LIBER-LV-NMC BATTERY

SAFETY

Patented system for measuring the temperature and voltage of each cell.

PERFORMANCE

High power density or high energy density configuration available.
Strong mechanical protection and sealing.

MODULARITY

Maximum flexibility, modules can be connected in series or in parallel to achieve the desired configuration

SELF-SUPPORTING

The self-supporting structure of LiBER modules allows the installation of batteries without additional frames

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LIBER-LV-NMC BATTERY

FEATURES

ACTIVE SAFETY

The LiBER solution has the unique feature of carefully measuring the temperature of each cell of the pack with an advanced Battery Management System BMS architecture. The BMS processes all cells temperatures for an accurate estimate of the State of Safety (SOS) of the battery pack.

The BMS can detect the activation of thermal anomalies of the cell at their initial stage, thus preventing the triggering of destructive phenomena at module or pack level.

PASSIVE SAFETY

The LiBER cell to module integration encapsulates and separates the cells from the adjacent ones reducing the risk of thermal runaway propagation.

The insulating material of the LiBER container adds protection from the direct contact with live parts at post-crash, even in case of extremely severe events.

Electrical abuse is managed at both module and cell level, reducing the risk of activation of uncontrolled thermal events

SERVICE SAFETY

Low voltage modules with dedicated disconnection and protection. When tuned off, there are no parts at high voltage inside the battery pack leading to safer assembly and maintenance operations.

SYSTEM INTEGRITY

The redundant architecture of the BMS system guarantees the continuity of service in case of first severe fault of BMS peripherals.

1. Description

A LiBER-LV-NMC-BATTERY pack composes by 1 to 4 modules that can be connected in series or parallel to form packs of different voltages and capacities. See Section 4 for available pack configurations.

A LiBER-LV-NMC-BATTERY module can be configured with a variable number of cells connected in series. Number of cells in series (Fig. 1) determines the length of the module. Available number of cells in series per module are in Table I and Table II.

A LiBER-LV-NMC-BATTERY module contains up to 16 *(-S16)* cells in series*,* corresponding to a maximum voltage of 63V. The maximum voltage of the pack is limited to 126V.

A LiBER-LV-NMC-BATTERY module has the internal power circuit (internal fuse, main switch and circuit scheme) depending on the configuration of the pack, the position of the module along the pack and the chosen power connector configuration. See Section 5 for pack configuration.

The LiBER-LV-NMC-BATTERY modules are sealed and equipped with power and control connectors available in different arrangements to facilitate the electrical connection of the module inside the pack and the integration of the pack with the final application. See Section 4 for power connector configuration.

The cell type defines the power and energy performance of the module. Two main configuration available: Standard Energy – High Power SEHP and High Energy – Standard Power HESP. See Table IV and V for module electrical configuration.

The LiBER-LV-NMC-BATTERY module is equipped with an internal liquid cooling circuit. The module can be used without liquid cooling at reduced power performance See Table IV and Table V. Installation position and ambient temperature affect the performance of the system.

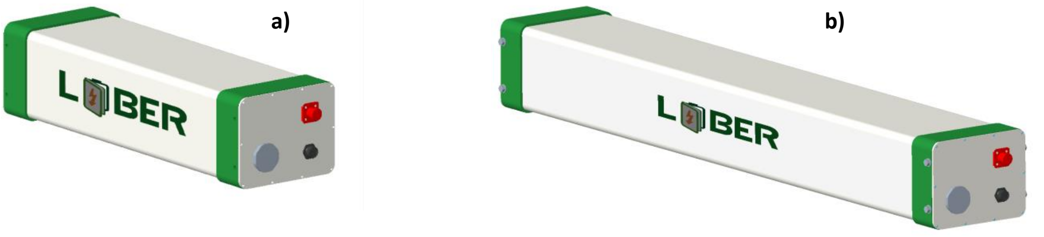


Fig. 1 a) module containing 7 cells in series (S7); b) module containing 15 cells in series (S15)

In a A LiBER-LV-NMC-BATTERY pack, modules having different number of cells in series can be connected in series. Modules with the same number of cells in series can be connected in parallel.

A LiBER-LV-NMC-BATTERY pack can be arranged as:

- All-in-one. Pack composed by one module only.
- Master-slave. Pack composed by two or more modules with different possible electric connections. The position of the master module is defined by the position in the power circuit. See Section 5 for pack configuration.

The Battery Management System of a LiBER-LV-NMC-BATTERY pack is based on a master-slave configuration. The master module is placed behind the terminal 1 (positive) of the module at the highest potential. Interfacing with the application is obtained through a single connection based on the connector J1. See Section 2 for BMS configuration.

In a LiBER-LV-NMC-BATTERY, the slave modules are connected with the master through a daisy chain connection based on connectors J11 and J21. See Section 3 for control connectors details.

Fig. 2 shows an example of the mechanical arrangement of a LiBER-LV-NMC-BATTERY pack composed by 4 modules. Admissible electric configurations of a pack composed by four modules are 4S, 2P2S. See section 8 for details on mechanical arrangement and layout.

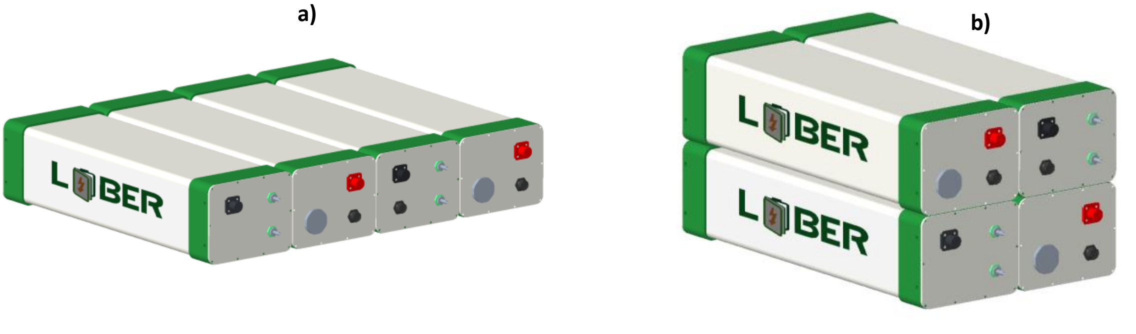


Fig. 2 Possible mechanical assembly of 4 modules. a) in line; b) matrix

Table I. LiBER module Technical Data

	Data	Unit
Technology	Li-ion 21700	
BMS	Single cell monitoring	
Thermal system	Liquid cooling No cooling	
Ambient Temperature range	-40 to +60	°C
Altitude range	0 – to 4000	m
Energy density	140	Wh/kg
Protection Index	IP69	
Fire test	UL94V0	

Table II. Liquid Cooling System

	Data	Unit
Fluid	Water + glicole	
Fluid pressure	1	bar
Fluid pressure drop of	220	mbar
Fluid flow	1	l/min
Rated fluid temperature	20	°C

Table III. Certification

	Regulation
Homologation	ECE R100.2 (1)
Standards	ISO 62660
Tansportation	UN38.3

Note 1: upon request and verification of the final configuration

Table IV. LiBER NMC - Standard Energy - High Power SEHP

SEHP	type	type	S3	S4	S7[1]	S8[1]	S9	S10	S11	S12	S13	S14[1]
Type		NMC	NMC	NMC	NMC	NMC	NMC	NMC	NMC	NMC	NMC	NMC
Nominal voltage	[V]	10,8	14,4	25,2	28,8	32,4	36,0	39,6	43,2	46,8	50,4	54,0
Nominal capacity	[Ah]	201										
Nominal energy	[Wh]	2100	2903	5080	5806	6532	7258	7983	8709	9435	10161	10886
Max voltage	[V]	12,6	16,8	29,4	33,6	37,8	42	46,2	50,4	54,6	58,8	63
Min voltage (absolute)	[V]	7,5	10	17,5	20	22,5	25	27,5	30	32,5	35	37,5
Weight	[kg]	24,2	29,6	45,8	51,2	56,6	62	67,4	72,8	78,2	83,6	89
Rated discharge power	[kW]	2177	2903	5080	5806	6532	7258	7983	8709	9435	10161	10886
Rated charge power	[kW]	2177	2903	5080	5806	6532	7258	7983	8709	9435	10161	10886
Max discharge current 60s [(2)]	[A]	504										
Max. charge current 60s [(2)]	[A]	384										
Thermal current no cooling	[A]	240										
Thermal current with cooling	[A]	350										
Module cross section WxH	[mm]	242x190										
Module length L	[mm]	440	525	775	855	940	1020	1100	1190	1270	1355	1440

Table V. LiBER NMC - High Energy - Standard Power HESP

HESP	type	S3	S4	S7[1]	S8[1]	S9	S10	S11	S12	S13	S14[1]	S15[1]
Type		NMC	NMC	NMC	NMC	NMC	NMC	NMC	NMC	NMC	NMC	NMC
Nominal voltage	[V]	10,8	14,4	25,2	28,8	32,4	36,0	39,6	43,2	46,8	50,4	54,0
Nominal capacity	[Ah]	230										
Energy	[Wh]	2488	3318	5806	6636	7465	8294	9124	9953	10783	11612	12442
Max voltage	[V]	12,6	16,8	29,4	33,6	37,8	42	46,2	50,4	54,6	58,8	63
Min voltage (absolute)	[V]	7,5	10	17,5	20	22,5	25	27,5	30	32,5	35	37,5
Weight	[kg]	22,4	27,2	41,6	46,4	51,2	56	60,8	65,6	70,4	75,2	80
Rated discharge power	[kW]	498	664	1161	1327	1493	1659	1825	1991	2157	2322	2488
Rated charge power	[kW]	746	995	1742	1991	2239	2488	2737	2986	3235	3484	3732
Max discharge current 60s [(2)]	[A]	400										
Max. charge current 60s [(2)]	[A]	230										
Thermal current no cooling	[A]	230										
Thermal current with cooling	[A]	300										
Module cross section WxH	[mm]	242x190										
Module length L	[mm]	440	525	775	855	940	1020	1100	1190	1270	1355	1440

Note 1: preferred
Note2: not for lifecycle

2. BMS - Battery Management System configurations

LiBER-LV-NMC-BATTERY BMS configuration refers to the definition of BMS architecture and to the connection of the external control circuit with the BMS.

LiBER-LV-NMC-BATTERY BMS configuration applies to any power connection and pack power circuit schemes described in Section 4 and 5 respectevly.

ALL IN ONE -*MA*

Pack composed by one module only, with internal BMS.

- Communication and control connection with external circuit through connector J1 only.
- J1 is installed on terminal 1, as shown in Fig. 3
- See Section 3 for J1 specification
- See Section 6 for BMS functional description.

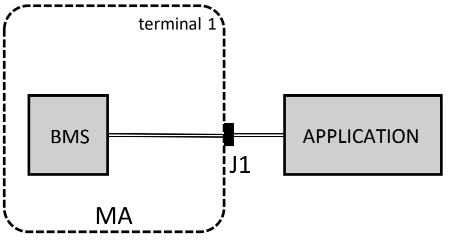


Fig. 3 All-in-one. Control function connector J1

MASTER - SLAVE

Pack is composed by one MASTER MODULE (MM) and 1 to 3 SLAVE MODULES(MS)

MASTER MODULE (MM)

- Contains the BMS control circuit that manages the cells installed inside the master module
- Contains the BMS control circuit that interfaces with the external circuit.
- It is located in (one of) the module(s) at terminal 1.
- Communication and control with external circuit through connector J1 only.
- Communication lines with slave modules through connector J21 placed on terminal 2 of the module.
- See Section 3 for J1 specification
- See Section 6 for BMS functional description.

SLAVE MODULEs (MS)

- Contains the BMS circuitry that manages the cells inside the slave module
- Communication and control lines with the MASTER MODULE and other SLAVE MODULES is obtained with the daisy-chain connection through J11 and J21.
- J11 and J21 are installed on terminal 1 and 2 respectively, according to Fig. 4.
- See Section 3 for J11 and J21 specification
- Addressing of the slave modules is defined by their position in the power connection schemes of Section 5.

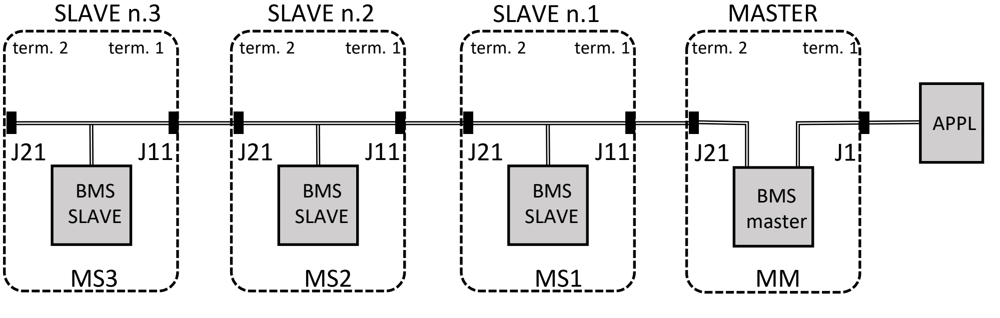


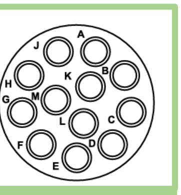
Fig. 4 MASTER-SLAVE configuration. Control lines.

3. Control Connectors

Connector J1 provides the interface of the LiBER battery pack with the application.
The application schemes and external connections of J1 are given in Section 7.
Table III gives the characteristics and pinout of connector J1.
Connector J11 and J21 connects the modules of the pack. J11 and J21 functionality is reserved.
Table III gives the characteristics of connectors J11 and J21.

Table VI J1 PINOUT

SERIES	SOURIAU UTS - SERIES 1412 (1)
p/n	UTS71412S
Mates with	UTS6JC1412P

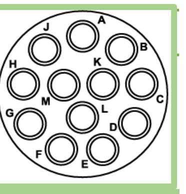


NAME	PIN	TYPE	DESCRIPTION
+VBAT_KEY	A	P	Battery permanent positive voltage output for supplying the main external activation circuit (e.g. vehicle keyswitch) Internal 500 mA fuse protection shared with +VBAT_BC
EN_BMS_KEY	B	I	BMS positive power-supply from +VBAT_KEY through external switch. Traction mode activation.
+VBAT_BC	C	P	Battery permanent positive voltage output for supplying the auxiliary external activation circuit (e.g. battery charger) Internal 500 mA fuse protection shared with +VBAT_KEY
EN_BMS_BC	D	I	BMS positive power-supply from +VBAT_BC through external contact. Charging mode activation.
GND_BMS	E	I	BMS negative power-supply from GND_BMS through external contacts: battery disconnection, MSD. GND_BMS=-VBAT: BMS power ready. GND_BMS=floating: BMS power OFF & MAIN SWITCH OPEN
-VBAT	F	P	Battery permanent negative voltage output for supplying the external protection circuit (e.g. MSD). Protected by internal fuse 500 mA.
CANL_A SERVICE	G	I	SERVICE CAN BUS communication. CAN-L
CANH_A SERVICE	H	O	SERVICE CAN BUS communication. CAN-H
CANL_B	J	I	MAIN CAN BUS communication. CAN-L (same as L)
CANH_B	K	I	MAIN CAN BUS communication. CAN-H (same as M)
CANL_B	L	I	MAIN CAN BUS communication. CAN-L (same as J)
CANH_B	M	I	MAIN CAN BUS communication. CAN-H (same as K)

Note 1: other connectors available on request

Table VII. J11, J21 PINOUT

SERIES	SOURIAU UTS - SERIES 1492 (1)
p/n	UTS71492S
Mate with	UTS6JC1492P;

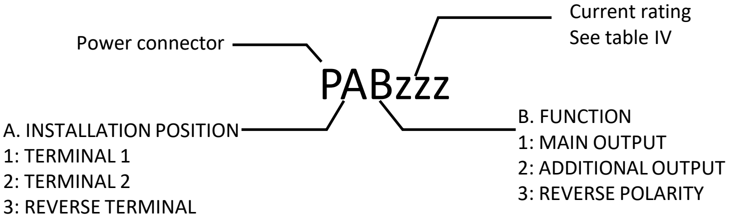


NAME	PIN	TYPE(1)	DESCRIPTION
all	A to M	/	Communication, supply and control signals for connection of slave modules

Note 1: other connectors available on request

4. Power Connectors -P

Coding



Description

The LiBER-LV-NMC-BATTERY can be equipped with one or two power connectors at each terminal of the module (see Fig. 4), enabling the internal power circuits given Fig. 4 and then, the pack power circuits introduced in Section 5.

The power connector P11 and P21 are the main connectors. See Fig. 4a.

Additional power connectors P12 and P22can be connected in parallel to P11, P21 respectively. Two main configuration for additional power converter available:

- Current sharing. Two configurations available: for current sharing (Fig.4b) and for parallel connection of modules (Fig.4f). All power connectors must have the same current rating.
- Auxiliary output. For for battery charger, auxiliaries loads, etc. Two configurations (Fig. 4d and Fig. 4e) available. Auxiliary connectors P12 and P22 may have lower current rating than P11, P21.

The all-in-one (-MA) configuration allows the installation of both positive and negative power connectors on terminal 1. In this case the negative power connector is named P33. See fig. 4c.

Fig. 4 shows the positioning of control and power circuit for the three possible module configuration: MA, MM, MS.

Table VIII. Power connectors specs.

Type	Amphenol SurLok Plus™ Series (*)			
Code P	Current rating [A]	Cable section [mm²]	color	Mate plug p/n
P1x350	350	50	red	SLPPC50BSR3
P1x200	200	35	red	SLPPB35BSR3
P2x350**	350	50	black	SLPPC50BSB1
P2x200**	200	35	black	SLPPB35BSB1

(*) other connector type on request
(**) also applies to P33

Table IX. Exampes of power connectors specs.

Code P	Description
P11350 P21350	P11 red on terminal 1 for positive. In=350 A P21 black on terminal 2 for negative. In=350 A
P11350 P12200 P21350	P11 red on terminal 1 for positive. In=350 A P12 red on terminal 1 for positive. In=200 A P21 black on terminal 2 for negative. In=350 A
P11350 P21350 P22200	P11 red on terminal 1 for positive. In=350 A P21 black on terminal 2 for negative. In=350 A P22 black on terminal 2 for negative. In=200 A
P11350 P12350 P21350 P22350	P11 and P12 red (in parallel) on terminal 1 for positive. In=350 A each P21 and P22 black (in parallel) on terminal 2 for negative. In=350 A each

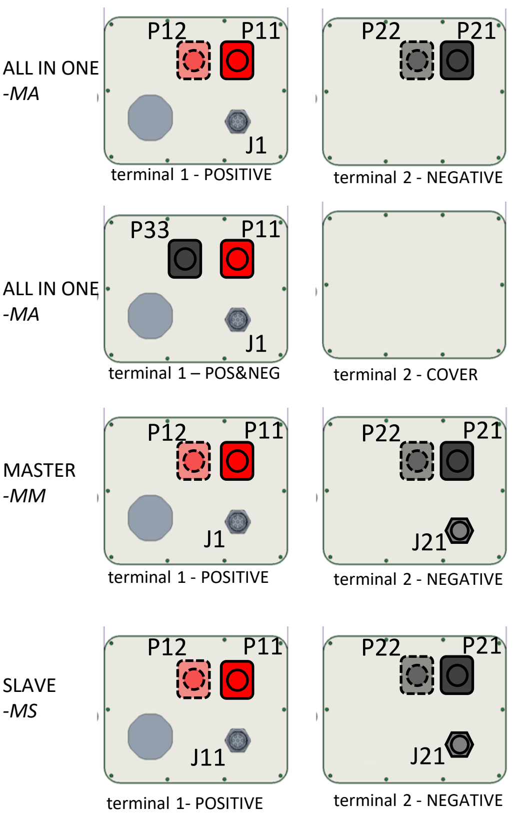


Fig. 4 Power and signal connectors on the two terminals of the module.

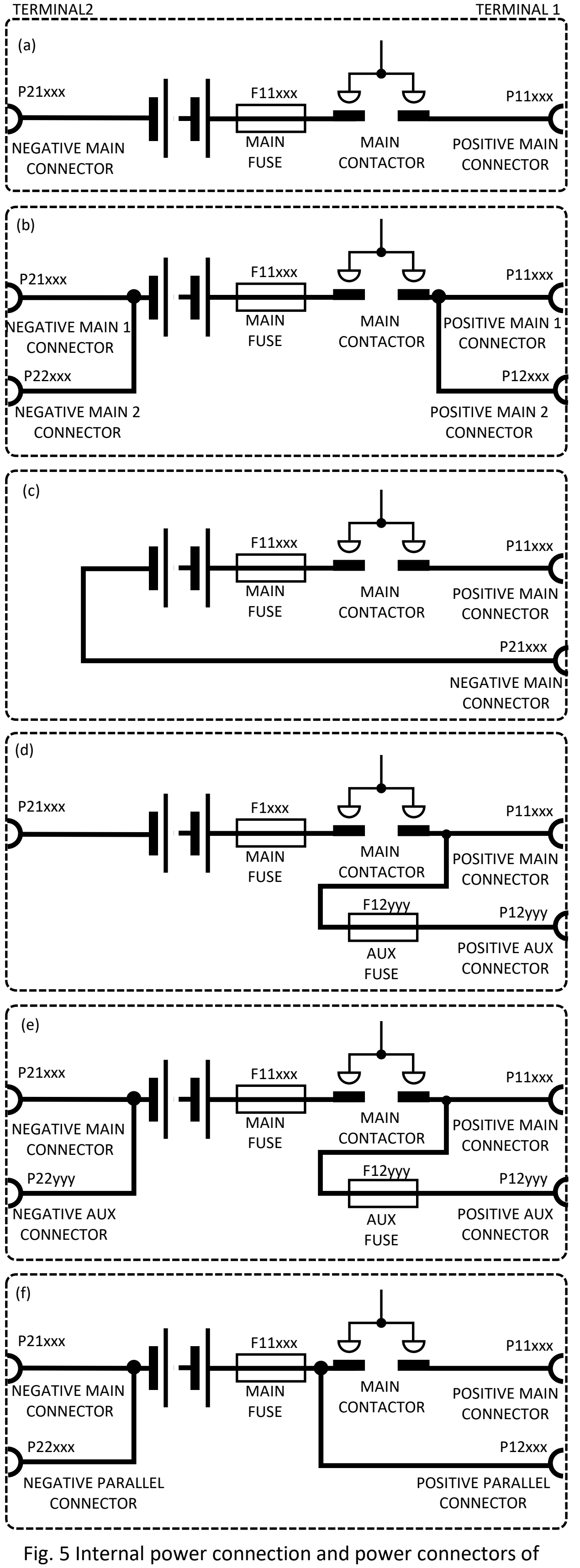


Fig. 5 Internal power connection and power connectors of either the MA or MM module.

5. Pack configurations

SINGLE MODULE
(all-in-one)

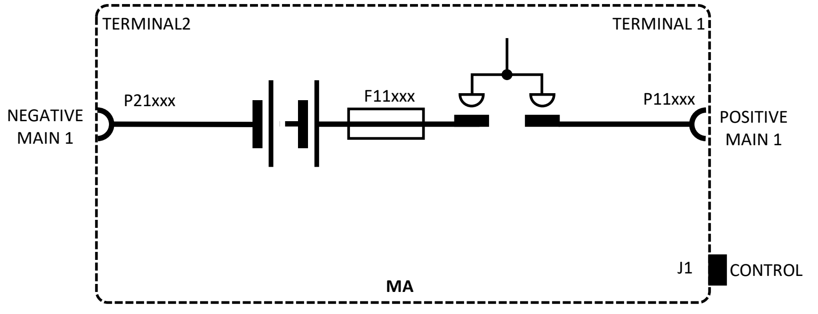


Fig. 6 ALL-IN-ONE. ONE MODULE. SINGLE OUTPUT

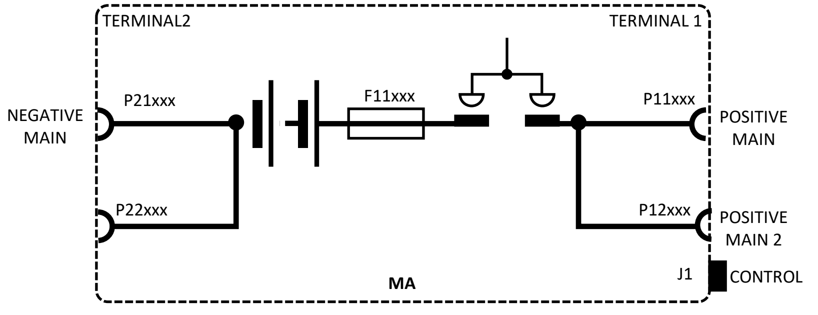


Fig. 7 ALL-IN-ONE. HIGH CURRENT. TWO POWER OUTPUT CABLES

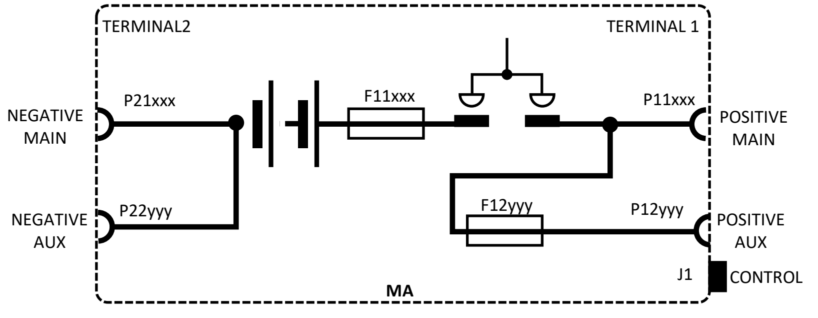


Fig. 8 ALL-IN-ONE. AUXILIARY CONNECTORS AT BOTH TERMINALS

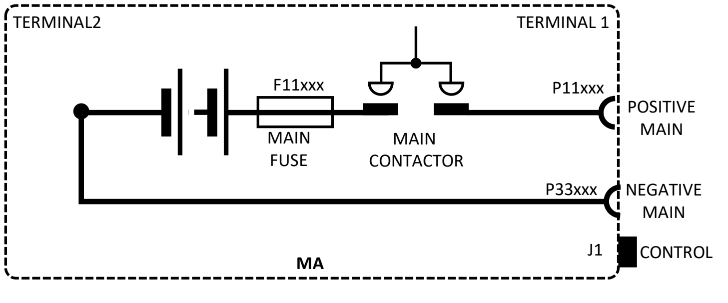


Fig. 9 ALL-IN-ONE. BOTH POWER CONNECTORS AT TERMINAL 1

TWO MODULES IN SERIES

- The two modules may have different number of cells in series. NS from 3 to 15.

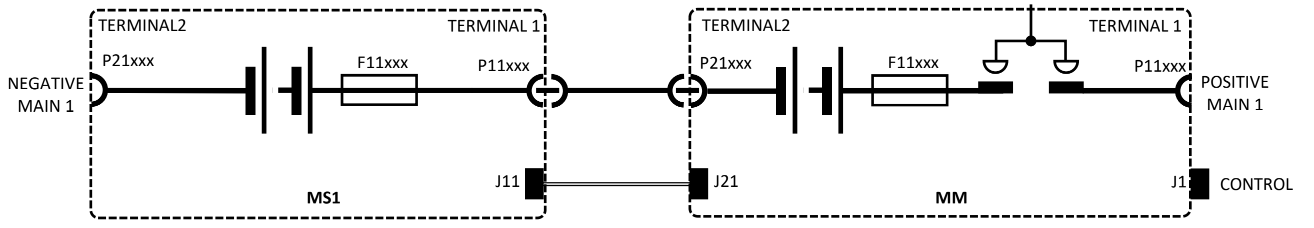


Fig. 10 TWO MODULES IN SERIES. SINGLE OUTPUT

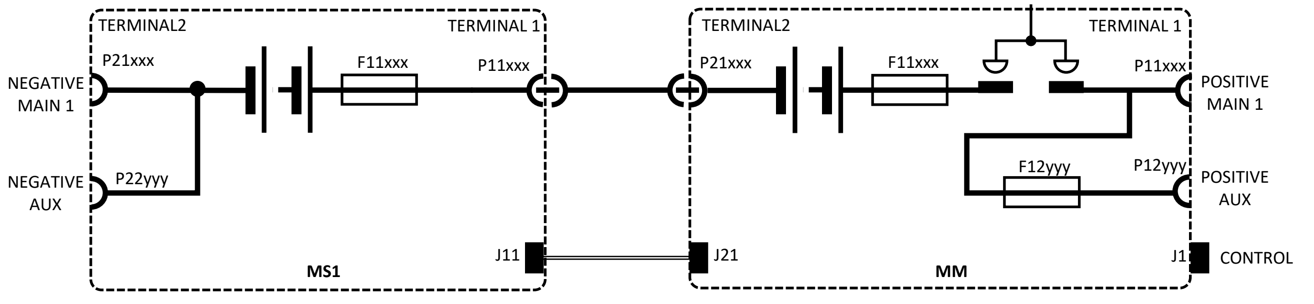


Fig. 11 TWO MODULES IN SERIES. WITH AUXILIARY OUTPUT CONNECTOR

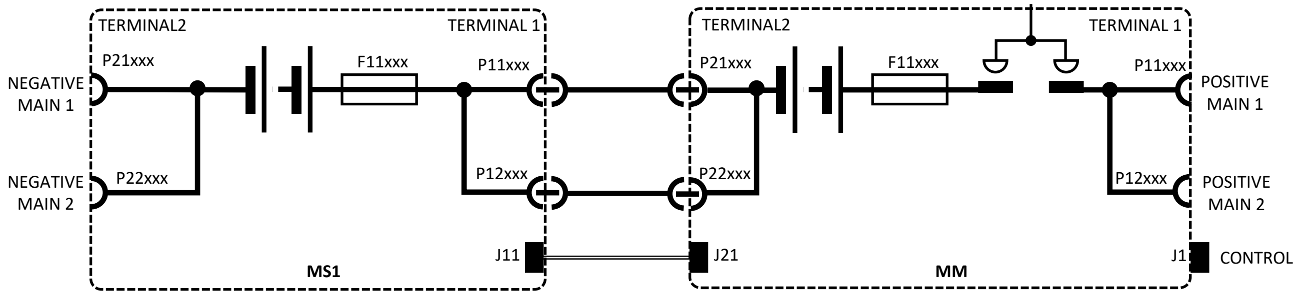


Fig. 12 TWO MODULES IN SERIES. HIGH CURRENT CONFIGURATION, TWO POWER OUTPUT CABLES

THREE MODULES IN SERIES

- The three modules may have different number of cells in series. NS from 3 to 15.

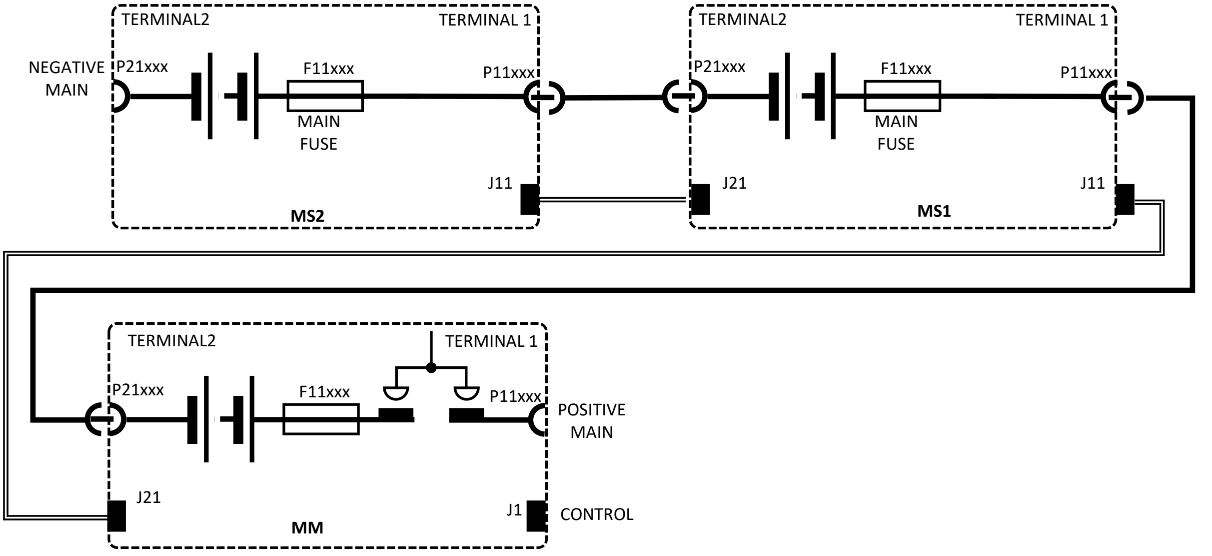


Fig. 13 THREE MODULES IN SERIES. SINGLE OUTPUT

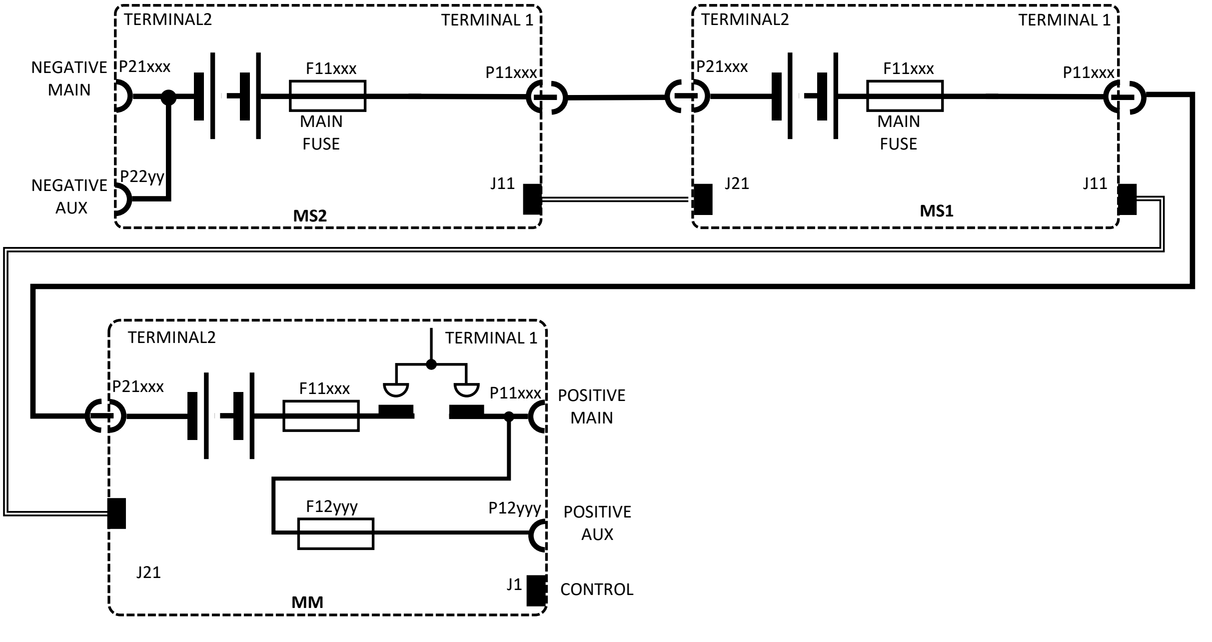


Fig. 14 THREE MODULES IN SERIES, WITH LOW POWER AUX CONNECTORS

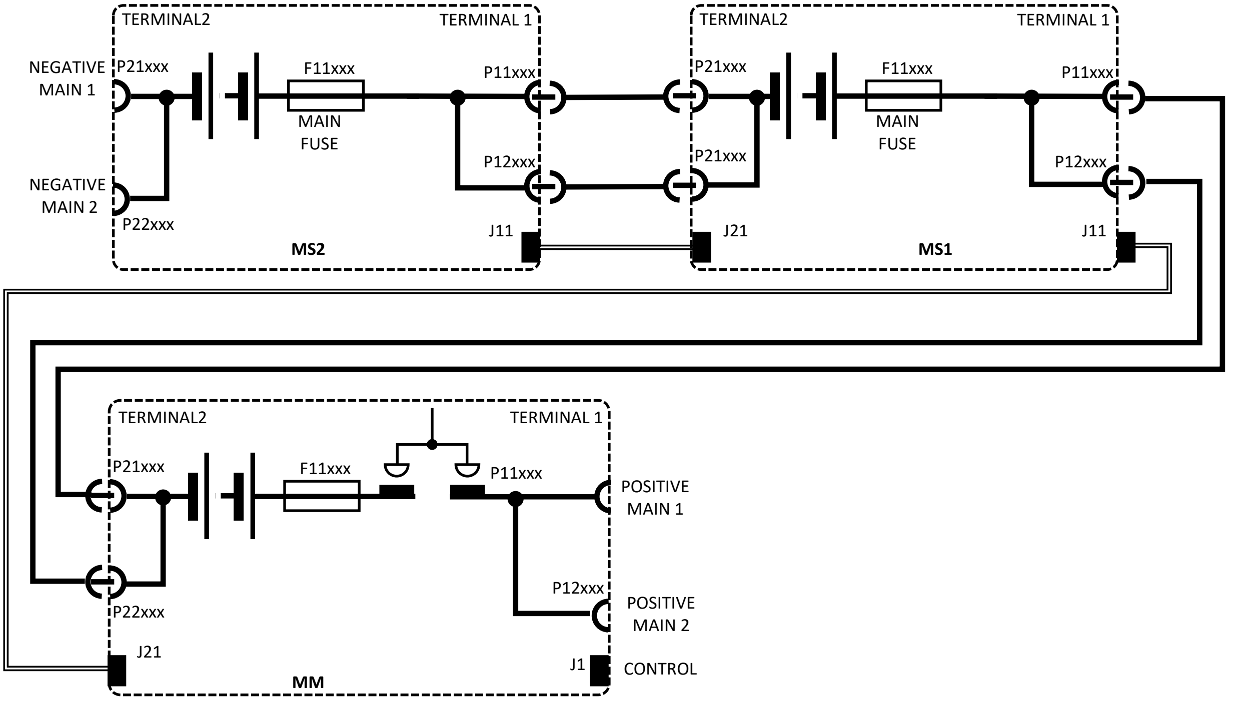


Fig. 15 THREE MODULES IN SERIES. HIGH CURRENT. TWO POWER OUTPUT CABLES

FOUR MODULES IN SERIES

- The four modules may have different number of cells in series. NS from 3 to 15.

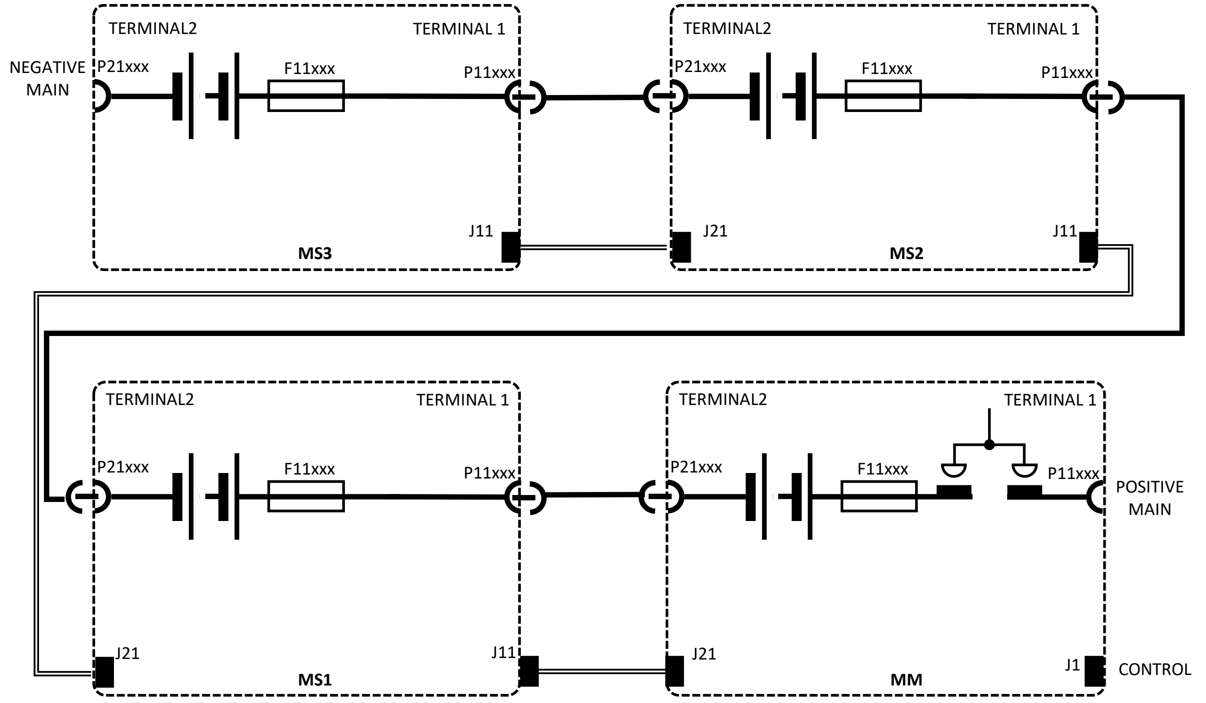


Fig. 16 FOUR MODULES IN SERIES. SINGLE OUTPUT

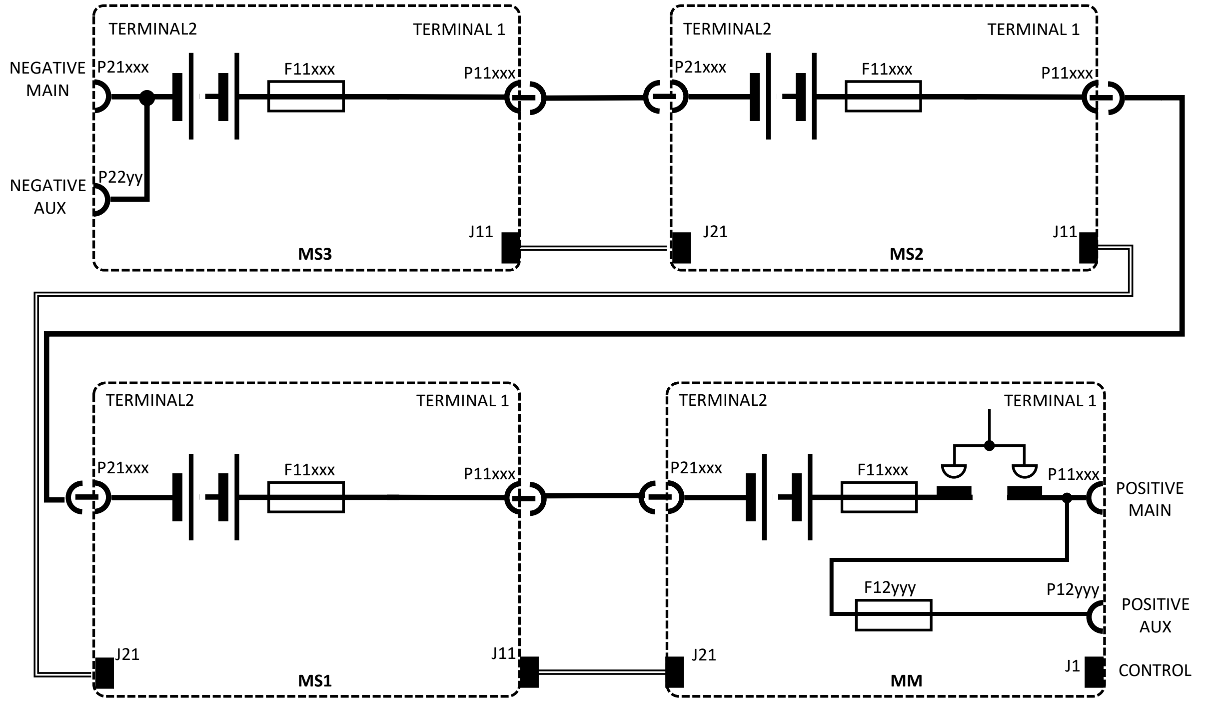


Fig. 17 FOUR MODULES IN SERIES, WITH LOW POWER AUX CONNECTORS

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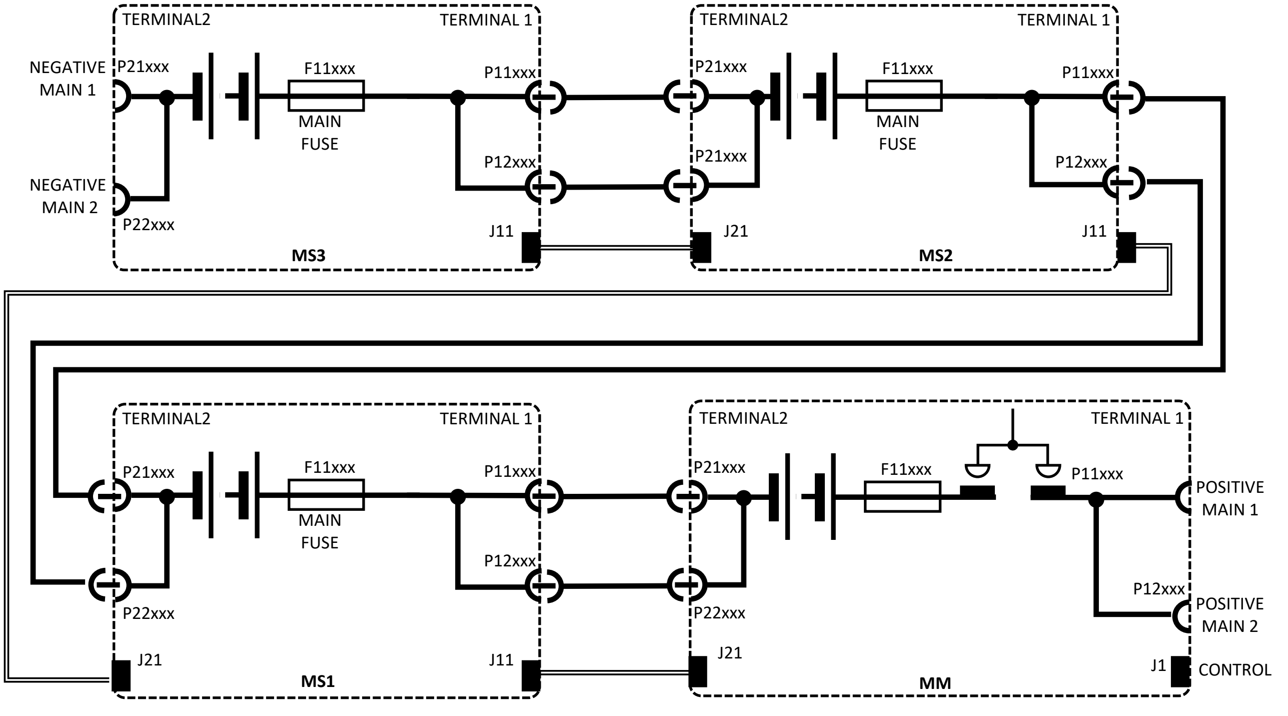

Fig. 18 FOUR MODULES IN SERIES. HIGH CURRENT. TWO POWER OUTPUT CABLES

TWO MODULES IN PARALLEL

- The two modules must have the same number of cells. NS from 3 to 15.

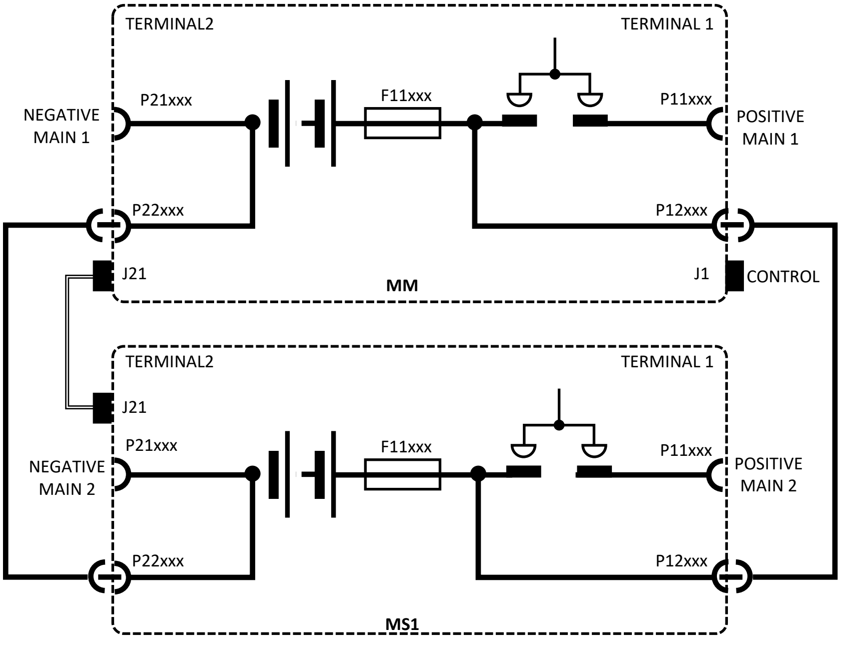

Fig. 19 TWO MODULES IN PARALLEL. TWO POWER OUTPUT CABLES

TWO MODULES IN PARALLEL, TWO IN SERIES

- The two pairs of modules in parallel must have the same number of cells in series. NS_{MM}= NS_{MS1} & NS_{MS2}= NS_{MS3}
- The two blocks in series may have different number of cells.
- NS from 3 to 15

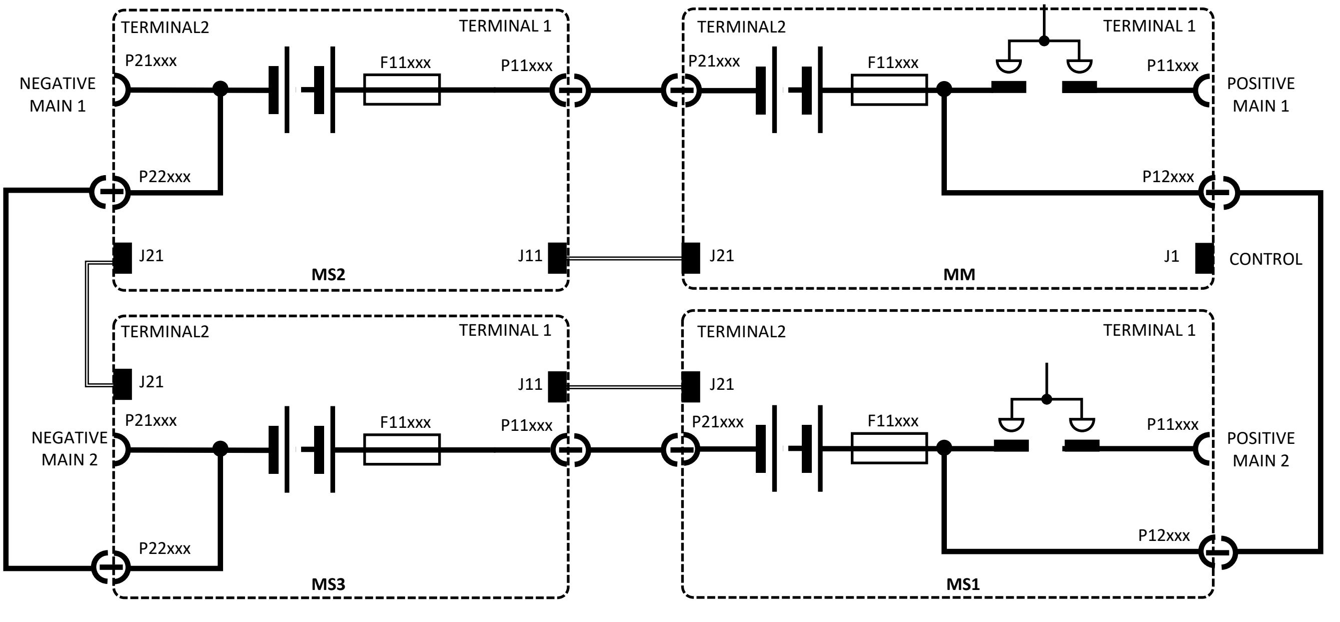

Fig. 20 TWO MODULES IN PARALLEL, TWO IN SERIES. TWO OUTPUT CABLES

6. BMS Battery Management System

BMS ACTIVATION, POWER ON-OFF AND OPERATING MODE SELECTION

The activation of the BMS, the selection of the operating mode and the drive of the main switch are controlled by the user, through the application of the supply voltage at the three input of connector J1:

- EN_BMS_KEY
- EN_BMS_BC
- GND_BMS

The electrical scheme for the external connection of the activation inputs EN_BMS_KEY, EN_BMS_BC, GND_BMS are given in Section 7.

Additional power on CAN command: CAN_MS_ENABLE is available for remote switch-on and -off of the main switch through the CAN BUS. This function can be disabled.

Table X gives the states of BMS, MAIN SWITCH and OPERATING MODE as a function of the electric supply inputs and power-on command.

Table X. ACTIVATION, POWER ON-OFF, OPERATING MODE of the battery pack

EN_BMS_KEY	EN_BMS_BC	GND_BMS	CAN MS ENABLE	BMS	MAIN SWITCH	OPERATING MODE
+VBAT_KEY	OPEN	-VBAT	1	ON	ON	TRACTION
OPEN	+VBAT_BC	-VBAT	1	ON	ON	CHARGE
+VBAT_KEY	+VBAT_BC	-VBAT	1	ON	ON	CHARGE
+VBAT_KEY	OPEN	-VBAT	0	ON	OFF	STAND-BY
OPEN	+VBAT_BC	-VBAT	0	ON	OFF	STAND-BY
+VBAT_KEY	+VBAT_BC	-VBAT	0	ON	OFF	STAND-BY
OPEN	OPEN	-VBAT	Any	OFF	OFF	POWER OFF
Any	Any	OPEN	Any	OFF	OFF	POWER OFF

The power-on of the main switch is subject to the verification of the battery pack integrity and the absence of critical battery conditions (e.g. overtemperature, overvoltages) that could be triggered during the turning off of the battery. See PROTECTION or TERMINATE state in Table XI and Fig. 21.

The power-off command of the main switch is automatically applied in case of severe fault or critical battery state. See PROTECTION or TERMINATE in Table XI and Fig. 21.

LIMITATION AND PROTECTION FUNCTIONS

- Preserve the pack integrity in case of thermal and electrical abuse of the cells.
- Preserve the continuity of operation of the battery pack in case of moderate thermal and electrical stress of the cells.
- Relies on direct sensing of 100% of cell temperature, voltage and current.
- Exchange data with the application (e.g. inverters, VCU, battery chargers) through the CAN BUS. The application must follow the reference and the commands sent by the BMS. In case of abnormal operating conditions, communication failure or ineffective action from the connected devices the BMS can autonomously open the main switch and permanently terminate the operation of the battery.
- The limitation and protection function strategies are common to CHARGE and TRACTION mode, while the parameterization and mapping are different.

The BMS limitation and protection functions and their activation in traction or charge mode are listed in Table X .

Table XI. Main limitation and protection functions in traction and charge mode

CODE	NAME	DESCRIPTION	TRACTION MODE	CHARGE MODE
OVCL	Over Voltage Charge Limitation	BMS demands a charge current reduction	ON	ON
OVCS	Over Voltage Charge Stop	BMS demands zero charge current	ON	ON
OVCP	Over Voltage Charge Protection.	BMS directly controls system shutdown	ON	ON
OVCT	Over Voltage Charge Termination	BMS locks battery. Service required.	ON	ON
OVDL	Over Voltage Discharge Limitation	BMS demands a discharge current reduction	ON	ON
UVDL	Under Voltage Discharge Limitation	BMS demands a discharge current reduction	ON	OFF
UVDS	Under Voltage Discharge Stop	BMS demands zero discharge current.	ON	OFF
UVDP	Under Voltage Discharge Protection	BMS directly controls system shutdown	ON	OFF
UVDT	Under Voltage Discharge Termination.	BMS locks battery. Service required.	ON	OFF
UVCL	Under Voltage Charge Limitation	BMS demands a charge current reduction	ON	ON
OTCL	Over Temperature Charge Limitation	BMS demands a charge current reduction	ON	ON
OTCS	Over Temperature Charge Stop	BMS demands zero charge current	ON	ON
OTDL	Over Temperature Discharge Limitation	BMS demands a discharge current reduction	ON	OFF
OTDS	Over Temperature Discharge Stop	BMS demands zero discharge current.	ON	OFF
OTP	Over Temperature Protection	BMS controls system shutdown	ON	ON
UTCL	Under Temperature Charge Limitation	BMS demands a charge current reduction	ON	ON
UTCS	Under Temperature Charge Stop	BMS demands zero charge current.	ON	ON
UTDL	Under Temperature Discharge Limitation	BMS demands a discharge current reduction	ON	OFF
UTDS	Under Temperature Discharge Stop.	BMS demands zero discharge charge current	ON	OFF
OTT	Over Temperature Termination	BMS locks battery. Service required.	ON	ON

Fig. 21 represents the intervention of the limitation and protection function as a function of the value of a single monitored variable. The five resulting operating regions are defined as State of Function SOF and are described as follows.

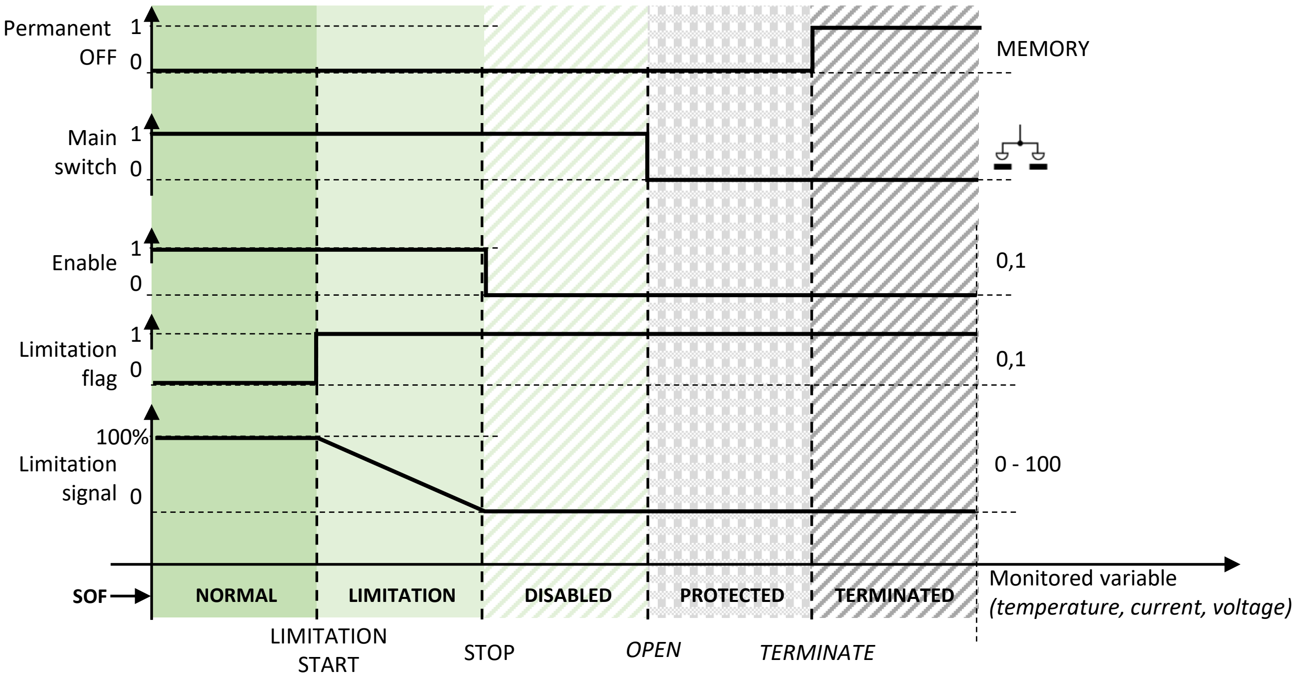

Fig.21. Graphical representation of limitation and protection functions.

SOF - NORMAL

Monitored variables are all in the range of admissible value. 'Limitation request' is set to the maximum: 100% or absolute positive (discharging) and negative (charging) current [A].

Limitation flag is set to 0.

Limitation signal and limitation activation flag are broadcasted on the CAN B. See Tables XIV-XV for CAN encoding.

SOF - LIMITATION

The limitation functions (OVCL, UVDL, OVDL, UVCL, OTCL, UTDL) generate a current limitation request that must be followed by the devices connected to the battery pack, to prevent the operation of the cells in abnormal operating conditions.

Limitation signal can be generated either as pu (0-100%) or as absolute positive (discharging) and negative (charging) current [A].

Limitation maps and combination of different limitation functions are tuned for the cell types and the requirements of the application.

Limitation operating region is assumed as standard operation. No error nor warnings generated in limitation region.

Limitation signal and limitation activation flag are broadcasted on the CAN B. See Tables XIV-XV for CAN encoding.

Limitation maps can be generated as a function of additional state variables of the battery pack, such as State of Charge SOC, State of Health SOH as shown in Fig. 22.

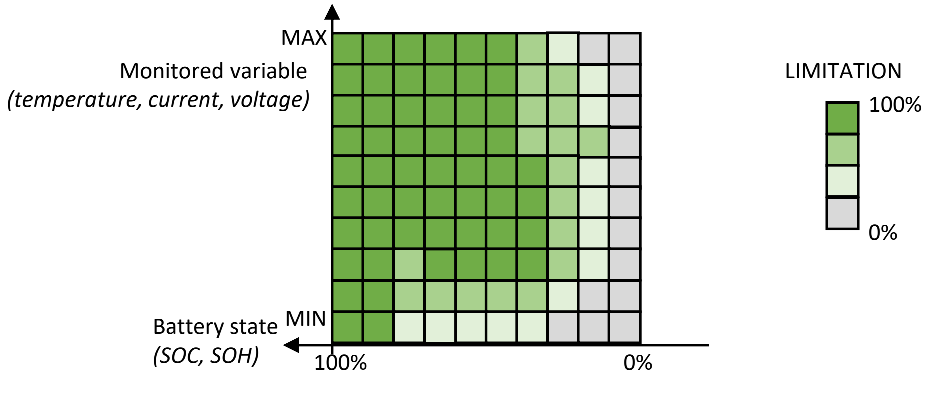

Fig. 22. Example of limitation map as a function of a battery state

SOF - DISABLED

The disabling functions (OVCS, OVDS, OTCS, OTDS, UTCS, UTDS) generates a disabling request for the connected devices in case of a monitored variable overcome the STOP threshold.

The flag ‘ENABLE=0’ is generated.

This protection function activates in case the ‘limitation function’ is not effective.

The flag ‘ENABLE=0’ must disable the connected devices and leading the current in the battery output circuit to zero.

Disabled operating region generates a non-erasable error in the log memory of the BMS.

Exit from ‘DISABLED’ state by return of controlled variables within the admissible ranges.

‘ENABLE’ state flag is broadcasted on the CAN B. See Tables XIV-XV for CAN encoding.

SOF - PROTECTED

The protection functions (OVCP, OVDP, OTP) open the main contactor of the battery pack in case a monitored variable exceeds the OPEN threshold.

The ‘PROTECTED’ state of the BMS is represented by flag ‘PROT_MAIN_SW =0’

The protection function activates in case the ‘limitation function’ and protection function are not effective.

Intervention of protection function generates a non-erasable error in the log memory of the BMS.

Exit from ‘PROTECTED’ state by switching OFF and ON the BMS.

‘PROT_MAIN_SW’ flag is broadcasted on the CAN B. See Tables XIV-XV for CAN encoding.

SOF - TERMINATED

The termination functions (OVCT, OVCT, OTT) permanently disable the operation of the BMS in case a monitored variable exceeds the TERMINATE threshold.

The ‘TERMINATED’ state of the BMS is represented by flag ‘TERMINATED=1’

The termination function activates in case the other protection functions are not effective.

Intervention of termination function generates a non-erasable error in the log memory of the BMS.

The activation of the termination function permanently locks the battery OFF. Exit from ‘TERMINATED’ state requires intervention of LiBER service.

‘TERMINATED’ flag is broadcasted on the CAN B. See Tables XIV-XV for CAN encoding.

SOF - OVERRIDE

The SOF determined by the conditions of the monitored variables, as listed in table XI, is overridden by a BMS failure event.

Table XII gives the corresponding SOF and the state of general BMS states WARNING and ERROR as a consequence of a failure events.

Detailed list of WARINIG and ERROR codes is given in the programming manual.

Table XII. Override of the SoF - State of Function

FAILURE CODE	FAILURE NAME	FAILURE DESCRIPTION	OVERRIDEN SOF TRACTION	OVERRIDDEN SOF CHARGE	WARNING	ERROR
MSWE	Main switch error	State of the main switch not corresponding to the command. Switch stuck open or closed.	PROTECTED	PROTECTED	ON	ON
F1BE	Power fuse Blown	Detection of power fuse F11 blown	PROTECTED	PROTECTED	ON	ON
INCE	Invalid Non Critical	Invalid reading from non critical sensor	NORMAL	LIMITATION	ON	OFF
ISEW	Invalid State Estimation	Invalid estimation of SOC, SOH	NORMAL	LIMITATION	ON	OFF
ICRE	Invalid Critical Redundant	Invalid reading from critical sensor. Variable estimated from other sensors	LIMITATION	DISABLED	ON	ON
ICNE	Invalid Critical Non redundant	Invalid reading from critical sensor.	DISABLED	PROTECTED	ON	ON
CFCE	CAN BUS Fatal Communication Error	Checksum error or low level communication error	DISABLED	PROTECTED	ON	ON
CTCE	CAN BUS Temporary Communication Error	Non permanent communication error	NORMAL	DISABLED	ON	ON
IBFE	Internal BMS Fatal Error	Control system error	DISABLED	PROTECTED	ON	ON

PACK STATE ESTIMATION

The BMS implements the fundamentals state estimations of the battery pack:

- Actual capacity. Pack capacity in Ah with SOC=100%.
- SOC – State of charge. Based on Coulomb counting combined with Extended Kalman Filter observer.
- SOH – State of Health. Based on the estimation of internal resistance combined with actual capacity.

The complete list of estimate output is given in the summary of broadcasted CAN messages in Table XIII.

EQUALIZATION

The equalization algorithm balances the charge of the cells with a strategy that minimizes the energy lost in the equalization phase.

Equalization is enabled in charge mode only and is preferably activated when charging current is low.

Activation of the equalization process and number of cells under equalization is transmitted on the CANBUS. See table XV.

Estimate of the equalization state is given through the variable SOE - State of Equalization.

MONITORING FUNCTIONS

The BMS calculates quantities representing the operation of the battery pack, referred to either the current state or the past battery history.
This quantities are broadcasted on the CAN BUS.
The complete list of monitored or calculated quantities is given in the summary of broadcasted CAN messages in Table XIII.

HARDWARE CONTROL FUNCTIONS

The BMS monitors the state of the main switch of the power fuse (F11) and of the equalization power stage, and transmits the resulting states on the CAN B.

Functional state:

- Main switch state

Fault events:

- Main switch stuck open
- Main switch stuck closed
- Power fuse blown.
- Equalization power stage fault

Fault events are encoded by following the list given in table XII and broadcasted as ERROR CODE. See table XV.

BATTERY CHARGER CONTROL

The BMS operates as BCC - Battery Charger Control by calculating the current reference for the battery charger. The BMS transmits the current reference to the charger, thus the charger shall operate as current follower.

The charge current profile is based on a CC-CV curve based on the charging specification of the cells. See Fig. 222

Charge curve is also optimized for synergic operation with the equalization process.

The reference charge current is calculated according to the actual maximum charge current of the battery charger.

During the charge process the battery charger transmits the measured actual current to the BMS.

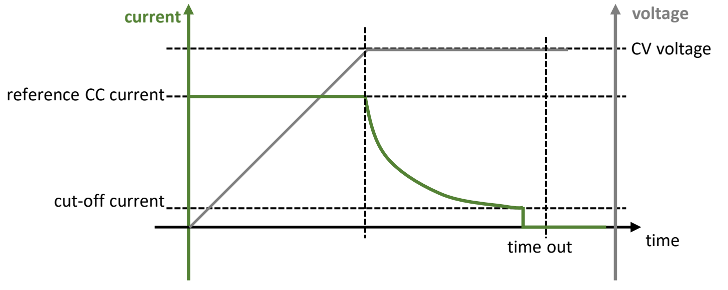

Fig. 23.. BMS operation as battery charger control. CC-CV charge curve

The battery may be charged with an independent external battery charger which does not receive the current reference from the BMS. In this case the battery charger must use the BMS SYSTEM STATES for activation and protection and send the measurements on CAN B, as listed in table XVII.

CAN BUS MESSAGES

Messages broadcasted on CAN B include measurements, state of the battery pack, limitation request, references for the battery chargers. The list of main variables is given in Table XIII-XV.

Messages that can be received by the application on the CAN B are the soft command for the main switch and the necessary information for the operation of the battery charger. See table XVI – XVII.

Refer to the programming manual for the full list and the details on the CAN protocol.

Table XIII. CAN B Tx - Measurements

Variable	unit
SOC percentage	%
Actual capacity at 100% SOC	Ah
Residual charge	Ah
Depleted charge since the last charge	Ah
Max cell temperature	°C
Min cell temperature	°C
Average cell temperature	°C
Cell number at max temperature	#
Cell number at min temperature	#
Max cell voltage	V
Min cell voltage	V
Average cell voltage	V
Cell number at max voltage	#
Cell number at min voltage	#
Pack current	A
Pack voltage. Direct measurement	V
Pack power	W
Pack voltage. Indirect measurement	V
Charged capacity in current charging session	Ah
Charged energy in current charging session	Wh
Discharged capacity since the last charge	Ah
Discharged energy since the last charge	Wh
Cumulative discharged energy	kWh
Cumulative discharged Ah	Ah
Estimated SOH State of Health	%
Estimated SOE State of Cells Equalization	%

Table XIV. CAN B Tx – Limitation & references

Variable	unit
Limitation request for battery current in pu	%
Maximum positive current limitation request	A
Maximum negative current limitation request	A
Maximum estimated positive power	kW
Maximum estimated negative power	kW
Charger current reference	A

Table XV. CAN B Tx – System state

Variable	unit
BMS general state	CHARGE DISCHARGE STAND-BY
SOF – State of function	NORMAL LIMITATION DISABLED PROTECTION TERMINATED
State of equalization process	OFF ON TIMEOUT
Number of cells in equalization	#
MAIN SWITCH STATE	0-1
ERROR	#
WARNING	#

Table XVI. CAN B Rx – Commands and references

Variable	unit
BMS MAIN SWITCH power on	0-1
Battery Charger state	#
Battery Charger actual current	A
Battery Charger Maximum current	A
Battery Charger Minimum current	A

Table XVII. CAN B Rx – Application and battery charger

Variable	unit
BMS MAIN SWITCH power on	1-0
Battery charger state	#
Battery Charger actual current	A
Battery Charger Maximum current	A
Battery Charger Minimum current	A

7. Electrical schemes

The external standard electric connection scheme of the LiBER-LV-NMC-BATTERY pack is based on the scheme of Fig. 24 which is referred to the all-in-one configuration.

Even all the master-slave configurations interface with the application through J1 connector installed on master module. Master-slave configurations require additional J11-J21 daisy chain connection as shown in the scheme of Fig 3. An example of master – slave electrical scheme for a 2S configuration is given in fig.25

The interfacing of the BMS with the application relies on signals made available on J1 only.

The BMS is directly supplied by the battery pack through external activation wiring.

The positive supply of the BMS circuit is given by either EN_BMS_KEY or EN_BMS_BC which takes the positive voltage of the pack from +VBAT_KEY and +VBAT_BC, respectively.

The positive pack voltages: +VBAT_KEY and +VBAT_BC are at the same potential and are protected by the same internal fuse. +VBAT_KEY and +VBAT_BC are made available on two different pins of J1 for simplifying the external wiring harness.

The negative supply of the BMS circuit is given by the GND_BMS which takes the negative voltage of the pack from –VBAT.

The use of a MSD – Manual Service Disconnection device is recommended in the power circuit. Auxiliary contacts of the MSD can be used for interrupting the negative supply of the BMS control circuitry. The opening of the negative supply line GND_BMS determines the direct opening of the main switch.

The CAN B is the main communication bus between the BMS and the application. For simplifying the external wiring harness, CAN B is made available on two pairs of pin of J1. Termination with 120 Ω resistor is required depending on the characteristics of the external wiring.

A separated service CAN line, called CAN A, should be wired on J1 for connecting either the LIBER programmer or the LiBER diagnostic tools.

Different external circuits, including the activation of the BMS with independent power source, can be realized upon request.

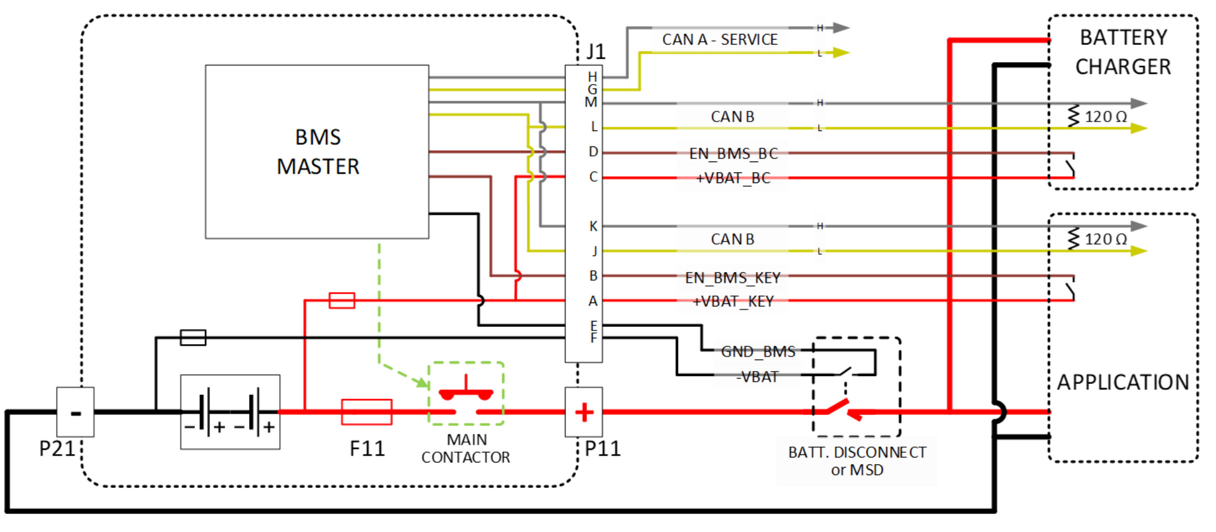

Fig. 24. Electric scheme of external wiring of the all-in-one configuration of the LiBER-LV-NMC-BATTERY battery pack

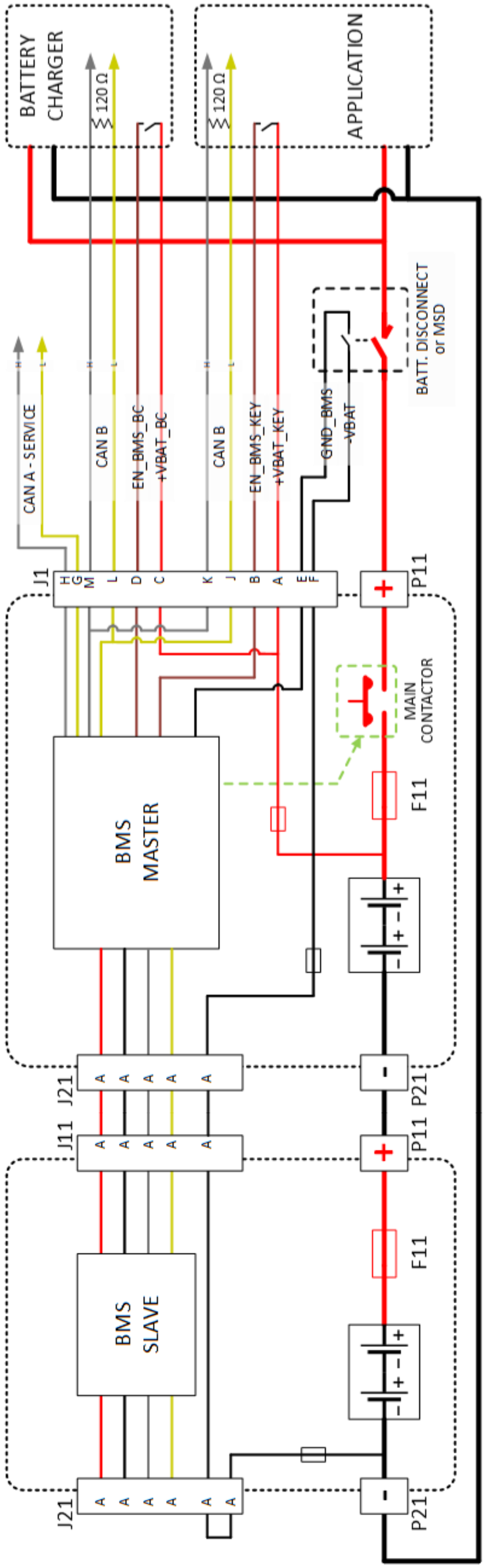

Fig. 25.. Electric scheme of external wiring of the 2S configuration of the LiBER battery pack

8. Mechanical drawings and installation

The length of the LiBER module and the position of the anchoring points are determined by the number (–S) of cells in series, according to Fig. 26 and Table XVIII.

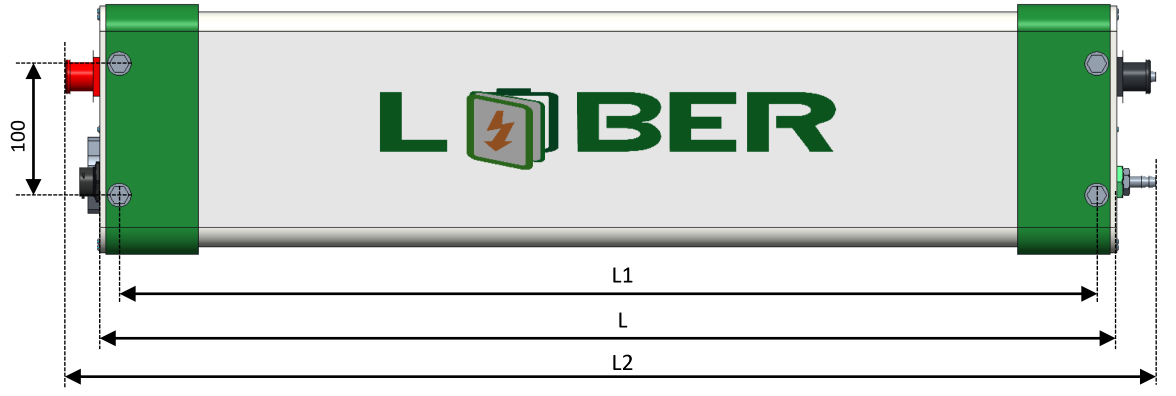

Fig. 26. Side view of the LiBER module

Table XVIII. Length of the module

	-S	S3	S4	S7	S8	S9	S10	S11	S12	S13	S14	S15
L	[mm]	440	525	775	855	940	1020	1100	1190	1270	1355	1440
L1	[mm]	410	495	745	825	910	990	1070	1160	1240	1325	1410
L2	[mm]	500	585	835	915	1000	1080	1160	1250	1330	1415	1500

The LiBER module is equipped with 8 fixing point on each terminal. See fig. 27. It is required to use at least 4 fixing points for each side of module.
M8 eyebolts can be inserted in the anchoring points for lifting the module.

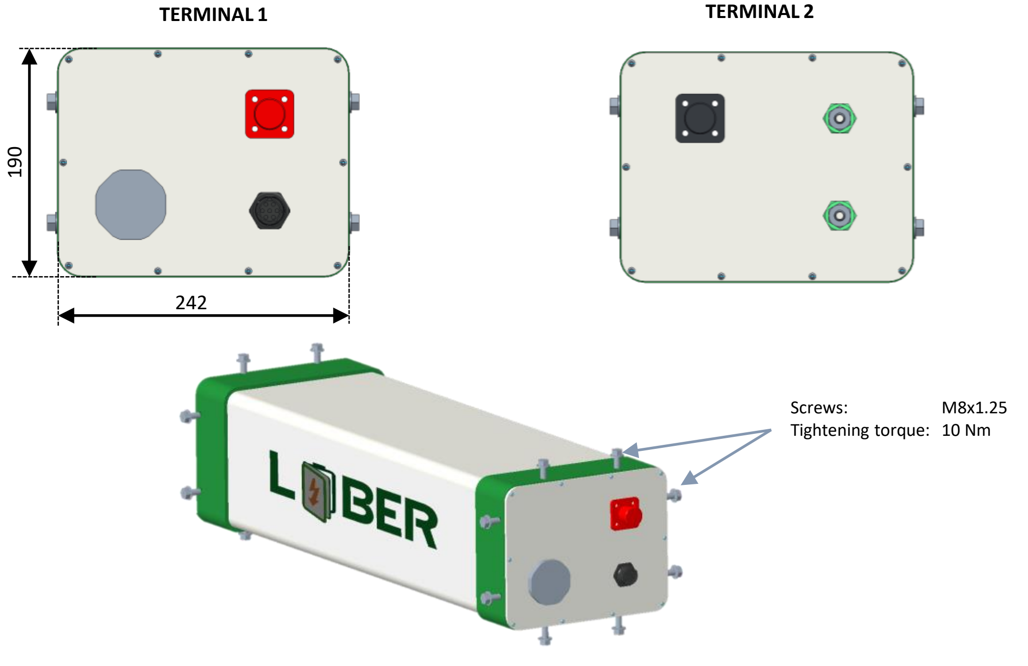

Fig. 27 View of the terminals and of the anchoring points

MODULE AND PACK LAYOUT

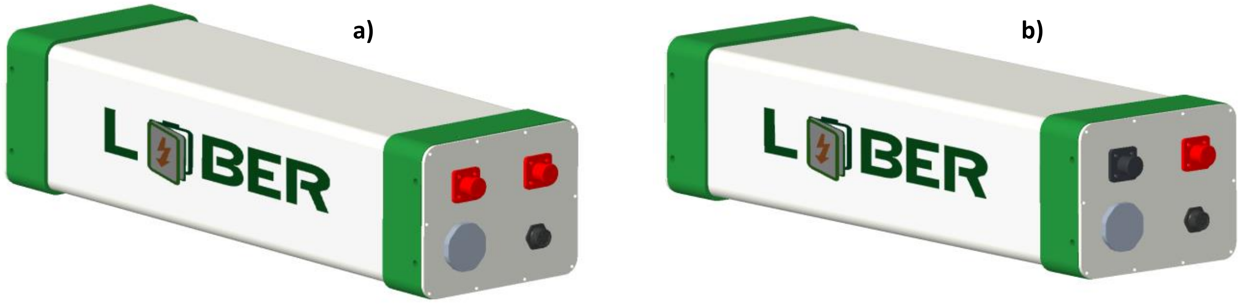

Fig. 28 View of TERMINAL 1. a) two parallel power connectors P11 and P12. b) positive P12 and negative P33 power connectors.

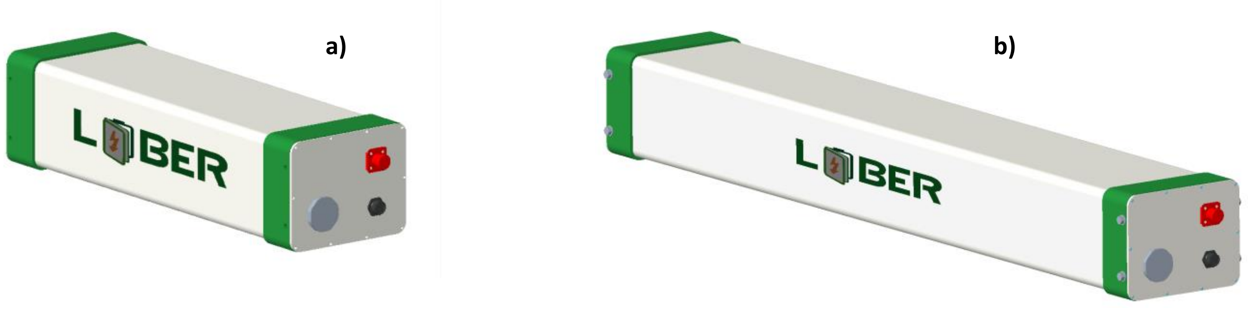

Fig.29 a) module containing 7 cells in series (S7); b) module containing 15 cells in series (S15)

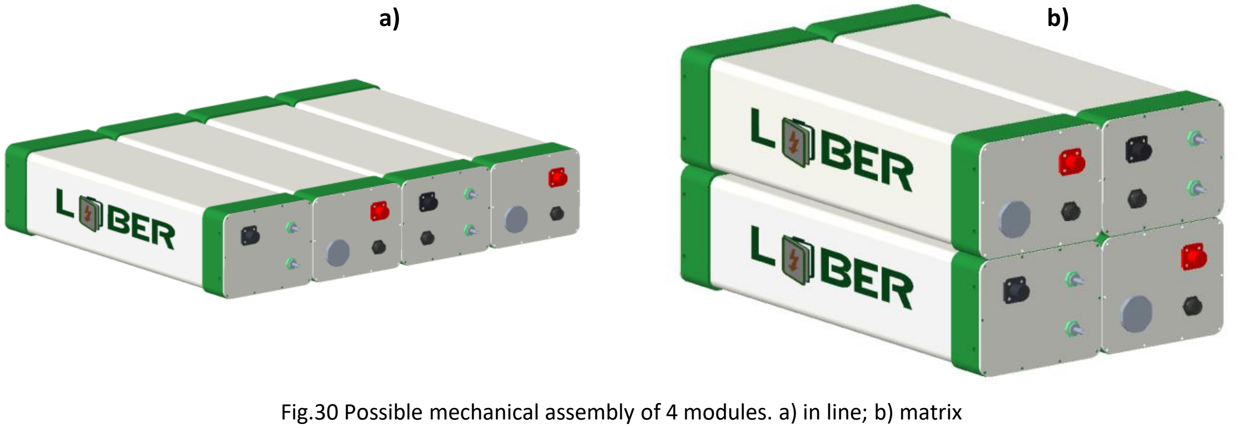

Fig.30 Possible mechanical assembly of 4 modules. a) in line; b) matrix

9. Monolithic battery pack

The LiBER modules can be supplied as a single pre-assembled, sealed monolithic battery pack. Users can choose:

- Pack configuration
- External power connections
- Position of power and signal connectors
- Position of cooling connectors
- Position of the anchoring points

a) b)

Fig. 31 Possible pre-assembled monolithic battery pack. a) 15 cells in series (S15); ; b) 7 cells in series (S7);

a) b)

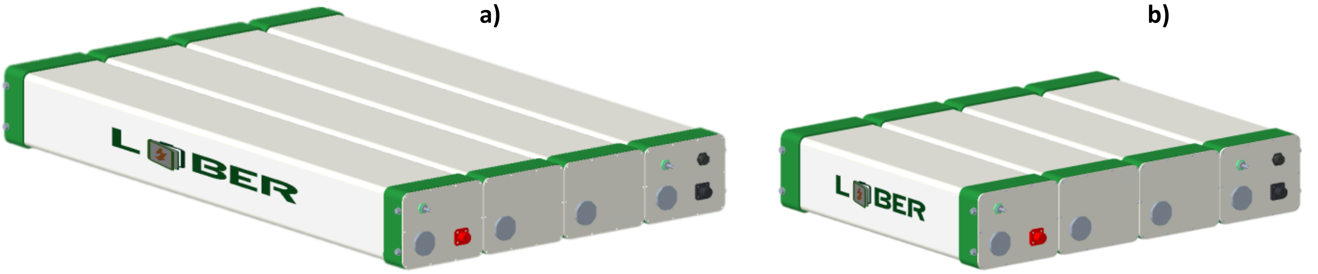

Fig. 32 Possible pre-assembled monolithic battery pack. a) 15 cells in series (S15); ; b) 7 cells in series (S7);

a) b)

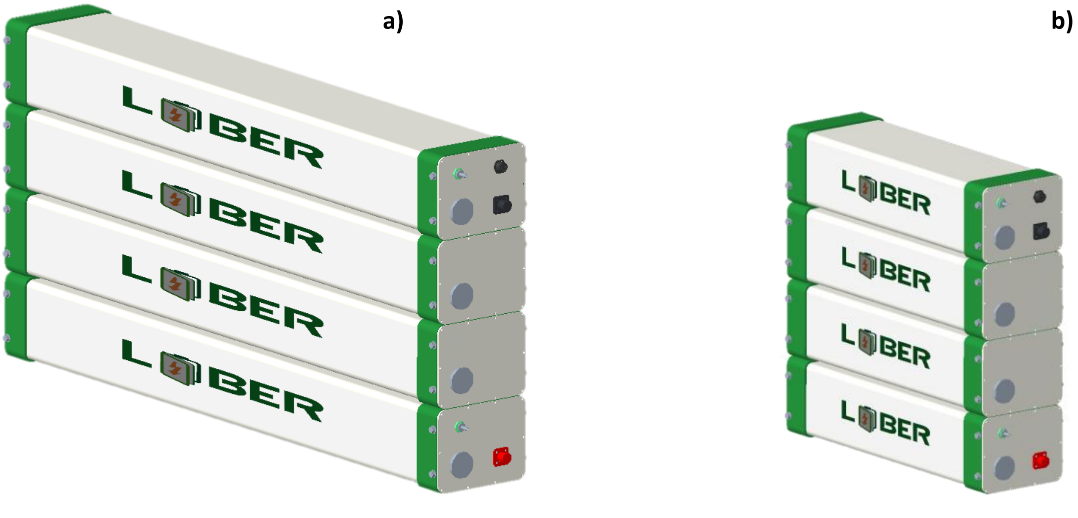

Fig. 33 Possible pre-assembled monolithic battery pack. a) 15 cells in series (S15); ; b) 7 cells in series (S7);

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