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ACTIVE BATTERY MANAGEMENT SYSTEM
REC ACTIVE BMS

Features:

- robust and small design (135 mm x 105 mm x 44 mm)
- suitable for 4 cells
- 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 (up to 2 temperature sensors)
- under temperature charging protection
- active cell balancing up to 2 A DC per cell
- shunt current measurement (resolution 7.8 mA @ ± 200 A)
- 2 galvanically isolated user defined multi-purpose digital output/input
- 2 programmable relay (normally open or normally closed)
- galvanically isolated RS-485 communication protocol
- CAN communication
- error LED + buzzer indicator (option)
- PC user interface for changing the settings and data-logging (optional accessory)
- hibernate switch
- one IP65 protected connector for all connections
- one-year warranty

General Description of the BMS Unit:

Battery management system (BMS) is a device that 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 maximum allowed voltage. Overcharging the cell additionally lowers its capacity and number of charging cycles. The BMS equalizes cells' voltage by diverting some of the charging current from higher voltage cells to whole pack or from whole pack to lower voltage cells – active balancing. The device temperature is measured to protect the circuit from over-heating due to unexpected failure. Battery pack temperature is monitored by Dallas DS18B20 digital temperature sensor/s. Maximum 2 temperature sensors per unit may be used. Current is measured by 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 the new battery pack. The BMS default parameters are listed in Table 1.

Default Parameters:

Table 1: Default BMS parameter settings.

parameter	**value**	**unit**
chemistry	3 ($LiFePO_4$)	n.a.
capacity	180	Ah
balance start voltage	3.5	V
balance end voltage	3.65	V
maximum diverted current per cell	up to 2 (4A peak in ramp)	A
cell over voltage switch-off	3.85	V
cell over voltage switch-off hysteresis per cell	0.05	V
charger end of charge switch-off pack	3.65	V
charger end of charge switch-off hysteresis	0.15	V
cell under voltage protection switch-off	2.7	V
under voltage protection switch-off hysteresis per cell	0.05	V
pack under voltage protection switch-off timer house	4	s
battery pack under voltage protection house	12.0	V
battery pack under voltage protection house hysteresis	0.5	V
battery pack under voltage protection main	11.0	V
battery pack under voltage protection main hysteresis	0.2	V
pack under voltage protection switch-off timer house	4	s
pack under voltage protection switch-off attempts main	10	n.a.
cells max difference	0.25	V
BMS maximum pack voltage	**16.8**	**V**
BMS charge hysteresis per cell	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
under temperature charging disable	-10	°C
voltage to current coefficient	0.0078125	A/bit
max DC current relay @ 60 V DC	0.7	A
max AC current relay @ 230 V AC	2	A
BMS unit stand-by power supply	< 60	mW
max DC current @ optocoupler	15	mA
max DC voltage@ optocoupler	62.5	V

BMS unit disable power supply	< 1	mW
BMS unit cell balance fuse rating (SMD)	3	A
internal relay fuse	2 slow	A
dimensions with enclosure (l × w × h)	111 x 135 x 44	mm
IP protection (BMS in enclosure)	IP65	

System Overview:

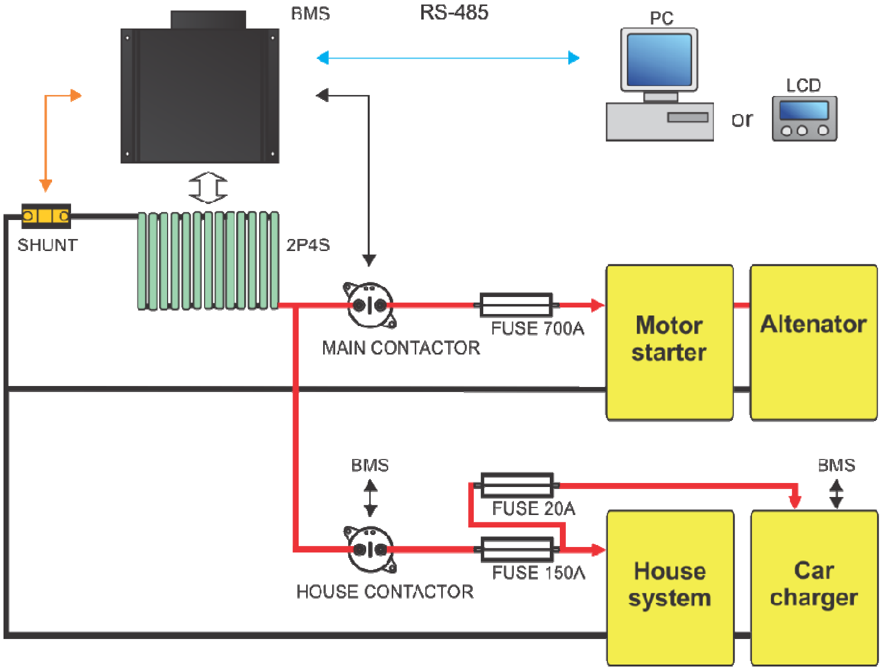

Figure 1: System overview.

BMS Unit Connections:

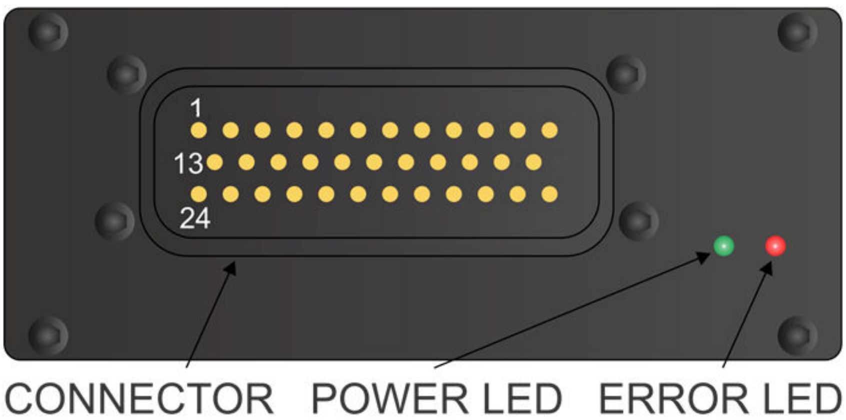

Figure 2: BMS unit function overview.

Table 2: BMS unit connections.

connection	description	
1	Internal Relay – house system contactor control	Normally closed
2	Internal Relay – house system contactor control	Fused input
3	Internal Relay – starter contactor control	Normally closed
4	Internal Relay – starter contactor control	Normally open
5	Internal Relay – starter contactor control	Fused input
6	Hibernate switch ground	-
7	Hibernate switch signal	-
8	Cell 4 positive	Analog signal
9	Cell 3 positive	Analog signal
10	Cell 2 positive	Analog signal
11	Cell 1 positive	Analog signal
12	Cell 1 ground	Analog signal
13	Internal Relay – house system contactor control	Normally open
14	Optocoupler Car charger collector	-
15	Optocoupler Car charger emitter (darlington + reverse protection diode + polyfuse)	-
16	Optocoupler Alarm collector	-
17	Optocoupler Alarm emitter (darlington + reverse protection diode + polyfuse)	-
18	CAN Vcc	-
19	CAN Low	-
20	RS485 Vcc	-
21	RS485 A	-
22	RS485 ground	-
23	RS485 B	-
24	Shunt-	System ground
25	Shunt+	Cell 1 ground
26	Dallas 18B20 temp. sensor	Ground + shield
27	-	-
28	Dallas 18B20 temp. sensor	+ 5 V
29	Dallas 18B20 temp. sensor	1-wire digital signal
30	CAN High	-
31	CAN ground	-
32	-	-
33	Address pin 3	Normally 0, connect to pin 35 to change to 1
34	Address pin 2	Normally 0, connect to pin 35 to change to 1
35	Address pin ground	Fused ground for Address pins

Setting the RS-485 Address:

Address of the BMS unit is selected via Address pins. Factory address is 2 . Formula for changing address is:

$$\text{ActiveBMS } ADDRESS = 2^2 * \overline{Address\ pin\ 3} + 2^1 * \overline{Address\ pin\ 2} + 2^0$$

! If multiple BMS units are used distinguished addresses should be set to avoid data collision on the RS-485 communication bus!

BMS Unit Connector:

Before starting assembly please go to website:

http://www.te.com/catalog/pn/en/776164-1?RQPN=776164-1

…and read connector assembly datasheet:

AMPSEAL Automotive Plug Connector and Header Assembly in Application Specification and
AMPSEAL Automotive Plug Assemblies 776268… in Instruction Sheet (U. S.).

You can find the connector's datasheet at the end of this manual.

BMS Unit Connector, Cells part:

Connect each cell to the BMS unit cell connector plug. Use silicon wires with cross section of 0.5 – 1.4 mm^2 (20-16 AWG). ! **Before inserting the connector check voltages and polarities with voltmeter of each connection!**

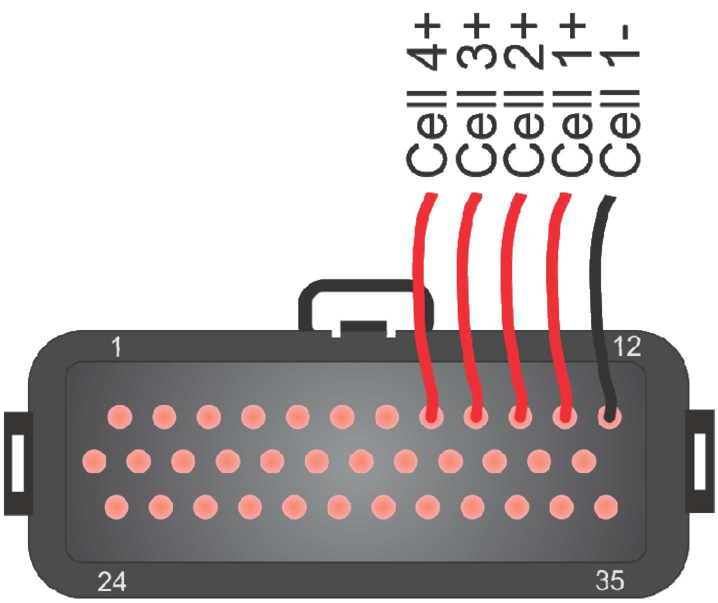

Figure 3: Battery pack to BMS connection.

BMS Unit Power Supply:

BMS unit is always supplied from the 4-th cell connection.

BMS Unit Connection Instructions:

Connect all necessary connections to the BMS connector first, check the polarities and then plug the female connector into the BMS. When the system components are plugged in, the enable switch can be turned ON and the BMS unit starts the test procedure.

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

RS-485 Communication Protocol:

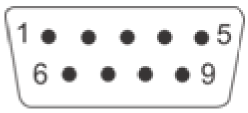

Figure 4: RS-485 DB9 connector front view.

Table 3: RS-485 DB9 connector pin designator.

Pin	Designator
1	-
2	GND
3	B
4	A
5	-
6	+5V
7	-
8	-
9	-

Galvanically isolated RS-485 (EN 61558-1, EN 61558-2) serves for logging and changing BMS parameters. Dedicated PC BMS Master Control Software or another RS-485 device may be used for the communication.

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, for the whole message except STX in ETX
- ETX - end transmission <0xAA> (always)

Dataflow:

- Bit rate: 56k
- Data bits: 8
- Stop bits: 1
- Parity: None
- Mode: Asynchronous

Table 4: RS-485 instruction set.

INSTRUCTION	DESCRIPTION	BMS ANSWER
'*','I','D','N','?'	Identification	Answer "ACTIVE"
'L','C','D','1','?'	Main data	Returns 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%
'C','E','L','L','?'	Cell voltages	BMS first responds with how many BMS units are connected, then it sends the values of the cells in float format
'P','T','E','M','?'	Cell temperatures	BMS first responds with how many BMS units are connected then it sends the values of the temperature sensors in float format
'R','I','N','T','?'	Cells internal DC resistance	BMS first responds with how many BMS units are connected then it sends the values in float format
'B','T','E','M','?'	BMS temperature	BMS first responds with value 1, then it sends the values of the BMS temperature sensor in float format
'E','R','R','O','?'	Error	Responds with 4 bytes as follows ERRO [0] = 0 – no error, 1 – error ERRO [1] = BMS unit ERRO [2] = error number (1-13) in ERRO [3] = number of the cell, temp. sensor where the error occurred
'B','V','O','L', '?'/ 'B','V','O','L', ' ','x.xx'	Cell END balancing	Returns float voltage [V]
'C','M','A','X','?'/ 'C','M','A','X',' ','x.xx'	Max allowed cell voltage	Returns float voltage [V]
'M','A','X','H', '?'/ 'M','A','X','H', ' ','x.xx'	Max allowed cell voltage hysteresis	Returns float voltage [V]
'C','M','I','N', '?'/ 'C','M','I','N', ' ','x.xx'	Min allowed cell voltage	Returns float voltage [V]
'M','I','N','H', '?'/ 'M','I','N','H', ' ','x.xx'	Min allowed cell voltage hysteresis	Returns float voltage [V]
'T','M','A','X', '?'/ 'T','M','A','X', ' ','x.xx'	Maximum allowed cell temperature	Returns float temperature [°C]
'T','M','I','N', '?'/ 'T','M','I','N', ' ','x.xx'	Minimum allowed temperature for charging	Returns float temperature [°C]
'B','M','I','N', '?'/ 'B','M','I','N', ' ','x.xx'	Balancing START voltage	Returns float voltage [V]
'C','H','A','R', '?'/ 'C','H','A','R', ' ','x.xx'	End of charging voltage per cell	Returns float voltage [V]
'C','H','I','S', '?'/ 'C','H','I','S', ' ','x.xx'	End of charging voltage hysteresis per cell	Returns float voltage [V]
'I','O','F','F','?'/ 'I','O','F','F',' ','x.xx'	Current measurement zero offset	Returns float current [A]
'T','B','A','L','?'/ 'T','B','A','L',' ','x.xx'	Max allowed BMS temperature	Returns float temperature [°C]
'B','M','T','H','?'/ 'B','M','T','H',' ','x.xx'	Max allowed BMS temperature hysteresis	Returns float temperature [°C]

'V','M','A','X','?'/ 'V','M','A','X',' ','xxx'	Number of exceeded value of CMAX	Returns integer value
'V','M','I','N','?'/ 'V','M','I','N',' ','xxx'	Number of exceeded value of CMIN	Returns integer value
'C','Y','C','L','?'/ 'C','Y','C','L',' ','xxx'	Number of battery pack cycles	Returns integer value
'C','A','P','A','?'/ 'C','A','P','A',' ','x.xx'	Battery pack capacity	Returns float capacity [Ah]
'I','O','J','A','?'/ 'I','O','J','A',' ','x.xx'	Voltage to current coefficient	Returns float value
'R','A','Z','L','?'/ 'R','A','Z','L',' ','x.xx'	Package cell difference	Returns float voltage [V]
'C','H','E','M', '?'/ 'C','H','E','M', ' ','xxx'	Li-ion chemistry	Returns unsigned char value
'S','O','C','H','?'/ 'S','O','C','H',' ','x.xx'	Charger SOC hysteresis	Returns float value 0 - 0.99
'S','T','O','N','?'/ 'S','T','O','N',' ','x.xx'	Voltage to enable starter contactor	Returns float voltage [V]
'S','T','O','F','?'/ 'S','T','O','F',' ','x.xx'	Voltage to disable starter contactor	Returns float voltage [V]
'H','O','O','N','?'/ 'H','O','O','N',' ','x.xx'	Voltage to enable house contactor	Returns float voltage [V]
'H','O','O','F','?'/ 'H','O','O','F',' ','x.xx'	Voltage to disable house contactor	Returns float voltage [V]
'M','N','S','A','?'/ 'M','N','S','A',' ','xxx'	Maximum number of start attempts	Returns unsigned char value
'M','T','S','A','?'/ 'M','T','S','A',' ','xxx'	Maximum timer for start attempt	Returns unsigned char value
'C','R','E','F','?'/ 'C','R','E','F',' ','xxx'	Voltage reference value	Returns float value [V] 3.00 V ± 12 mV
'R','N','S','A',' ','0'	Resets discharge attempts and discharge SOC hysteresis	Accepts only value 0 (write only)

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><0x01><0xD9><0xAA>

RS-485 message are 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.

CAN Communication Protocol (not programmed):

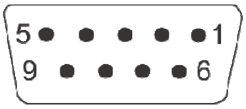

Figure 5: CAN female DB9 connector front view.

Table 4: CAN DB9 connector pin designator.

Pin	Designator
1	TERMINATION
2	CANL + TERMINATION
3	GND
4	
5	-
6	GND
7	CANH
8	-
9	

BMS Unit Start Procedure:

When the BMS unit is turned ON it commences the test procedure. BMS checks if the user tries to upload a new firmware by turning on the red error LED. After the timeout red error LED turns off and the BMS unit starts working in normal mode.

BMS Unit LED Indication:

Power LED (**green**) is turned on in 1 s intervals, if the BMS is powered. Error LED (**red**) is turned on in case of system error and blinks number of error with 50 % duty cycle. Between every number blinking, a small timeout is present.

Cell Voltage Measurement:

Cell voltages are measured every second. The cell measurement algorithm performs several measurements to digitally filter the influence of 50, 60, 100 and 120 Hz sinus signal. 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 actively with very high efficiency in opposite to passive balancing, where all energy is lost in heat. Another benefit of active balancing is charging of dangerously low cell, if other cells are above dangerous level, consequently longer pack usage is possible.

Balancing START Voltage:

If errors 2, 4, 5, 8, 10, 12 are not present, highest cell voltage rises above Balancing START voltage and current is > 0.2 A (charging stage), the BMS initiates balancing algorithm. A weighted cell voltage average is determined including cells DC internal resistance. Balancing algorithm calculates the voltage above which the cells are balanced. The lowest cell voltage is taken into account determining balancing voltage.

Balancing END Voltage:

If errors 2, 4, 5, 8, 10, 12 are not present, the cells above balancing END voltage are 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 20 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 sensors. Up to eight sensors can be used in parallel. BMS should be turned off before adding additional sensors. If the temperature sensors wiring is placed near the power lines shielded cables should be used.

BMS Current Measurement:

A low-side precision shunt resistor for current measurement is used. A 4-wire Kelvin connection is used to measure the voltage drop on the resistor. As short as possible **shielded cable** should be used to connect the power shunt and BMS. The battery pack current is measured every second. A high precision 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. Shunt connection is shown in Fig. 6.

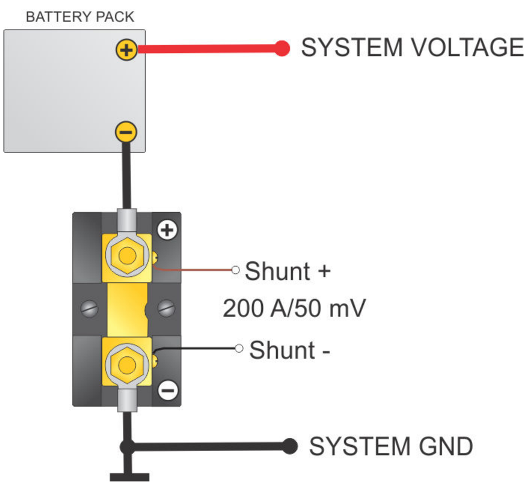

Figure 6: Shunt resistor connection.

Voltage-to-current Coefficient:

Different size and resistance shunts can be used, since the voltage-to-current coefficient can be changed in the BMS Control software as 'I','O','J','A',' ','xxxxx'   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 different shunt resistor at current $I_{currentx}$.

ADC has a pre-set gain of 8. With a maximum input voltage difference of 0.256 V.

Battery Pack SOC Determination:

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

Table 5: 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 $LiMn_2O_4$

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 cell 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 minimum SOC of 35 % or less was reached in the cycle.

Battery Pack's Charging Algorithm:

When all the cells reach End of Charge voltage SOC is reset to 100 %. If maximum cell voltage is reached, main contactor and car charger are disconnected. Some of the BMS errors also disconnect charging sources from the battery.

Battery Pack's Discharging Algorithm:

When the lowest cell falls below cell under voltage protection switch-off or battery pack voltage falls below house or main contactor threshold house/main contactors are switched off after set time interval. House contactor has 4 s under-voltage time interval. Main contactor has 6 s under-voltage time interval with maximum 10 attempts. If 10 attempts are made and voltage does not rise above threshold, SOC is set to 0 %. Only car charger relay is turned on. Attempts are reset when SOC rises for 20 %. Contactors are turned on. Some of the BMS errors also disconnect charging sources from the battery.

Digital outputs:

Digital outputs are implemented with galvanical isolation. Darlington optocouplers with diode reverse protection are used. When closed, 0.9 V voltage drop over the digital output should be taken into account. Optocoupler output can drive enable/disable charger inputs, small signal relays and LED diodes. Figure 7 shows two different connection schematics.

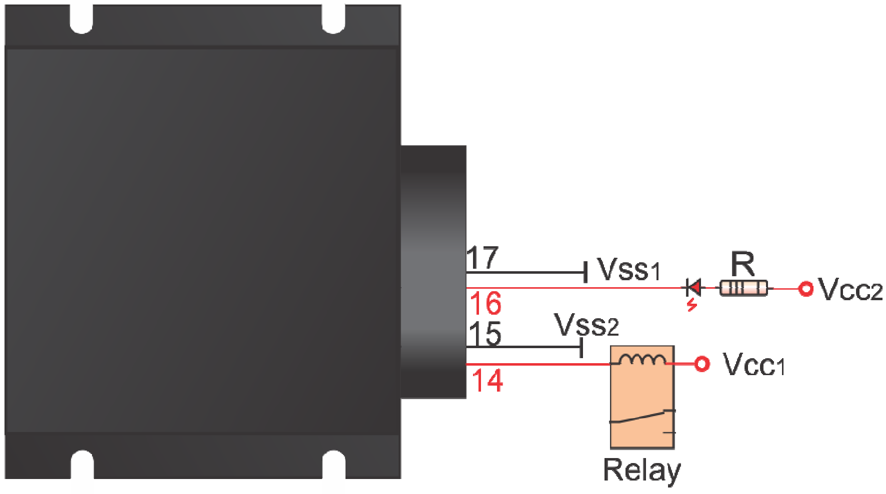

Figure 7: BMS digital outputs schematics.

Current limit resistor R can be calculated as:

$$R = \frac{V_{\mathrm{CC2}} - 0.9\ V\ - V_{\mathrm{FVLED}}}{I_{\mathrm{LED}}}$$

V_{FVLED} represents LED forward voltage drop (typ. 1.9 – 2.3 V) while I_{LED} represents LED current (2-5 mA).

Contactor Connection:

Charging/discharging contactors are driven by charge/discharge relays in the BMS. If there is high input capacity (> 2,000 uF) at the charging sources/discharging loads, pre-charge should be used to avoid high current spikes when the contactor is turned on. High current spikes degrade the contactor, cells and input capacitors in the electronic device. Figure xx shows contactor connection with or without the pre-charge circuit.

System Error Indication:

System errors are indicated with **red** error LED by the number of ON blinks, followed by a longer OFF state.

Table 6: BMS error states.

Number of ON blinks	ERROR	BMS	OWNER
1	Single or multiple cell voltage is too high (cell over voltage switch-off).	BMS will try to balance down the problematic cell/cells to safe voltage level (10 s error hysteresis + single cell voltage hysteresis is applied). Charging is disabled, discharging is enabled.	• Wait until the BMS does its job.

2	Single or multiple cell voltage is too low (cell under voltage protection switch-off).	BMS will try to charge the battery (10 s error hysteresis + single cell voltage hysteresis is applied). Car charger is enabled.	• Plug in the charger.
3	Cell voltages differs more than set.	BMS will try to balance the cells (5 s error hysteresis + 20 mV voltage difference hysteresis). Charging is enabled, discharging 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 (over temperature switch-off).	Cells temperature or cell inter-connecting cable temperature in the battery pack is/are too high (10 s error hysteresis 2°C hysteresis). Charging is disabled, discharging is disabled.	• Wait until the pack cools down.
5	BMS temperature is too high –internal error (BMS over temperature switch-off).	Due to extensive cell balancing the BMS temperature rose over upper limit (5 s error hysteresis + 5 °C temperature hysteresis). Charging is disabled, discharging is disabled.	• Wait until the BMS cools down.
6	Number of cells, address is not set properly.	Number of cells at the back of the BMS unit was changed from the default manufacturer settings.	• Set the proper number of cells, address.
7	The temperature is too low for charging (under temperature charging disable).	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). Car charger 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 s error hysteresis). Charging is disabled, discharging is disabled.	• Turn-off BMS unit and try to re-plug the temp. sensor. If the BMS still signals error 8, contact the service. The temperature sensors should be replaced.

9	Communication error. (RS-485 Master-Slave communication only).		
10	Cell in short circuit or BMS measurement error.	Single or multiple cell voltage is close to zero or out of range, indicating a blown fuse, short circuit or measuring failure (20 s error hysteresis + 10 mV voltage difference hysteresis). Charging is disabled, discharging 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. When the error is detected, the BMS tries to un-shorten the main relay by turning it ON and OFF for three times. Charging is disabled, discharging is disabled.	• Restart the BMS unit. If the same error starts to signal again contact the service.
12	Error measuring current.	Current sensor is disconnected or not working properly. Charging is disabled, discharging is disabled.	• Turn-off the BMS and check the sensor connections, re-plug the current sensor connector. Turn BMS back ON. If the BMS still signals error 12, contact the service.
13	Wrong cell chemistry selected.	In some application the chemistry pre-set is compulsory (5 s error hysteresis). Charging is disabled, discharging is disabled.	• Use PC Control Software to set proper cell chemistry.

BMS Unit Dimensions:

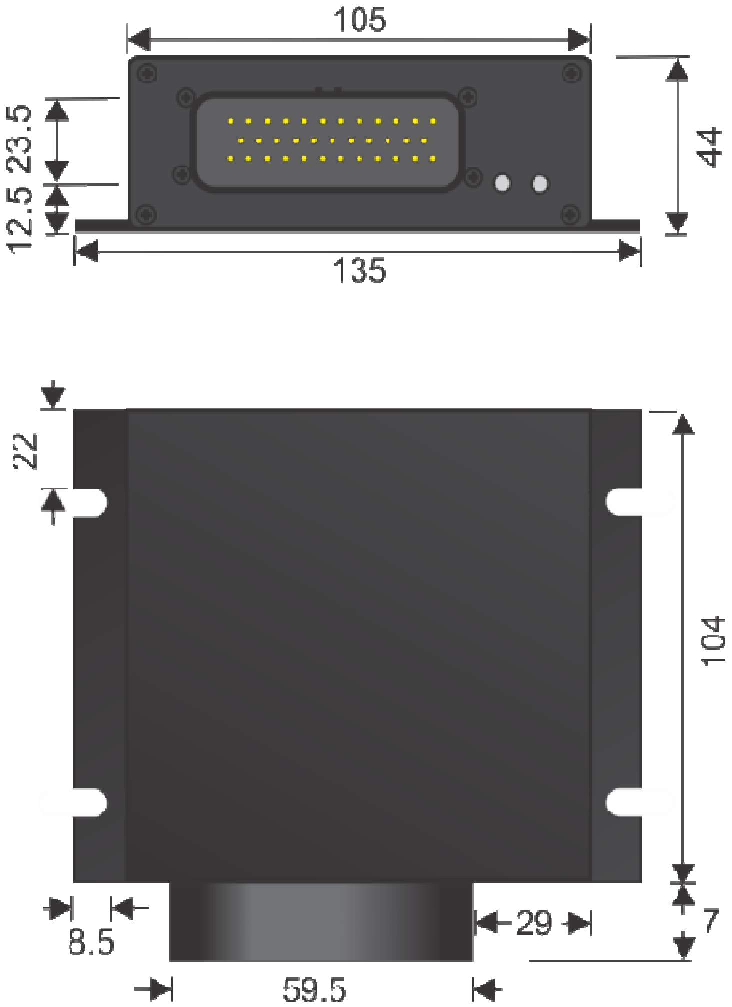

Figure 8: BMS dimensions.

BMS unit can be supplied without the enclosure, if an application is weight or space limited. The dimensions of the BMS (including connector) without the enclosure are 109 mm x 100 mm x 38 mm. The PCB has four 3.2 mm mounting holes.