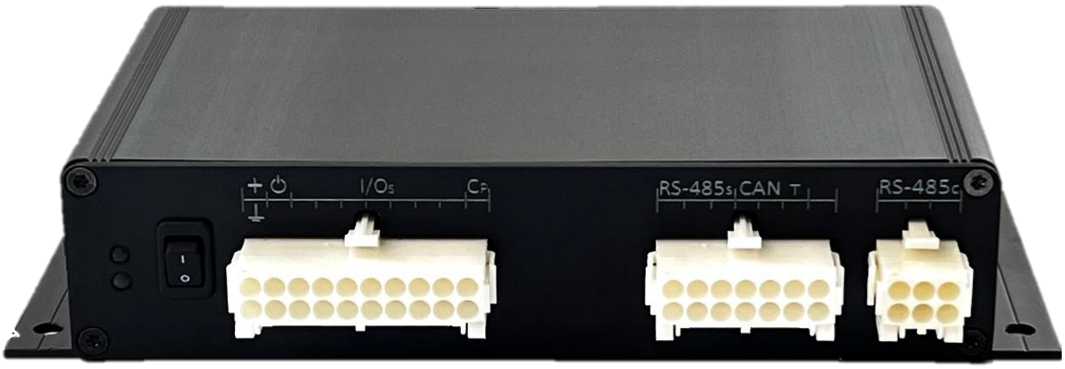
BATTERY MANAGEMENT SYSTEM MASTER-SLAVE CONFIGURATION



Novi trg 9, 6230 Postojna, Slovenia
mail: info@rec-bms.com; www.rec-bms.com

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mail: info@rec-bms.com; www.rec-bms.com

Features:

- Master BMS unit + up to 12 Slave BMS units configuration
- up to 8 digital temperature sensors DS18B20 per Slave BMS device
- 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
- 4.0 Ω passive cell balancing
- shunt current measurement (resolution 19.5 mA @ ± 500 A)
- internal battery powered real time-clock (RTC)
- galvanically isolated user defined multi-purpose relay and digital output
- 3 additional internal relays output (normally opened)
- galvanically isolated RS-485 communication protocol
- galvanically isolated CAN bus
- error LED + buzzer indicator
- error acknowledge and forced connect function
- Wide range supply (10.5-90 V)
- PC user interface/Wi-Fi for changing the settings and data-logging (optional accessory)
- hibernate switch
- ISO16315, ISO10133, EN61558-1, EN61558-2 and EN50498 compliant

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mail: info@rec-bms.com; www.rec-bms.com

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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 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.

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Hardware Parameters:

Table 1: Slave BMS unit hardware parameters.

PARAMETER	VALUE	UNIT
BMS maximum pack voltage	68.0	V
BMS minimum pack voltage	10	V
BMS minimum pack voltage (HW UVP)*	-	V
BMS cell voltage range	0.0 to 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	+/-1	mV
Pack voltage accuracy	+/-5	mV
DC current accuracy	+/- 1	LSB
Temperature measuring accuracy	+/-0.5	°C
DC Current sample rate	4	Hz
Cell voltage sample rate	1	Hz
Cell balancing resistors	4.0	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 continuous DC current opto-relay @ 100 V DC	3	A
BMS unit disable power supply @ 48 V	1.5	mW
BMS pre-charge resistance	25	Ω
BMS unit operation power supply @ 48 V	180 - 190	mW
BMS unit cell balance fuse rating	3 slow	A
Internal relay fuse	3.15 slow	A
Internal RTC battery	CR1632	n.a.
Dimensions (w × l × h)	190 x 98.4 x 38	mm
IP protection	IP32	
HW version	1.36/1.37	n.a.

*installed on request
**defined by internal RTC back-up 2032 battery

Table 2: BMS 9M Master BMS unit hardware parameters.

PARAMETER	VALUE	UNIT
Master BMS unit 9M maximum supply voltage	10.5	V
Master BMS unit 9M minimum supply voltage	90	V
Master BMS unit 9M minimum supply voltage (HW UVP)*	10.4	V
BMS maximum cell voltage	5.0	V
Cell voltage sample rate	1	Hz
Maximum operating temperature	70	°C
Minimum operating temperature	-20	°C
Maximum storage temperature	30	°C
Minimum storage temperature	0	°C
Maximum humidity	75	%
Max continuous DC current relay @ 60 V DC	0.7	A
Max continuous AC current relay @ 230 V AC	2	A
ACK/forced connect digital input impedance	47	kΩ

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Internal relay fuse	3.15 slow			A
Max DC current @ optocoupler 1	15			mA
Max DC voltage@ optocoupler 1	85			V
Master BMS unit 9M unit disable current supply @ 12 V	0			mA
Master BMS unit 9M unit stand-by current supply @ 12 V**	17	18	19	mA
Master BMS unit 9M unit stand-by current supply @ 24 V**	8	9	10	mA
Master BMS unit 9M unit stand-by current supply @ 48 V**	6	6.5	7	mA
Master BMS unit 9M unit stand-by current supply @ 80 V**	3	3.5	4	mA
Internal RTC battery	CR1632			n.a.
Dimensions (w × l × h)	190 x 98 x 38			mm
IP protection	IP32			
HW version	1.1			n.a.

*installed on request, may be set from 12 to 60 V.
**relays and optocouplers all off.

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Default Software Parameters:

Table 3: Default Master BMS unit parameter settings*.

PARMETER	VALUE	UNIT
Chemistry	3 ($LiFePO_4$)	n.a.
Capacity	280	Ah
Balance start voltage	3.45	V
Balance end voltage	3.55	V
Cell over-voltage switch-off per cell	3.75	V
Over-voltage switch-off hysteresis per cell	0.20	V
Cell end of charge voltage	3.55	V
End of charge hysteresis per cell	0.25	V
SOC end of charge hysteresis	5	%
Maximum cell float voltage coefficient	0.5	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	2.95	V
Battery pack under voltage protection switch-off timer	2	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	0	°C
Under temperature charging disable hysteresis	2	°C
Voltage to current coefficient - Slave BMS units	0.01953125	A/bit
Integrated pre-charge time - Slave BMS units	4	s
Current measurement zero offset - Slave BMS units	0.0	A
Maximum charging/discharging current per inverter device	100/150	A
Number of inverter/charger devices	1	n.a.
Charge coefficient	0.6	1/h
Discharge coefficient	1.5	1/h
CAN communication frequency	250	kbit/s
System configuration (serial/parallel)	serial	n.a.
Forced connection timer	10 + precharge timer	s
Relay 1 digital output task	disabled	n.a.
Optocoupler 1 digital output task	disabled	n.a.
		n.a.
SW version	1.0	n.a.

*all parameters' values may be changed with PC Software Master BMS unit Control user interface/Wi-Fi module.

System Overview:

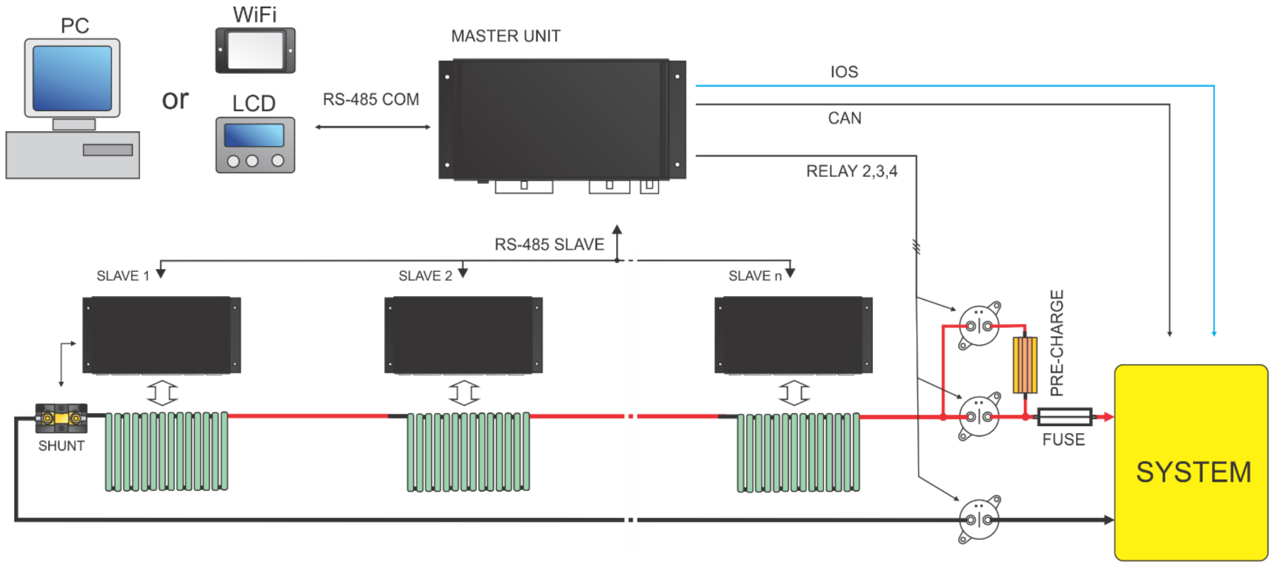

Figure 1: System overview - serial HV connection.

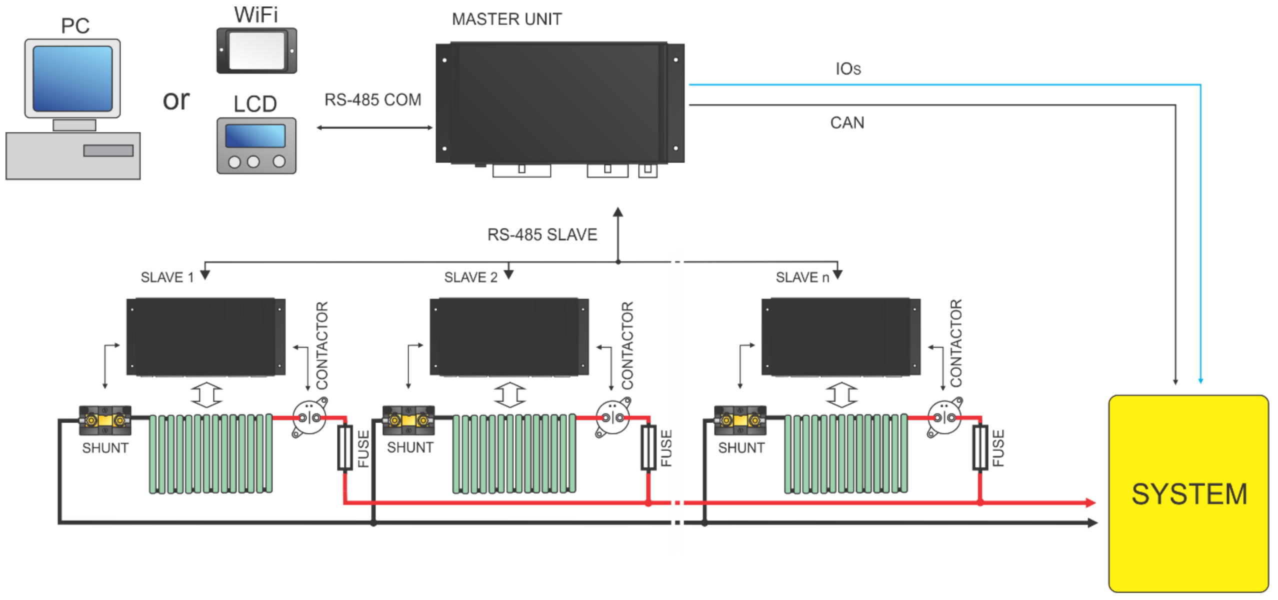

Figure 2: System overview - parallel connection.

Slave BMS Unit Connections:

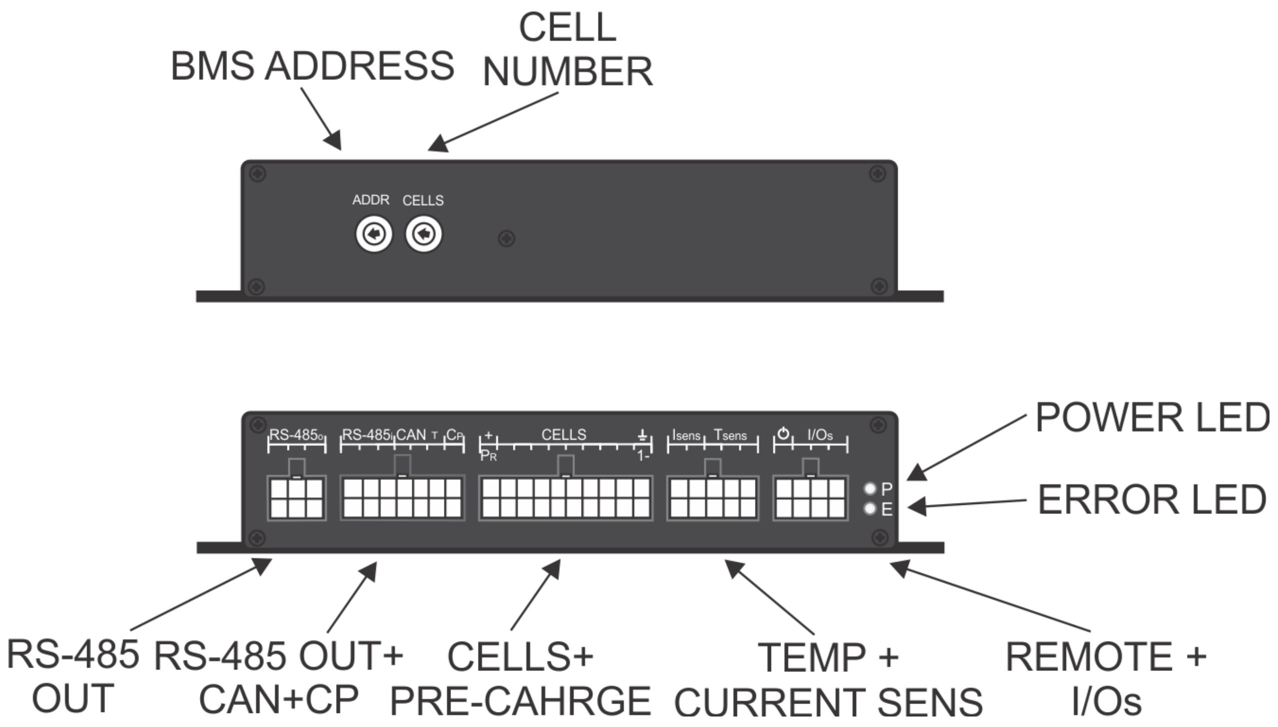

Figure 3: BMS Slave unit function overview.

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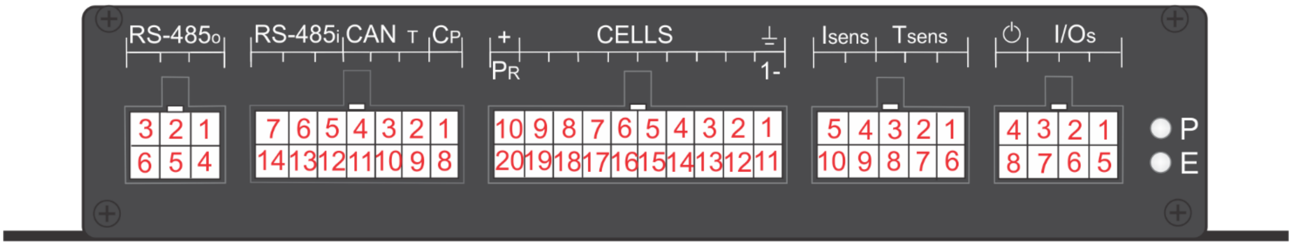

Figure 4: Slave BMS unit connections description.

Table 4: RS-485 communication output connector's pin description.

Pin	Connection	Description	Plug
1	RS-485 B out	Signal B out	794190-1
2	RS-485 A out	Signal A out	
3	RS-485 +5 V ENABLE out	Master BMS unit controlled REMOTE ON/OFF	
4	RS-485 +5 V out	RS-485 +5 V Power supply	
5	RS-485 GND out	RS-485 Power supply GND	
6	RS-485 CABLE SHIELD out	SHIELD OUT	

Table 5: RS-485 communication input, CAN communication and Control Pilot connector's pin description.

Pin	Connection	Description	Plug
1	-	-	794202-1
2	-	-	
3	-	-	
4	-	-	
5	RS-485 +5 V ENABLE in	Master BMS unit controlled REMOTE ON/OFF	
6	RS-485 B in	Signal B in	
7	RS-485 A in	Signal A in	
8	-	-	
9	-	-	
10	-	-	
11	-	-	
12	RS-485 CABLE SHIELD in	SHIELD IN	
13	RS-485 GND	RS-485 Power supply GND	
14	RS-485 +5V	RS-485 +5 V Power supply	

* Galvanically isolated CAN communication is upgraded upon request.

Table 6: Power supply, cell measurement and pre-charge connector's pin description.

Pin	Connection	Description	Plug
1	CELL 1-	Cell 1 negative (PACK -)	794210-1
2	CELL 2+	Cell 2 positive	
3	CELL 4+	Cell 4 positive	
4	CELL 6+	Cell 6 positive	
5	CELL 8+	Cell 8 positive	
6	CELL 10+	Cell 10 positive	
7	CELL 12+	Cell 12 positive	
8	CELL 14+	Cell 14 positive	

9	CELL 16+	Cell 16 positive	
10	PRE-CHARGE OUT	Pre-charge out – connect to System + side of the contactor (parallel string system only)	
11	PACK-	BMS Power supply negative (Cell 1 negative)	
12	CELL 1+	Cell 1 positive	
13	CELL 3+	Cell 3 positive	
14	CELL 5+	Cell 5 positive	
15	CELL 7+	Cell 7 positive	
16	CELL 9+	Cell 9 positive	
17	CELL 11+	Cell 11 positive	
18	CELL 13+	Cell 13 positive	
19	CELL 15+	Cell 15 positive	
20	PACK +	BMS Power supply positive	

Table 7: Current and temperature sensor connector's pin description.

Pin	Connection	Description	Plug
1	1-WIRE GND port 1	1-WIRE temperature sensor DS18B20 Supply GND	794196-1
2	1-WIRE SIGNAL port 1	1-WIRE temperature sensor DS18B20 signal	
3	1-WIRE +5 V port 1	1-WIRE temperature sensor DS18B20 Supply +5 V	
4	CURRENT SENS -	Shunt sensor Kelvin connection negative	
5	CURRENT SENS CABLE SHIELD	Current sensor cable shield	
6	1-WIRE GND port 2	1-WIRE temperature sensor DS18B20 Supply GND	
7	1-WIRE SIGNAL port 2	1-WIRE temperature sensor DS18B20 signal	
8	1-WIRE +5 V port 2	1-WIRE temperature sensor DS18B20 Supply +5 V	
9	CURRENT SENS +	Shunt sensor Kelvin connection positive	
10	-	-	

*Slave BMS unit with address 1 only.

Table 8: Remote ON/OFF and I/O connector's pin description.

Pin	Connection	Description	Plug
1	-	-	794192-1
2	-	-	
3	OPTO-RELAY OUT	Opto-relay output signal	
4	REMOTE ON/OFF -	BMS Remote ON/OFF input	
5	-	-	
6	-	-	
7	OPTO-RELAY IN	Input supply + for the OPTO – RELAY (parallel string system only)	

8	REMOTE ON/OFF +	BMS Remote ON/OFF source (connect to REMOTE ON/OFF – pin 4 to enable the BMS or use RS-485 +5 V ENABLE to turn the Slave BMSes on)*	

*Slave BMS may be turned ON by the Remote ON/OFF button or automatically by the Master BMS using RS-485 +5 V ENABLE connection.

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** rotary switch, while the BMS address is set via **ADDR** rotary switch at the back of the BMS unit. User should set 4-16 cell and address from 1-15. Address 16 is used for Master BMS unit 9M.

Figure 5: BMS address and cell selection rotary switches.

Table 9: Number of cells **CELLS** settings.

Selection	Setting
0	1 cell (ERROR 6)
1	2 cell (ERROR 6)
2	3 cells (ERROR 6)
3	4 cells
4	5 cells
5	6 cells
6	7 cells
7	8 cells
8	9 cells
9	10 cells
A	11 cells
B	12 cells
C	13 cells
D	14 cells
E	15 cells
F	16 cells

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Table 10: BMS address ADDR settings.

Selection	Setting
0	Address 0 (ERROR 6)
1	Address 1
2	Address 2
3	Address 3
4	Address 4
5	Address 5
6	Address 6
7	Address 7
8	Address 8
9	Address 9
A	Address 10
B	Address 11
C	Address 12

BMS Cell Connector:

Connect BMS power supply, each cell and pre-charge BMS cell connector 20-pin plug. We recommend 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 may be damaged!

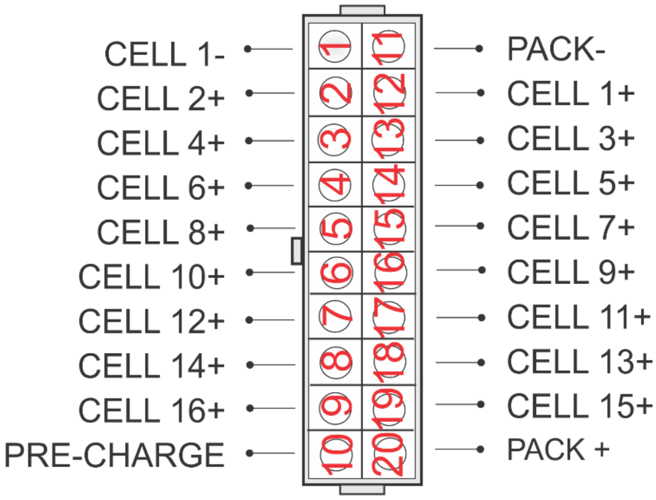

Figure 6: Battery pack BMS cell connector.

BMS Unit Power Supply:

BMS unit is always powered from the PACK + and PACK – connections. **An additional connection from the battery pack positive voltage (Pack +) and the battery pack negative voltage (Pack -) should be connected to pins 20 and 11. Do not bypass the Cell 1- and the highest cell to this connection. It decreases the measurement accuracy since the power is connected through the measurement cells connection.**

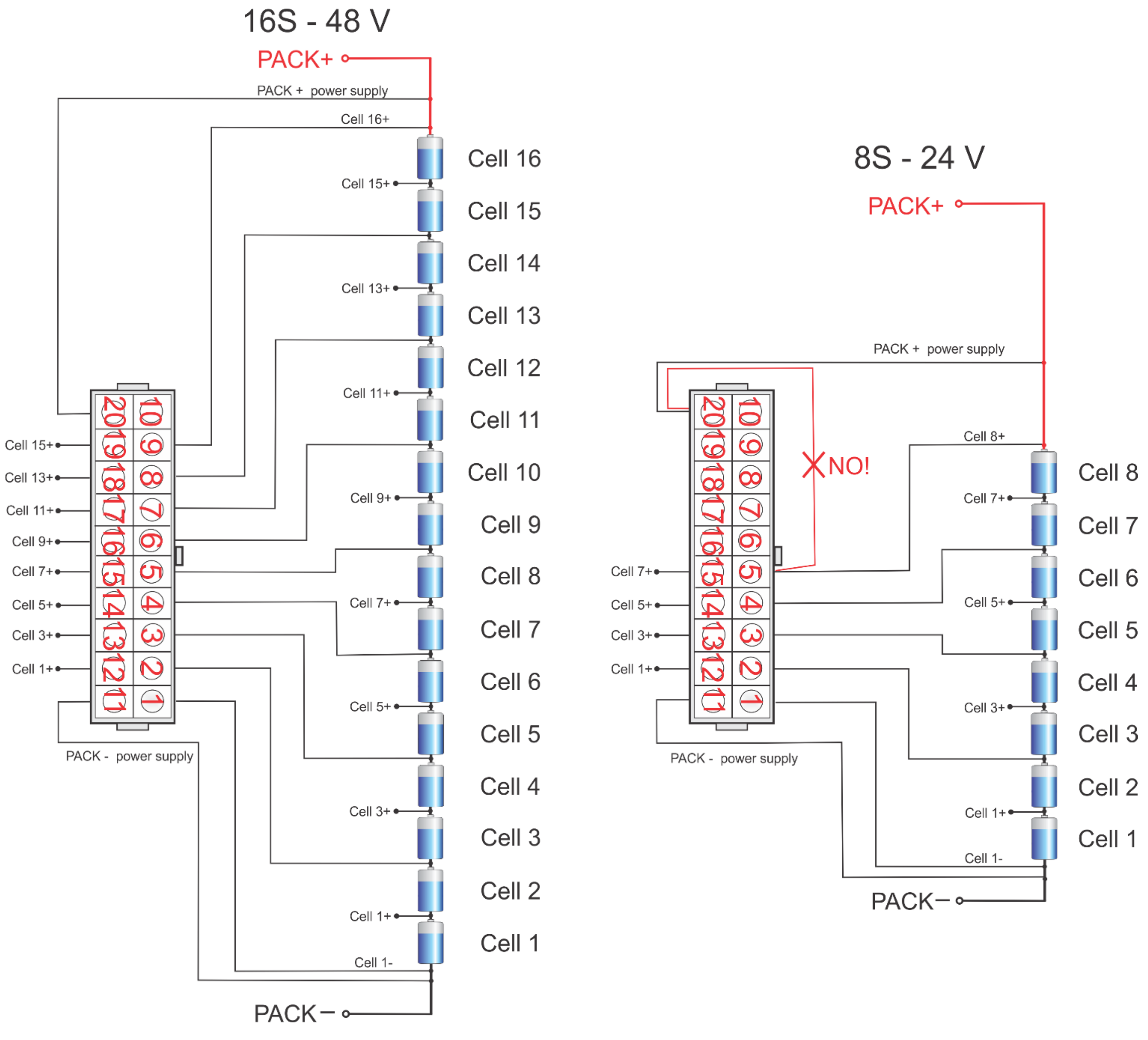

Figure 7: BMS unit power supply.

If multiple Slave BMS units are used in series, care should be taken how to connect each. Two separate wires should be wired to the same cell: first wire for the lower Slave BMS unit as the end-cell voltage potential, and second wire as GND potential for the higher Slave BMS unit. See Fig. 7! **Do not bypass the higher cell!**

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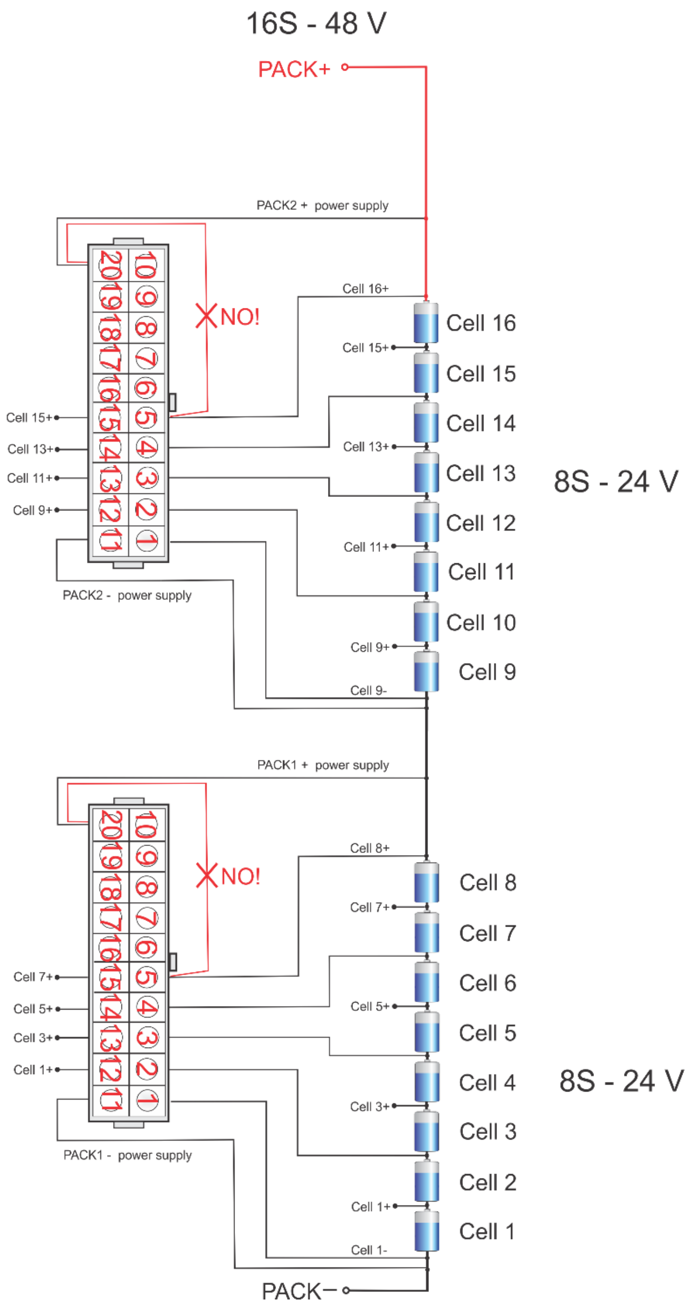

Figure 8: Multiple Slave BMS units for series cell connection.

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Paralleling Cells:

Battery pack capacity may be increased in two ways. By adding a parallel string with the same cells using BMS Master unit and multiple 2Q BMS in Slave configuration or paralleling on the cell connection level. 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 ages faster than the rest of the cells in the sub-pack.
This is a centralized BMS and it is not suitable for connection of multiple sub-packs with a power cable between them. This connection introduces a voltage rise/drop on the adjacent cell due to the increased internal impedance. A distributed BMS should be used in this case.

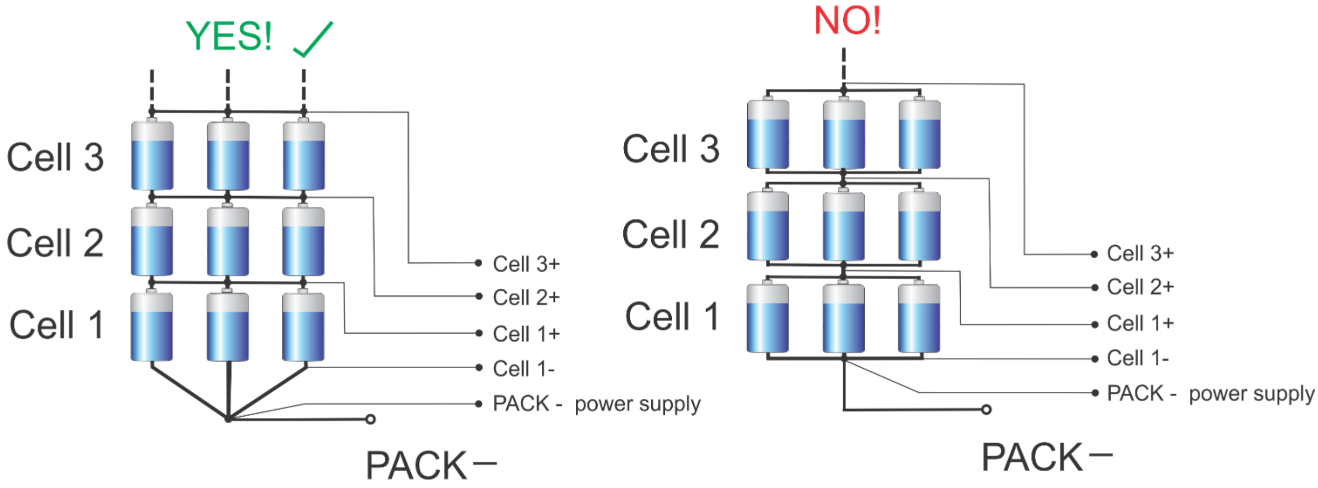

Figure 9: Parallel cell connection.

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BMS Unit Connection Instructions:

Connect the BMS unit to the system by the following order described in Fig. 10. 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. RS485 +5V ENABLE may be used for Master BMS remote ON/OFF.

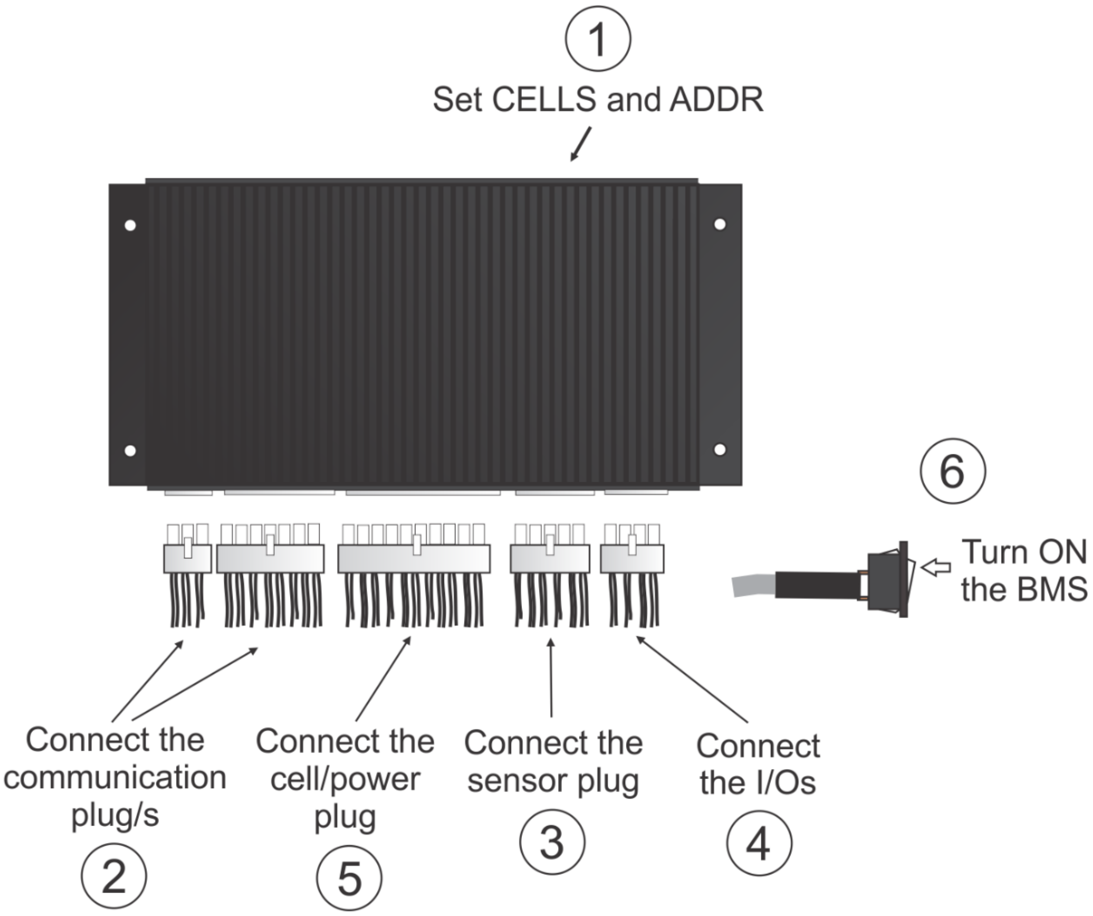

Figure 10: BMS connection/disconnection procedure.

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

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. 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 under 2 seconds. In case of no Errors the RED LED turns off and the BMS unit starts working in normal mode after a beep sound.
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 16 or a cell number <4, error 6 informs the user to properly set the rotary switches. BMS has to be turned off before the pins are changed.
- Error 8 = temperature sensor not detected.
- Error 10 = reference/BMS temperature measurement 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.

Slave BMS Unit LED Indication:

Power LED (green) signals the state when the Slave BMS unit is measuring its battery pack values.

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 16-bit 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 or 15 to notify the user.

Battery Pack Temperature Measurement:

Battery pack temperatures are measured by Dallas DS18B20 digital temperature sensor/s. Up to two sensors can be used in parallel @ each 1-wire port, 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 the sensor 10-pin connector should be disconnected before adding sensors. Temperature sensor/s use shielded 3-wire cable and a common mode line chock to prevent EMI. 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.

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BMS Current Measurement:

Low-side **only** precision shunt resistor for current measurement is used on the Slave BMS unit with the address 1. 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 positive - before the contactor, since the CAN GND may be supplying the inverter negative rail.
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 Slave BMS unit. 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. Four more 300 ms measurements are performed through the whole BMS measurement interval Shunt connection is shown in Fig. 10. 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 a shunt, contactor and fuse protection in case of the short circuit.

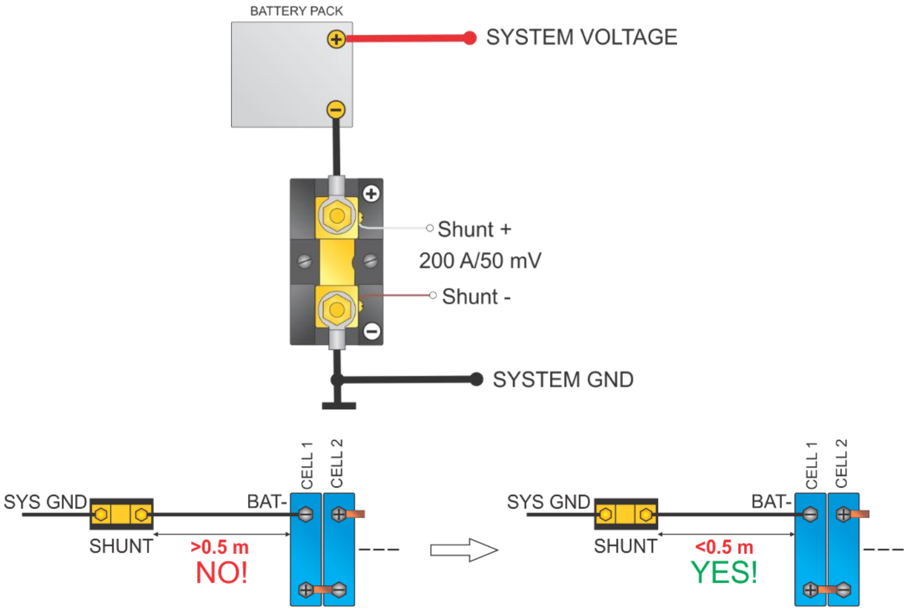

Figure 11: Shunt resistor connection.

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 Wi-Fi 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:

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

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

Table 11: 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

Master BMS Unit:

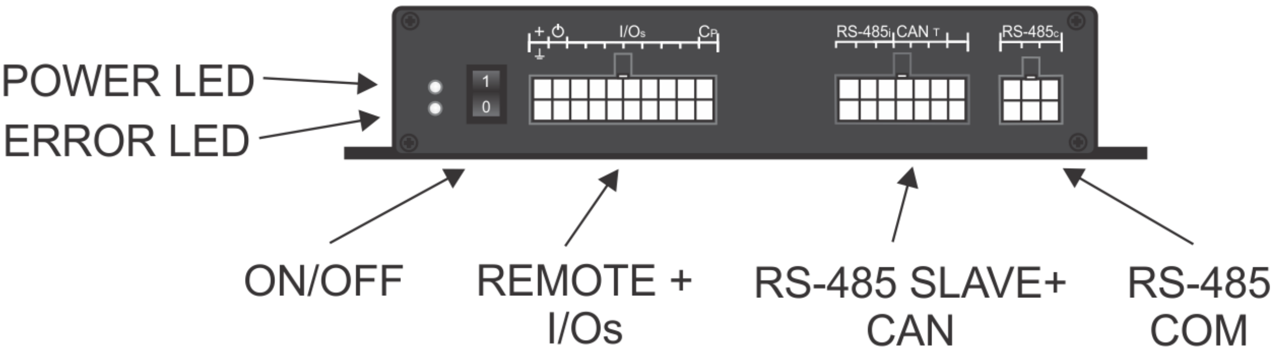

Figure 12: Master BMS Unit function overview.

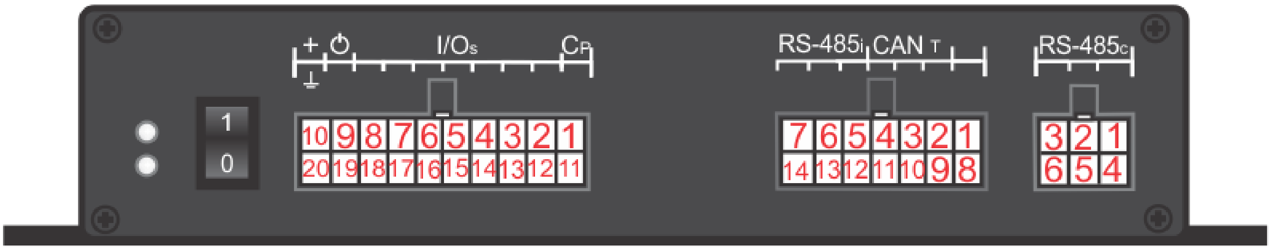

Figure 13:Slave BMS unit connections description.

Table 12: RS-485 COM communication output connector’s pin description to WiFi/PC user interface.

Pin	Connection	Description	Plug
1	RS-485 B COM	Signal B COM	794190-1
2	RS-485 A COM	Signal A COM	
3	-	-	
4	RS-485 +5 V COM	RS-485 +5 V Power supply	
5	RS-485 GND COM	RS-485 Power supply GND	
6	-	-	

Table 13: RS-485 SLAVE communication output, CAN communication description.

Pin	Connection	Description	Plug
1	-	-	794202-1
2	CAN TERMINATION L	120 Ω CAN termination low	
3	CAN L	CAN signal low	
4	-	-	
5	RS-485 +5 V REMOTE ENABLE SLAVE	BMS Enable input from Master BMS unit in Master-Slave configuration **– remote SLAVE ON**	
6	RS-485 B SLAVE	Signal B SLAVE	
7	RS-485 A SLAVE	Signal A SLAVE	
8	-	-	
9	CAN TERMINATION H	120 Ω CAN termination high	
10	CAN H	CAN signal high	
11	CAN GND	CAN ground - galvanically isolated from BMS supply GND	
12	RS-485 CABLE SHIELD SLAVE	SHIELD SLAVE	
13	RS-485 GND SLAVE	RS-485 Power supply GND	
14	RS-485 +5V SLAVE	RS-485 +5 V Power supply	

* Galvanically isolated CAN communication is upgraded upon request.

Table 14: Power supply, remote on/off, IOs and CP connector's pin description.

Pin	Connection	Description	Plug
1	Relay 4 – fused input	Relay 4 internal fused input	
2	Relay 4 - NO	Relay 4 output	
3	Relay 3 – fused input	Relay 3 internal fused input	
4	Relay 3 - NO	Relay 3 output	
5	Relay 2 – fused input	Relay 2 internal fused input	
6	Relay 2 - NO	Relay 2 output	
7	Relay 1 – fused input	Relay 1 internal fused input	
8	Relay 1 - NO	Relay 1 output	
9	Master BMS remote ON/OFF positive	Master BMS remote ON/OFF positive – short to pin 11 for remote OFF (do not connect any voltage source)	
10	Master BMS supply +	Master BMS power supply positive (10.5-90 V)	
11	CP AGND	EVSE CP signal negative	
12	CP Positive	EVSE CP signal	
13	OPTOCOUPLER 1 EMITTER	Optocoupler 1 emitter (negative)	
14	OPTOCOUPLER 1 COLLECTOR	Optocoupler 1 collector (positive)	
15			
16			
17			
18			
19	Master BMS remote ON/OFF negative	Master BMS remote ON/OFF negative - power supply negative	

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		potential (do not connect any voltage source)	
20	Master BMS supply GND	Master BMS power supply negative	

Power Supply:

Supply voltage is limited to 10.5 – 90 V DC by internal protection circuit with a reverse polarity protection. Under-voltage protection UVP is set to 10.4 V. Power consumption differs according to the switched-on relays, digital IOs and communication. If no relay is turned on, the Master BMS unit consumes about 220 mW of power @ 12 V. Power supply entry is not isolated from the rest of the circuit. CAN bus and RS485 COM bus are galvanically isolated from the BMS Master supply. Voltage spikes over 90 V may reset the BMS by enabling OV protection circuit.

Remote ON/OFF input:

Remote ON/OFF input is used to remotely turn ON or OFF the Master BMS. It shorts its under-voltage enable protection UVP to supply negative. If the connection between pins 2 and 12 is opened, Master BMS is in turns ON, while if the connection between pins is shorted, Master BMS turns OFF. Do not apply any voltage source to pins 2 and 12.

Master BMS Relay Outputs:

Relay 1 is a user defined relay output. Its function is set in WiFi “TASK” tab under the “Relay 1”.

Master BMS unit - relays 2, 3 and 4 are used to pre-charge the input capacitors of inverter/s or controllers and prevent high in-rush currents. Relay 3 is programmed as the time configurable (*PRCT*) pre-charge relay. Relay 3 and Relay 2 (negative DC rail DC-) start at the same time. After the configured time delay, Relay 4 (positive DC rail DC+) turns on and relay 3 turns off. Pre-charge should be performed by using an external power resistor to enable 2-4 A of initial current @ empty capacitors (82 – 240 Ohm @ 400 V). System input capacitors should be pre-charged to 80-90 % of the battery voltage in the set pre-charge time delay. Take into account the power rating of the power resistor when designing the system. Relays 2-4 are controlled this way in case off serial or parallel string system configuration.

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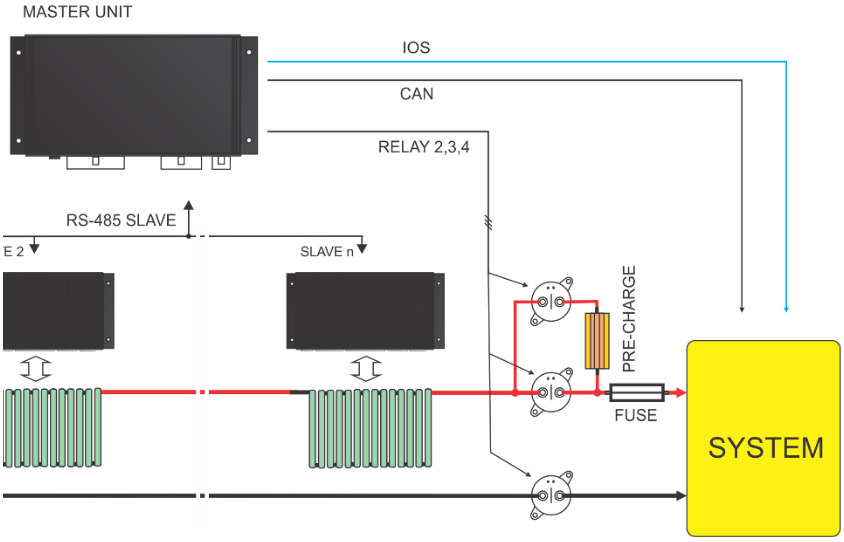

Figure 14: Master BMS HV unit contactors control electrical schematics.

Digital Output:

Master BMS 10M offers a single digital output – OPTOCOUPLER 1. It uses Darlington NPN transistor optocoupler and employs over-voltage protection using SMBJ90A 90 V, reverse voltage output protection with BAT46WH 100 V diode and an over-current protection using a 160mA resettable fuse.
OPTOCOUPLER 1 function is set in WiFi "TASK" tab under the "Opto 1".

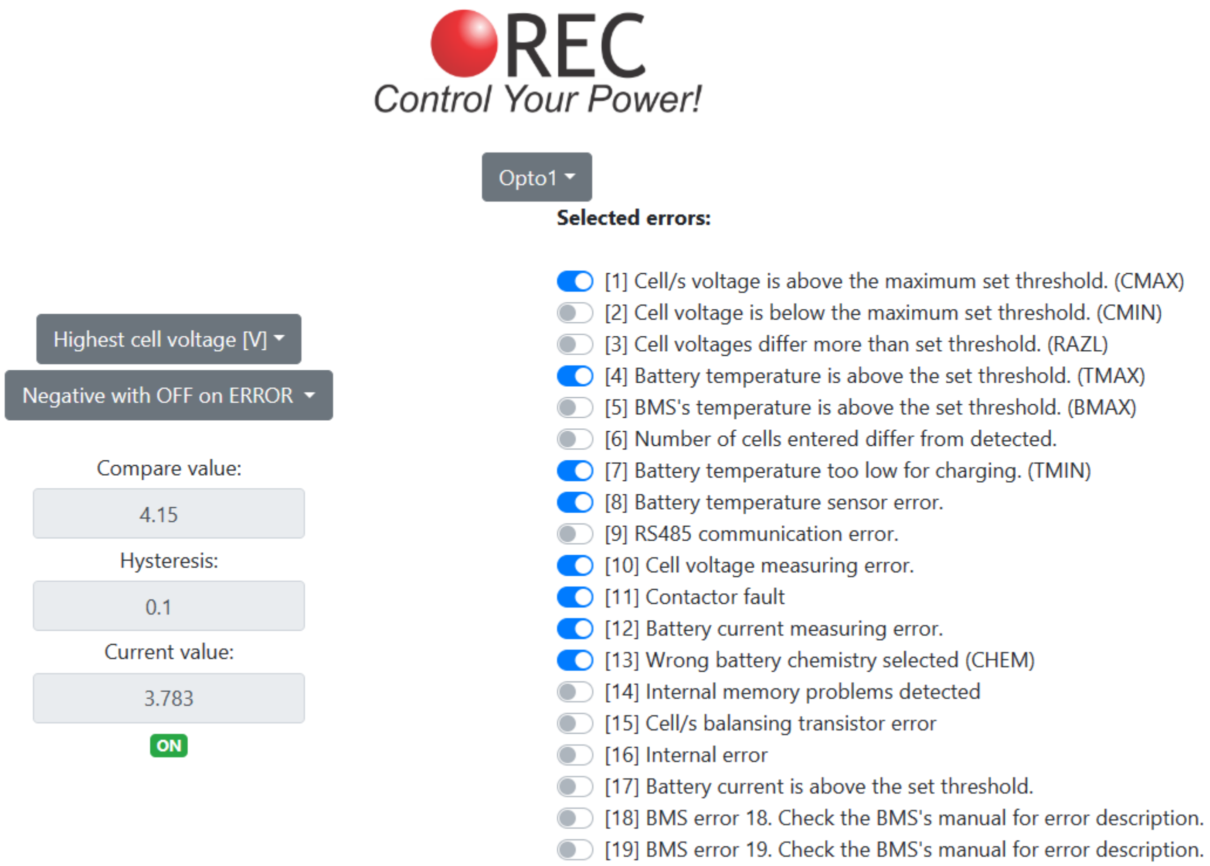

Figure 15: Digital output configuration in Task tab - Wi-Fi module.

Control pilot CP:

Master BMS 10M offers two wire Control Pilot (CP) connection control. CP and AGND should be connected to the BMS. BMS controls the maximum AC charging current, when a charger is set by a dedicated charger with *CHRG* (**please send note about CP and charger used when order**).

Error acknowledge/forced connect input:

Galvanically non-isolated input is used to acknowledge the error and to force the BMS to connect the battery to the system in case of cell over-voltage (error 1) or under-voltage (error 2 with condition that all cell voltages are > 0.85 * Minimum cell voltage *CMIN* setting). A momentary push button may be used between pins 15 and 16 on the 20-pini IOs connector. Do not apply any voltage source on either pin. Error acknowledge works as a short button press (momentary short signals between pins 15 and 16). Error alarm is silenced but error LEDs keep signaling the error until it disappears. Long button hold (>1.2s) forces battery connect to the system in case of cell over-voltage (error 1) or under-voltage (error 2 with condition that all cell voltages are > 0.85 * Minimum cell voltage *CMIN* setting). Battery stays connected to the system for 10 s + pre-charge timer *PRCT*. If the error does not disappear the system is disconnected again. Forced re-connect is possible after 1 min.

RS-485 Communication Protocol:

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 Master BMS unit address is 16.
Unlock password: Serial without the first minus e.g. 2Q-XXXX, 10M-YYYY.

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/115k2(default) – set by the *RSBR* instruction
- Data bits: 8
- Stop bits: 1
- Parity: None
- Mode: Asynchronous
- Little endian format when an array is sent

Table 15: RS-485 instruction set.

INSTRUCTION	DESCRIPTION	BMS ANSWER	SETTING INTERVAL
*IDN?	Identification	Answer “REC-BMS”	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 Slave 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 Slave 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 Slave 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
WCIB?	Which cell is being balanced	BMS first responds with how many Slave BMS units are connected, then it sends unsigned integer values where each bit represents equivalent cell number	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 Should be set to 90 % SOC	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 MIN x.xxx	Cell uder-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
UBDI? or UBDI x.xxx	End of charging cell imbalance voltage	Returns float voltage [V]	0.001 to 0.03 V
CFVC? or CFVC x.xxx	Maximum cell float voltage coefficient	Returns float value	0.0 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
SLAVE BMS UNIT CURRENT SETTINGS INSTRUCTIONS*			
IOFF? or IOFF x.xxx	Current measurement zero offset	Returns float current [A]	-2.0 to 2.0 A

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IOJA? Or IOJA x.xxx	Voltage to current coefficient broadcast to all Slave BMS units	Returns float value	0.0005 to 0.5
BATTERY PACK SETTINGS INSTRUCTIONS			
CCMX? or CCMX x.xx	Maximum system charge current	Returns float current [A]	0 to 700
DCMX? or DCMX x.xx	Maximum system discharge current	Returns float current [A]	0 to 1000
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
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 3.0
DCHC? or DCHCx.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 set to 3-5% SOC	Returns float voltage [V]	1.8 to 4.20 V
CANS? or CANS xxx	CAN bitrate	Returns unsigned char value of 0-4 and 128-132	See Table 18
RSBR? or RSBR x	RS485 COM bitrate	Returns byte value	1 – 56k 2 – 115k2
ERROR LOG INSTRUCTIONS			
FUSE? or FUSExx	First use	Returns byte value	Setting First use to 1 clears the whole Error log after the Maser BMS is restarted and broadcasted to all Slave BMS units
ERRL?	Error log	Returns error log FiFO line, by sending Query multiple times user gets all 6 logs.	Error, BMS with error, BMS element number with error; mm:hh; dd.mm.yyy
MASTER BMS UNIT SETTINGS INSTRUCTIONS			
OP1V? or OP1V xxx	Optocoupler 1 task compare value	Returns float value	Optocoupler 1 task instruction set

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OP1H? or OP1H xxx	Optocoupler 1 task compare value hysteresis	Returns positive float value	
OP1T? or OP1T xxx	Optocoupler 1 task settings	Returns unsigned long	
OP1V? or OP1V xxx	Optocoupler 1 compare current value	Returns float value	
RE1V? or RE1V xxx	Relay 1 task compare value	Returns float value	Relay 1 task instruction set
RE1H? or RE1H xxx	Relay 1 task compare value hysteresis	Returns positive float value	
RE1T? or RE1T xxx	Relay 1 task settings	Returns unsigned long	
RE1V? or RE1V xxx	Relay 1 task compare current value	Returns float value	
WHIN? or WHIN xxx	Master BMS charge Wh counter	Returns float value [Wh]	0 - …
WHOU? or WHOU xxx	Master BMS discharge Wh counter	Returns float value [Wh]	0 - …
WHRE x	Master BMS charge/discharge Wh counter reset	Returns “WH counter reset”	Write only
RSTN?	Master BMS Rest counter	Returns unsigned long value	Read only
NOSU? or NOSU x	Number of Slave BMS units	Returns byte value	0 - 12
SYST? or SYST x	Battery configuration	Returns byte value	0 – serial connection 1 – parallel strings **Master BMS reset required after setting**
CHRG? or CHRG xx	ESS/Charger CAN protocol	Returns byte value	See Table 17
SWVR?	BMS software version	Returns string “2.7”	Read only
HWVR?	BMS hardware version	Returns string “4.2”	Read only
DATE? or DATE xx.xx.xxxx	RTC date	dd.mm.yyyy format	Date is also broadcasted to all Slave BMS units
TIME? or TIME xx:xx:xx	RTC time	hh:mm:ss format	Time is also broadcasted to all Slave BMS units
PRCT xx	Master BMS/Slave BMS unit integrated pre-charge timer	Returns byte value	1-16 s. Setting is broadcasted to all Slave BMS units

* Connect to the dedicated Slave BMS unit.

Parameter accepted and changed value is responded with 'SET' answer.
Example: proper byte message for 'LCD1?' instruction for BMS address 1 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

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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

In case of interrupted Master/Slave BMS firmware update procedure, bootloader stays programmed in the device. To upload the firmware again ON/OFF or remote ON/OFF should be used to restart the BMS device from bootloader and enable firmware update procedure.

Master-Slave RS-485 communication:

Master BMS unit uses the same protocol to asynchronously send instruction messages and queries to all the Slave BMS units on the bus. After the Master BMS unit initial test, bus is scanned for Slave BMS devices. Each Slave BMS unit should have its own distinguished RS-485 address to prevent data collision and to be properly identified. Each found Slave BMS unit is then controlled by Master BMS unit with instructions on when to perform measurement *MEAS*, balance *BALV*, turn on outputs *TYCO*, signal errors *ERRO*,..

All BMS Slave units should be daisy-chained to the SLAVE BMS Master unit slave RS-485 communication port. A 1k2 termination plug should be used @ the last Slave out port. Master BMS unit has an internal 1k2 termination resistor

Table 16: RS-485 Master and Slave BMS units connector pin designator.

RS485 - DESIGNATOR	MASTER BMS RS485 Slave port (14 pin)	SLAVE BMS RS485 input port (6 pin)	SLAVE BMS RS485 output port (14 pin)
RS-485 CABLE SHIELD	12 black - shield	6 black - shield	12 black - shield
AGND - MASTER	13 - gray	5 - gray	13 - gray
RS-485 B	6 - green	1 - green	6 - green
RS-485 A	7 - yellow	2 - yellow	7 - yellow
RS-485 +5 V	14 - pink	4 - pink	14 - pink
RS-485 +5 V ENABLE	5 - white	3 - white	5 - white

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CAN Communication:

CAN communication is used to communicate with the system. There are ten ESS hybrid inverter protocols pre-programmed in the BMS and three CAN supported chargers. ESS/charger selection is performed by the RS-485 instruction *CHRG*. After changing the protocol, the user must also select the CAN bitrate using RS-485 instruction *CANS*, that is updated with ethe instruction without BMS restart. Both parameters are described in the tables below. **HWVR galvanic isolation driver with floating ground is used with isolation level up to 5000 Vrms. RC filters and voltage protection are used to limit the inrush current when establishing the system ground connection.**

Table 17: CHRG and CANS instruction selection list.

ESS/CHARGER	*CHRG* SETTING	*CANS* SETTING	DESCRIPTION
REC BMS CAN protocol	0	Select desired bit-rate from the table 11	250kb 11-bit ID default
Victron	1	2 or 3	250kb or 500kb @ 11-bit ID; 500kb default,
SMA	2	3	500kb @ 11-bit ID
Solax	3	3	500kb @ 11-bit ID
Studer Innotec	4	3	500kb @ 11-bit ID
Growatt	5	3	500kb @ 11-bit ID
Solis	6	3	500kb @ 11-bit ID
Pylontech, Deye, SofarSolar	7	3	500kb @ 11-bit ID
TBB power	8	3	500kb @ 11-bit ID
TC Charger	9	130	250kb @ 29-bit ID
Zivan	10	1-3 see charger settings	125kb, 250kb or 500kb @ 11-bit ID 250kb default
Custom	11	Select desired bitrate from the table	
Piktronik	12	1-4 see charger settings	250kb @ 11-bit ID
Pylontech HV	13	131	500kb @ 29-bit ID
Solis HV	14	131	500kb @ 29-bit ID

Table 18: CANS instruction description.

BAUDRATE	STANDARD 11-BIT ID	EXTENDED 29-BIT ID
100k	0	128
125k	1	129
250k	2	130
500k	3	131
1M	4	132

Examples:
250k with standard 11-bit ID, send CANS 2.
500k with extended 29-bit ID, send CANS 131.

CAN bus should be terminated at each end of the daisy chain connection. **Short pins 2 and 9 to enable 120 Ohm termination inside the BMS.** Additional RJ45 connector plug with 120 Ohms across CANL and CANH is usually used for the end device on the CAN bus for end termination.

REC BMS CAN Protocol:

11-bit TX identifiers: 0x041, 0x042, 0x043, 0x044 and 0x045.
CANS bitrate/ID is set by default to 2. User may set the desired *CANS*.

CAN messages are sent every 150 ms.

Table 19: CAN message description for ID=0x041.

Byte	Description	Type	
1	State of charge [%]	Unsigned char	0-200 LSB = 0.5 % SOC
2	State of health [%]	Unsigned char	0-200 LSB = 0.5 % SOH
3	Battery pack voltage high byte	Unsigned integer	0-65535, LSB = 100 mV
4	Battery pack voltage low byte		
5	Battery pack current high byte	Signed integer	−32768 to 32767 LSB = 50 mA
6	Battery pack current low byte		
7	Battery pack max temperature	Signed char	-127 to 127 LSB = 1° C
8	Battery pack min temperature	Signed char	-127 to 127 LSB = 1° C

Table 20: CAN message description for ID =0x042.

Byte	Description	Type	
1	Low cell voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
2	Low cell voltage low byte		
3	High cell voltage high byte	Unsigned integer	0-65535, LSB = 1 mV
4	High cell voltage low byte		
5	Low cell – Slave BMS position	Unsigned char	1-16
6	Low cell – Slave number	Unsigned char	1-12
7	High cell – Slave BMS position	Unsigned char	1-16
8	High cell – Slave number	Unsigned char	1-15

.

Table 21: CAN message description for ID =0x043.

Byte	Description	Type	
1	Max temperature – Slave BMS position	Unsigned char	1-16
2	Max temperature – Slave number	Unsigned char	1-12
3	Min temperature – Slave BMS position	Unsigned char	1-16
4	Min temperature – Slave number	Unsigned char	1-12
5	Max BMS temperature	Signed char	-127 to 127 LSB = 1° C
6	Error number	Unsigned char	0-16
7	Error number – unit address	Unsigned char	0-12
8	Error number – unit position	Unsigned char	0-16

Table 22: CAN message description for ID =0x044.

Byte	Description	Type	Property
1	Charge voltage high byte	Unsigned integer	LSB = 0.1 V
2	Charge voltage low byte		
3	Max charging current high byte	Signed integer	LSB = 0.1 A
4	Max charging current low byte		
5	Max charging current high byte	Signed integer	LSB = 0.1 A
6	Max charging current low byte		
7	Discharge voltage high byte	Unsigned integer	LSB = 0.1 V
8	Discharge voltage low byte		

Table 23: CAN message description for ID =0x045.

Byte	Description	Type	Property
1	Discharged Ah high byte	Unsigned integer	LSB = 1 Ah
2	Discharged Ah low byte		
3	Connection status	Unsigned char	0 - unconnected 1 - pre-charge 2 - connected 3 - shutting down
4	Relay status	Unsigned char	Bit 1 – Relay 1 Bit 2 – Relay 2 Bit 3 – Relay 3 Bit 4 – Relay 4 Bits 5-8 not used - 0

Victron

11-bit TX ID identifiers: 0x351, 0x355, 0x356, 0x35A, 0x35E, 0x35F, 0x360, 0x372, 0x373, 0x374, 0x375, 0x376, 0x377, 0x378, 0x379, 0x380 and 0x381.
11-bit RX heart-beat 0x305 message from GX unit is neglected.
CANS bitrate/ID is set by default to 3. User may set the desired *CANS* to 2.
CAN messages are sent every 150 ms. Use the RJ45 CAN BMS input on Cerbo/Ekrano with 500k or 250k for Ve.CAN connection. RJ45 pinout: 3: - CAN GND, 7: CANH, 8: CANL

SMA

11-bit TX ID identifiers: 0x351, 0x355, 0x356, 0x35A, 0x35E and 0x35F

CANS bitrate/ID is set by default to 3. User may set the desired *CANS*.
CAN messages are sent every 200 ms. RJ45 pinout: 2: - CAN GND, 4: CANH, 5: CANL

Solax
11-bit TX ID identifiers: 0x351, 0x355, 0x356, 0x359, 0x35C and 0x35E
CANS bitrate/ID is set by default to 3. User may set the desired *CANS*.
CAN messages are sent every 200 ms.

Studer Innotec
11-bit TX ID identifiers: 0x351, 0x355, 0x356, 0x359, 0x35C and 0x35E
CANS bitrate/ID is set by default to 3. User may set the desired *CANS*.
CAN messages are sent every 200 ms. RJ45 pinout: 2: - CAN GND, 4: CANH, 5: CANL or user defined with Xcom-CAN device

Growatt
11-bit TX ID identifiers: 0x311, 0x312, 0x313, 0x314, 0x315, 0x316, 0x317, 0x318, 0x319, 0x320 and 0x321
CANS bitrate/ID is set by default to 3. User may set the desired *CANS*.
CAN messages are sent every 100 ms.

Solis ESS
11-bit TX ID identifiers: 0x351, 0x355, 0x356, 0x359
CANS bitrate/ID is set by default to 3. User may set the desired *CANS*.
CAN messages are sent every 150 ms.

Pylontech/Deye ESS
11-bit TX ID identifiers: 0x351, 0x355, 0x356, 0x359, 0x35C and 0x35E
CANS bitrate/ID is set by default to 3. User may set the desired *CANS*.
CAN messages are sent every 100 ms.

TBB
11-bit TX ID identifiers: 0x351, 0x355, 0x356, 0x359, 0x35C and 0x35E
CANS bitrate/ID is set by default to 3. User may set the desired *CANS*.
CAN messages are sent every 100 ms.

TcCharger
29-bit TX ID identifiers: 0x1806E5F4, 0x1806E7F4 and 0x1806E9F4 + REC BMS CAN protocol
CANS bitrate/ID is set by default to 130. User may set the desired *CANS* to 131. Maximum charging current per device *MAXC* is multiplied by Charge current coefficient *CHCU* and sent to all three IDs.
Number of inverters/chargers *SISN* should be set properly to enable proper error 17 check.
CAN messages are sent every 100 ms.

Zivan
11-bit TX ID identifiers: 0x6C1 and 0x6A1 + REC BMS CAN protocol
CANS bitrate/ID is set by default to 2. User may set the desired *CANS*.
CAN messages are sent every 100 ms.

Custom
If a custom CAN protocol is required, REC Team can implement it as a CUSTOM protocol set as *CHRG* = 11.
CANF may be changed to the desired bitrate and ID length.

Piktronik chargers
11-bit TX ID identifiers: 0x181+ REC BMS CAN protocol
CANS bitrate/ID is set by default to 2. User may set the desired *CANS*.
CAN messages are sent every 100 ms.

Pylontech HV
29-bit TX ID identifiers: 0x4210, 0x4220, 0x4230, 0x4240, 0x4250, 0x4260, 0x4270, 0x4280, 0x4290, 0x7310, 0x7320, 0x7330, and 0x7340.
CANS bitrate/ID is set by default to 131.
CAN messages are sent every 80 ms.

Solis HV
29-bit TX ID identifiers: 0x1801, 0x1872, 0x1873, 0x1874, 0x1875, 0x1876, 0x1877 and 0x1878.
CANS bitrate/ID is set by default to 131.
CAN messages are sent every 80 ms.

Master BMS Unit Start Procedure:

When the BMS Master unit is turned ON it commences the internal initialization procedure, enables RS-485 +5 V ENABLE Slave supply and after 4 s start searching for Slave BMS units on the RS-485 Slave bus. If no Slave BMS unit is detected, error 9 is signaled and the BMS stays in the Slave BMS detection mode. If Master BMS unit detects different number of Slave BMS units than programmed by Number of Slave units "*NOSU*" setting, BMS goes to normal operation without starting the relays for connection and alarms error 21. "XXXX" should be used to properly set number of Slave BMS. When set a restart is required to eliminate error 20 alarm.

Master 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 consecutives ON blinks while the balancing mode is indicated by 3 consecutives 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.

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 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. Master BMS unit sends the instruction to each Slave BMS unit individually which cells should be balanced. If the Slave BMS unit does not get a refreshed value in 5 s, all balancing is switched off.

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. BMIN cell voltage setting should be set to the voltage that corresponds to 90 % of the usable capacity.

Balancing Voltage END(BALV):

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 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 24: 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.

Battery Pack's Charging Algorithm:

The communication between the REC Master BMS unit and the SMA SI 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 each 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 x *parallel Strings*. 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 25: Maximum charging current calculation.

SETTING	VALUE	UNIT
Battery Capacity (CAPA)	100	Ah
Parallel Strings detected	2	n.a.
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 x *parallel strings* = 0.6 1/h x 100Ah x 2 = 120 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 **120 A** due to lower value of the *Charge Coefficient* CHAC x *Battery Capacity* CAPA x *parallel strings*.

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. If CFVC is set to 0.0, charging current is set to 0.0 A until the *End of Charge Hysteresis* CHIS and *End of Charge SOC hysteresis* SOCH have been met.
SOC is calibrated to 100 % and Power LED lights ON 100 % Charger enable relay 1 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.

BMS forces a full charge if the pack was not fully charged for more than three weeks.

In case BMS is not able to control the MPPT/Non-SMA SI charging sources directly (MPPT should be set to charge when the remote is in short), relay 1 can be used to controlled the charger. MPPT should be programmed with its own charging curve set as End of charge voltage x number of cells.

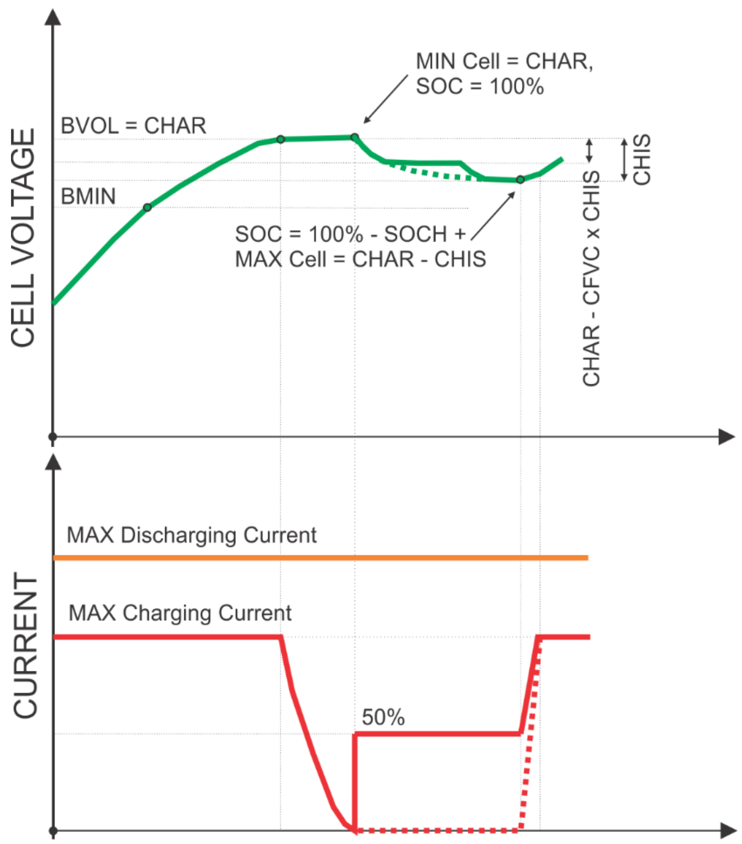

Figure 16: Charging diagram.

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 0.0 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. If CFVC is set to 0.0, charging current is set to 0.0 A until the *End of Charge Hysteresis* CHIS and *End of Charge SOC hysteresis* SOCH have been met

Novi trg 9, 6230 Postojna, Slovenia
mail: info@rec-bms.com; www.rec-bms.com

Battery Pack's Discharging Algorithm:

Calculated maximum discharging current is sent to the GX device by CAN communication in each 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 x *parallel strings*. 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 26: Maximum discharging current calculation.

SETTING	VALUE	UNIT
Battery Capacity (CAPA)	100	Ah
Parallel Strings detected	2	n.a.
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 x *parallel strings* = 1.5 1/h x 100Ah x 2 = 300 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 **200 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. At discharge currents lower than 0.05 C or positive, 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. If the battery current is lower than 0.05 C or positive, SOC is reset to 1 %. 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. CLOW cell voltage setting should be set to the voltage that corresponds to 3 % of the usable capacity.

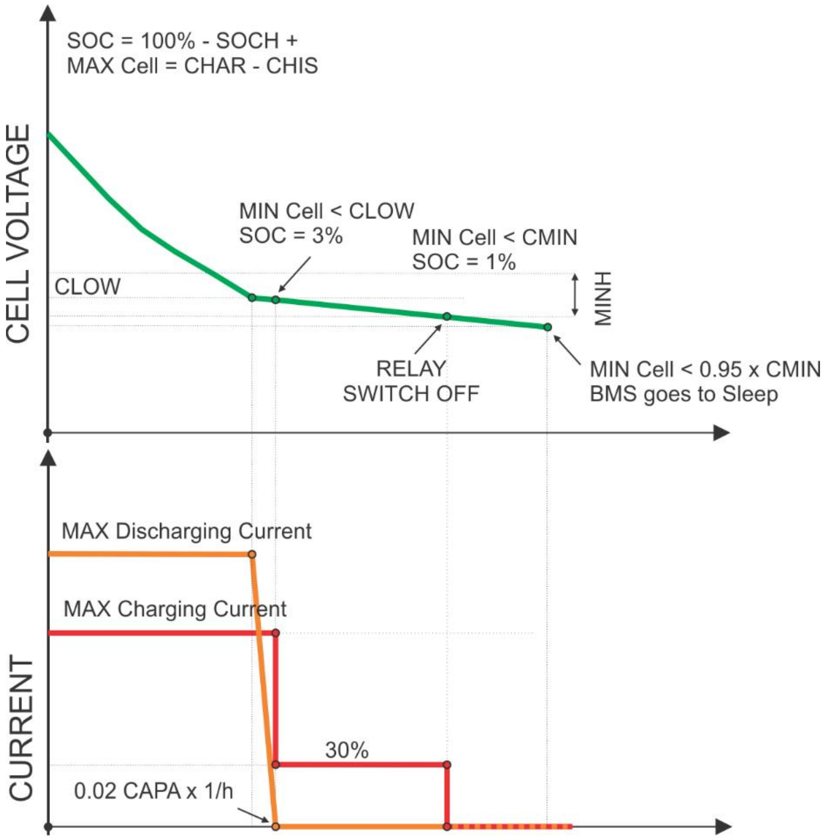

Figure 17: Discharging diagram.

System Error Indication:

System errors are indicated On the Master BMS and Slave BMS units 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 27: 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. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Wait until the BMS does its job or use force connect.
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 % in case of discharge current lower than 0.05C or positive. Charging is enabled, discharging is disabled. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Plug in the charging sources. Lower MIN VCell setting CMIN for enabling the internal relay. Use force connect to charge.
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. Master BMS unit relay 2 and 4 are connected. Charge relay 1 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. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 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. Master BMS unit relay 2 and 4 are connected. Charge relay 1 is enabled.	• Wait until the BMS cools down.

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mail: info@rec-bms.com; www.rec-bms.com

6	Number of cells, address is not set properly.	Charging is disabled, discharging is disabled. All relays are disconnected.	• Set proper Slave BMS unit 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. Master BMS unit relay 2 and 4 are connected. Charge relay 1 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. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Turn-off Slave BMS unit and try to re-plug the temp. sensor. If the Slave BMS still signals error 8, contact the service. The temperature sensors should be replaced.
9	Communication error.	RS-485 Master-Slave communication only. Charging is disabled, discharging is disabled. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	
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. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Turn-off the Master BMS unit and check the cells connection to the BMS and fuses. Restart the Master BMS unit. • 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. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Restart the Master 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. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Check the system settings/HW configuration. If the BMS still signals error 12, contact the service or change the BMS settings.

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13	Wrong cell chemistry CHEM selected.	In some application the chemistry pre-set is compulsory. Charging is disabled; discharging is disabled. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Use PC Control Software/Wi-Fi module 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. Master BMS unit relay 2 and 4 are connected. Charge relay 1 is enabled.	• Use PC Control Software/Wi-Fi module to set proper settings
15	Cell balancing/measurement failure	During the start-up a burned fuse or cell balancing failure was detected. Charging is enabled; discharging is enabled. Master BMS unit relay 2 and 4 are connected. Charge relay 1 is enabled.	• Restart the Master 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. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Restart the Slave 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 is reduced. Charging is enabled; discharging is enabled. Master BMS unit relay 2 and 4 are connected. Charge relay 1 is enabled.	• Wait until the Master BMS unit reduces the charge/discharge battery current.

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18	Parallel string current distribution error	Battery current over the parallel string is not distributed evenly. One or more strings detects very low current – possible fuse/contactor failure. Charging is enabled; discharging is enabled. Master BMS unit relay 2 and 4 are connected. Charge relay 1 is enabled.	• Check the parallel string packs and their contactors
19	Parallel string Voltage/SOC difference	String battery sub-pack have different voltage/SOC level and should not be connected in parallel due to high balancing equalization in-rush current. Charging is disabled; discharging is disabled. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Connect higher voltage/SOC strings and try to discharge them or charge lower voltage/SOC sub-packs. *NOSU* has to be set accordingly and only dedicated Slave units have to be turned on.
20	Cell-under-voltage lock < 0.8 * CMIN	Some application requires cell under-voltage Lock. Unlock is performed by special instruction set after battery inspection. Charging is disabled; discharging is disabled. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Contact REC for implementation instructions.
21	Master BMS does not find set number of Slave BMS *NOSU* in the system	Master BMS did not discover set *NOSU* number of Slave BMS on the Master-Slave RS485 bus. Charging is disabled; discharging is disabled. Master BMS unit relay 2 and 4 are disconnected. Charge relay 1 is disabled.	• Check if *NOSU* is set properly or why Master BMS did not found *NOSU* number of Slave units. Check communication cables, RS485 addresses, termination and if all Slave BMS are turned on/start.

Slave BMS Unit Dimensions:

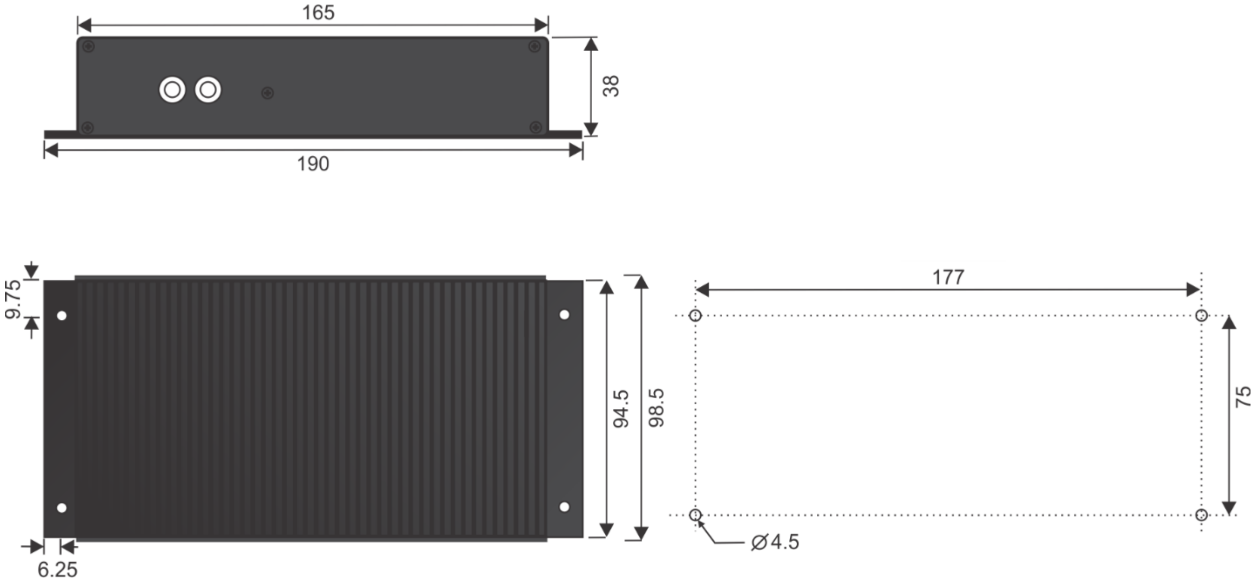

Figure 18: Slave BMS unit dimensions.

Master BMS Unit Dimensions:

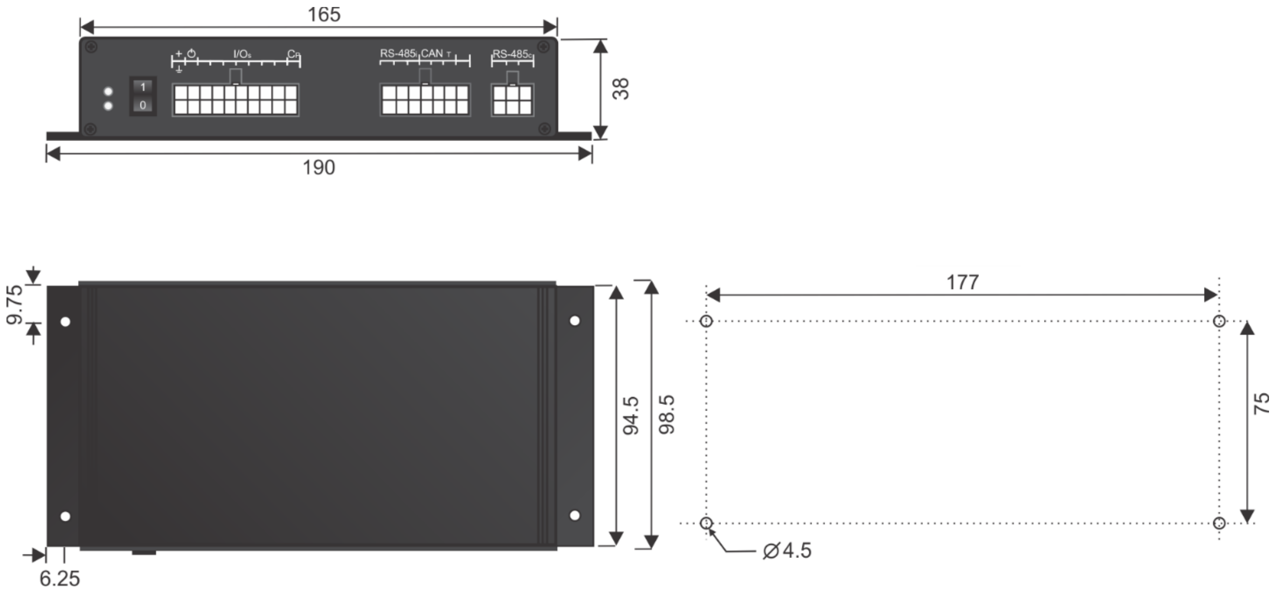

Figure 19: Master BMS unit dimensions.