge coefficient (0-3C)	Returns float value 0-3.0 (default 0.6)	0.01 to 5.0
CHCU? or CHCU x.xxx	Charger coefficient (0.1-1.0)	Returns float value 0.1-1.0 (default 1.0)	0.1 to 1.0
DCHC? or DCHC x.xxx	Discharge coefficient (0-3C)	Returns float value 0-3.0 (default 1.5)	0.01 to 10.0
MAXC? or MAXC x.xxx	Maximum charge current	Returns float current [A]	10.0 to 1000.0 A
MAXD? or MAXD x.xxx	Maximum discharge current	Returns float current [A]	10.0 to 1000.0 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 0 or 2	CANF=0 => 125 kb/s CANF=1 => 250 kb/s CANF=2 => 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 "3.1"	Read only
HWVR?	BMS hardware version	Returns string "3.0"	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 when 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 instructions for changing the BMS settings: https://www.youtube.com/watch?v=sRr_5vBKupw
Video instructions for BMS firmware update: https://www.youtube.com/watch?v=2di-Dpv2Nf8

CAN Communication:

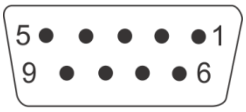

Figure 10: CAN female DB9 connector front view.

Table 6: CAN DB9 connector pin designator.

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

120 Ω termination is used inside the BMS. * **Terminate pins 2 and 7 with 120 Ohm resistor or short pins 1 and 2 to prevent BMS to reset.** 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: 0x031, 0x032, 0x033, 0x034, 0x035, 0x036, 0x037 and 0x038.

CAN messages are sent every 200 ms.

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

Table 7: CAN message structure description for ID=0x031, dlc=8.

Byte	Description	Type	
1	State of charge (SOC) [%]	Unsigned char	0-200 LSB = 0.5 % SOC
2	State of health (SOH) [%]	Unsigned char	0-200 LSB = 0.5 % SOH
3	Battery pack voltage high byte	Unsigned integer	0-65535, LSB = 10 mV
4	Battery pack voltage low byte		
5	Battery pack current high byte	Signed integer	LSB = 20 mA
6	Battery pack current low byte		
7	Error number	Unsigned char	0-16
8	Number of the cell or temp. sensor where the error occurred	Unsigned char	0-16

Table 8: CAN message structure description for ID=0x032, dlc=8.

Byte	Description	Type	
1	Cell temperature sensor 1	Signed char	-127 to 127 LSB = 1° C
2	Cell temperature sensor 2	Signed char	-127 to 127 LSB = 1° C
3	Cell temperature sensor 3	Signed char	-127 to 127 LSB = 1° C
4	Cell temperature sensor 4	Signed char	-127 to 127 LSB = 1° C
5	Cell temperature sensor 5	Signed char	-127 to 127 LSB = 1° C
6	Cell temperature sensor 6	Signed char	-127 to 127 LSB = 1° C
7	Cell temperature sensor 7	Signed char	-127 to 127 LSB = 1° C
8	Cell temperature sensor 8	Signed char	-127 to 127 LSB = 1° C

Table 9: CAN message structure description for ID=0x033, dlc=8.

Byte	Description	Type	
1	Cell 1 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
2	Cell 1 voltage low byte		
3	Cell 2 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
4	Cell 2 voltage low byte		
5	Cell 3 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
6	Cell 3 voltage low byte		
7	Cell 4 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
8	Cell 4 voltage low byte		

Table 10: CAN message structure description for ID=0x034, dlc=8.

Byte	Description	Type	
1	Cell 5 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
2	Cell 5 voltage low byte		
3	Cell 6 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
4	Cell 6 voltage low byte		
5	Cell 7 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
6	Cell 7 voltage low byte		
7	Cell 8 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
8	Cell 8 voltage low byte		

Table 11: CAN message structure description for ID=0x035, dlc=8.

Byte	Description	Type	
1	Cell 9 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
2	Cell 9 voltage low byte		
3	Cell 10 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
4	Cell 10 voltage low byte		
5	Cell 11 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
6	Cell 11 voltage low byte		
7	Cell 12 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
8	Cell 12 voltage low byte		

Table 12: CAN message structure description for ID=0x036, dlc=8.

Byte	Description	Type	
1	Cell 13 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
2	Cell 13 voltage low byte		
3	Cell 14 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
4	Cell 14 voltage low byte		
5	Cell 15 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
6	Cell 15 voltage low byte		
7	Cell 16 voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
8	Cell 16 voltage low byte		

Table 13: CAN message structure description for ID=0x037, dlc=8.

Byte	Description	Type	
1	Max charge voltage high byte	Unsigned integer	0-65535, LSB = 0.1 V
2	Max charge voltage low byte		
3	Max charge current high byte	Unsigned integer	0-65535, LSB = 0.1 A
4	Max charge current low byte		
5	Min discharge voltage high byte	Unsigned integer	0-65535, LSB = 0.1 V
6	Min discharge voltage low byte		
7	Max discharge current high byte	Unsigned integer	0-65535, LSB = 0.1 A
8	Max discharge current low byte		

Table 14: CAN message structure description for ID=0x038, dlc=5.

Byte	Description	Type	
1	Ah high byte	Unsigned integer	0-65535, LSB = 1 Ah
2	Ah low byte		
3	BMS temperature	Signed char	-127 to 127 LSB = 1 °C
4	Relay output status	Unsigned char	0 - OFF 1 - PRE-CHARGE 2 - ON
5	Optocoupler output status	Unsigned char	0 - OFF 1 - ON

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 sensors 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 and blinking red LED signal will notify the user. Each error is coded to a number. The most common errors at system startup are:

- 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 is 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.

BMS Unit LED Indication:

Power LED (green) is turned on in 2 seconds intervals, when the BMS is powered. When the battery pack is fully charged and SOC/end of charge hysteresis are set, power LED is turned on constantly. 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 second 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 4.1 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:

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. The BMS determines which cell will be balanced based on the calculated average.

Balancing END Voltage:

If errors 2, 4, 5, 8, 10, 12 are not present, any cell above balance END voltage is balanced regardless 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 additional temperature sensors. If the temperature sensors wiring is placed near the power lines, shielded cables should be used.

BMS Current Measurement:

Low-side only precision shunt resistor for current measurement is used. 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 Figure 11. 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.

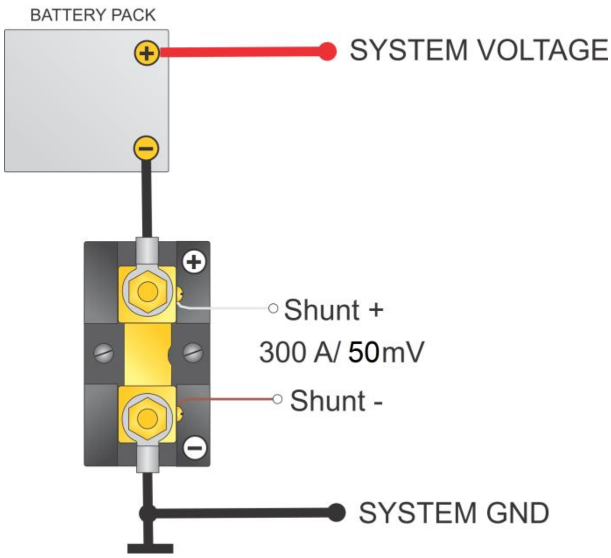

Figure 11: Shunt resistor connection.

Voltage-to-current Coefficient:

Different size and resistance shunts can be used, since the voltage-to-current coefficient can be changed with the PC Software BMS Master Control. The instruction is IOJA x.xxxx

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}.

Battery Pack SOC Determination:

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

Table 15: Li-ion chemistry designators.

Number	Type
1	Li-Po Kokam High power
2	Li-Po Kokam High capacity
3	Winston/Thunder-Sky/GWL LiFePO4
4	A123
5	Li-ion NMC/ $LiMn_2O_4$

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. Actual cell capacity is recalculated by the number of the charging cycles as pointed out in the battery manufacturer's datasheet.

When the 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.

Battery Pack's Charging Algorithm:

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

The charging current is controlled by the Maximum charging current parameter. It is 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 Charger coefficient CHCU.

When the highest cell reaches the Balance start voltage setting, the charging current starts to ramp down to 1.1 A until the last cell rises to the End of charge voltage. At that point the Maximum charging voltage allowed is set to Number of cells x (End of charge voltage per cell – 0.5 x End of charge hysteresis per cell). End of charge SOC hysteresis and End of charge cell voltage hysteresis is set to prevent unwanted switching. SOC is calibrated to 100 % and power LED light is on. Charge optocoupler is turned off.

Charging is stopped in case of system errors (see System Error Indication section). SOC is calibrated to 96 % when the maximum open circuit cell voltage rises above the 0.502 x (Balance start voltage + Balance end voltage), minimum open circuit voltage above balance start voltage and system is in charge regime.

Custom firmware and hardware may be installed for PWM charge control.

Battery Pack's Discharging Algorithm:

Calculated maximum discharging current is sent with 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. If this value is higher than Maximum discharging current per device MAXD, maximum discharging current is decreased to MAXD. 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 (5 % of cell's capacity in amperes). After decreasing, 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 %.

When the lowest cell is discharged under 0.98 x CMIN for more than 30 seconds, BMS goes to sleep to conserve energy. Manual restart of the BMS is required to wake it up.

In case BMS is not able to control the charging sources by optocoupler output directly, a small signal relay can be used to amplify the signal. Charger should be programmed with its own charging curve set as End of charge voltage x number of cells.

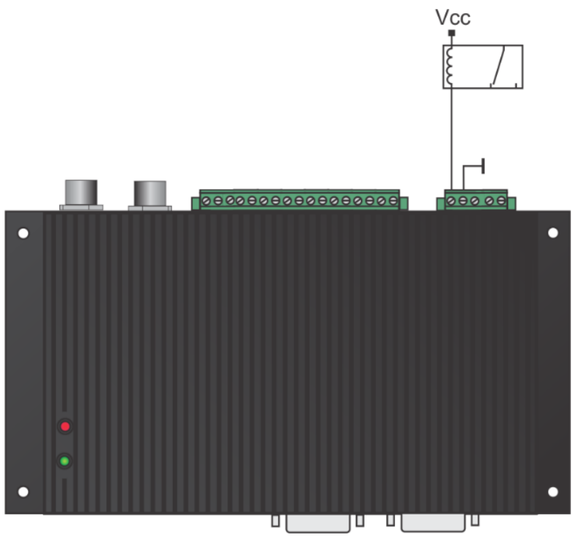

Figure 12: External signal relay with V_{CC} rated coil connection schematics.

Pre-charge Connection:

Pre-charge circuit is used to charge the input capacitors of controllers/inverters/chargers. When the BMS turns the internal relay on, battery voltage starts to charge the capacitors via 66 Ω power resistors inside the pre-charge circuit. After 2 to 11 seconds (pre-charge default setting is 4 seconds), the contactor is turned ON. When the BMS encounters an error and the contactor should be turned OFF, it sends an alarm massage via CAN bus, so the system can start the Stand-by or Turn-off procedure prior to contactor shut down. Figure 13 shows how to connect the pre-charge unit into the system.

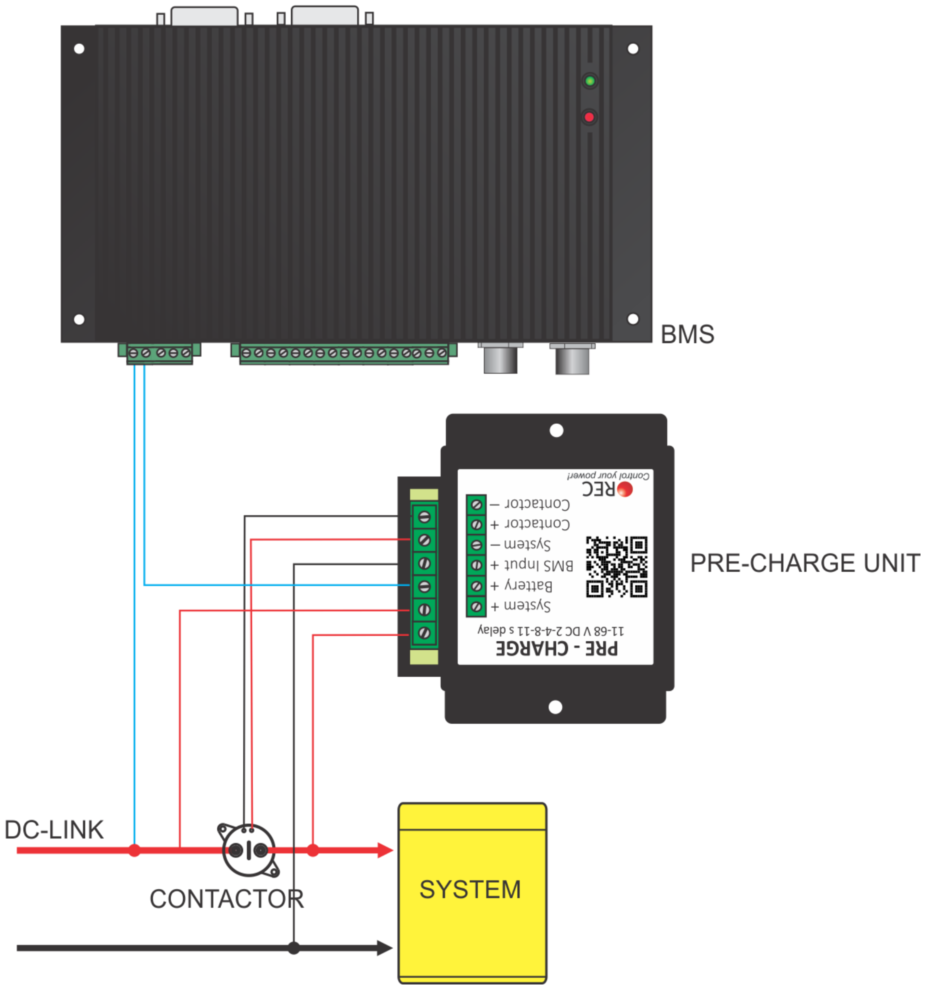

Figure 13: Pre-charge circuit connection schematics.

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 these two errors are not present normal delay timer is set.

Table 16: BMS error states.

Number of ON blinks	ERROR	BMS	WHAT TO DO
1	**Single or multiple cell voltage is too high** (cell over voltage switch-off + cell over-voltage switch-off hysteresis).	BMS will try to balance down the problematic cell 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 + cell under voltage protection switch-off hysteresis).	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 parameter in PC Software BMS Master Control to change 'CMIN' for enabling the internal relay.
3	**Cell voltages differs more than set** (cells max difference).	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 + cell over temperature switch-off hysteresis).	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 battery pack cools down.

5	**BMS temperature is too high – internal error** (BMS over temperature switch-off + BMS over-temperature switch-off hysteresis).	Due to extensive cell balancing (HW 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 or BMS address is not set properly.**	Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is enabled.	• Set proper BMS address with DIP Switches.
7	**The temperature is too low for charging** (under temperature charging disable + under temperature charging disable hysteresis).	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 pack's temperature rises to usable range.
8	**Temperature sensor error.**	Temperature sensor is unplugged 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 the BMS and try to re-plug the temp. sensor. • If the BMS still signals error 8, contact the service. The temp. 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.

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 is 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 and HW configuration. • If the BMS still signals error 12, contact the service or change the BMS settings.
13	**Wrong cell chemistry selected.**	In some applications the chemistry pre-set is compulsory. Charging is disabled, discharging is disabled. Internal relay is disconnected. Charge optocoupler is disabled.	• Use PC Software BMS Master Control to set proper cell chemistry.
14	**EEPROM data corruption.**	During start-up or shut-down EEPROM read/write was interrupted. The corrupted settings were set to a default value. If the settings were changed after the first installation, they should be corrected. Charging is enabled, discharging is enabled. Internal relay is connected. Charge optocoupler is enabled.	• Use PC Software BMS Master Control to set proper settings.
15	**Cell balancing or measurement failure.**	During 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.

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BMS Unit Dimensions:

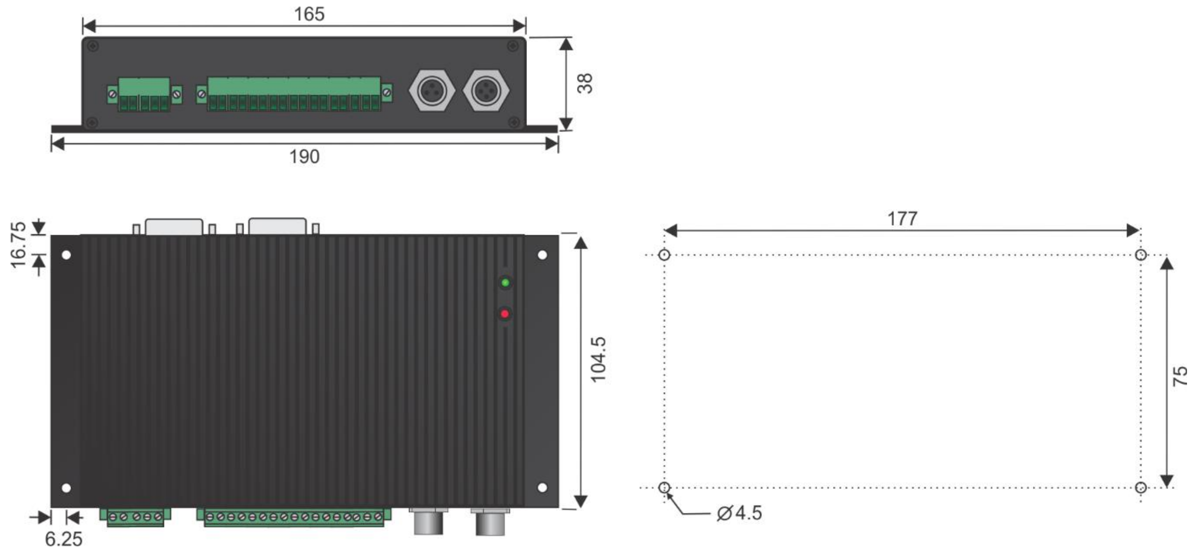

Figure 14: BMS dimensions.