ZEBRA® Battery Handbook
for
Vehicle Applications

Confidential

Revision	Date	Description	Author
1.0	10.12.04	First Issue	R. Manzoni
1.1	19.07.05	General review	RM FR
1.2	14.10.05	Chapter 4 review , ZM error's list review, appendix B	RM FR
1.3	08.05.06	Chapter 4, 8 Paragraph 2.2, 2.3 . 8.5 8.6 , Appendix B, C, Safety instruction	RM
1.4	01.02.07	Paragraph 2.2, 2.3, 3.2, 3.3 , 6, 8.4 Appendix D,E,F	RM
1.5	09.07.07	Overview, Paragraph 3.2, 3.3, Chapter 7, Appendix A	RM
1.6	16.01.08	Introduction, 2.2, 2.3, 2.7, 3,4,5 8.2, 8.4, 9, Appendix B, C	RM
1.7	12.04.10	MSD updating	CM
1.8	7.06.10	Paragraph 1.3.5, 2.2, 2.4	RM
		Paragraph 1.3.5, 1.3.6, 1.3.7, 2, 2.1, 2.3, 3, 3.2.2, 3.7, 4, 7.4, 8.2, 8.3, 8.4, App A.	AB
1.9			

THE ZEBRA® BATTERY TECHNOLOGY

OVERVIEW

ZEBRA® batteries, with a specific energy of ca. 120Wh/kg and a specific power greater than 150W/kg can be used for any mobile or stationary energy storage application which requires more than ca. 2kWh of stored energy.
In general the recommended usage is a mean discharge rate of 2 hours or longer, power peaks are possible during the discharge.

ZEBRA® means Zero Emission Battery Research Activity.

ZEBRA® batteries are intrinsically maintenance free and have a long life and high reliability. Their safety features make ZEBRA® batteries especially suitable for mobile applications like cars, vans and buses.

The project was initiated in South Africa and developed in England and Germany. Today ZEBRA® batteries are produced by FZ SONICK, with a 20.000 m² production plant located in southern Switzerland, bordering Italy.

A ZEBRA® battery is composed of series and parallel connected single cells.
The open circuit voltage (OCV) of ZEBRA® cells is 2,58V/cell and is nearly constant over the complete operating range.

ZEBRA® Battery technology has shown in laboratory tests that it provides a calendar life of more than 10 years and a cycle life of 1000-2000 nameplate cycles. This data is supported by batteries in the field that are still in operation after more that 1000 nameplate cycles.

Please always take in consideration that a battery can store a relative large amount of electrochemical energy and consider that if any energy is released or dissipated in an uncontrolled way can arise in possible danger.

A ZEBRA® battery is a high temperature battery; the normal operating temperature for the cells is in the range 260-360°C. The battery enclosure has a good thermal insulation thanks to the vacuum between the inner and the external box, and in normal condition a ZEBRA® battery will dissipate from the battery case some thermal energy (60-190 W), depending on the battery type.

A ZEBRA® battery is controlled by an electronic unit, the BMI as all the electronic units needs to operate at limited temperature. The battery compartment should be designed to keep the ambient temperature to say 50°C max in normal operation.

Please carefully read this manual before installation and use of a ZEBRA® battery.
Do not hesitate to contact FZ SONICK for any question.

INDEX

FIGURE INDEX

RELATED DOCUMENTS

BMI user interface
MBS user interface
UM-ZEBRA® Battery System

DEFINITIONS

ZEBRA®:	Zero Emission Battery Research Activity
Nameplate cycles:	cumulated discharged capacity (Ah) / nameplate capacity (Ah)
SOC:	State Of Charge: actual battery capacity (Ah) /nameplate capacity (Ah)
DOD:	Depth Of Discharge: discharged capacity (Ah) / nameplate capacity (Ah)
EOC:	End Of Charge
MBS:	Multiple Battery Server
BMI:	Battery Management Interface with Interface
BMS:	Battery Management System
IFB:	Interface Box (electric part of the BMI, connected directly to the battery)
LV:	Low Voltage
HV:	High Voltage
EV:	Electric Vehicle

1. ZEBRA® BATTERY TECHNOLOGY

1.1 ZEBRA® CELL

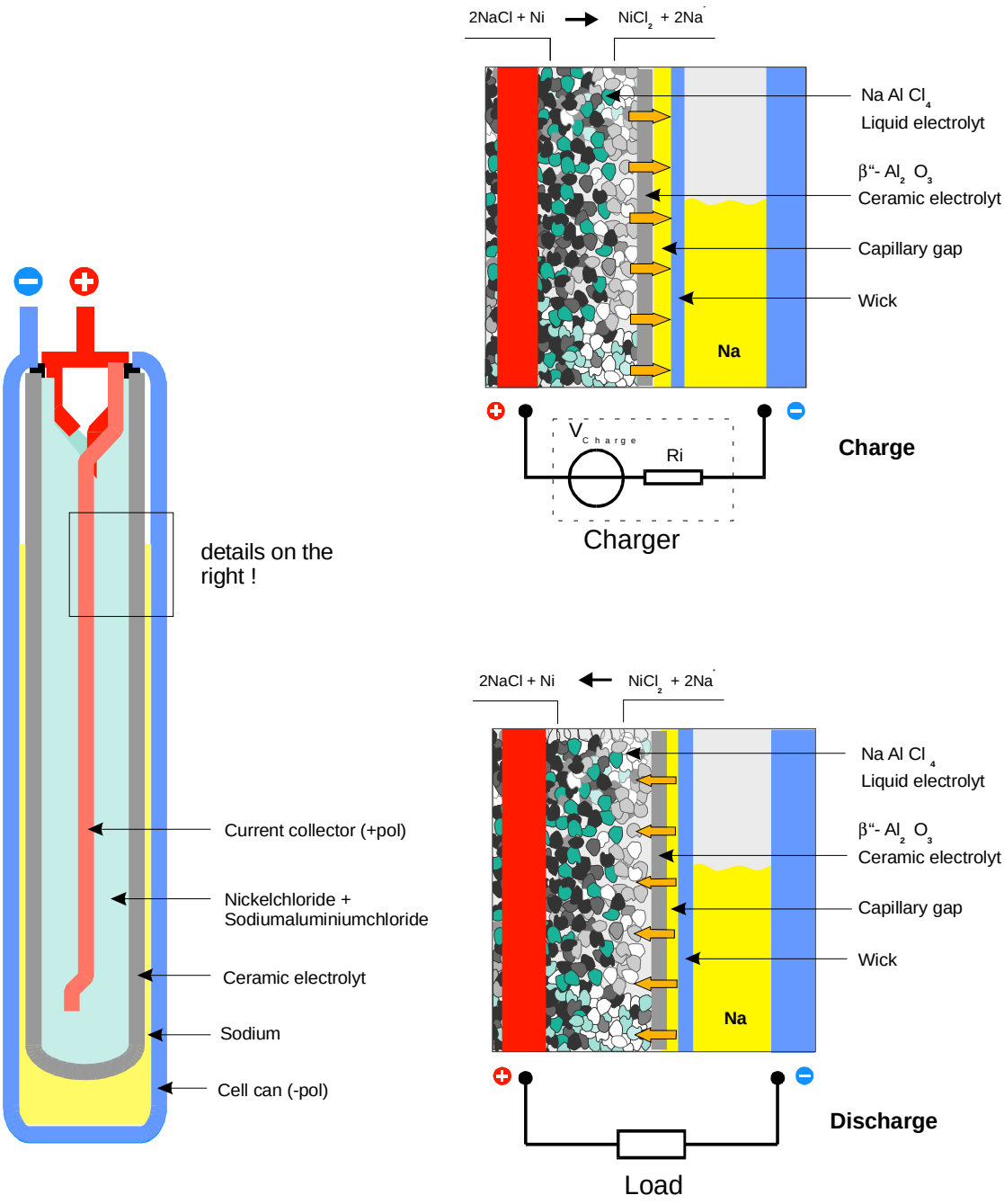
1.1.1 Basic design

A ZEBRA® battery consists of an assembly of single cells.
Each single cell in the charged state contains sodium as the negative electrode and nickel chloride as the positive electrode.
The sodium reacts with the nickel chloride on discharging to form sodium chloride (common salt) and nickel. The process takes place in the reverse direction on charging.
The cell reaction requires an electrolyte which conducts sodium ions: ß“alumina is used for this purpose.
This ceramic substance conducts sodium ions and is adequately conductive at higher temperatures.
The cell and battery are operated at temperatures between 270℃ and 350 ℃.
As the positive electrode (nickel chloride or common salt and nickel) is used as a solid electrode, a second liquid electrolyte (sodium aluminium chloride) provides the ion conducting properties inside the positive electrode. Neither of the electrolytes is involved in the cell reactions, but they are only used for conducting sodium ions.
The main component of the cell is the ß" alumina ceramic. Its properties and shape determine the resistance and therefore the efficiency of a cell. The ß" alumina ceramic divides the cell into one chamber for the positive electrode and one chamber for the negative electrode.
The positive electrode and the current collector are located inside the ceramic electrolyte tube.
The negative electrode - the sodium - is located between the ceramic and the cell case, which is also the negative pole of the cell.

1.1.2 Data for ZEBRA® single cell

ZEBRA® technology can be applied to different types of cells: cells can differ in dimensions, typically the height, and capacity depending on the composition of the active material.
Different types of cells will have different capacity, current ratings and can require a different thermal management.
For data relative to ZEBRA® single cell see table in APPENDIX A.

1.1.3 Basic design of cell including the cell reaction



$$2NaCl + Ni \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} NiCl_2 + 2Na$$

Figure 1: Basic design of cell & cell reaction

1.2 ZEBRA® BATTERY

1.2.1 Basic design

The ZEBRA® battery is built with single cells of the same type which are interconnected by brazed connectors. Several different connection configurations are possible for each battery design, i.e. the cells are connected in series and parallel inside the battery to obtain the required battery voltage and rated capacity.
The battery terminal voltage is determinated by the number of cells connected in series and the battery capacity is determinated by the number of cell chains connected in parallel.
The battery footprint can be adapted to the requirements of the dimensions of the cell array; the battery height is determined by the cell height plus space for cooling, heating, thermal and electrical insulation.
The cell pack is surrounded by a double walled box with a vacuum insulation.
This consists of metallic inner and outer skins, with the space between the metal boxes filled with suitable insulating support material. The support material is required to enable the box to withstand the external air pressure after the air is evacuated.
The battery maintains the operating temperature by means of an insulated heater located on top of the cells. Depending on the application, a ZEBRA® battery may require cooling.
In the air cooled version of a ZEBRA® battery, ambient air is blown by a dedicated fan into cooling plates between the cells, to ensure that excess heat is removed as and when required.

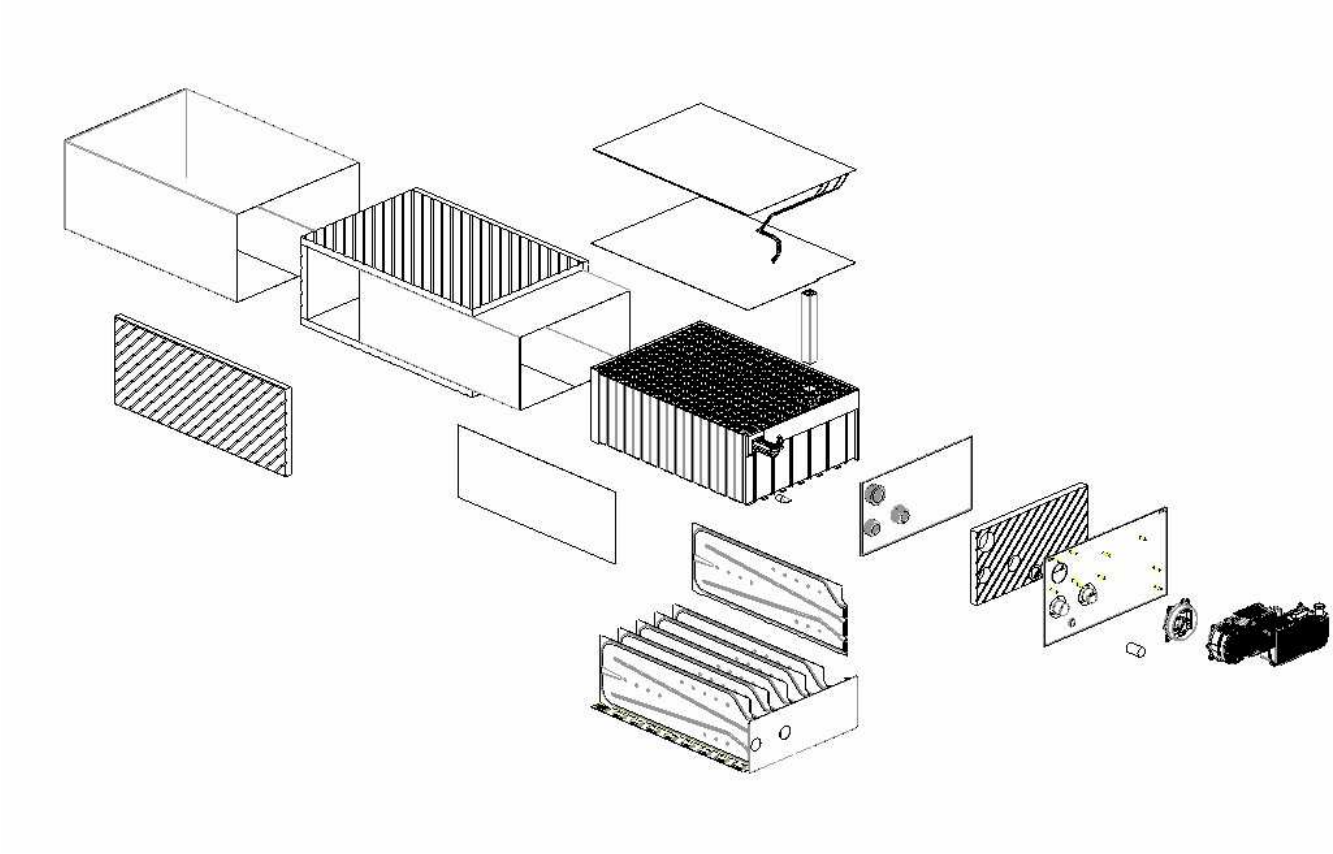


Figure 2: ZEBRA® battery building up

1.3 BMI – BATTERY MANAGEMENT INTERFACE

1.3.1 General description

For the operation of ZEBRA® batteries, the following parameters have to be controlled:

1) Current
2) Terminal voltage
3) Temperature
4) Status of Charge
5) Insulation resistance between main circuit and battery box

Each battery includes a **Battery Management with Interface (BMI)** assembly. It provides the **battery management** system and the connections to the vehicle.
It is connected to the battery directly over the cable lead through on the battery box.

The battery management system BMI supervises the battery operation, monitoring battery parameters and operating temperature.

The battery management system is integrated in the BMI. It consists in two sections: the BMS unit and the IFB unit.
The BMS unit includes a microprocessor controlled board that performs the measurement of the parameters of the battery and the control of the battery operation. The BMS has two sections, the High voltage and the Low voltage section and includes the connectors for the vehicle interface, the ac mains power and the battery charger.
The IFB unit includes the connectors for the high voltage DC traction power, the main relays and the shunt for the on board measurement of the current.

<u>Communication between BMI and the other components in the vehicle</u>
The BMI communicates with other components of the vehicle via the CAN interfaces or discrete signals. Critical signals such as the emergency signal and the ignition signal are directly input to the BMI without using the vehicle CAN interface.

1.3.2 BMI block diagram

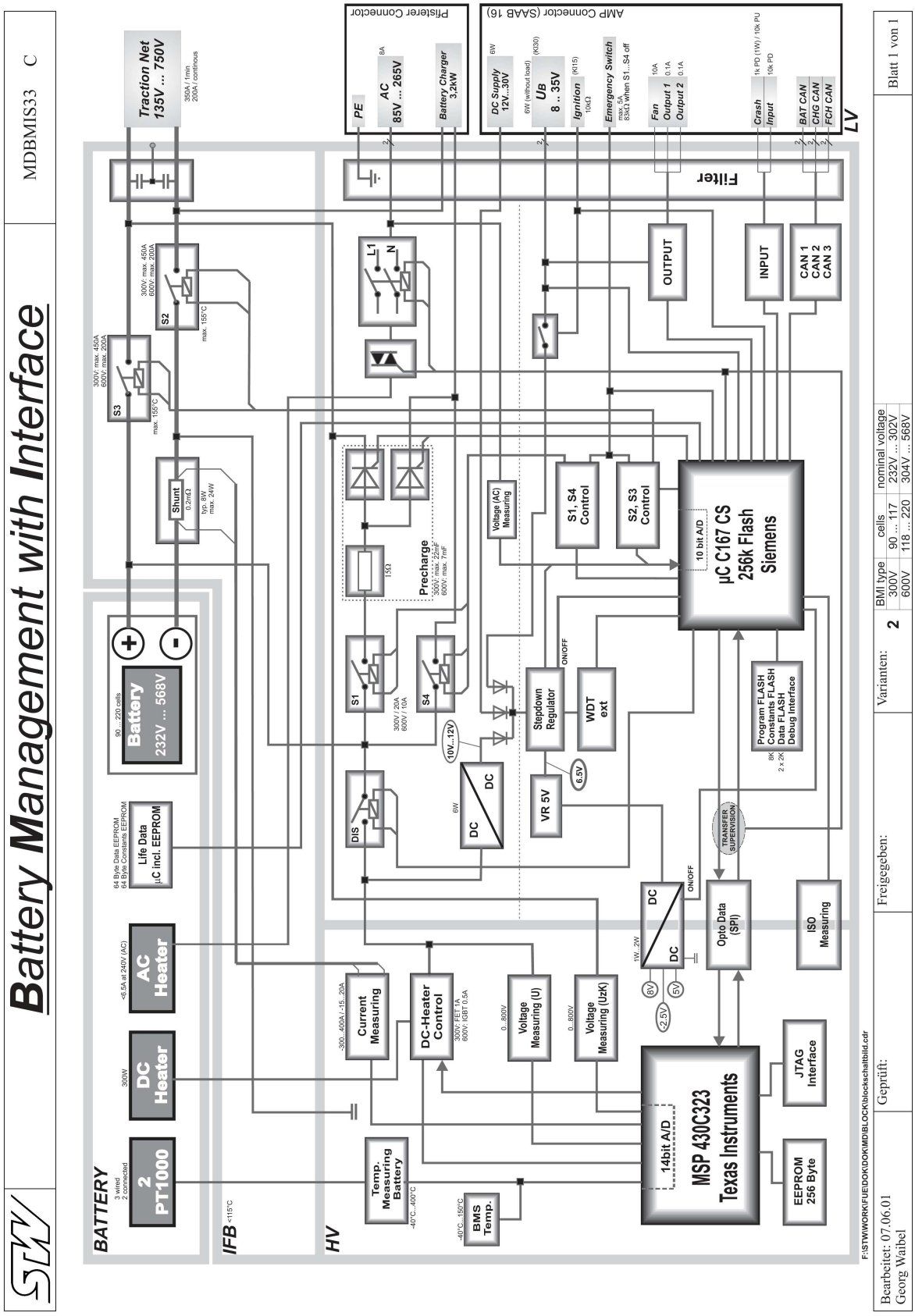


Figure 3: BMI block diagram

1.3.3 BMI interfaces

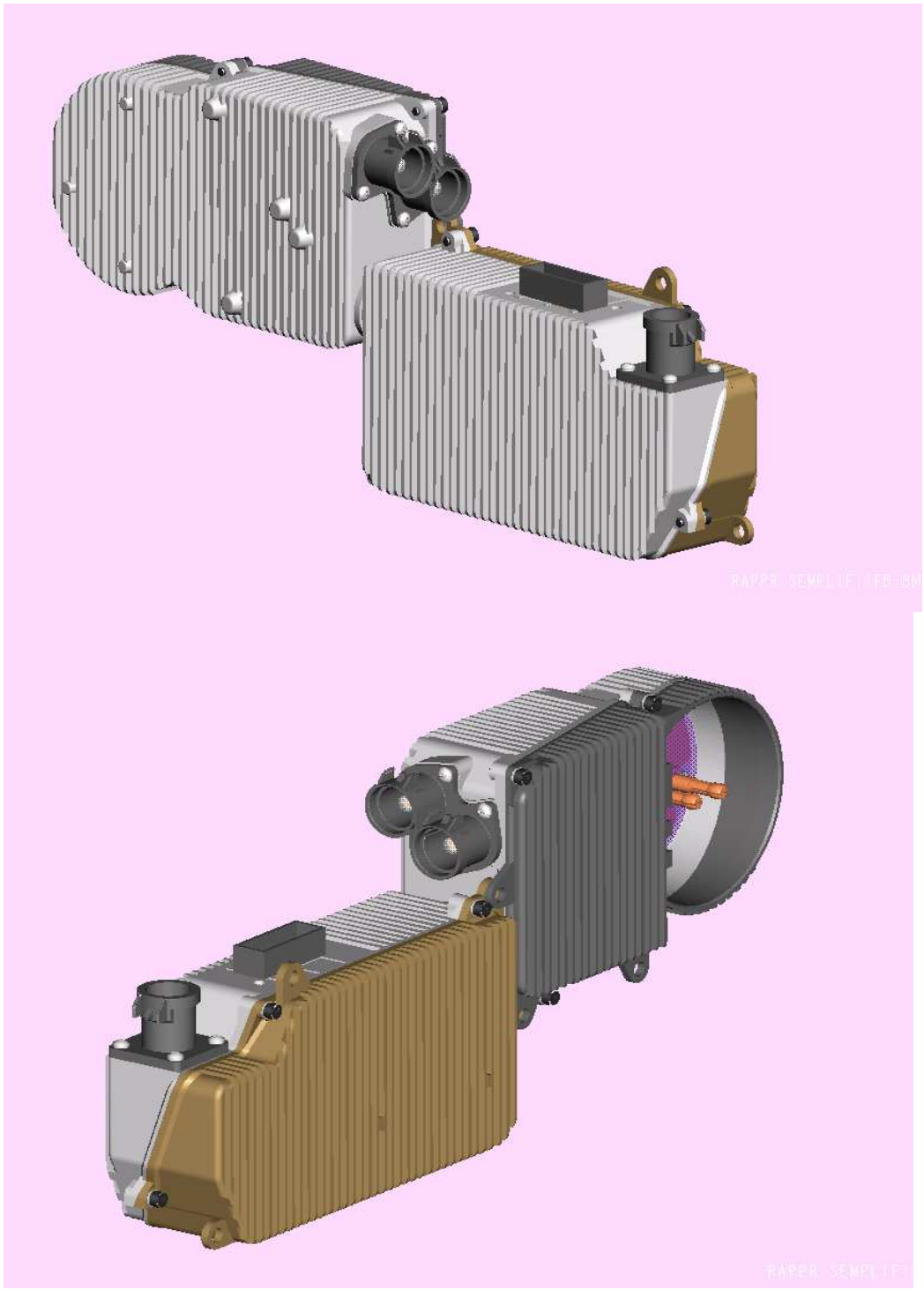


Figure 4: BMI interfaces

1.3.4 Connectors and pin assignment of BMI

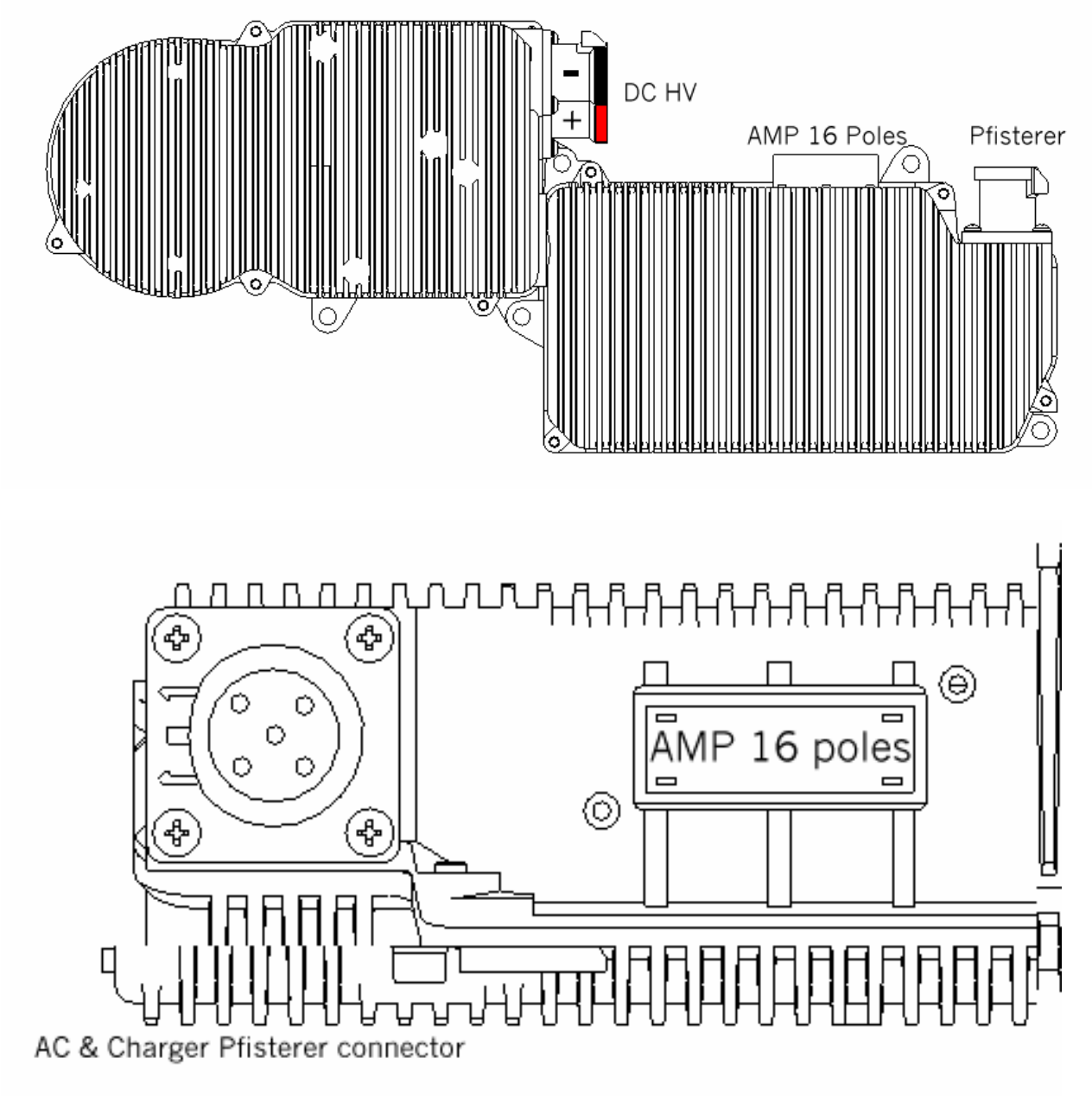


Figure 5: BMI connectors

1.3.5 Vehicle control connector

Manufacturer: AMP

Protection class: IP20 when not connected, IP67 when connected to the relative cable connector correctly wired.
For the relative cable connector see the List of items available as spare parts.

pin	*signal*	*dir.*	*use*	*driver*	cable cross section	*comment*
1	KL31	I	**GND**		2,5 mm²	
2	INPUT	I	**RESET**	logic circuit I < 50 mA	0,75 mm²	**Open : Normal operation** Closed to the positive power supply: BMI Reset (pull-up max 10 KΩ)
3	KL15	I	**IGNITION**	logic circuit I < 50 mA	0,75 mm²	On: high:4,8V...Ubatt Off: low:0..1,2V
4	FAN OUTPUT	O	**BATTERY COOLING FAN**	BTS 650P <protected> Imax:10A	2,5 mm² Use fuse 7,5A (*1)	high side driven port
5						Reserved
6	CRASH 2	I	*CRASH INPUT 2*			Not used
7	FCHCANH	IO	**Charge CAN** high	*PCA82C251T*	Twisted 0,75 mm²	No Termination resistor in the BMI
8	CANH	IO	**Battery /Vehicle CAN high**,	*PCA82C251T*	Twisted 0,75 mm²	No Termination resistor in the BMI
9	EMERGENCY	I	**EMERGENCY switch**	6A pickup 2A continuously	2,5 mm² Use fuse 7,5A (*2)	High level: Normal Operation (8V...Ubatt). Low level : Emergency: (open or 0...7V). effects directly the coil of the main switches.
10	DC SUPPLY	I	**EXT 12 V DC SUPPLY**	12..30 V 6W	0,75 mm² Use fuse 1A	
11	KL30	I	**BATTERY DC SUPPLY**	8..35V 6W+ outputs	2,5 mm² Use fuse 10A	
12	OUTPUT 1	O	**PWM OUTPUT** (charger)	Imax:100mA <protected>	0,75 mm²	high side driven port
13	OUTPUT 2	O	**PWM OUTPUT** (SOCr) or DC/DC or MCU Enable	Imax:100mA <protected>	0,75 mm²	high side driven port
14	CRASH 1	I	CRASH INPUT 1			not used 1 KΩ pull-down (1W)
15	FCHCANL	IO	**Charge CAN** low		Twisted 0,75 mm²	No Termination resistor in the BMI
16	CANL	IO	**Battery /Vehicle CAN low**,		Twisted 0,75 mm²	No Termination resistor in the BMI

Table 1: *Signals on vehicle control connector of BMI AMP 16 poles*

BMI PWM outputs function depends on the BMI firmware:
a) on standard SW:
- pin 12 is the PWM output for the charger BC Z 3 (usually 5% to 95% PWM)
- Pin 13 is a DcDc enable output

b) on request:
- pin 12 is the PWM output for the charger in charge mode and a discharge current reduction signal (10% PWM : full reduction 90 PWM : no reduction) in discharge mode
- pin 13 is a SOC output (15% PWM : SOC =0 85% PWM : SOC ≥ 100%)

Other configurations are possible on special applications, for example PIN 13 could be used to power on the Chain Monitor Unit (CMU)

Notes:

(*1): On pin 4, with 12V batt. on Pin 11, has been tested the fuse “miniblade” from Littelfuse of 7,5A 32V
With fan with free pipe, EBM PAPST model
12V (10-14V) 62W 4560 RPM 30x00066.00 SN: G1G 144 - AB53-07
24V (16-28V) 61W 4720 RPM 30x00067.00 SN: G1G 144 - AB11-06
has been measured the following current:

9V power supply: 6A for 100ms, > 4A for 3000ms, 3,5A in constant current zone
12,5V power supply: 9A for 500ms, > 8A for 1000ms, 4,0A in constant current zone
13,8V power supply: 11A for 100ms, > 10A for 200ms, 4,1A in constant current zone

18V power supply: 46A peak, > 3A for 400ms, 1,8A in constant current zone
24V power supply: 5,8 peak, > 4A for 200ms, 2,0A in constant current zone
27V power supply: 6A peak, > 5A for 300ms, 2,2A in constant current zone

With a fan installed on a Z36 has been measured, with 13,8V:
t=0 ms 1,5A; t=3000ms 4A ; t=3001ms 10,4A ; t=3021ms 10,0A;
t=3221ms 8A; t=5221ms 6A ; t=const current zone 4,25A

(*2): On pin 9, the following current have been measured, while closing the main switches on traction net, with cables 2,5mm^2 length 1m between BMI and power supply.

9V	t< 180ms	2A	t=181...281msec	4,5A	t const current 1,01A
12,5V	t<150ms	3A	t=151…251msec	6A	t const current 0,76A
13,8V	t<150msec	3,5A	t=151…251msec	6,8A	t const current 0,70A
18V	t<150msec	4A	t=151…251msec	7,5A	
24V	t<200msec	3,1A	t=201…501msec	5,5A	
27V	t<175msec	3,0A	t=176…276msec	6,0A	

1.3.6 AC-mains and battery charger connector

Manufacturer: Pfisterer
Protection class: IP20 when not connected, IP67 when connected to the relative cable connector correctly wired and sealed.

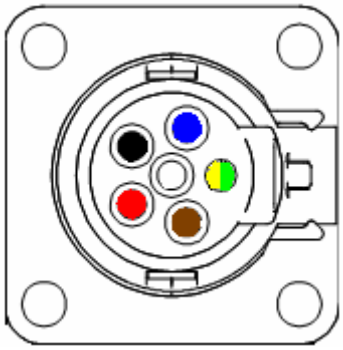
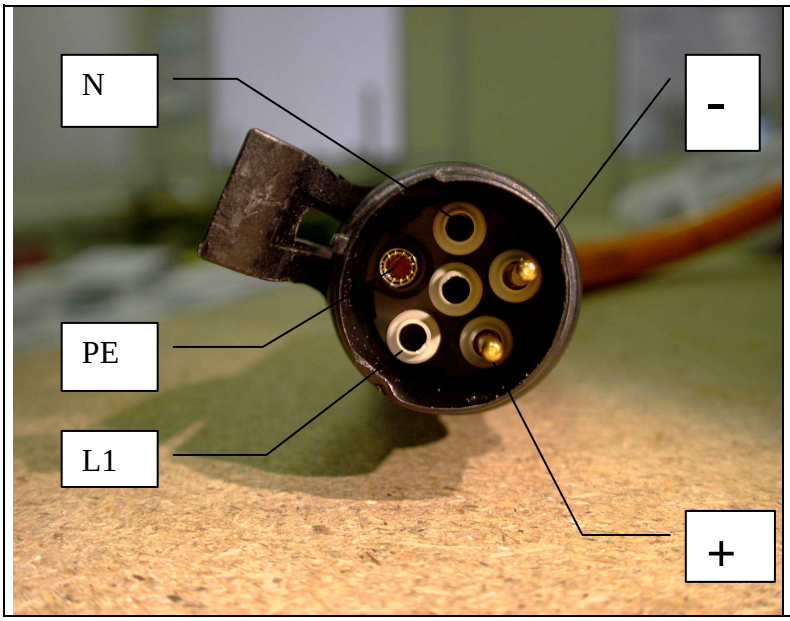


Figure 6: Ac / Charger connector X01-BMI

pin position	description	BMI	Notes
	UCharge -	female	(max 20A / 670V)
	Power Line N	male	(max.8A)
	n.c.		
	Power Line L1	male	(max.8A)
	UCharge +	female	(max 20A / 670V)
	Power Line PE	male	Protective ground

Figure 7: Ac / Charger connector X01-BMI

AC/Charger Cable connector :

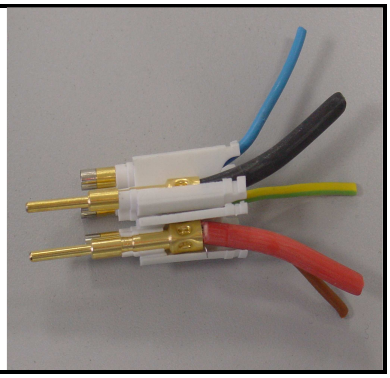


BMI AC-Charge connector
5 poles + PE

Type PFISTERER
350 208-001
Id. Nr. 30X00064.02

Suggested cable : 5 x 2.50 mm² G-PUR H07BQ-F 450/700V

pin number	Description	Pin type	
5 (*1 fuse)	UCharge -	male	(max. 20A / 670V)
4 (*2 fuse)	Power Line N	female	(max.8A)
3	n.c.		
2 (*2)	Power Line L1	female	(max.8A)
1 (*1)	UCharge +	male	(max. 20A / 670V)
PE	Power Line PE	female	Protective ground



The pin numbers refer to the marks on the plastic insert/ pin pick-up of **white** colour.

NOTE In a pre-series delivery the plastic insert/ pin pick-up was **grey** colour, and had a different marking
please contact FZ Sonick before using a grey plastic insert/ pin pick-up.

(*1): When pin 1 and 5 are used in the vehicle to charge the battery, they MUST be protected with a fuse located on line connected with them, as close as possible to the BMI connectors;

The fuse must be selected considering:
-max 20A, lower value are admitted depending on the charging current in normal operation
(for more then 16A, a cross section higher then 2,5mm^2 for external cables)
-the rated voltage for the fuse must be higher then the max voltage generated by the charger.
On a new battery, max 2.9 Volt per cell, from the charger, are allowed.
Z5-557 (216 Cell/string) Z36-371 (144Cell/string)
626Vdc - 20amp 417Vdc - 20 amp.

Example of fuse on this line:
Bussmann, 10x38 FWC-16A10F fast acting, 600Vac 16 amp.
6,9 GS 000 PV016 (NH000GS69V16PV) from Ferraz Schwmut, Protistor family.

FZ Sonick is available to support the customer in the selection of the fuse.

(*2): Pin 2 and 4 MUST be protected with a fuse.
With 230Vac the fuse must be 250Vac, very fast type, 6,3A.

Example of tested fuse on Z5 and Z36 are, for 230Vac:
OMEGA FF (ultra fast) 250Vac, 6,3A, 5x20
(for Z36 can be accepted Littlefuse, 505 series, 10amp, fast acting)

For different type of battery, please contact FZ Sonick to check the right sizing of the fuse

Warning: The **AC Line Supply (**85V…265V 50-60 Hz Vac allowed range in BMI) used to power the BMI, must include, besides the fuse for short circuit protection, a residual-current device (RCD) with a trip current of (or lower then) 30mA.

Warning: The AC cable must contains the ground connection PE and on vehicle all the accessible parts must be connected to ground.
Protective ground PE has to be connected to PE line of the BMI, to the battery case and to the vehicle chassis
Warning: in case of connection with a 3 phase 400VAC system the neutral line **must** be present

Warning: The charger must be CE marked, class 1 (with ground connection), provide a galvanic separation between AC mains and the output of the charger.

Example of charger suggested to be used with ZEBRA® batteries is the BCZ3 family of MES.

Warning: The charger must not produce, on a new battery, more then 2.9 V/c in all the conditions.

Example	Z5-557 (216c/s)	Z36-371 (144c/s)
Charger must be limited to	626V (suggested 605V)	417,6V (suggested 403,2V)

Warning:
A surge arrester to limit over voltages to 2.5kV is suggested on AC line.

Warning : Depending on charger configuration, the battery voltage can be present on the wiring when the battery is in charge mode also if the charger is not connected

Warning : Before of the connection of the output connector of the charger, carefully check the polarity on the battery DC voltage on the wiring to the charger: a reversed polarity can damage the charger.

FZ Sonick is available to provide all the information required by the customer to select the right charger and charger connections to be compatible with the ZEBRA® system and all normative.

1.3.7 HV DC voltage connectors

Manufacturer: FZ Sonick
Protection class: IP20 when not connected,
IP67 when connected to the relative cable connector correctly wired.

WARNING: DANGEROUS VOLTAGE - DC Line Supply: 40V…600 VDC

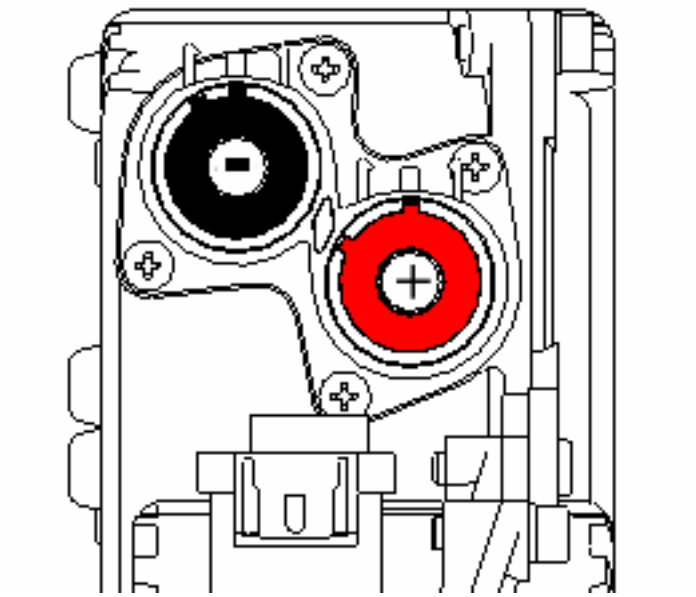


Figure 8: BMI DC High voltage power connector

Warning: A fuse, or a device which removes voltage on pin 9 of AMP16 in case of the battery current exceeds a threshold depending on the application, MUST be used on traction net to protect the wiring and the equipment powered by ZEBRA® batteries. The wire must curry the short circuit current before the fuse blow. The fuse must be located as close as possible to the BMI connectors.
A possible family of fuse for traction net can be the “Protistor” from Ferraz-Shawmut.

When more battery are connected in series a fuse must be used between each of them according EN 1987-1 A2.

For the selection of the fuse consider the following data:
Typical Maximum Current that can be provided in drive mode by the battery on traction net:

Z5-557	Z36-371
90A peak	178A peak
85A after 30s	155A after 30s

The short circuit current on the battery depends on SOC, temperature and other factors; the minimum and maximum measured values are:

Z5-557	Z36-371
209,5A min	584A min
323A max peak; 312A after 1 sec	777A max peak; 722A after 1s

Warning: During the braking and in all conditions in hybrid applications, the drive system must not produce, on a new battery, more then 2.9V/c.

Example	Z5-557 (216c/s)	Z36-371 (144c/s)
Max voltage must be limited to	626V	417,6V

The BMI could detect high currents and low voltages and would open the main contactors in case of overcurrent or short circuit. Depending on the battery size and configuration, it is possible that dangerous values for the installation can be evaluated as a correct current value for the battery when in the discharge condition and will therefore not be detected as dangerous by the BMI.

FZ Sonick is available to provide all the information required by the customer to select the right fuse, traction system and charger to be compatible with the ZEBRA® system.

1.3.8 BMI Power Supply

The power supply for the BMI-LV electronics may be derived from three different sources:
1. for normal use: from AUXILIARY BATTERY DC SUPPLY on pin 11, the vehicle 12-24V DC voltage, when the ignition signal on pin 3 is present:

2. from the external DC supply on pin 10

3. in case of an absence or low voltage of both BATTERY DC SUPPLY and external DC supply: the BMI can be powered by a voltage converted from the traction battery voltage. This source is not available in case of a cold or discharged battery.
A step down DC/DC converter generates the power voltage for BMI-LV and BMI-HV circuits. Without vehicle 12-24VDC voltage, the main switches in the IFB will not close (neither charging nor discharging is possible).
The BMI-HV electronics is supplied by a DC/DC converter with galvanic separation, from the power supply for the BMS-LV electronics.

Generally a ZEBRA® battery includes two independent heaters. The first, the AC-heater, is powered by an AC voltage when available, the other, the DC-heater, is powered by the voltage of the ZEBRA® battery. The DC-heater is used only if AC voltage is not available or during charge before measuring the open circuit voltage.
To protect the ZEBRA® battery from over temperature caused by an error in the AC heater control the circuit has a double control with relay and Triac. In case of a fault in one of the components the other component will open the circuit.
In case of a fault of the control circuit the BMI should be replaced.
In case of a fault on the heater resistor the ZEBRA® battery has to be returned to the manufacture.

1.3.9 Potentials in the ZEBRA® battery system

In the BMI there are three different potentials present:

- ✓ potential of the ZEBRA® battery:
  - HV processor system
  - system measurement
  - insulation observation
- ✓ main potential:
  - Input
  - AC-heater
- ✓ 12-24V potential (LV):
  - processor system
  - output drivers
  - input comparators
  - CAN interface

1.4 THE BATTERY FLANGE

1.4.1 Overview

The battery flange is part of a ZEBRA® battery and must not be removed: in case of BMI replacement the flange must not be dismounted.
The battery flange includes the connectors for the battery positive and negative poles, for the heaters and for the temperature sensors and the circuits for the storage of the main parameters and the life data (basic battery configuration parameters as number of cells and of chains, cell type, historical data and life data as SOC and nameplate cycles).

1.4.2 Components of the battery flange

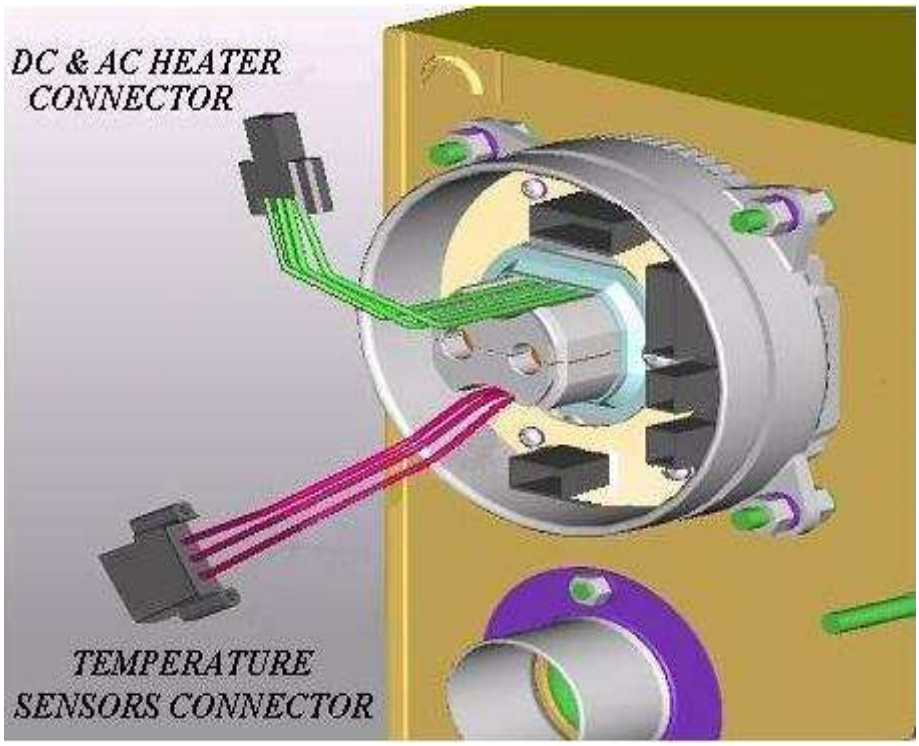


Figure 9: Battery flange

2. GENERAL INSTRUCTIONS AND HANDLING

ATTENTION!
The battery system is a power plant.

Due to the potential risk of the voltage of the battery, the personnel that operates on the battery system (installation, fault clearance, and all other phases of handling, etc) must be qualified and well trained.

The shipment, installation, use and maintenance as well as the sell off of the batteries must be executed following the instructions contained in the User Manual.

The batteries are suited to be used on electric or hybrid vehicles, in the traction system.

Is required that the batteries are located in a space not accessible by the driver during the normal usage.

The ZEBRA® battery must be electrically connected to the chassis of the vehicle in order to have all the accessible parts at the same potential. FZ Sonick is available to provide any information to analyse the battery location inside the vehicle. See chapter 1.3.6 for the other connections.

The producer of the vehicle must follow all the normative related to the use of the batteries in electric vehicles such:
- avoid motion of the vehicle when the AC plug is connected
- motion of the vehicle can be possible only after a start up sequence that, for BMI, is a positive edge on pin 3, ignition key
- provide to the driver an emergency switch to allow the disconnection of the battery
- provide to the driver information of state of charge, reduced power, etc using the “BMI or MBS User interface manual” with the description of the can messages sent by BMI or MBS

Contact FZ Sonick for any other additional information not contained in this manual.

2.1 ELECTRICAL SHOCK PROTECTION

Dangerous voltage could be present on the BMI connectors.

The BMI includes the mains voltage contactors, which, when are open, insulate the battery.

In case of faulty BMI, there is the remote possibility that the mains contactors remain closed.

The power connectors, when unplugged, have a protection index IP20 (protection by direct physical contact). The connectors must be connected/disconnected, only when the power lines (220V) or 12/24V auxiliary voltage are not plugged in and the emergency switch is in the EMERGENCY position.

The BMI unit is rated as protection class IP67, if all connectors, correctly mounted and sealed, are plugged in.

If the connectors are disconnected, the protection class of BMI is IP20.

Sealing: To guarantee the protection from water and obtain the IP67 the connectors must be mounted correctly, including the o-ring those ensure the seal.

Attention: If it is necessary to disassembly the BMI, before reset the BMI by pin 2 on AMP16 connector and then remove all the connectors.

Do not supply mains voltage to the BMI while disconnected from the battery

2.2 ZEBRA® BATTERY INSTALLATION

A ZEBRA® battery must be permanently fixed on the vehicle.
A ZEBRA® battery must be placed on a horizontal flat surface; the maximum inclination allowed during the utilization is 30 degrees.

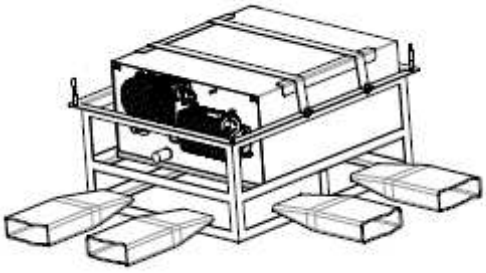
The battery fixing should be designed to not be damaged in case of over-temperature.
Ensure that no **combustible and flammable** materials of any kind are located in the surroundings of the battery and of the cooling hoses.

To avoid possible deformation on the battery case, due to localized pressure, the recommendation is to install the battery on a flat surface protected with a fender cushion, with an angle, running across the battery edges, to stop any slide on the horizontal directions.
As minimum requirement, the battery must be mounted on angle iron brackets of at least 50mm wide, running across the battery edges. The mounting brackets should have a fender cushion for the protection of the battery case.
The upper part of the battery should be fastened to avoid vertical movement.

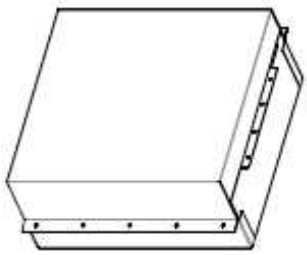
A possible configuration is to use angle iron complete with a fender cushion and fixed by metallic straps: to avoid any concentrated pressure causing distortion of the outer case of the battery, the straps should not fix directly to the battery case.
The fender cushion must be of a heat resistant type, non-combustible, for example in fibre glass material as New Componit Insulcom 800.
Ensure that no **combustible and flammable** materials of any kind are located in the surroundings of the battery.
A 50 mm gap between battery case and enclosure is recommended to enable natural convection air cooling

Enclosed some example of possible mounting, see more **details in appendix E and F**

FZ Sonick supplies mounting tips and installation information currently available at the time of writing.
The installation is in any case under the responsibility of the system integrator.



Battery rack, typical for bus application



Battery containment box, typical for car application

Figure 10: Fixing examples

The handling of a battery could be difficult, should be done with the maximum care using the lifting device supplied by **FZ Sonick.**
Consider the possibility to have a rack that could be easily dismounted from the vehicle by a fork-lift and operate later on the battery at ground level.

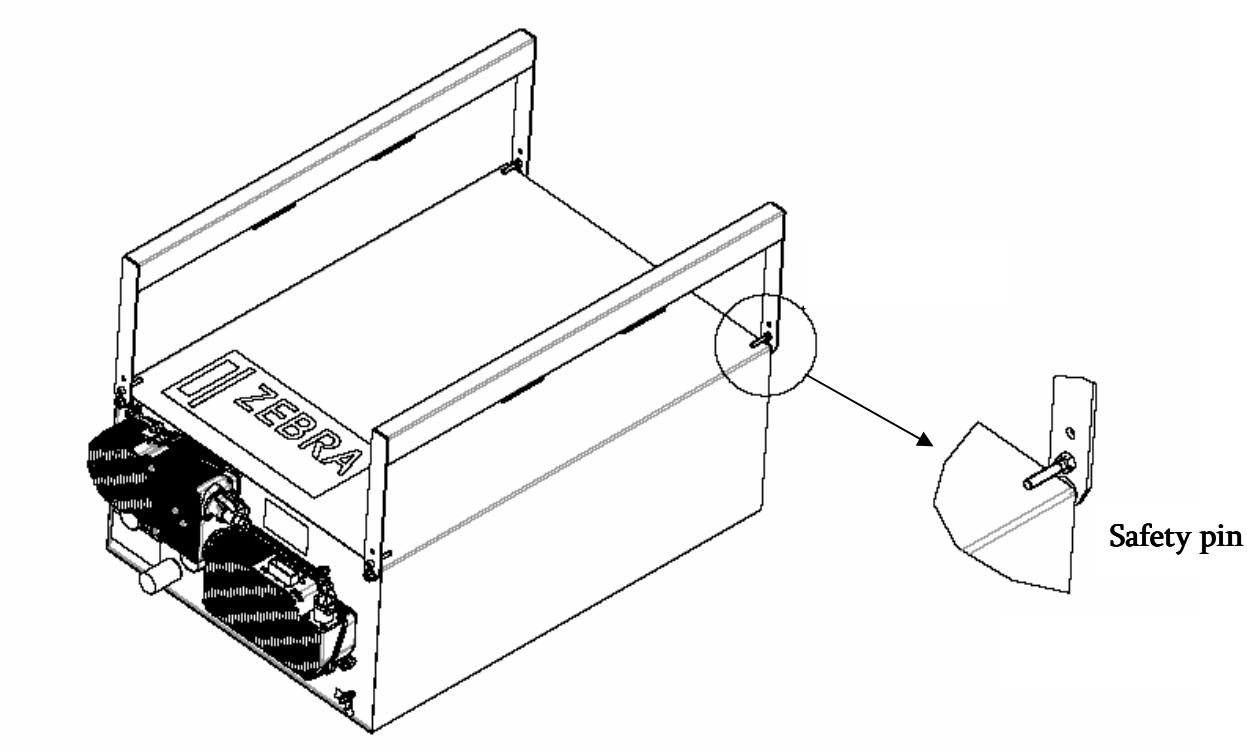


Figure 11: Handling device

To allow battery handling a lifting device is required.
The 4 lifting points should be easily accessible: a free space at least 30 mm wide is recommended in front of each lifting point.

Please carefully check the correct insertion of all the 4 hooks and insert the safety pins before to move the battery.
To allow installation and maintenance tasks, for connection or disconnection of the battery or the replacement of the BMI unit, the BMI side of the battery should be easily accessible: a free space at least 100 mm wide is recommended in front of the BMI assembly.

During operation the maximum inclination is 30 degrees.
Ensure that no flammable materials of any kind are located in the surroundings of the battery.

2.2.1 Overvoltage protection

See chapter 1.3.6 and 1.3.7 for max voltage that should not be exceed by the charger and the drive system.
A surge arrester to limit over voltages to 2.5kV is suggested on AC line.

2.2.2 Outlet hose of air cooling system

The surrounding of the outlet hose must be temperature resistant and thermal insulated: in normal operation the outlet hose and the outlet air can heat up to 350℃.
The inlet and outlet air hoses must be INOX type (metal).

2.3 HEAT FLUX

The thermal loss of a ZEBRA® battery depends on the size of the battery, for example for the Z5 battery in normal operation has a thermal loss of about 120W.

Suitable measures must be adopted to continuously remove heat from the mounting compartment of the ZEBRA® battery in order to have the ambient temperature in the mounting compartment below 50℃ in normal operation .
The battery compartment should be designed to remove the excess heat and keep the ambient at a temperature that do not damage the components of the vehicle, taking in consideration that in the worst case all the energy stored in the battery can be dissipated as heat.

Ensure that no **combustible and flammable** materials of any kind are located in the surroundings of the battery.
In fault situations the losses may rise considerably and the battery surface and air temperatures are very dependent on the design of the mounting compartment.
A possible scenario that may cause over temperature is a very fast electrical discharge, due to penetration of external parts inside the battery case that can cause a battery short circuit.
The system integrator should apply all the precautions, to avoid these risks, for example the vehicle should not have sharp components near the battery that could damage and penetrate the battery case crash situation.
In fault conditions, for example in case of crash, penetration of objects or a major fault inside the battery, a battery could heat up internally and occasionally show hot spots higher than 500 ℃ on the external case **or in the air hoses.**

Small flames have been occasionally observed in heavily damaged batteries with damaged box.
Use special gloves to be used up to 300°to handle the battery.

In order to keep the skin temperature of the battery below a defined limit, the heat must be removed.
The temperature limit depends on the material that is used in the battery compartment.
The removal of the heat depends on the configuration of the battery compartment: the battery can be cooled by conduction, for parts with direct mechanical contact or by convection, for the surface of the battery where air can easily circulate.

2.4 HANDLING

The handling of a battery could be difficult, should be done with the maximum care using the lifting device supplied by FZ SONICK.
Ensure that the battery case is not damaged.
Sharp objects and sharp edges can damage the battery box surface which can result in a loss of vacuum thermal insulation.
A battery with a reduced vacuum insulation has a higher heat loss and shows a higher surface temperature. A battery with a high heat loss cannot be properly operated.
Under no circumstances can any work be carried out on the battery housing (e.g. bending protruding edges, removing burrs, filing, welding, brazing etc.).
If a welding operation is necessary on the vehicle, disconnect the connectors of the BMI and protect the battery from sparks.
Never push or pull the battery by applying force to the BMI.
Under no circumstances should the protruding parts of the battery surface (e.g. BMI and air inlet/outlet hoses fixing points) be placed under tension.
The battery handling should be performed by the provided lifting device.

2.5 LIFTING

Lifting device is required for movement of the battery; this must be correctly located on to the lifting points provided for this purpose.
Ensure that all the 4 lifting points are correctly located, and then insert the safety pins to avoid the unhooking of the lifting points.
Ensure that only vertical forces are applied.

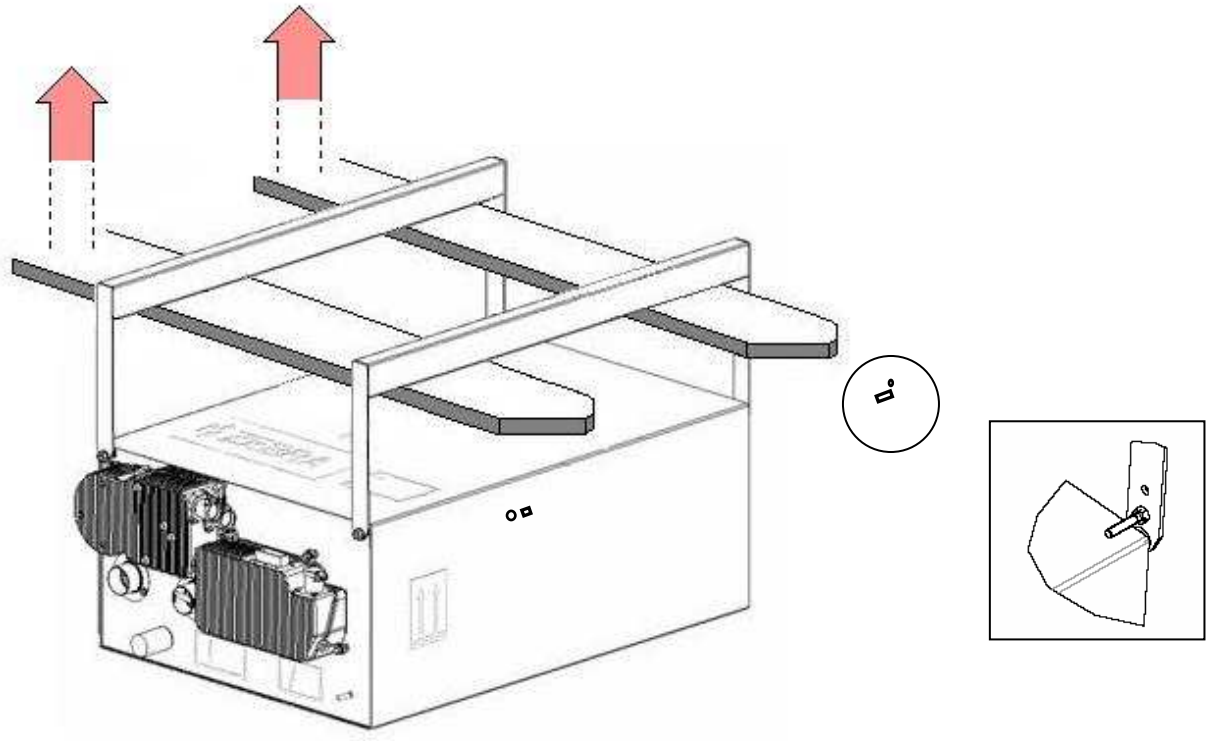


Figure 12: *ZEBRA® battery lifting*

2.6 STORAGE

The battery can be cooled down for transport, storage and long periods without operation by disconnecting the external AC power supply.
This causes the battery system to operate the DC-heater from its own energy and the battery becomes discharged and cold. The cooling process could require some days depending on the amount of energy stored in the battery.
The battery could be also cooled down without discharging: a command (reset input) can switch off the BMI with the immediate deactivation of the heaters.
The battery can be stored for any length of time in the cold state without changing its characteristics or state of charge. The conditions for long storage periods should be a dry, ambient and no condensation of moisture must be possible. The storage temperature should be between –40℃ and +50℃.
The atmosphere must not be aggressive.
The battery has an extremely high resistance in the cold state on a very low current in the cold state can damage the battery. Do not any measurements; do not connect any load on the terminals of a ZEBRA® battery when it is in cold state.
If the battery is stored without BMI, the flange must be protected to avoid involuntary contact and against moisture and dust.

2.7 TRANSPORT

A ZEBRA® battery must be transported cold and possibly discharged.
The battery should be packed in the original wooden box, fixed with straps to avoid any risk of uncontrolled movement or drops.
The battery must be packed on the wooden box only when is cold.
Battery with a heavily damaged external case should be wrapped with polyethylene sheets before of the packing, to avoid the risk of release of material or smell.
The package should include the relevant safety information for the transport: please contact FZ Sonick for the details.

3. GENERAL OPERATION OF A ZEBRA® BATTERY

Contact FZ Sonick to have the last software version released for BMI and MBS (that are supposed used in the vehicle) and to have any other detail on the description of the algorithm and threshold used in the software version in use.
Here the description for BMI's sw version V4B0R5 on standard batteries with ML3X cells and with temperature sensors close the BMI.

3.1 GENERAL

General warning: **the voltages of a ZEBRA® battery are dangerous**, the sockets are only physical touch protected. The connection of a ZEBRA® battery is only for electrical trained staff.

To connect a battery:

1. Check that the vehicle is not connected to the mains power
2. Connect the HV battery connectors to the traction net
3. Connect the mains-charger connector
4. Connect the control connector (AMP 16 poles)
5. Connect the diagnostic PC (optional).
6. Power on the BMI to start-up the operation
7. Connect the mains power AC to heat up the battery , if necessary

3.2 TEMPERATURES MANAGEMENT ON ZEBRA® BATTERIES

3.2.1 Battery operation

A ZEBRA® battery operates with an internal temperature of about 270℃..300℃.
A ZEBRA® battery must be heated up before of the operation.
In a standard ZEBRA® battery there are 2 heaters present: an AC heater and a DC heater. The AC heater is used to heat up a cold battery and keep the battery temperature at the heating set point when an AC source is available. The DC heater is used to keep the battery temperature at the heating set point using the energy stored in the ZEBRA® battery.

To heat up a ZEBRA® battery the BMI must be powered and connected to an AC line. The BMI can be powered by a positive 12/24 Supply on BATTERY DC SUPPLY (pin 11) together with IGNITION (pin 3) or on the EXT 12 V DC SUPPLY (pin 10)
The connection to the AC line does not power on the BMI.
The heat up process will require several hours, depending on the AC supply voltage. Typical heat up time with 230 Vac is 24 hours.

A battery must be in cold status for storage and transport.
The battery will cool down if discharged and not plugged to an AC source. The battery can be cooled down (heaters de-activated) in case of errors on the temperature measurement, if the BMI detect an internal insulation error, if the battery temperature is too high (temp fatal error) or if the communication between the BMI and the battery flange is not correctly working (LDM com errors).

If the BMI is switched off, typically by a reset procedure, the battery will start the cool down.
Because of the thermal insulation, the cool down process will require several hours, a typical value is a temperature decreases of 2-4℃/h our.

With reference to the temperature management, the battery operating modes are:

- battery discharge
- battery charge
- battery in park mode
- battery in cold state

NOTES:
A) In the present generation of batteries the temperature sensors are located near of the front panel. In the previous generation of batteries the sensors where located in different positions, therefore the temperature management has been modified.
In Appendix D the temperature setting relative to the old battery models

B) The following data are general information that could be different in some specific applications or types of battery.

3.2.2 Heating set point

***CHARGE, DISCHARGE and PARK mode* 245 ℃**

In special applications or in batteries with ML8 cells, the heating set point can be different.
The AC heater keeps the Tavg. to the heating set point with a hysteresis of +/- 3.0 ℃.
The DC heater keeps the Tavg. to the heating set point with a hysteresis of +/- 2.5 ℃.

3.2.3 Temperature Operating Range

DISCHARGE mode:

The discharge is allowed for temperatures between 235℃ and 340℃ for all type of cells
A power reduction algorithm is applied if the maximum temperature is higher than 290℃: the reduction applies to current max charge and current max discharge and includes full reduction for max temperature higher than 310℃ and a linear reduction between 290℃ and 310℃.
Between 310℃ and 340℃ the maximum discharge curre nt is set to full reduction. If the temperature of 340℃ is exceeded the discharge enab le is set to off and the discharge current limit is zeroed. When the battery reaches a temperature of 345℃ the battery temp fatal error is set and the BMI is reset.

In special application the limits can be different.

CHARGE mode:

Upper limit
For both C, P and X type cells the charge, and fast-charge for C type, is NOT allowed if the temperature is higher than indicated in the **upper red** line on the graph illustrated below.
Fast-charge is not allowed if the gradient of the temperature is higher than 5.0℃/min.

Lower limit
For C type cells, the normal charge, including fast-charge is NOT allowed if the temperature is lower than 235℃.
The BMI will consider a thermal cycle if the battery temperature is increased from 160℃ to 260℃.
The reduction of charging current for balancing is not applied for P type cells.

In some applications the limits profile and thresholds can be different.

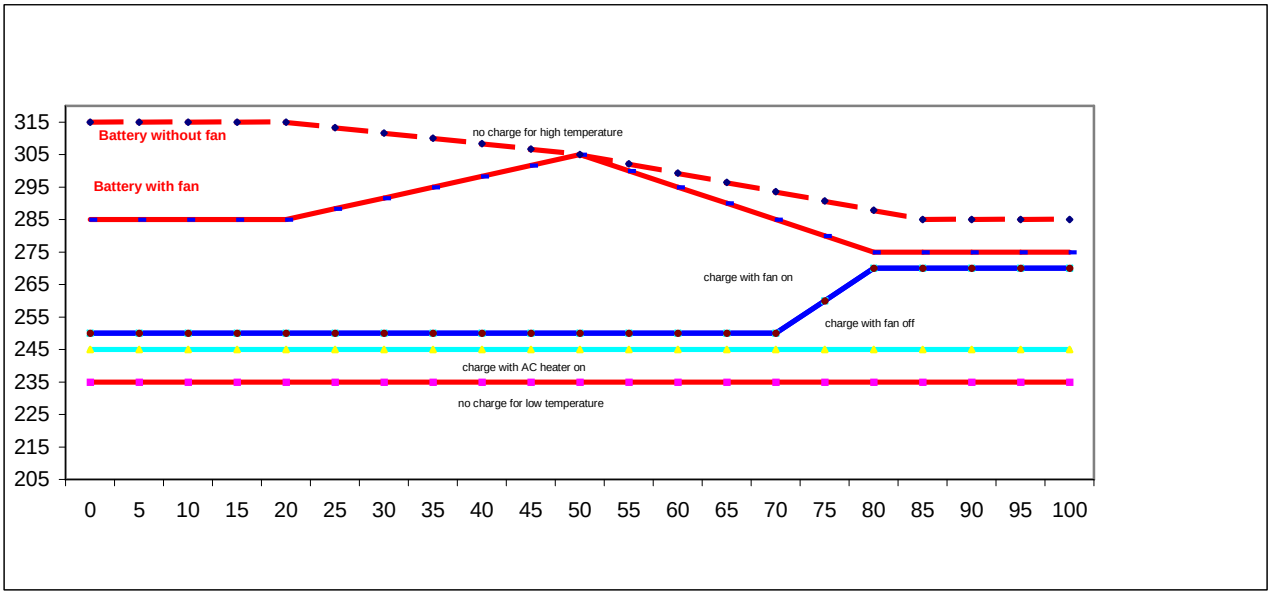


Figure 13: Upper and lower limits for charge versus SOC

3.2.4 Battery Cooling

Depending on the model, a ZEBRA® battery can be air cooled. Each battery requires a dedicated cooler, supplied by FZ SONICK (see Appendix B). The fan is automatically activated by the BMI battery controller when necessary.
If the power supply of the BMI (voltage on pin 11) drops below a specific limit, the fan is switched off to avoid the complete discharge of the vehicle 12/24V battery.
By default the limits are 12.3 V for a 12V system and 24V for a 24 V system.
Fan Test is not effected.

CHARGE mode: The fan is active if the temperature is above the upper blue line:
250 ℃ - 270 ℃. For SOC higher than 80% the limit is 270 ℃

PARK mode: Generally the cooler is off.
In special applications the cooler could be operational.

EMERGENCY mode: The fan is off if the BMI sets an emergency error, the fan test can then be activated.

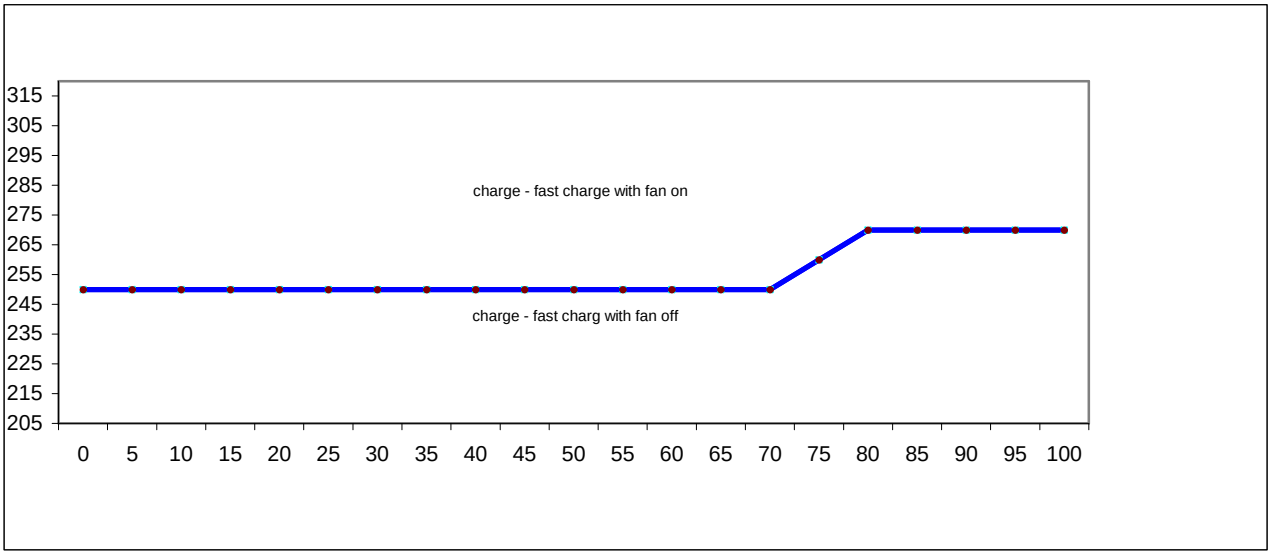


Figure 14: Fan operation in normal charge and fast charge versus SOC

DISCHARGE mode:
The fan is active if the temperature is above a line (depending on temperature gradient) contained between the two lines. (±2, 5℃ hysteresi s).
Some limits could be adjusted by the user via diagnostic software.
In special application the cooling set point can be different.

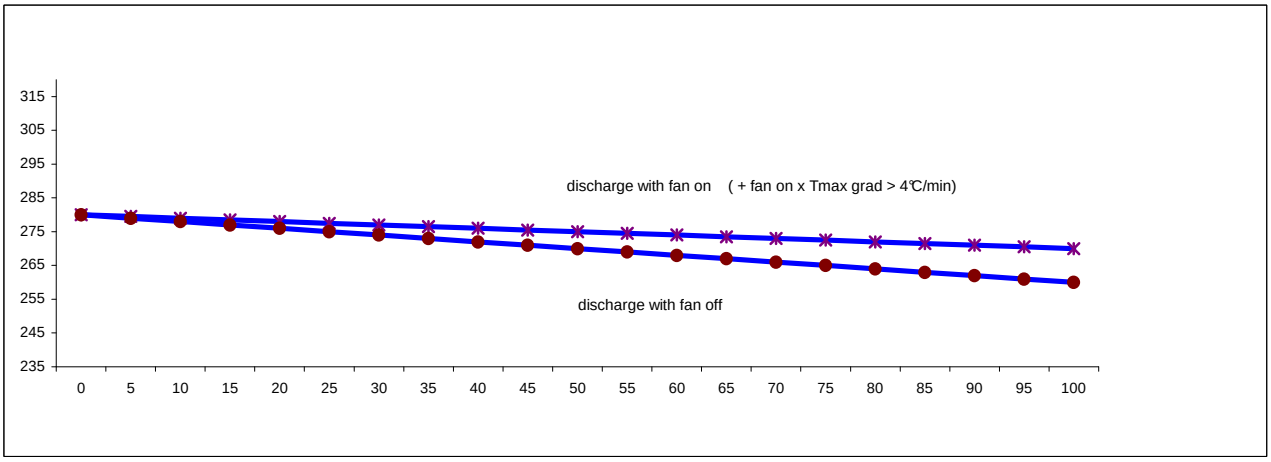


Figure 15: Fan operation in discharge mode versus SOC

3.3 VOLTAGE AND CURRENT LIMITS ON ZEBRA® BATTERIES

3.3.1 Battery operation

The battery operating modes are:

- battery normal charge
- battery fast charge
- battery discharge with regenerative braking
- battery park mode

A ZEBRA® battery is constructed with an assembly of single cells with series and parallel connections: one or more strings connected in parallel, each string with the same number of cells connected in series.
The State of Charge (SOC), is calculated by the integration of current over time and is adjusted when some well defined conditions are detected, for example end of charge condition.
Note: the mentioned limits apply to batteries with cells ML3C, ML3X or ML3P and are expressed in Voltage/Cell and Current/String; for different types of cells please refer to the table in APPENDIX A.

3.3.2 Normal charge

Normal charge can take place when the battery is in right temperature and voltage range and is not fully charged and the number of failed cells doesn't exceed a max limit (10% typically) and there isn't external iso error.
The limits are 2.67V/cell, 10A/chain for ML3C-ML3C type and 6A/chain for ML3P type.
In standard applications, AC must be connected to the battery controller.

Only when a ZEBRA® battery is in normal charge mode, the detection of end of charge condition will reset the SOC to 100% if the SOC value is between 80% and 103,8%.
Outside these limits a specific error will be set (refer to error's list: eoc with SOC<80% error and SOC>103,8% error).

END of CHARGE condition:
For all type cells: 180 mΩ per cell for 1 or 3 min. (2.67Vcell, current<0.5A/c, for 1 or 3minutes).

Important note: the SOC is calculated by the integration of current over time. As all the measurement include errors, the calculated electronic SOC, can differ from the true chemical SOC. The difference between electronic SOC and chemical SOC is adjusted by the detection of the End of Charge and the setting of electronic SOC to 100%.

In order to keep the possible errors below safe limits, it is recommended to allow ZEBRA® battery to reach end of charge every day.

3.3.3 Fast charge

- Fast charge mode is not available for P and X type cells.
- The limits are 2.70V/cell and 30A/chain, AC must be connected to the battery controller.
- Fast charge stops at 80% SOC, a new fast charge cycle cannot be started if SOC > 77%.
- If SOC < 70% normal charge (2.67V/cell, max 10A/cell) can take place after fast charge cycle, without depolarisation discharge.
- If fast charge is ended with SOC > 70% a depolarisation discharge of 3% SOC is necessary before starting normal charge.

3.3.4 Battery discharge

- Discharge is possible if SOC > 0% or 18% in some applications, or 10% for ML8 cell.
- Discharge is possible down to 1.7V/cell, 117A/chain for ML3 cells.
- Limitation can apply because of high temperature or low SOC or high regeneration, the limitation applies to the Current_Max_Discharge limit.
  The limitation due to high temperature starts at 290 ℃ with a linear reduction to 20A/chain at 310 ℃, and is constant at 20A/chain b etween 310 ℃ to 340 ℃.
  The limitation because of low SOC starts at 5% SOC for ML3C cells and 20% SOC for ML3P-X cells, with a linear reduction to 0A at 0% SOC.
  The limitation due to regeneration starts when SOC_{regen} exceeds 2%: SOC_{regen} is increased when the battery voltage exceeds voltage max generation.
- Both the linear limitation can apply at the same time: result is the product of the two reductions.

During the discharge the internal temperature of a ZEBRA® battery will increase because of the heat dissipation due to Joule losses on the internal resistance. The operation of a ZEBRA® battery could require an appropriate cooling, depending on the discharge rate and the starting condition.

Generally, a ZEBRA® battery can be discharged without cooling if the discharge takes more than 3.5 hours and the discharge is started at less than 255°C.

A ZEBRA® battery can be discharged at higher discharge rate if the battery is properly cooled.

The operation of the cooling fan is managed by the BMI.
The recommended minimum discharge time is 120 minutes for batteries with cooling and 300 minutes for batteries without cooling.

Higher discharge rates are possible for short periods.
Depending on the discharge rate the battery temperature could rise up to the upper limit.
The BMI could limit the maximum discharge current to a value that depends on the actual battery temperature or its gradient, before the battery reaches the temperature limit.
If the temperature is too high, the BMI will stop the discharge by opening the main contactors.

3.3.5 Regenerative braking

- Regenerative braking is possible during battery discharge.
- The threshold value *VoltageMaxGenerator* is calculated as a function of SOC.
- All values of battery voltage above *voltageMaxGenerator* are considered as **regenerative braking.**
- Regenerative braking has to be reduced if ΔSOC_{regen} > 2% and will be reset after a depolarisation discharge.

Regen braking:

- *(Ubat > voltageMaxGenerator)* → regenerative braking.

ΔSOC_{regen} algorithm

ΔSOC_{regen} is calculated as following:

$(0 \leq \Delta SOC_{regen} \leq 4\%)$

SOCregen is computed in charge if Ubattery > V max generator.

- *If the battery is charged by* ΔSOC
  (Ibat < 0, charging) and (Ubat > VoltageMaxGenerator)

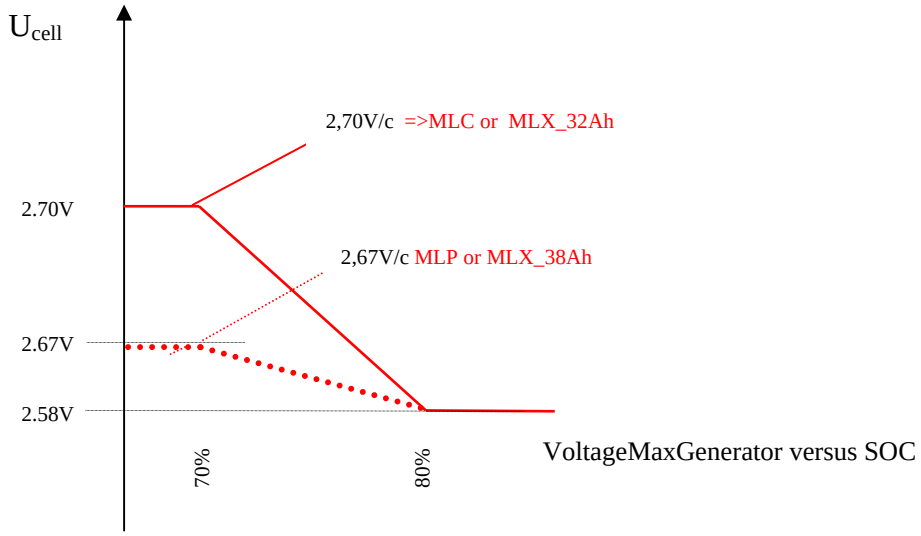
  $\Delta SOC_{regen} = \Delta SOC_{regen} + \Delta SOC$

- *If the battery is discharged by* ΔSOC
  (Ibat > 0, discharging, minimum discharge 10As)

  $\Delta SOC_{regen} = \Delta SOC_{regen} - \Delta SOC * 60$

- *If* ΔSOC_{regen} > 2% a limitation applies, maximum limitation is set with ΔSOC_{regen} = 4%.

- Limitations depend on both battery SOC and ΔSOC_{regen}
  a limitation applies if ΔSOC_{regen} > 2%.
  Maximum limitation (regen braking is disabled) is set with ΔSOC_{regen} = 4%.
  A limitation applies if SOC > 102%.
  Maximum limitation (regen braking is disabled) is set with SOC = 104%.



VoltageMaxGenerator versus SOC

3.3.6 Park mode:

The main contactors are open. AC is not available.
The operation of the DC heater maintains the battery temperature, if SOC > 5% and V/C > 2,38V/C typically.

3.4 ERROR SETTING:

The BMI set a window with the limits of the allowed values. The limits are ***voltageMaxCharge, currentMaxCharge, voltageMinDischarge*** and ***currentMaxDischarge***
and can dynamically change depending on the type of operation and actual SOC and Temperature.
If the system exceeds the limits some errors can be set:

- *(Ubat > voltageMaxCharge)* → peakdeviation/longdeviation voltage max charge.
- *(Ibat > currentMaxCharge)* in charge or fast charge mode or
  (Ibat > currentMaxCharge) and *(Ibat>10A or*
  (Ibat > currentMaxCharge) and *(Ubat > voltageMaxGenerator*) in regenerative braking mode → peakdeviation/longdeviation current max charge.
- *(Ubat < voltageMinDischarge)* → peakdeviation/longdeviation voltage min discharge
- *(Ibat > currentMaxDischarge)* → peakdeviation/longdeviation current max discharge

3.5 BATTERY PROTECTION

To reduce the risk of a battery over discharge the calculated SOC is artificially reduced by an artificial offset of 0.1 Ah/h for each string, when the BMI has the main contactor S2 closed.

3.6 U/I LIMITATION, I LIMITATION, NO LIMITATION

3 types of management of limitation are available: U/I, I, No limitation.

By default the BMI sets I-limit upon power up.

The MBS can change the type of limitation used by the BMI, by sending, on battery CAN, the information MBS SysConfig with the correct value.

The default configurations for MBS sw are:

STD29, ALTRA29 -> U/I limitation ,

VPA600, SIEMENS->No limitation ,

Other cases-> I limitation

No limitation applies to BMI sw Digatron version, used for battery testing.

Notes:

- **1. Note** the following diagrams, shows a situation where in case of regenerative braking limitation *voltageMaxChargeRed* < *voltageMaxGenerator*. In this case it is not possible to check if the limit of *voltageMaxChargeRed* is respected.

- **2. Note** the following diagrams, shows a situation where in case of regenerative braking limitation *voltageMaxChargeRed* > *voltageMaxGenerator*. In this case it is not forseen to check if the limit of *voltageMaxGenerator* is respected. Even if the generator is set to *voltageMaxChargeRed* (2,67V/cell), BMI will not react.

Systems where U/I limitation is possible

		Upper line. → Lower line	
(SOC < 70%)			
VoltageMaxCharge	(C X-32h cells)	2,9V/c → 2,89V/cl	($\Delta SOC_{regen\ depending}$)
	(P X-38Ah cells)	2,9V/c → 2,67V/c	($\Delta SOC_{regen\ depending}$)
CurrentMaxCharge		30A/c →1 0A/c	($\Delta SOC_{regen\ depending}$)
(70% < SOC < 72%)			
VoltageMaxCharge	(C X-32h cells)	2,9 V/c → 2,89 ÷ 2,67V/c	($\Delta SOC_{regen\ depending}$)
	(P X-38Ah cells	2,9V/c → 2,67V/c	($\Delta SOC_{regen\ depending}$)
CurrentMaxCharge		30A/c → 10A/c	($\Delta SOC_{regen\ depending}$)
(72% < SOC < 102%)			
VoltageMaxCharge		2,9V/c → 2,67V/c	($\Delta SOC_{regen\ depending}$)
CurrentMaxCharge		30A/c → 10A/c	($\Delta SOC_{regen\ depending}$)
(102% < SOC < 104%)			
VoltageMaxCharge		2,9÷2,67 V/c → 2,67V/c	($\Delta SOC_{regen\ depending}$)
CurrentMaxCharge		30A/c ÷ 0 A/c → 10A/c ÷ 0 A/c	($\Delta SOC_{regen\ depending}$)
(SOC > 104%)			
VoltageMaxCharge		2,67V/c → 2,67V/c	
CurrentMaxCharge		0A/c → regenBraking = DISABLED	

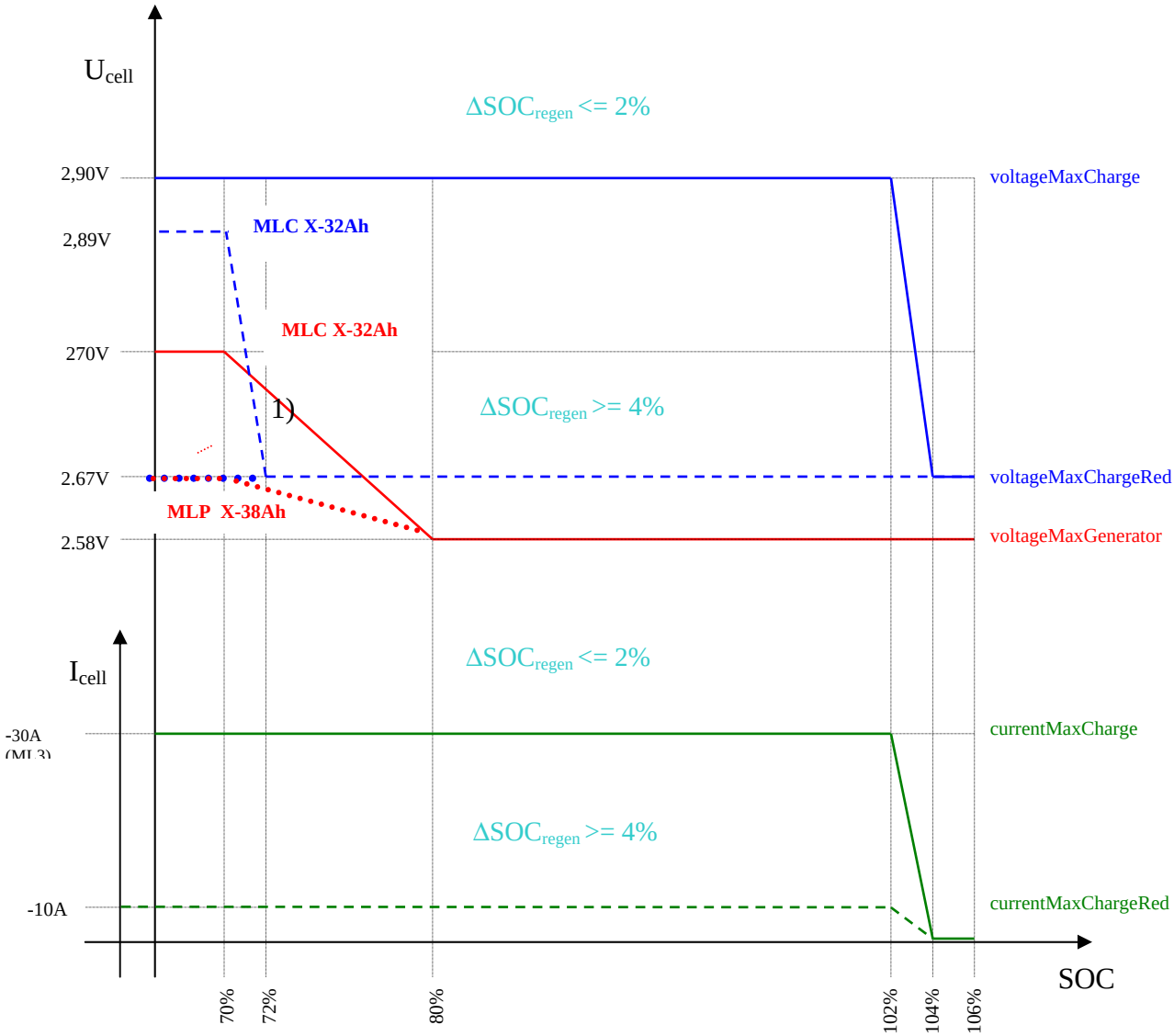


Figure 16 U/I limitation

Systems where only I limitation is possible

Upper line. → Lower line.

(SOC < 102%)

VoltageMaxCharge	2,9V/c	→ 2,9V/c	
CurrentMaxCharge	30A	→ **0A/c**	($\Delta SOC_{regen\ depending}$)

(102% < SOC < 104%)

VoltageMaxCharge	2,9V/c	→ 2,9V/c	
CurrentMaxCharge	30A ÷ 0A	→ **0A/c**	($\Delta SOC_{regen\ depending}$)

(SOC > 104%)

VoltageMaxCharge	2,9V/c	→ 2,9V/c
CurrentMaxCharge	0A/c	→ regenBraking = DISABLED

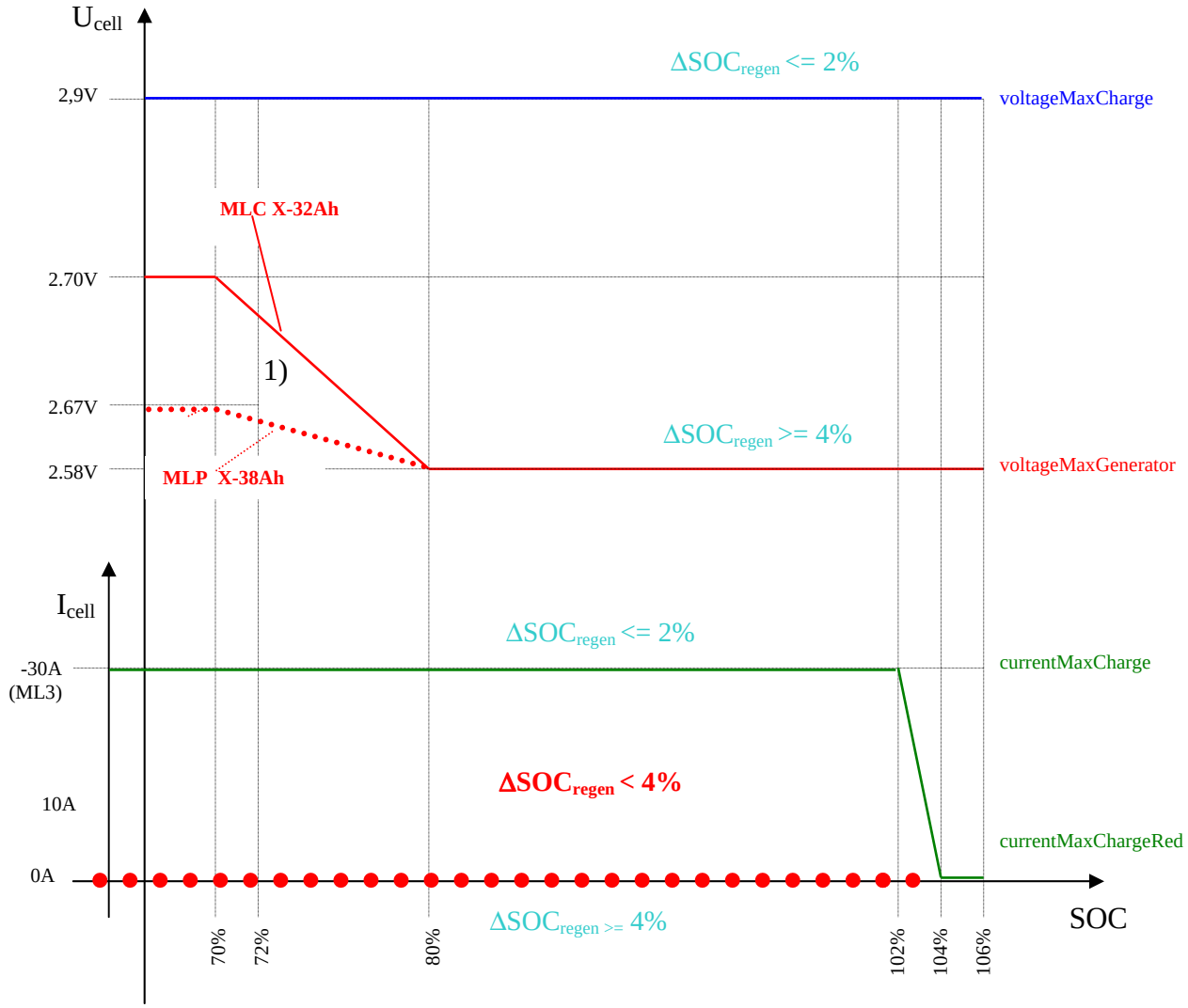


Figure 17:I limitation

3.7 PRECHARGE

Before closing the traction net and charge net a precharge with a fixed resistor on 15Ω 60W is executed. The precharge is stopped if the energy on this resistor exceeds the max allowed (precharge or chort circuit), the precharge on charge net is stopped after 0,5 sec, the precharge on traction net is stopped when the voltage reach 0,95% of battery and anyway after 1 sec.

4. CHARGE PROCESS

Important note: the SOC is calculated by the integration of current over time.
As the current measurement include errors, the calculated electronic SOC, can differ from the true chemical SOC. In electronic SOC computation the current is considered higher in discharge and lower in charge of 100mA/string. The difference between electronic SOC and chemical SOC is adjusted by the detection of the End of Charge and the setting of electronic SOC to 100%.
In order to keep possible errors below safe limits, it is recommended to allow a ZEBRA® battery reach end of charge every day.

A ZEBRA® battery can be set in charge mode if the condition *End of charge detected* is not set, the battery temperature and voltage is in the right window, the BMI does not show switch off or delayed switch off errors like external error a and the number of failed cells doesn't exceed the max allowed (typically 10%).
Typically to start the charge it is necessary to connect AC to the BMI. The connection of AC will erase the errors vehicle reset type.

During charge, the battery will have an operating window for voltage and current:

- Voltage Max Charge (Maximum Voltage)
- Voltage Min Discharge (Minimum Voltage)
- Current Max Charge (Maximum CHARGING Current)
- Current Max Discharge (Maximum DISCHARGING Current)

The limits can change depending on SOC and Battery temperature
The limits are available on the CAN and if the system will not follow the limits the BMI could set errors and open the main contactors
While charging with normal or vehicle charge, the BMI will check for END of CHARGE condition, and reset the SOC to 100% if the EOC is detected. It is recommended to have frequent EOC detection, every cycle if possible.

The charge operation depends on the type of charger
The BMI can support:

Charger type BC Z 3	(10)
Charger type PWM on traction net	(9)
Vehicle charge on traction net with NO AC	(8)
PWM controlled Charger	(7)
Charger type BC Z3 on traction net	(6)
NLG 5	(5)
NLG 4	(4) (obsolete charger model)
No charger	(0): only vehicle charge is possible

If the charger is not supplied from FZ SONICK, the system integrator has to prove that the charger has the correct functionality. As a general specification, the charger must be insulated: the ZEBRA® Battery Voltage section must be insulated from AC and from Low voltage (vehicle auxiliary voltage) sections, the maximum safety voltage should be less than 2,9 V/cell, the minimum step for power regulation should be 0,4 A * 2.67V * Ncell minimum, the charger must be able to follow up the limits of maximum current and maximum voltage set by the BMI and available via CAN bus, and in case of PWM control the power must linearly increase with PWM usually in range 1% .. 95%, and the values 0% and 100% PWM means charger off.

Contact FZ SONICK for a detailed specification.

The charger should provide a current with a ripple as little as possible.
The charger must provide a max voltage as described at point 1.3.6

Normal charge
Charger type BC Z 3 (10) or PWM controlled Charger (7)
Each battery has its dedicated charger.
The battery is set in charge mode when AC is connected to the BMI.
In case of a multi-battery system the MBS must be ON and enable to the BMIs.
If the battery is in condition to be charged, the BMI will close **S2 and S4 (**charge NET) and control the charger by a PWM signal .

Charger type PWM on traction net (9) or Charger type BCZ3 on traction net (6)
Each battery has its dedicated charger.
The battery is set in charge mode when AC is connected to the BMI.
In case of a multi-battery system the MBS must be ON and enable to the Bmis.
If the battery is in condition to be charged the BMI will close **S2 and S3** (traction NET) and control the charger by a PWM signal .

NLG 5 (5) or NLG 4 (4)
are 2 charger types with a specific CAN communication.
Each battery has its dedicated charger.
The battery is set in charge mode when the BMI receives a request signal from the charger via a specific CAN message on the **charge CAN** of the BMI (pin 7 and 15) and AC is connected .
In case of multi-battery system the MBS must be ON and enable to the BMIs.
If the battery is in condition to be charged, the BMI will close **S2 and S4** (charge NET) and control the charger by CAN communication

Vehicle charge
The system (vehicle) must send a **vehicle charge request** via CAN message **on the vehicle CAN**. In case of multi-battery system the request must be sent to the MBS.

The battery is set in charge mode when the BMI receives a request signal from the CAN and AC is connected.
If the battery is in condition to be charged, the BMI will close **S2 and S3** (traction NET) and will control the charger by CAN communication:
The BMI (or MBS in multibattery) will send to the vehicle a **charge enable** when ready and the information relative to the limits

- Voltage Max Charge (Maximum Voltage)
- Voltage Min Discharge (Minimum Voltage)
- Current Max Charge (Maximum CHARGING Current)
- Current Max Discharge (Maximum DISCHARGING Current)

It is possible to charge more than one battery when batteries are connected in parallel: the charge can be longer than normal if batteries with different number of failed cells are connected in parallel.

Vehicle charge on traction net NO AC (8)
As vehicle charge but AC connection is not required.

Fast charge (available only on C type cells)
The system (vehicle) must send a **fast charge request** via CAN message **on the vehicle CAN.**
In case of a multibattery system the request must be sent to the MBS.

The battery is set in fast charge mode when the BMI receives a request signal from the CAN and **AC is connected**
If fast charge of the battery is allowed, the BMI will close **S2 and S3** (traction NET) and control the charger by CAN communication:
The BMI (or MBS in multibattery systems) will send a fast **charge enable** signal and with the information relative to the limits for:

Voltage Max Charge (Maximum Voltage)
Voltage Min Discharge (Minimum Voltage)
Current Max Charge (Maximum CHARGING Current)
Current Max Discharge (Maximum DISCHARGING Current)

It is possible to charge more than one battery when batteries are connected in parallel
The fast charge is limited to 80% SOC and there is no detection of an EOC condition

Notes on normal charge
The following more detailed description is relative to the charge process of a ZEBRA® Battery using a MES battery charger BCZ3. Some details can be different if another type of charger is used.

When AC is connected to the BMI, the BMI will activate the heater or the fan if necessary.
The heating set point for the charge depends on the battery size and cell type.
The connection of AC will erase eventually errors that are of a vehicle erasable type.

When the temperature is correct and the max number of failed cell doesn't exceed the max allowed, if the BMI receives the system enable from the MBS, the BMI will check the battery voltage for a reasonable value relative to the electronic SOC and if everything is correct the BMI will close S2 and S4 for charge.
In a single battery system, with BMI address 0, the enable from the MBS is not required.
To avoid peak currents on the main plug during the activation of the chargers, the start up of the charge will have a delay that depends on the battery address: the charge starts immediately for BMI 1, after 5 seconds for BMI 2, 10 seconds for BMI 3 and so on.
The process could be stopped in the pre-charge phase, if the energy dissipated in the pre-charge circuit reaches the BMI limit. In this case the BMI will set a *pre-charge error* and the charge will not start. A possible reason could be a short circuit in the wiring or in the charger
After S2 and S4 are closed, the BMI will activate the charger by ramping-up the PWM signal.
If the charging current does not start or is lower than 0,24A for more than 5 minutes, the BMI will set the error, *charging current too low for T> 5 minutes*, and open S2 and S4.
A possible reason could be a fault on the charger or incorrect wiring.

If the charger does not provide the requested current (current less than 2A with PWM >90% for more that 10 seconds), the BMI will set the error *Charger not provides current (2A) even if PWM>90%*, and will stop the charger for 2 minutes by setting the PWM signal to 0%, then the charger will be restarted.

The charging process will continue and the BMI will regulate the PWM signal to maintain the current and voltage limits: a maximum current of 10A/6A /chain (C/P type batteries) and a maximum voltage of 2.67V/Cell.
If the charger does not correctly regulate the PWM signal, or voltage or current limits are exceed the BMI will open S2 and S4 and set an error.
(Long/peak *deviation current/voltage errors*)
During the charging process the BMI will continuously monitor:
- the battery temperature, and will activate the heater or the fan if necessary.
- the battery voltage max value.
- the battery charge resistance:
If the value of the charge resistance measured by the BMI is the value expected at 100% chemical SOC (180 mohm/cell end of charge criteria), and in some application if the dynamic OCV is available and higher then 2,58V/C, the electronic SOC will be corrected to 100 if its value is between 80 and 103.8% and the charge will end.

If the End of charge criteria is detected at SOC values lower that 80% the BMI could set the error, *EOC with SOC lower that 80%*, depending on the actual value of the cumulated integral offset, and the charge will be stopped. A manual reset of the SOC value is necessary for charging to re-start.

If the End of charge criteria is not reached, the charge will be stopped at 103,9% SOC, the error *SOC too high: Reset BMI and then Discon. relay kept open (Typ. 103,9%)*will be set. A manual reset of the error and of the SOC value is necessary for charging to re-start.

During the charge, if 103,8% SOC is reached, is set the error *SOC too high: Warning Check SOC consistency! (Typ. 103,8)* and the SOC is set, for max 4 times, to 100% after a depolarization with the DC heater to measure the OCV.

After 1 hour since the first EOC, a second charge is started automatically by the BMI.

During the charge, when 80%SOC is reached the first time, the charge process will be interrupted, the battery will be discharged by 0, 3% SOC by the DC heater, then the BMI will maintain the current at 0A for 5 minutes and measure the open circuit voltage.
The OCV will be used to calculate the number of failed cells. Then the charge process will be restarted with the corrected number of failed cells.

In some application, if the number of string is lower then 4, the number of failed cell is computed also with an additional method, by reducing the charging current for 10sec each 1% SOC.
The number of failed cell used in other computations, depending on application, is the max among the two number or only the value computed at 80%.

If AC is disconnected or if the MBS is switched off, the charge process will stop.

5. DISCHARGE PROCESS

The condition to set the battery into the discharge mode is:
- Battery temperature between 235 and 340°C
- Battery with SOC > 0% or 10% or 18% depending on the application.
- no delayed switch off or switch off errors with diagnostic reset.
- the number of failed cells doesn't exceed th emax allowed (typically 10%).

The discharge process will start after a switch, OFF to ON, of the ignition signal.
All the vehicle type errors will be erased by the switch, OFF to ON, of the ignition signal.
AC must be disconnected at least 20 seconds before the switch, OFF to ON, of the ignition signal.
The switch, OFF to ON, of the ignition signal will start the pre-charge operation on the traction net: after a hardware check on the pre-charge circuit, S1 will be closed , then S2 will be closed and the traction net will be pre-charged by a 15 ohm resistor.
If the voltage on the traction net reaches 0, 95 of the open circuit voltage within 1 sec, the BMI will close S3 and set the battery in discharge mode.
The process could be stopped in the pre-charge phase, if the energy dissipated in the pre-charge circuit reaches the BMI limit or if the voltage on the traction net does not rise to 0,95 OCV within the specified time, 1 second by default. In this case the BMI will set a "Precharge resistors" or Precharge time elapsed".
A possible reason for a pre-charge error could be a load across the battery before discharge enable is set by the BMI. In case of parallel connected batteries a reason could be batteries with different voltages.
The BMI application will consider 2 types of pre-charge errors:
pre-charge resistor error means that the energy dissipated in the pre-charge circuit reached its maximum limit;
pre-charge time elapsed error means that the voltage on the traction net did not reach the voltage of 0,95 OCV within 1 sec.
In order to keep the main contactor closed, the MBS must be activated and should send the system enable to the BMI within 5 seconds from the switch, OFF to ON, of the ignition signal, the system enable from the MBS must be confirmed at least every 5 sec to keep the main contactors closed.
In single battery system, with BMI address 0, the enable from the MBS is not required.
After S2 and S3 are closed, the BMI will activate the load by setting the voltage and current limits and raising the *discharge enable* flag.
During the discharge, the battery will have an operating window for voltage and current:
Voltage Max Charge (Maximum Voltage)
Voltage Min Discharge (Minimum Voltage)
Current Max Charge (Maximum CHARGING Current)
Current Max Discharge (Maximum DISCHARGING Current)

The limits can change depending on SOC and Battery temperature.
If the system does not follow the required voltage or current limits, the BMI could open S2 and S3 and set an error. (Long/peak *deviation current/voltage errors*)

If the ignition signal is set OFF, if AC is connected to the BMI or if the MBS is switched off, the discharge process will stop and the main contactors S2 and S3 open.
In a multi battery system the MBS checks the operation of each BMI and transmits the

enable and overall limit of the battery system to the vehicle, via CAN messages and/or dedicated signals.
In a multi battery system, depending on the MBS software, a BMI can be temporary disconnected from the traction net for SOC balancing.

Because of variations in energy consumption due to variations in drive cycles and battery aging, it is recommended that the system is designed and the schedule of service considers not to use more than 80% of the capacity on daily operation and to reach end of charge every day. The discharge to SOC values lower than 20% is allowed, but must only be performed when absolutely necessary. In some applications below 18% SOC the discharge is disabled.

6. MULTI BATTERY OPERATION

ZEBRA® batteries can be used in parallel to obtain the necessary energy and power to cover the requested operation. Because of variations in energy consumption due to variations in drive cycles and battery aging, it is recommended that the system is designed and the schedule of service considers not to use more than 80% of the capacity on daily operation and to reach end of charge every day. The discharge to SOC values lower than 20% is allowed, but must only be performed when absolutely necessary.

In case of a multi battery system it is necessary to use an MBS.

The unit is a system supervisor that works as interface between the battery system and the vehicle. The MBS will communicate with all the batteries on the Battery CAN and with the vehicle on the Vehicle CAN. The MBS can manage up to 16 batteries of the same model connected in parallel.
The battery CAN is reserved to FZ Sonick.

The MBS must be powered ON for both the charge and discharge mode : in a multi battery system every BMI must receive a system enable from the MBS in order to keep the main contactors closed, both in the charge and in discharge mode.

In general the MBS collects the operational conditions of all batteries and will inform the vehicle about SOC, Voltage and Current limitations available for operation. The description of the can messages is available on specific documents

The aging of batteries can determine the failure of some cells.
As a ZEBRA® cells typically fails to short circuit, a ZEBRA® battery can be operated with the presence of failed cells, with a reduced Open Circuit Voltage.
If batteries with different number of failed cells are operated in parallel, the charge and discharge rates can be different, so the SOC of the batteries can be unbalanced.
If the difference between ZEBRA® batteries is higher than 5% in terms of cell failures, then it can be difficult to operate all the batteries because of possible precharge problems during the start up of parallel operation.

The SOC unbalance depends on the difference between the batteries and the type of operation: in general ZEBRA® batteries can be effectively operated in parallel if the

difference in failed cells is less than the limit specified in the supply agreement and/or in the warranty conditions.
The responsible of the maintenance of the battery system must take care that the maximum difference of failed cells is kept within the specified limit.
If the limit is not specified in the supply agreement and/or in the warranty conditions, the standard limit of a maximum difference of 5 cell failures applies.

It is possible to reduce the SOC unbalance between batteries by applying some control algorithms.
For example, a vehicle can be operated with a battery disconnected. The MBS can apply the standard Balancing algorithm to try to keep the SOC difference below 5% SOC. Alternative solutions are possible depending on hardware configuration.

Standard Balancing

If the difference in the SOC value between the batteries is more than 5%, a battery will be disconnected for balancing.
The MBS will detect if the vehicle is in electric operation (SOC system decrease) or hybrid operation (SOC system increase) by checking the change in SOC each minute.
The detection of the change of trend is used to check if the battery to be disconnected is the battery with the lower or higher SOC.
If the MBS detects electric vehicle operation
If SOCmax - SOC min > 5% then SOCmin is disconnected.
If SOCmin <= SOCoff - 5% then SOCoff is reconnected to disconnect SOCmin.
If SOCoff >= SOCmax - 1% then SOCoff is reconnected.
If the MBS detects hybrid vehicle operation:
If SOCmax - SOC min > 5% then SOCmax is disconnected.
If SOCmax >= SOCoff + 5% then SOCoff is reconnected to disconnect SOCmax.
If SOCoff >= SOCmin - 1% then SOCoff is reconnected.
The MBS will send to the BMI to be disconnected the command, Balancing Batt OFF, and the BMI will open S3 when its battery current is less than 20A
The MBS will send to the BMI to be reconnected the command, Balancing Batt ON, and the BMI will close S3 when the difference between the battery voltage and the traction net voltage is less than 10% OCV.
The balancing process will be disabled and all the available batteries reconnected if a BMI will open the main switches because a switch off error, a delayed switch off error, temperature out of the range 260℃÷360℃ or SOC = 0 %, or if the MBS receives a specific message from the vehicle can.

If the application allows the disconnection of more that one battery for SOC balancing, the relative MBS application is available.
For a correct set up of the application software, please contact FZ SONICK.

7. BMI DIAGNOSTIC

7.1 ERROR CATEGORIES

The errors pertain to different categories depending on the reaction performed by the BMI. In case of errors, the battery system gives a warning to the vehicle and the BMI could provide a warning function or a switch off function with a delay time that is dependent on the error categories:

- ✓ STATISTIC: the BMI will not react, errors are only for information purpose
- ✓ NOTICE: the FZ SONICK display will show the message **System Notice or System Warning**. The BMI will not react; the error should be check**ed** by a technician at the first scheduled maintenance.
- ✓ DELAYED_SWITCH_OFF: the FZ SONICK display will show the message **Delayed SW OFF** the BMI will **open** the main contactors after a delay of five minutes (if the first D-SW-OFF error is an external iso error the delay is 9 minutes)
- ✓ SWITCH_OFF: the FZ SONICK display will show the message **SW OFF** the BMI will immediately **open** the main contactors.

7.2 ERROR RESET CONDITIONS

- ✓ IMMEDIATE: the fault will be automatically reset when the fault condition disappears
- ✓ VEHICLE: the fault will be reset when an ignition signal is applied to the BMI (ignition is switched off and on again) or when AC is connected to the BMI.
- ✓ DIAGNOSIS: the fault will be manually reset by ZEBRA® monitor by the button  (ZEBRA® monitor with customer access level is required)

Note: Before resetting errors read and save the errors stack list, the active errors and
send them to FZ-SONICK.

WARNING: never delete, by using ZEBRA® monitor, an INTERNAL ISO ERROR or CMU DETECTED PROBLEM ERROR detected by the BMI without FZ SONICK technician authorization.

7.3 GUIDELINE ON BMI ERROR MANAGEMENT

In general an error set by a BMI could be related to
- Expected operating condition.
- Application and battery usage
- System fault
- BMI fault
- Battery fault

The task of the technician is to understand what is the reason of the error set by the BMI. Determine the reason of an error and the defective part could be a relative difficult task, as the source of some errors could be more than one:

7.3.1 Expected operating condition

In some conditions a ZEBRA® battery could be not available for the operation, also if there are no failures. The condition can be reported as error as the battery cannot be operated.

Typical expected operating conditions that can be reported as error are related with the battery temperature: if a battery is cold, for example, it must be heated before of the operation, or if the fan should cool the battery before the start of the charge when the temperature is higher than the required value.

7.3.2 Application and battery usage related errors

The BMI computes and reports to the system the limits for a safe usage of the battery. If the system does not follow the limits, the BMI can set errors and could open the main contactors.
Typical errors are Long and peak deviation errors or Emergency error.

Possible actions:
- system analysis
- determination of the condition when the error appears
- data acquisition for deep analysis

7.3.3 System faults related errors

The BMI will monitor some system variables, for example the insulation resistance, system voltage and current and could set errors if the measured values are out of the expected range.
Typical errors are External ISO error, Short Circuit, Precharge errors, low voltage error on the on board battery (On-board battery voltage<12V/24V)

possible actions:
- system analysis
- determination of the condition when the error appears
- data acquisition for deep analysis

7.3.4 BMI related errors

The BMI software includes a set of self check on the BMI hardware and its operation.

Typical errors could be:
- HV µC related errors
- LDM communication errors
- ISO self test errors

Actions:
- determination of the condition when the error appear
- data acquisition for deep analysis
- BMI replacements

7.3.5 Battery related errors

Fault reported could be related to the battery pack.
In general other reasons are possible.

Typical errors could be:
- Internal ISO error
- Short circuit
- Charge not allowed (OCV too low)
- Battery Thermal Insulation
- AC heater related error
- DC heater related error
- T sensor related error

Actions:
- determination of the condition when the error appears
- data acquisition for deep analysis
- BMI replacements
- Battery replacements

Some battery related errors could result in a replacement of the battery. As the replacement and the return of a battery can require a significant effort it could be useful to confirm the error by some additional tests.
Enclosed a guideline on how to confirm some errors

7.3.6 Battery Thermal insulation error

The BMI reports that the battery cools down when the DCheater is operated. It is possible that the battery has a reduced thermal insulation.

The typical sign is the temperature of the outer skin higher than normal. It is difficult to define the surface temperature as it depend on the installation in the battery compartment, other batteries in the same type of installation will give a good information.

To confirm the problem it would be necessary to know of the energy necessary to keep the battery in temperature by measuring:

- The cumulated AC power provided to the BMI for the AC heater operation in 24 hours
- Or the self-discharge of the battery for the DC heater operation in 24 hours

- It could be also helpful an acquisition of the temperature behaviour when the DC heater is active, typically it will be necessary at least 60 minutes of DC heater operation in park mode or an acquisition of the temperature behaviour when the AC heater is active, typically it will be necessary at least 60 minutes of AC heater.

7.3.7 Time max elapsed while AC heating

The BMI reports that the battery does not heat up when the ACheater is operated. It is possible that the battery has a reduced thermal insulation.

The typical sign is the temperature of the outer skin higher than normal. It is difficult to define the surface temperature as it depend on the installation in the battery compartment, other batteries in the same type of installation will give a good information.

To confirm the problem it would be necessary to know the AC energy provided to the BMI for the AC heater operation in 24 hours

7.3.8 End of charge with SOC < 80% error

Possible reasons could be:

- The battery has been operated a long time without getting the end of charge condition.
- that one or more chain are not operating correctly

To confirm the problem it will be necessary to monitor the behaviour of the battery during the discharge. The recommended procedure is:

- reach end of charge
- at end of charge, correct the SOC to 100% with ZEBRA® monitor (it will be necessary call FZ SONICK to get a password
- discharge the battery in a controlled way
- Evaluate the Open Circuit Voltage at different SOC values. (the OCV should be measured every 100/Number of string SOC , so at 50% SOC for a 2 string battery, at 75%, 50%, 25% for a 4 string battery)
- an acquisition during the discharge in parallel with other batteries or with some peak power steps could be also useful to evaluate the behaviour of the battery

7.3.9 ACheater / DCheater related errors

Possible reason could be:
- BMI error
- Heaters problems

To confirm the problem it will be necessary to

- remove the BMI
- measure the Resistance value of AC heater and DC heater (contact FZ Sonick communicating battery type and serial number to get correct values)
- eventually replace the BMI

7.3.10 Temperature sensors related errors

Possible reason could be:

- BMI error
- T sensor problem
- Flange-BMI communication error

To confirm the error it will be necessary to:
- try to reset the BMI and check if it is able to read correctly the temperature sensors
- remove the BMI
- measure the resistance values of all the PT 1000 temperature sensors
- eventually use the spare temperature sensor
- eventually replace the BMI

7.3.11 Short circuit error

The BMI sets a Short circuit error if the measured current is higher than 270A/string or the measured voltage is less than 1.3V/Cell

Possible reason could be:
- Real short circuit on the system
- Battery problem
- BMI measurement error

The error could be set in case of battery that shows a high resistance as for an open contact.
To confirm a battery problem check the voltage behaviour

7.3.12 Internal ISO error

The BMI reports that the electrical insulation of the battery pack is less than the safety limit.
The BMI will let the battery cool down
NEVER operate a battery that showed an internal ISO error. The battery must be dismounted from the vehicle as soon as possible.
Do not reset in any case an internal iso error detected by the BMI and do not substitute a BMI that detects an internal iso error to continue to use the battery without FZ SONICK's technician written authorization.

It can be possible to confirm the error by a direct measurement on the battery poles.
The correct measurement will require an isolation resistance tester ***(Megger),***
a standard DDM Voltmeter could give some indications.
The battery is only to be measured in the warm state (operating temperature reached); please refer to the section 8.5

ERRORS' LIST APPLY TO BMI's SW V4B0R5 3.02.2010

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
AC heater relay	AC heater heats the battery using power from the main line. A relay and a semiconductor switch are used to control the heating. AC heater relay error happens when close relay or open relay commands don't have a successful conclusion DPH_NTB_AC_HEATER_RELAY_ERROR	S	D	Battery BMI
AC heater switch	AC heater heats the battery using power from the main line. A relay and a semiconductor switch are used to control the heating. AC heater switch error happens when close switch or open switch commands don't have a successful conclusion. (Vac<0,7*Vac-off 3 s after closing) (Vac>1,3* Vac-off 3 s after opening or Vac overflow) DPH_NTB_AC_HEATER_SWITCH_ERROR	S	D	Battery BMI
AC switch/relay wrong sequence	AC_ERROR means a wrong sequence on the relay and semiconductor switch chain controlling the AC heater. DPH_NTB_AC_MEAS_ERROR	N	D	BMI
AC voltage overflow	AC supply > 320V for more than 4 s DPH_NTB_AC_OVERFLOW_ERROR	S	I	BMI System
Battery switch off with I > I_OPEN_MAX	During switch off procedure of traction or charger net, main switches opened even if after 4 sec | current | not < roughly20 A (the value of 20A depend on battery voltage and switch model used on bmi) DPH_NTB_LOAD_NOT_DISABLED_ERROR	N	V	System *BMI*
Battery temp. > (360℃ or 340℃)	Battery temperature is too high for more than 9 sec: T average >=361,5℃; reset if <=358,5℃ in old batt . T average >=341,5℃; reset if <=338,5℃ in new batt . DPH_NTB_TEMPHIGH_ERROR	N	I	Battery BMI
Battery thermal isolation	Temperature decreased even if DC heater on since 1 hour; possible thermal losses. (AC off, DC heater on: after 1 hour temp is decreased) (T1 used or T2 if gradient error on T1 and no error on T2) DPH_NTB_THERMAL_ISOLATION_ERROR	N	D	Battery BMI
Battery voltage too high	For more than 1sec Battery Voltage > Voltage Max (CellVoltageMax * NumIntactCells) (CELL_VOLTAGE_MAX= 3,4V) DPH_NTB_MAXVOLT_ERROR	D-OFF	V	BMI System *Battery*
Battery voltage too low	For more than 1sec Battery Voltage < Voltage Min (CellVoltageMin * NumIntactCells; this disable DC heater) (CELL_VOLTAGE_MIN = 1,4V) DPH_NTB_MINVOLT_ERROR	D-OFF	V	Battery BMI System
Bmi Temperature too high	Only A306 apply: For more then 1 sec the "Temp. BMI" was higher the max allowed (90℃ Typ) DPH_NTB_TEMPBMI_ERROR	OFF	D	System

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Chain*Monitor*Unit detected problems	On batteries predisposed for Chain Monitor Unit (in battery setup “Extra connector for CMU” is at true) during charge, at 80%, is done an extra test on one cell voltage of each chain: it must be between min (2,4V/C typ) and max (2,817V/C typ). See “last previous CMU final status test result” for the type of error stored; “Command to power the CMU” is effective only if the disconnection relay is closed. DPH_NTB_BOX_FC_ERROR	OFF	D	Battery - CMU
Charge CAN bus off	Bus off error while reading or writing on chargerCanBus DPH_NTB_CAN_CHARGER_BUSOFF_ERROR	N	I	BMI System
Charge CAN bus warning	Bus warning error while reading or writing on chargerCanBus DPH_NTB_CAN_CHARGER_BUSWARN_ERROR	S	I	BMI System
Charge current too high	For more than 1sec charging current higher than Limit Charge. (CellCurrentLimitCharge*NumString); (Z5/ML3 B1/B2 300V: CELL_CURRENT_LIMIT_CHARGE = 100A) DPH_NTB_MAXCURRENT_CHARGE_ERROR	D-OFF	V	Battery BMI System
Charge not allowed (OCV out of range)	Charge or fast charge isn’t enabled because of a too low or too high battery voltage. (battery voltage <= OCVCellMinCharge * 94% (BchVch) or 96% (Fch)* NumCelllOkPerString); or (battery voltage > 2,7V/C)* NumCelllOkPerString) (OcvCellMinCharge is SOC depending) DPH_NTB_CHARGING_OCV_ERROR	N	I	Battery BMI
BMI's pwm out shorted	Only with charger managed with PWM: found a short on BMI PWM output line (pin 12) (PWM value controls charger's current) (set if short detected for more than 1 min) (reset if not verified for 1min) DPH_NTB_CHARGER_OVERTEMP_ERROR	N	I	BMI System
Charge stopped for EOC with low temperature P cells	If an EOC condition is detected with T < 233,5℃; Only with cell MLP or MLX Heating up executed before reenable charge. DPH_NTB_LOW_TEMP_EOC_PCELLS_ERROR	N - S (On req. Autod.)	I	
Charger not provide current (2A)even if PWM > 90%	After 10 sec with less then 2A even if PWM > 90%; the PWM for chargers is zeroed for 2 min. to cool the charger after the set of the error. DPH_NTB_CHARGER_PROVIDE_NO_POWER_ERROR	S	I	BMI System
Charging current too low (for 5 min)	No connection with charger detected: charger not connected or not working properly. (If |charging current| < 240mA per string continuosly for more than 5 minutes, timer start from beginning if DcDC is enabled) DPH_NTB_CHARGING_CURR_ERROR	N	V	BMI *Battery* System

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Charging temp waiting OK	Charge stopped due to wrong temperature: Typically-> - If T>T (Soc) where T (Soc) is: 285℃ for SOC < 20% (fan present),315℃ for SOC <20 % (fan not present), 305℃ for SOC = 50%, 285℃ for SOC > 80% (fan present) , 275℃ for SOC > 80% (fan present) . - If T< 235℃ DPH_NTB_CHARGING_TEMP_ERROR	N - S (On req. Autod.)	I	
Coil S2	Main switch S2 closed, but coil current >1,5A or <0,4A. DPH_NTB_S2_ERROR	OFF	V	BMI
Coil S3	Main switch S3 closed, but coil current >1,5A or <0,4A. DPH_NTB_S3_ERROR	OFF	V	BMI
Crash	Crash sensor active (pin 14 of AMP6 connector, and 6 optionally) DPH_NTB_CRASH_ERROR	OFF	D - V (on req. A306)	BMI
DC heater error	DC heater current is checked, error set if : for more than 9 sec DC heater on and I < 0,5 I nominal. The control is made with disconnection relay close. The DIS relay isn't opened by this error. Dc heater disabled if voltage lower than 2,38V/Cell for 1 min. DPH_NTB_DC_HEATER_ERROR	N	I	Battery BMI
DC heater emergency	The LV controller received the Status Word indicating DC heater emergency switch off activated (OVC) HV controller detected DC heater current > 5A DPH_NTB_DC_HEATER_EMERGENCY_SWITCH_OFF	N	I	Battery BMI
DC heater out of control	DC heater current is checked, error set if : for more than 9 sec, DC heater off and I > 0,5 Inominal or for more than 9 sec, Dcheater on and I > 2 Inominal or for more than 9 sec, Dcheater current < -1/10 Inominal The DISconnection relay will be opened. With DIS open charge or discharge aren't possible, because isn't possible read battery voltage; the only way to keep warm the battery is AC heater. The control is made with disconnection relay close. DPH_NTB_DC_HEATER_OUT_OF_CONTROL_ERROR	N	I	Battery BMI

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Difference T1 - T2 too high	After 2 hours of continuous AC or DC heating: the temperatures, reads by 2 temperature sensors, with too high difference ->AcHeatingReduced. Both T1> T2 +D both T1<T2 + D can set th error. The delta (D) depends on the battery type. For Digatron application, the error can be set also during the test to check T1 and T2 swapped. DPH_NTB_DIFF_T1T2_ERROR	N	I	Battery BMI
Discharge current too high	For more than 60msec discharging current bigger than Current Limit Discharge. (CellCurrentLimitDischarge*NumString) (ML3: CELL_CURRENT_LIMIT_DISCHARGE = 140A) DPH_NTB_MAXCURRENT_DISCHARGE_ERROR	N	V	BMI System
Discharging temp waiting OK	The Battery temperature doesn't allow to discharge the battery (for discharge and/or external DcDc) : both low or high temperature can produce this error. DPH_NTB_DISCHARGING_TEMP_ERROR	N	I	
Disc.Relay open due to Tbatt.low (<210℃ Typ)	Battery temperature is too low. (For more than 9 sec: T average <=208.5℃; error is reset immediately if Tav >=210℃) DPH_NTB_TEMPCOLD_ERROR	N	I	
Emergency	Power supply on Emergency pin (pin 9 of AMP16 connector) has been removed (lower than 8V/16V), for more than 1 s. (if pin 2 (reset input) is active, emergency error is not set) DPH_NTB_EMERGENCY_ERROR	OFF	V	BMI System
End of charge with SOC too low: New charge disabled (Typ. 80%)	End of charge reached with SOC < 80%. SW calculated SOC can be different (lower in this case) than real SOC. To set a well known value of SOC an end of charge must takes place: one EOC per day is recommended (Soc + int offset < 80% has been detected). For both C and P cells stop any type of charge. DPH_NTB_EOC_WITH_SOC_TOO_LOW_ERROR	N	D	Battery BMI System
End of charge has not been reached for a long time	For 36 hours (or 180 hours in A306), end of charge has not been reached: please don't stop charge and wait end of charge. In application using 36h, the error is showed only if AC is applied. DPH_NTB_INT_OFFSET_TIME_BIG_ERROR	N	I	Battery BMI System
External ISO	Each 10 min an isolation test is made: if S2 was close when the test started the error is considered external. One of the battery poles is shorted to the chassis or anything on the traction net or charge net produce the error because of connected to chassis. Discharge is permitted but not charge and not regeneration. In multi-battery system the MBS send a message to start the test. Test made with disconnection relay close and without reset. Threshold to set the error 10Ohm/Vocv (or 500Ω/V on demand) with a min of (Bmi 100V):<13K, (Bmi 160V):<13K, (Bmi 300V):<38, (Bmi 600V): <75K DPH_NTB_EXT_ISO_ERROR	D-OFF (9 min if 1th error)	I	BMI System
External iso error set too often: check wiring please	External iso error has been reset for more than 20 times. There are no more automatic attempts of remove it after 216 times, but it is necessary to provide a positive edge on the ignition signal to restart the verification cycle: if external iso error is set the ignition is not able to close the switches but can only start the iso verification cycle. DPH_NTB_EXT_REMVED_ISO_ERR	N	I	BMI System

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
End of discharge detected	End Of discharge algorithm detected battery discharge. DPH_NTB_END_OF_DISCHARGE_DETECTED_ERROR	N	I	
Fan error	If fan command active: error set if for more than 2 sec fan current > 8A or If fan command not active: error set if for more than 2 sec fan current > 2A DPH_NTB_FAN_OUTPUT_ERROR	N	V	BMI System
Gradient on temp sensor 1 too high	Gradient on temp sensor 1 too high (For more than 9 sec: | T1 gradient | > 12℃/min) DPH_NTB_T1_GRAD_ERROR	N	V	Battery BMI
Gradient on temp sensor 2 too high	Gradient on temp sensor 2 too high (For more than 9 sec: | T2 gradient |> 12℃/min) DPH_NTB_T2_GRAD_ERROR	N	V	Battery BMI
HV status CE	The LV controller received the Status Word indicating CPU error (RAM/ROM etc.) DPH_NTB_HV_STS_CE_ERROR	S	V	BMI
HV status CS	The LV controller received the Status Word indicating checksum error in the last optobus protocol DPH_NTB_HV_STS_CS_ERROR	S	V	BMI
HV status E0	The LV controller received the Status Word indicating checksum error at calibration data page 1 (The word2 of the message received is the status word because previous command message sent to HV controller asked status word) DPH_NTB_HV_STS_E0_ERROR	S	V	BMI
HV status E1	The LV controller received the Status Word indicating checksum error at characteristic data page 1 DPH_NTB_HV_STS_E1_ERROR	S	V	BMI
HV status E2	The LV controller received the Status Word indicating checksum error at calibration data page 2 DPH_NTB_HV_STS_E2_ERROR	S	V	BMI
HV status E3	The LV controller received the Status Word indicating checksum error at characteristic data page 2 DPH_NTB_HV_STS_E3_ERROR	S	V	BMI
HV status LV	The LV controller received the Status Word indicating HV supply voltage is to low DPH_NTB_HV_STS_LV_ERROR	S	V	BMI
HV status WE	The LV controller received the Status Word indicating error during EEPROM access DPH_NTB_HV_STS_WE_ERROR	S	V	BMI

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
HV uC supply checksum	The received message indicates that the value of the supply voltage of HV controller isn't available because of: Incorrect checksum DPH_NTB_MSP_VOLTAGE_CHECKSUM_HV_ERROR	S	V	BMI
HV uC supply command unknown	The received message indicates that the value of the supply voltage of HV controller isn't available because of: Unknown command DPH_NTB_MSP_VOLTAGE_COMMAND_UNKNOWN_HV_ERROR	S	V	BMI
HV uC supply HW failure	The received message indicates that the value of the supply voltage of HV controller isn't available because of: Hardware error DPH_NTB_MSP_VOLTAGE_HARDWARE_HV_ERROR	S	V	BMI
HV uC supply no calibration	The received message indicates that the value of the supply voltage of HV controller isn't available because of: No calibration data available DPH_NTB_MSP_VOLTAGE_NO_CALIBRATION_HV_ERROR	S	V	BMI
HV uC supply not available	The LV controller received a message indicating that the value is not (yet) available. The analog value of the supply voltage of HV controller is requested each 640ms. The HV controller isn't able to send the requested analog value. (The word2 of the message received on LV controller is the value of the supply voltage of HV controller because previous command message sent to HV controller asked the supply voltage of HV controller. DPH_NTB_MSP_VOLTAGE_NOT_AVAILABLE_HV_ERROR	S	V	BMI
HV uC supply timeout	The received message indicates that the value of the supply voltage of HV controller isn't available because of: Protocol timeout generated by the LV controller DPH_NTB_MSP_VOLTAGE_TIMEOUT_HV_ERROR	S	V	BMI
HV uC supply too high	The received message indicates that the value of the supply voltage of HV controller is too high. V > 15V DPH_NTB_MSP_VOLTAGE_TOO_HIGH_HV_ERROR	S	V	BMI
HV uC supply too low	The received message indicates that the value of the supply voltage of HV controller is too low. V < 0V DPH_NTB_MSP_VOLTAGE_TOO_LOW_HV_ERROR	S	V	BMI
Internal ISO	Each 10 min an isolation test is made: if S2 was open when the test started the error is considered internal. One of the battery poles is shorted to the chassis. Charge or discharge are disabled because can be unsafe and dangerous for the battery: an accurate analysis must be done by authorized technician. In multi-battery system the MBS send a message to start the test. Test made with disconnection relay close and without reset. Threshold to set the error 10Ohm/Vocv (or 500Ω/V on demand) with a min of (Bmi 100V):<13K, (Bmi 160V):<13K, (Bmi 300V):<38, (Bmi 600V): <75K. (*1*) =the error can be automatically cleared before it becomes definitive DPH_NTB_INT_ISO_ERROR	OFF	D- (*1*)	Battery BMI
in msg 0x310 received bit of PCU error = active	Only A306 apply: The PCU sent to the BMI a notification of one error inside the PCU. DPH_NTB_PCU_FAULT_ERROR	N	I	

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Invalid Battery ID in flange	During initialisation the BMI reads an invalid Battery ID in the flange. (Many battery's parameters are with wrong value if th eerror appears after a sw download) DPH_NTB_INVALID_BATTERY_ID_ERROR	N	I	BMI Battery flange
ISO (-)"	In isolation circuit: error found in U- test cycle (measurement overflow) DPH_NTB_ISO_NEG_ERROR	N	V	BMI
ISO (+)	In isolation circuit: error found in U+ test cycle (measurement overflow) DPH_NTB_ISO_POS_ERROR	N	V	BMI
ISO 1 - Battery not grounded	In isolation circuit: no ground connection or error (ISO_SELFTEST1ERR & ISO_SELFTEST2ERR) DPH_NTB_ISO_SELFTEST1_ERROR	N	V	BMI System
ISO 2 - Battery not grounded	In isolation circuit: no ground connection or error (ISO_SELFTEST1ERR & ISO_SELFTEST2ERR) DPH_NTB_ISO_SELFTEST2_ERROR	N	V	BMI System
ISO 3 - HV resistors or relay"	In isolation circuit: error HV connection relays or resistor network DPH_NTB_ISO_SELFTEST3_ERROR	N	V	BMI
ISO hardware	In isolation circuit: hardware error (ISO_HARDERR returned by get_isotest) DPH_NTB_ISO_HARD_ERROR	N	V	BMI
ISO measurement unstable	In isolation circuit: measurement signal unstable, can't find settling point DPH_NTB_ISO_TIMEOUT_ERROR	N	V	Battery BMI System
ISO test circuit not supplied	In isolation circuit: no power DPH_NTB_ISO_NOPWR_ERROR	N	V	
LDM communication	In the communication with flange detected problem -> check correct communication with the flange. “LDM communication ": Lifedata communication error occurred while testing entry. It happens only after 10s time long communication problem: it resets “LDM Data Busy ". It isn't set if “LDM communication (init failed) “error is already set! (DATA_COMERROR) DPH_NTB_LDM_DATACOMM_ERROR	D-OFF	D	BMI Battery flange
LDM communication (init failed)	LDM data were not loaded properly from the flange or has been read Nameplate Capacity equal to zero from the flange -> check correct communication with the flange. It isn't resettable by vehicle-ignition key or by ZEBRA® Monitor's reset errors! *Resettable only by a BMI's reset.* " LDM communication (init failed) ": Entry could not be read at initialisation, RAM mirror is invalid (DATA_INITERROR) DPH_NTB_LDM_COMMUNICATION_ERROR	D-OFF	I - (BMI’s Reset to clear)	BMI Battery flange

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
LDM Data Busy	Warning, temporary problems in the communication with the flange, the communication is still running. It is reset in case of DATA_GOOD, DATA_ERROR, DATA_COMERROR. (DATA_BUSY_ERROR) DPH_NTB_LDM_DATA_BUSY_ERROR	N	I	BMI Battery flange
LDM data check failed	Wrong flange data detected: -> check correct communication with the flange and/or flange integrity. Lifedata EEPROM value in flange and RAM mirror value are not equal. This error clears “LDM Data Busy " error. Check "Handle For LDM data Check Failed". (DATA_ERROR) DPH_NTB_LDM_DATA_ERROR	N	D	BMI Battery flange
LDM write data failed	Error is set if the write operation is not successful within 5 sec. NOTE: Each 5 min SOC is written on LDM, if changed. DPH_NTB_LDM_WRITE_FAILED_ERROR	N	I	BMI Battery flange
Limitation imposed from ZEBRA® to drive system	Reduction on max discharge or regenerative current for inverter or block of charge. Reasons can be: Tmax >290℃, or Soc < 20% or Soc < 17% for ML8 cells , or external ISO error detected, or RegSoc > 2%, or current>200A and energy>330A^2min or S3 melted; in charge the reason can be also OCV out of allowed range for charge. DPH_NTB_BATTERY_LIMITATION_ACTIVE_ERROR	S	I	
Long dev. curr charge)	For more than <integral-cumulative timer> 60sec (10 sec in disch in same applications): Battery current > Current max Charge + 10% (+0% in same appl.) In charge or if SOCregn < 2%, the error is set with more then 2A. DPH_NTB_LONGDEVIATION_CURRENT_CHARGE_ERROR	D-OFF	V	System Battery
Long dev. curr discharge	For more than <integral-cumulative timer> 5minutes: Battery current > Current max discharge In BMI 100V-160V the error is set with more then 4A In BMI 300V-600V the error is set with more then 2,5A DPH_NTB_LONGDEVIATION_CURRENT_DISCHARGE_ERROR	D-OFF	V	System
Long dev. voltage max	For more than <integral-cumulative timer> 10sec (or 30s if charger connected on traction net): Battery voltage > Voltage MaxCharge during discharge Battery voltage > Voltage MaxCharge +1% during DC-DC activation Battery voltage > Voltage MaxCharge + 1% during CH or FCH. DPH_NTB_LONGDEVIATION_VOLTAGE_MAX_ERROR	D-OFF	V	Battery System
Long dev. voltage min	For more than <integral-cumulative timer> 20sec Battery voltage < Voltage Min Discharge DPH_NTB_LONGDEVIATION_VOLTAGE_MIN_ERROR	D-OFF	V	Battery System

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Main switch on positive pole could be melted	Main switches on positive and negative pole of the battery could be melted: service Investigation on the main switches is necessary if the error remains. Charge and regeneration are not allowed with this error. DPH_NTB_S3_MELTED_ERROR	N	I	BMI
Main switch supply	Power supply for the main switches S2 or S3 is to low (during and after precharge) Voltage too low on pin 11 of AMP 16 connector. DPH_NTB_SWITCH_SUPPLY_ERROR	OFF	V	BMI
Main switch wrong seq. 1	Precharge is running before the beginning of precharge procedure DPH_NTB_SWITCH_TIMING_ERROR1	OFF	V	BMI
Main switch wrong seq. 2	S2 and S3 ON (drive) before the beginning of precharge procedure DPH_NTB_SWITCH_TIMING_ERROR2	OFF	V	BMI
Main switch wrong seq. 3	S2 and S4 ON (charge) before the beginning of precharge procedure DPH_NTB_SWITCH_TIMING_ERROR3	OFF	V	BMI
Main switch wrong seq. 4	S2, S3 and S4 ON (drive & charge) before the beginning of precharge procedure DPH_NTB_SWITCH_TIMING_ERROR4	OFF	V	BMI
Main switch wrong seq. 5	Precharge is running after the end of precharge DPH_NTB_SWITCH_TIMING_ERROR5	OFF	V	BMI
Main switch wrong seq. 6	Precharge error (timeout) after the end of precharge DPH_NTB_SWITCH_TIMING_ERROR6	OFF	V	BMI
Manual switch-off performed	SW off error has been set with ZEBRA® monitor for diagnostic-test purpose DPH_NTB_SW_OFF_ZMONITOR_ERROR	OFF	D	BMI
Max delta FC has been exceeded for too long time	See “Warranty status" in page Battery Lifedata. The BMI received, for more then 6 days, from MBS, a message to inform that the difference, among all the batteries, between the max and min n°of failed cell per string exceed ed the max allowed. Once set this flag remains set even if the difference becomes acceptable. DPH_NTB_DELTA_FC_ERROR	S	I	System
MBS CAN communication	In multi-battery system the BMI must receive, continuously, within 5 s (while no bus errors), from the MBS, on battery can, a message of system enable: if this doesn't happen "MBS CAN communication" error is set. (on OFF to ON transition of the ignition signal, the BMI close switches without this message, but, after 5 sec they are opened if BMI doesn’t receive the system enable) DPH_NTB_CAN_MBS_TIMEOUT_ERROR	S	I	BMI System
MBS requires disconnection (to execute isolation test or other)	In case of isolation test or other, the MBS requires the disconnection of all the BMIs in order to execute the internal isolation test. DPH_NTB_MBS_DISCON_REQ_ERR	OFF	I	

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Measure DC heater curr too low	The received analog value of DC heater current indicates that the value is too high; for 60ms. I < 0 A DPH_NTB_DCHEATCURR_TOO_LOW_HV_ERROR	N	V	Battery BMI
Meas current HW failure	The received analog value of battery current indicates that the value is not available because of hardware problems; for 60ms. DPH_NTB_CURRENT_HARDWARE_HV_ERROR	OFF	V	BMI
Measured current checksum	The received analog value of battery current indicates that the value is not available because of checksum error; for 60ms. DPH_NTB_CURRENT_CHECKSUM_HV_ERROR	OFF	V	BMI
Measured current command unknown	The received analog value of battery current indicates that the value is not available because the HV controller didn't recognise the command received; for 60ms. DPH_NTB_CURRENT_COMMAND_UNKNOWN_HV_ERROR	OFF	V	BMI
Measured current no calibration	The received analog value of battery current indicates that the value is not available because of no calibration available; for 60ms. DPH_NTB_CURRENT_NO_CALIBRATION_HV_ERROR	OFF	V	BMI
Measured current not available	The received analog value of current voltage indicates that the value isn't (yet) available; for 60ms. (Analog value (of current voltage, from HV controller) is: not (yet) available. The value or battery current is sent, by HV controller, approximately each 20 ms). The HV controller isn't able to send the requested analog value. DPH_NTB_CURRENT_NOT_AVAILABLE_HV_ERROR	OFF	V	BMI
Measured current timeout	The received analog value of battery current indicates that the value is not available because of time out error generated from LV; for 60ms. DPH_NTB_CURRENT_TIMEOUT_HV_ERROR	OFF	V	BMI
Measured current too high	The received analog value of battery current indicates that the value is too high; for 60ms. I > 500A DPH_NTB_CURRENT_TOO_HIGH_HV_ERROR	OFF	V	BMI
Measured current too low	The received analog value of battery current indicates that the value is too low; for 60ms. I < -400A DPH_NTB_CURRENT_TOO_LOW_HV_ERROR	OFF	V	BMI
Measured DC heater curr checksum	The received analog value of DC heater current indicates that the value is not available because of checksum error; for 60ms. DPH_NTB_DCHEATCURR_CHECKSUM_HV_ERROR	N	V	BMI
Measured DC heater curr command unknown	The received analog value of DC heater current indicates that the value is not available because the HV controller didn't recognise the command received; for 60ms. DPH_NTB_DCHEATCURR_COMMAND_UNKNOWN_HV_ERROR	N	V	BMI
Measured DC heater curr no calibration	The received analog value of DC heater current indicates that the value is not available because of no calibration available; for 60ms. DPH_NTB_DCHEATCURR_NO_CALIBRATION_HV_ERROR	N	V	BMI

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Measured DC heater curr not available	The received analog value of DC heater current indicates that the value isn't (yet) available; for 480ms. The analog value of DC heater current is requested each 160ms. The HV controller isn't able to send the requested analog value. (The word2 of the message received on LV controller is the value of DC heater current because previous command message sent to HV controller asked DC heater current) DPH_NTB_DCHEATCURR_NOT_AVAILABLE_HV_ERROR	N	V	BMI
Measured DC heater curr timeout	The received analog value of DC heater current indicates that the value is not available because of time out error generated from LV; for 60ms. DPH_NTB_DCHEATCURR_TIMEOUT_HV_ERROR	N	V	BMI
Measured DC heater curr too high	The received analog value of DC heater current indicates that the value is too high; for 1s. I > 7,5A (100V-160V)or 2,5A (300V-600V) DPH_NTB_DCHEATCURR_TOO_HIGH_HV_ERROR	N	V	BMI
Measured DC heater HW failure	The received analog value of DC heater current indicates that the value is not available because of hardware error; for 60ms. DPH_NTB_DCHEATCURR_HARDWARE_HV_ERROR	N	V	BMI
Measured smoothcap voltage checksum	The received analog value of smoothcap voltage indicates that the value is not available because of checksum error; for 60ms. DPH_NTB_SMOOTHCAPV_CHECKSUM_HV_ERROR	OFF	V	BMI
Measured smoothcap voltage command unknown	The received analog value of smoothcap voltage indicates that the value is not available because the HV controller didn't recognize the command received; for 60ms. DPH_NTB_SMOOTHCAPV_COMMAND_UNKNOWN_HV_ERROR	OFF	V	BMI
Measured smoothcap voltage HW failure	The received analog value of smoothcap voltage indicates that the value is not available because of hardware error; for 60ms. DPH_NTB_SMOOTHCAPV_HARDWARE_HV_ERROR	OFF	V	BMI
Measured smoothcap voltage no calibration	The received analog value of smoothcap voltage indicates that the value is not available because of no calibration available; for 60ms. DPH_NTB_SMOOTHCAPV_NO_CALIBRATION_HV_ERROR	OFF	V	BMI
Measured smoothcap voltage not available	The received analog value of smoothcap voltage indicates that the value isn't (yet) available; for 120ms. The analog value of smoothcap voltage is requested each 40ms. The HV controller isn't able to send the requested analog value. (The word2 of the message received on LV controller is the value of smoothcap voltage because previous command message sent to HV controller asked smoothcap voltage) DPH_NTB_SMOOTHCAPV_NOT_AVAILABLE_HV_ERROR	OFF	V	BMI

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Measured smoothcap voltage timeout	The received analog value of smoothcap voltage indicates that the value is not available because of time out error generated from LV; for 60ms. DPH_NTB_SMOOTHCAPV_TIMEOUT_HV_ERROR	OFF	V	BMI
Measured smoothcap voltage too high	The received analog value of smoothcap voltage indicates that the value is too high; for 60ms. V > 800 V DPH_NTB_SMOOTHCAPV_TOO_HIGH_HV_ERROR	OFF	V	BMI System
Measured smoothcap voltage too low	The received analog value of smoothcap voltage indicates that the value is too high; for 60ms. V < 0 V DPH_NTB_SMOOTHCAPV_TOO_LOW_HV_ERROR	OFF	V	BMI System
Measured temp. Checksum	The received analog value of temperature indicates that the value is not available because of checksum error; for 60ms. DPH_NTB_TEMPERATURE_CHECKSUM_HV_ERROR	N	V	BMI
Measured temp. command unknown	The received analog value of temperature indicates that the value is not available because the HV controller didn't recognise the command received; for 60ms. DPH_NTB_TEMPERATURE_COMMAND_UNKNOWN_HV_ERROR	N	V	BMI
Measured temp. HW failure	The received analog value of smoothcap voltage indicates that the value is not available because of hardware error; for 60ms. DPH_NTB_TEMPERATURE_HARDWARE_HV_ERROR	N	V	BMI
Measured temp. not available	The received analog value of temperature (battery and BMS temperature) indicates that the value isn't (yet) available; for 1920ms. The analog value of temperature is requested each 640ms. The HV controller isn't able to send the requested analog value. Periodically T1, T2 and TBMS are requested to HV controller; only one value each time. (The word2 of the message received on LV controller is the value of temperature because previous command message sent to HV controller asked temperature) DPH_NTB_TEMPERATURE_NOT_AVAILABLE_HV_ERROR	N	V	BMI
Measured temp. no calibration	The received analog value of temperature indicates that the value is not available because of no calibration available; for 60ms. DPH_NTB_TEMPERATURE_NO_CALIBRATION_HV_ERROR	N	V	BMI
Measured temp. Timeout	The received analog value of temperature indicates that the value is not available because of time out error generated from LV; for 60ms. DPH_NTB_TEMPERATURE_TIMEOUT_HV_ERROR	N	V	BMI
Measured temp. too high	The received analog value of temperature indicates that the value is too high; for 60ms. T1,T2 > 400℃; TBMS> 150℃ DPH_NTB_TEMPERATURE_TOO_HIGH_HV_ERROR	N	V	BMI

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Measured temp. too low	The received analog value of temperature indicates that the value is too high; for 60ms. T1, T2 < -40℃; TBMS< -40℃ DPH_NTB_TEMPERATURE_TOO_LOW_HV_ERROR	N	V	BMI
Measured voltage checksum	The received analog value of battery voltage indicates that the value is not available because of checksum error; for 60ms. DPH_NTB_VOLTAGE_CHECKSUM_HV_ERROR	OFF	V	BMI
Measured voltage command unknown	The received analog value of battery voltage indicates that the value is not available because the HV controller didn't recognise the command received; for 60ms. DPH_NTB_VOLTAGE_COMMAND_UNKNOWN_HV_ERROR	OFF	V	BMI
Measured voltage HW failure	The received analog value of battery voltage indicates that the value is not available because of hardware error; for 60ms. DPH_NTB_VOLTAGE_HARDWARE_HV_ERROR	OFF	V	BMI
Measured voltage no calibration	The received analog value of battery voltage indicates that the value is not available because of no calibration available; for 60ms. DPH_NTB_VOLTAGE_NO_CALIBRATION_HV_ERROR	OFF	V	BMI
Measured voltage not available	The received analog value of battery voltage indicates that the value isn't (yet) available; for 60ms. (Analog value (of battery voltage, from HV controller) is: not (yet) available. The value or battery voltage is sent, by HV controller, approximately each 20 ms) The HV controller isn't able to send the requested analog value. DPH_NTB_VOLTAGE_NOT_AVAILABLE_HV_ERROR	OFF	V	BMI
Measured voltage timeout	The received analog value of battery voltage indicates that the value is not available because of time out error generated from LV; for 60ms. DPH_NTB_VOLTAGE_TIMEOUT_HV_ERROR	OFF	V	BMI
Measured voltage too high	The received analog value of battery voltage indicates that the value is too high; for 60ms. V > 800V DPH_NTB_VOLTAGE_TOO_HIGH_HV_ERROR	OFF	V	BMI
Measured voltage too low	The received analog value of battery voltage indicates that the value is too low; for 60ms. V < 0V DPH_NTB_VOLTAGE_TOO_LOW_HV_ERROR	OFF	V	Battery BMI
OCV obtained during charge has problem, check consistency	The open circuit voltage computed during charge, each 1%SOC by temporary reduction of charge, present possible anomalies. For details of the cause of the fault see, in Monitoring page: “OCV results; Double Click on Var to Show complete Status”. N°Of failed cell seems decreased, the 2 n°of fail ed cell with difference higher then 1, possible broken string or high resistance inside of the battery. DPH_NTB_MAYBE_NEW_FAILED_CELL_ERROR	S	V	Battery BMI

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
On-board battery voltage<12V/24V	The on-board battery is not properly charged. Check the right DCDC functionality. DPH_NTB_LOW_VOLT_ERROR	N	I	System
Peak dev. current charge	For more than 10 continuously sec: (20s if charger connected on traction net and 1sec in discharge in same appl) Battery current > Current MaxCharge + 50% during CH or FCH. Battery current > Current MaxCharge + 30% (+10% is same appl) during discharge In charge or if SOCregn < 2%, the error is set with more then 2A. (Procedure disabled for 2sec when DC heater start to discharge battery to measure OCV) DPH_NTB_PEAKDEVIATION_CURRENT_CHARGE_ERROR	D-OFF	V	System
Peak dev. current discharge	For more than 30 continuously sec: Battery current > Current MaxDischarge + 10% In BMI 100V-160V the error is set with more then 4A In BMI 300V-600V the error is set with more then 2,5A DPH_NTB_PEAKDEVIATION_CURRENT_DISCHARGE_ERROR	D-OFF	V	System
Peak dev. voltage max	For more than < integral-cumulative timer > 2sec (0,5s in discharge is same application): Battery voltage > Voltage MaxCharge + 5% DPH_NTB_PEAKDEVIATION_VOLTAGE_MAX_ERROR	D-OFF	V	Battery System
Peak dev. voltage min	For more than <integral-cumulative timer> 2sec Battery voltage < Voltage MinDischarge - 10% DPH_NTB_PEAKDEVIATION_VOLTAGE_MIN_ERROR	D-OFF	V	Battery System
Please check number of failed cells: it is too high->could stop the batt.	The number of failed cells detected from the BMI is too high, typically more then 10%. The battery can have a high number of failed cells and need to be repaired. DPH_NTB_MAX_FC_CELL_ERR	N	I	Battery
Precharge HW error	If during precharge (on traction or charge net) precharge thystors fail: current on it even if it hasn't been activated. BMI's hw must be replaced or tested carefully. DPH_NTB_PRECHARGE_HW_ERROR	S	D	BMI
Precharge resistors	During precharge procedure on traction or charge net, energy in precharge resistor exceeds max value (Energy = Σi^2R). A delay (1÷2 min) must occur before restart a new precharge in order to let to dissipate energy accumulated on the precharge resistor. DPH_NTB_PRECHARGING_ERROR	OFF	V	BMI System

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Precharge time elapsed	Precharge sequence on traction net not finished in max time of 1 sec. (for traction net: not reached, on precharging capacitors, 0,95% of battery voltage) (for charging net: precharge procedure not finished in maximum time of 0,5 sec) Check / try to reduce the value of the capacitors and loads connected on traction-charge net that must be precharged and/or check the number of battery connected in a multy battery system in order to reduce the probability to arise this error. DPH_NTB_PRECHARGE_TIME_ERROR	OFF	V	BMI System
Short circuit	For more than 60msec: Battery Voltage < 1,3 V per good cell in one chain OR discharging current > 270A per chain with ML3 cell (> 115A per chain with ML8 cell) DPH_NTB_BATT_SHORT_ERROR	OFF	D	Battery System BMI
SOC too high: Warning Check SOC consistency! (Typ. 103,8)	Calculated SOC >103,8%; in charge, after depolarization with DC heater, the SOC can be set to 100% for max 4 times. DPH_NTB_SOC_HIGH_ERROR	N	D	Battery System BMI
SOC too high: Reset BMI and then Discon. relay kept open (Typ. 103,9%)	Calculated SOC >103,9%, SOC is set to 103,9% and disconnection relay is opened! With DIS open charge or discharge aren't possible, because isn't possible read battery voltage; DC heater is also disabled with DIS open. The only way to keep warm the battery is AC heater. DPH_NTB_EOC_WITH_SOC_TOO_HIGH_ERROR	D-OFF	D	Battery System BMI
Switch coil open circuit error	Open coil circuit at any main switch DPH_NTB_SWITCH_COIL_OPEN_CIRCUIT_ERROR	N	V	BMI
Switch coil shortcut error	Coil shortcut at any main switch DPH_NTB_SWITCH_COIL_SHORTCUT_ERROR	OFF.	V	BMI
Switch overtemp error	Overtemperature at any main switch: check cable connection between the two mechanic part of BMI. DPH_NTB_SWITCH_OVERTEMP_ERROR	N	V	BMI
Switch under load (I > 50A)	During switch off procedure of traction or charger net, main switches opened even if after 8 sec current > 50A. Charge and discharge are disabled DPH_NTB_SWITCH_UNDER_LOAD_ERROR	N	D	System

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
T1 not available error	If for more than 9 sec, the LV controller receives T1 = not available. If T2 is available then T1=T2 . If also T2 is not available DIS relay is opened. DPH_NTB_T1_NOT_AVAILABLE_ERROR	N	V	Battery BMI
T2 not available error	If for more than 9 sec, the LV controller receives T2 = not available. If T1 is available then T2=T1. If also T1 is not available DIS relay is opened. DPH_NTB_T2_NOT_AVAILABLE_ERROR	N	V	Battery BMI
Temp. fatal	At least one sensor is out of range (-40℃..+355℃) or both the temperature sensors gradients are out of range (> 12℃/min). After having set this error the BMI is reset.!! DPH_NTB_TEMP_FATAL_ERROR	D-OFF	D	Battery BMI
Temp. sensor 1 out of range	Temp. Sensor 1 out of range. For more than 9 sec: T1 < -40℃ or T1 > 355℃, with temperature sensors in front position, in new batteries. (For more than 9 sec: T1 < -40℃ or T1 > 380℃, wit h temperature sensors in central position) DPH_NTB_T1_ERROR	N	V	Battery BMI
Temp. sensor 2 out of range	Temp. Sensor 2 out of range. For more than 9 sec: T1 < -40℃ or T1 > 355℃, with temperature sensors in front position, in new batteries. (For more than 9 sec: T1 < -40℃ or T1 > 380℃, wit h temperature sensors in central position) DPH_NTB_T2_ERROR	N	V	Battery BMI
timeout error: 0x310 msg not received for 1 sec while in discharge or in charge	Only A306 apply: problems on BMI and PCU communication DPH_NTB_CAN_310_TIMEOUT_ERROR	OFF	I	System
timeout error: 0x311 msg not received for 1 sec while in charge	Only A306 apply: problems on BMI and PCU communication DPH_NTB_CAN_311_TIMEOUT_ERROR	OFF	I	System
Time max elapsed while AC heating	AC heater doesn't heat properly or thermal losses: T1 below 200℃ for more than 22 hours -28hours for Z12. -22 or 28h with Vac>150V & AC heater on with max power. DPH_NTB_AC_HEATER_ONTIME_ERROR	N	D	Battery BMI
Time out for OCV meas (t > 60min)	During Vehicle and Battery charge, when SOC reaches 80%, a measure of OCV takes place: before measuring OCV the DC heater must discharge the battery of 0,3%. Discharge and measure must happen in max 60min: the message shows that it didn't happen. If DCheater doesn't discharge after 15min charge restarts. DPH_NTB_OCV_MEASUREMENT_ERROR	N	V	Battery BMI
Ubatt too low for ISO test	In isolation circuit: low battery voltage DPH_NTB_ISO_LOBAT_ERROR	N	V	Battery BMI
Vehicle crash	Crash signal from the server or from the vehicle DPH_NTB_VCL_CRASH_ERROR	OFF	V	System

ZEBRA® Monitor's Message	Description	Cat.	Reset	Possible defective item
Vehicle emergency	Emergency signal from the server or from the vehicle DPH_NTB_VCL_EMERGENCY_ERROR	OFF	V	System
Vehicle/battery CAN bus off	Bus off error while reading or writing on CanBus DPH_NTB_CAN_BUSOFF_ERROR	N	I	
Vehicle/battery CAN bus warning	Bus warning error while reading or writing on CanBus DPH_NTB_CAN_BUSWARN_ERROR	S	I	System
Vehicle/FastCharge CAN communication	If vehicle or fastcharge enabled, the vehicle or fastcharger must send to the BMI, continuously, within 5 s (while no bus errors), a message. DPH_NTB_CAN_VPA_TIMEOUT_ERROR	S	I	System
Voltage < 2,3V/c for 1h with AC applied or All switches open: BMI is reset and DISCON is kept open	For more then 1 hour the battery voltage was lower then 2,3Volt/cell with AC voltage applied or with all the main switches open; this error opens the disconnection relay to avoid to over discharge the battery with the BMI's electronic. Check if the charger works properly. DPH_NTB_LOW_VOLT_DISCHARGED_ERROR	N	D	System
Write flash constant failed	During an update of the constant in flash memory of BMI (Made by ZEBRA® monitor) an error occurs. DPH_NTB_FLASH_CONST_ERROR	OFF	I	BMI
Wrong temp. gradient while AC heating	AC heater doesn't heat or heats too much: on T1, in 1 hour, delta Temperature < 0℃ or > 30℃. (1 hour with T1>200℃ with Vac>150V & Acheater on with duty cycle > 70%) DPH_NTB_AC_HEATER_HEATUP_ERROR	N	D	Battery BMI
Wrong BMI type for this battery	This error is set if the BMI type is not compatible with the number of cell per chain of the battery. BMI 100V: error if battery with > 40 Cell/chain BMI 160V: error if battery with < 41 Cell/chain or > 65 C/c BMI 300V: error if battery with < 66 Cell/chain or > 117C/c BMI 600V: error if battery with < 118 Cell/chain This error isn't cleared with Zebra Monitor or ignition key, It can be cleared only at start up of the BMI DPH_NTB_BMI_TYPE_FAULT_ERROR	OFF	I	BMI type

8. MAINTENANCE TASKS

8.1 GENERAL RECOMMENDATION

The battery system is only to be maintained by FZ SONICK S.A. or expressly authorized and electrical trained staff.

8.2 REPLACEMENT OF BMI

Warning: the voltages inside the ZEBRA® battery can be dangerous: the replacement of a BMI unit must **not** be done in a wet or dusty environment. The BMI may be exchanged only by FZ SONICK S.A. or expressly authorized and electrical trained staff following strictly the enclosed instructions. Please contact FZ SONICK before the start of the operation and inform about the change. The BMI assembly does not contain any serviceable parts and must not be opened. Opening of a BMI will terminate the warranty period.

Removal of a BMI:

a) Connect the diagnostic PC to the battery CAN, start ZEBRA® Monitor program, read and take note of the actual data. The main data to be recorded are :
   i) The serial number of the battery
   ii) The actual status of charge
   iii) The number of the failed cell, if any
   iv) Number of nameplates cycles
   v) The battery address
   vi) Actual Km reading of the vehicle if available
   vii) Reset the BMI with the command in ZEBRA® Monitor program by pin 2.
b) Disconnect the mains (AC) from the vehicle
c) Remove the control connector (AMP 16 poles)
d) Remove the charger-AC connector from the BMI
e) Remove the HV plus and minus battery connectors
f) Remove the fixing bolts, the required tools are :
   a 10 mm tube spanner for BMI B1 type
   10 mm tube and fixed spanner and an 4 mm in-bus spanner for BMI B2 type
g) Lift out carefully the BMI
   Warning: **the voltages inside the ZEBRA® battery are dangerous**, the sockets on the battery box side must not be touched (dangerous voltage and high temperature)
h) If the replacement BMI will be not mounted immediately protect the BMI flange against dust, water and unauthorized access.

Assembly of a BMI

a) Check the integrity of the gasket on the flange, and replace if necessary
b) Check on the flange board that the connectors for heaters and temperature sensors are well inserted.
c) Slide in the new BMI, carefully tilting the unit.
d) Only for BMI/B1 model, to ensures a good insertion of the connectors between BMI and flange, push the BMI to a distance of 7.5 to 8 mm from the flange keepers
e) Fix the bolts (tight the screws at 4 Nm (max) and then the nuts at 5 Nm (max))
f) Connect the control connector (AMP 16 poles)
g) Connect the diagnostic PC to the battery CAN
h) If necessary, start the Flash Loader application and download the BMI program.
i) Start ZEBRA® monitor program and check the actual data: they have to be **identical** to the data recorded before the replacement, if necessary set the battery address and save the data to the BMI with *update constants* operation
j) Remove the control connector (AMP 16 poles)
k) Connect the HV plus and minus battery connectors
l) Connect the charger-AC connector
m) Check with ZEBRA® monitor the temperature and connect AC to the vehicle to heat up the battery if necessary
n) Check with ZEBRA® monitor for correct charge and discharge operation.

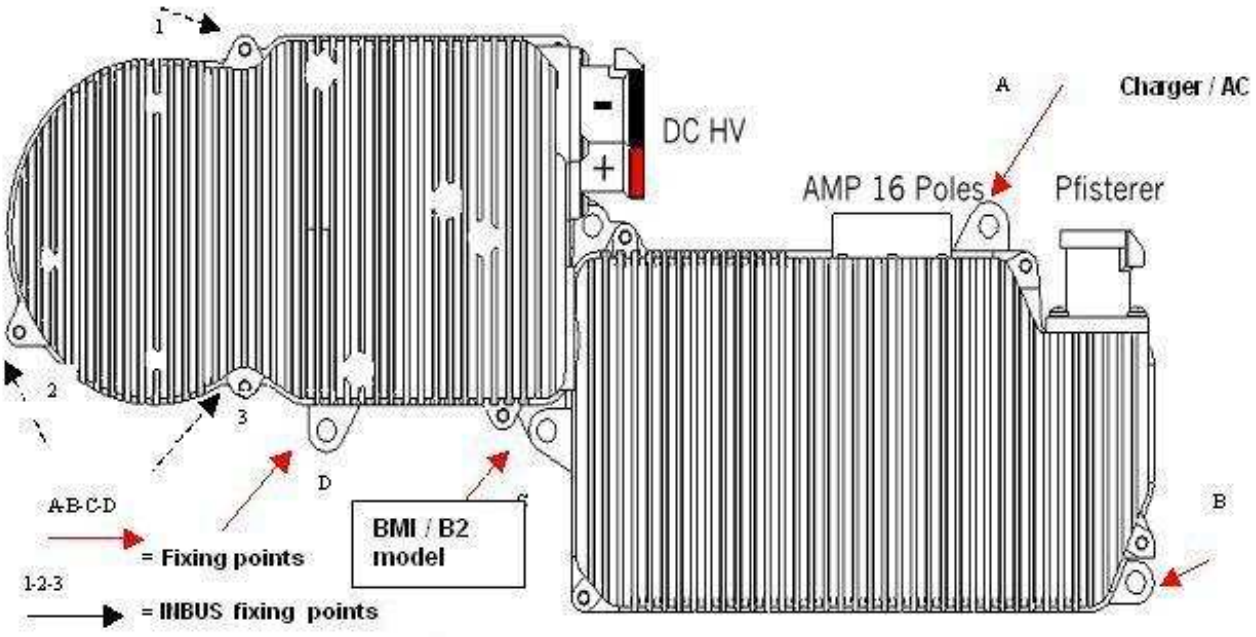


Figure 18: BMI details

8.3 EMERGENCY SWITCH-OFF

In a single battery system the emergency detection is allocated to the BMI.
For multiple battery systems this is performed by the Multiple Battery-Server (MBS).
The MBS communicates the detected emergency signal via the Battery CAN to the batteries.
In any case each-BMI is able to detect an interruption of its emergency input.
The voltage on the emergency input on pin 9 of control connector of a BMI powers the control circuit of the main relays: if the emergency signal is removed (off or open) the main relays S1,S2, S3 and S4 will open.
The number of time the switch can disconnect the battery depends on the value of the current interrupted (braking current).

Here some example of short circuit current measured:

Battery	max expected Icc (short circuit current)	Max n° of brake at Icc
Z5-557	300amp max	> 100 times
Z36-371	777amp max	roughly 40 times

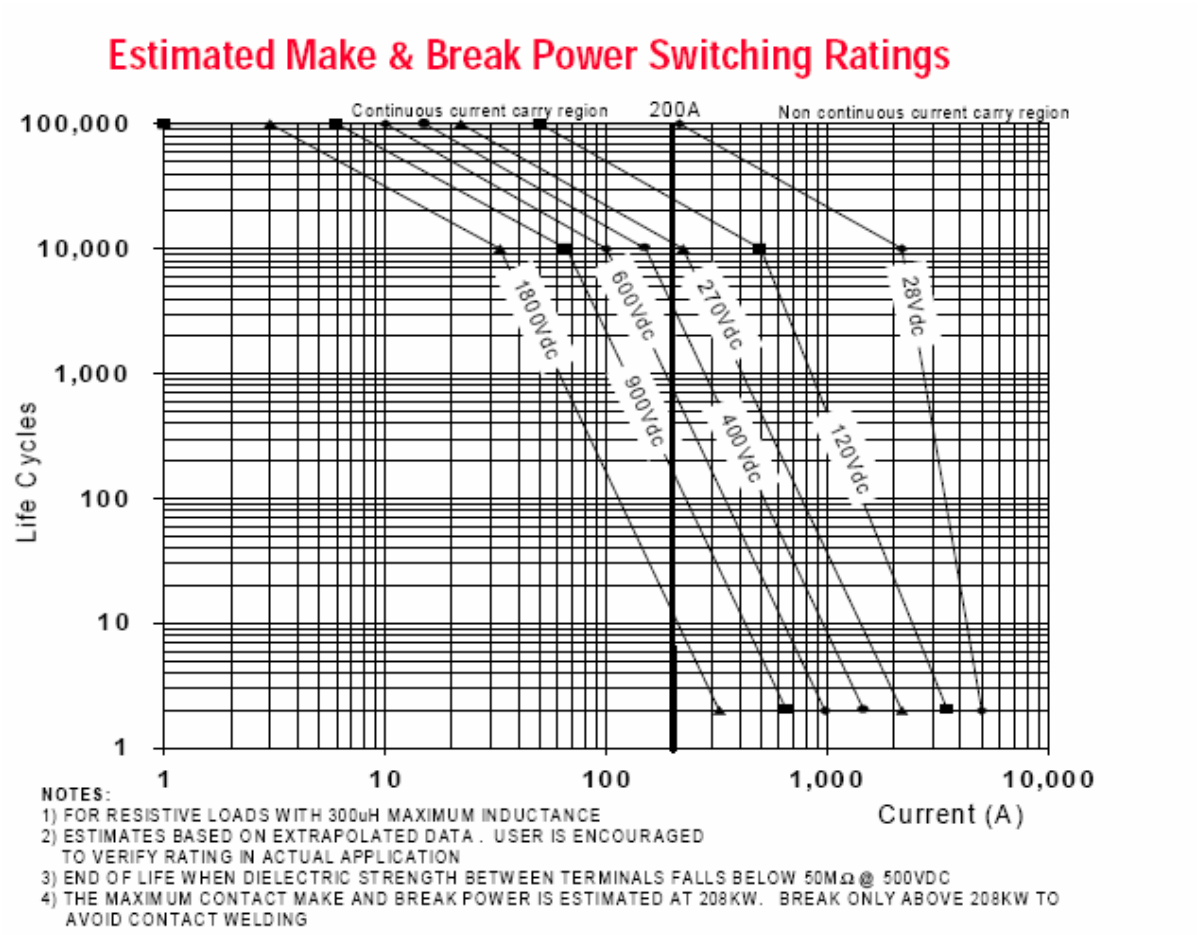


Figure 19: Estimated make & break power switching ratings.

FZ Sonick is available to provide support to find out the integrity of the main switches.

8.4 TEST OF THE BATTERY'S ELECTRICAL INSULATION

Included in the BMI is a circuit to measure the battery isolation resistance.

The BMI can measure the isolation resistance between the range of 10 to 1000 KΩ. The measurement is performed by a temporary connection of a resistor between the battery terminals HV+ or HV- and the chassis ground.
The procedure includes a self test that checks the circuit for proper operation. During the execution of the ISOTEST procedure, due to the connection of the resistor necessary for the measurement, the battery can temporarily show an isolation resistance of about 100 KΩ for a 300V BMI ; 200 KΩ for a 600V BMI; 50 KΩ per BMI 100 and 160V.
The isolation resistance must be greater than 100 Ω/V (UNI EN 1987-1),
optionally can be request a software with an higher threshold of 500 Ω/Vnominal.

The ZEBRA® Monitor diagnostic program can display the measured value.
The minimum value to set an isolation error depends on the BMI type and is 13, 20, 38 and 75 KΩ for 100, 160 , 300 and 600 V rated BMI's, respectively.

In case of isolation resistance which is lower than expected the BMI will set an error condition and the information *isolation error* will be available on the vehicle can.

An isolation error can be internal or external:
-an isolation error is defined external if detected when the battery contactor S2 (HV-) is closed
-an isolation error is defined internal if detected when the battery contactor S2 is open.
The ZEBRA® Monitor diagnostic program can display the error type.

A battery that shows an external ISO error can be discharged but not charged.
A battery that shows an internal ISO error cannot be operated.
In case of an internal ISO error the BMI will stop the operation of the heaters and of the fan and the battery will let cool down.

An external isolation error can be erased automatically; an internal isolation error can be reset only by the ZEBRA® Monitor diagnostic program.
To avoid false detections, the set of an internal ISO error must be confirmed by 3 consecutive tests.

If the external isolation error appears in discharge mode
- the discharge is allowed for a maximum of 9 minutes.
- regen braking is not allowed
- as soon as the BMI is set in park mode (S2 open) the BMI will automatically check for an internal ISO error.

If the isolation resistance is correct the External iso error will be removed and the counter **Number of ISO error removed after verification** will be incremented.
If the counter **Number of ISO error removed after verification** reaches the maximum of errors removed, the External ISO error will be not removed automatically and will be required to delete the error and reset the counter to 0 by ZEBRA® monitor.
In this case it is recommended to have additional checks to find the cause of repetitive

external isolation errors.

If the internal isolation resistance of the battery is found to be too low, an internal ISO error is set, and the BMI will perform two additional checks before a definitive set of the error is arisen. This is performed to avoid false detections. If in additional tests the isolation resistance is good, the error is erased.

If the external isolation error appears in charge mode
- the charge is stopped
- as soon as the BMI opens the main contactors the BMI will automatically check for an internal ISO error.

If the isolation resistance is correct the External iso error will be removed and the counter **Number of ISO error removed after verification** will be incremented. In this case the charge can restart.
If the counter **Number of ISO error removed after verification** reaches the maximum of errors removed, the External ISO error will be not removed automatically but it is necessary to delete the error and reset to 0 the counter by ZEBRA® monitor.
This means that in case of a real isolation problem, the charge can proceed and will stop when the counter **Number of ISO error removed after verification** reaches the maximum.

The maximum number of Number **of ISO error removed after verification** depends on the BMI software release (i.e.: *60 in version 3.0 21-06-05, 216 in version 3.3 23-01-06*)

If the internal isolation resistance of the battery is found to be low, an internal ISO error is set, and the BMI will perform two additional checks before of a definitive set of the error to avoid false detections. If in one of the two additional tests the isolation resistance is good, the error is erased.
In the case of a detection of a problem in the circuit, the BMI will set an *isoself test* error and a *warning* message, which will be available on the vehicle can.
The ZEBRA® Monitor diagnostic program can display the error type.

In a single battery system the isolation test is performed automatically every 10 minutes
In a multi-battery system the isolation test is enabled by the MBS: every 10 minutes, the MBS will start an ISOTEST cycle and activate the test on all the batteries sequentially. If an external ISO error is set, the check of the internal ISO error is performed automatically by the BMI as soon as the main contactor S2 is open.

In multi-battery system the ISOTEST of the BMI, when interfering with other system to measure the ISO on the vehicle, can be disabled with a can message : in this case the user must be aware that the safety- detection of iso error is executed only by devices different from BMI.

For a new battery the typical isolation resistance is higher than 50 MΩ. And the BMI shows 1000 KΩ.

Attention:
After the replacement of a BMI or BMI software update the counter **Number of ISO error removed after verification** can have wrong values and must be checked.

To ensure proper operation of the isolation measurement the maximum Y-capacity on the vehicle side is 3 µF (between HV+ and HV- poles and chassis) and **the case of the ZEBRA® battery must be grounded** (connected to the GND Negative Supply of the BMI on pin1 of control connector)

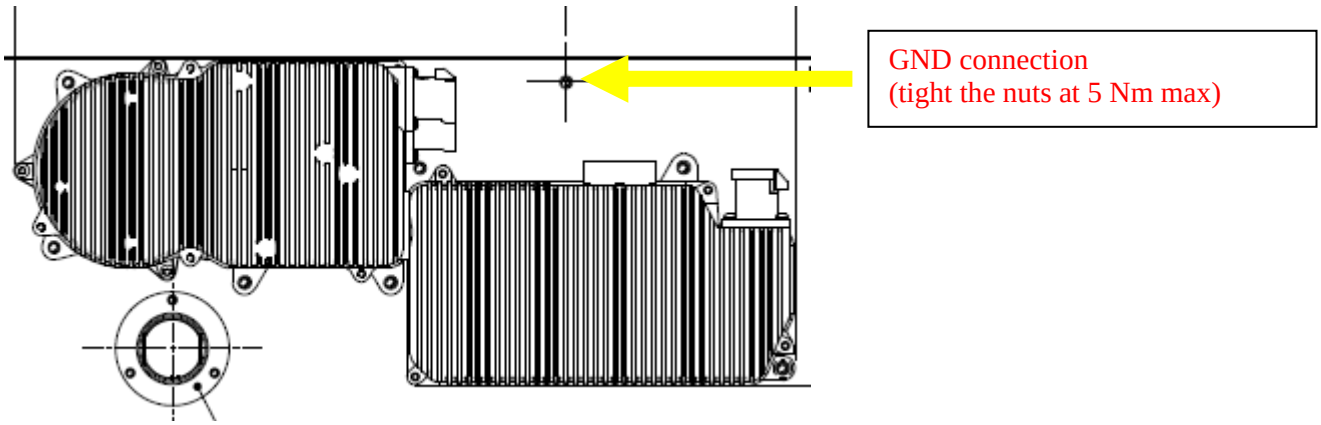


Figure 20: Example GND connection.

If a ZEBRA® battery shows an internal ISO error, the battery must be taken out of service and cooled down. It is necessary to coordinate with FZ SONICK the return of the battery for evaluation and repair. **Trying to operate a battery that showed an internal ISO error can be dangerous.**

Never delete, by using ZEBRA® monitor, an INTERNAL ISO ERROR detected by the BMI and not substitute a BMI that detects an internal iso error to continue using the battery (without FZ SONICK technician authorization).
A battery with an internal ISO error must be let cool down and removed from a vehicle as soon as possible.
The battery should be packed for transport when cold and if possible not charged.
Using a battery after the detection of an internal ISO error can result in dangerous situation.

8.5 GENERAL GUIDE LINE FOR BATTERY CHARACTERIZATION

The age measure and incorrect SOC of a battery can determine the failure of some cells.
As ZEBRA® cells typically fail to short circuit; a ZEBRA® battery can be operated also with failed cells, which results in a reduction of open circuit voltage, stored energy and available power.
The number of failed cells is detected by the BMI during the charge process.
The BMI will stop the operation of a battery if the number of failed cells reaches a maximum limit.
The limit for the usage of a battery depends on the requirement of the application.

The supply agreement and/or the warranty document specify the conditions for warranty claim.
In general it is necessary to measure the battery characteristics as open circuit voltage, battery capacity and battery peak power.

Open circuit voltage measurement

– The battery must first be fully charged with a normal charge; the BMI must detect the end of charge condition and set the SOC value to 100%
– The battery must be discharged to 6%....15% DOD
– The open circuit voltage is to be measured after a pause of 5 minutes (main switches open, DC-heater off).The actual OCV of the battery is displayed in the display or with ZEBRA® monitor
The open circuit voltage is measured automatically by the BMI during charge process to check the number of failed cells.

Internal resistance measurement

– The internal resistance R is obtained from (definition!):
R_{Batt} = (2.58V*number of cells in series - voltage) / I
R_{cell} =R_{Batt} * number of chains in parallel / number of cells in series.
The value depends on current, temperature and SOC

Battery capacity measurement

– The battery must be first fully charged with a normal charge; the BMI must detect the end of charge condition and set the SOC value to 100%
– The battery must be discharged at C/2 h-rate (constant current)
– The internal resistance is obtained from (definition!):
R_{Batt} = (2.58V*number of cells in series - voltage) / I
R_{cell} =R_{Batt} * number of chains in parallel / number of cells in series
– The battery will be considered discharged when the internal resistance rises to 35 mohm/cell
– The battery capacity will be evaluated considering the total amount of Amp hours discharged measured by the BMI

Battery peak power measurement

– The peak power must be measured discharging the battery to 2/3 OCV for ca. 30 seconds at 30% SOC at a battery temperature higher than 335℃ – 340℃

Thermal losses measurement

The measurement can be done by connecting the BMI to a 220VAC source and measuring the energy necessary to keep the battery at temperature for 24 hours.

– The battery is not to be charged, cooled or discharged for 24 h to allow a dynamic balance to be set
– The mean heating power is determined for further 24 h

– Ambient temperature 20 - 25 ℃ without forced air circulation in the battery compartment
– Battery internal temperature (set value) 270 ℃
– Still air
– No radiation effects

Isolation resistance measurement

In a single battery configuration, the BMI continuously monitors the isolation resistance between the terminals of the ZEBRA® battery and the chassis, in a multi battery configuration the test is enabled sequentially on all the BMIs by the MBS.

The following test instructions are to be complied with, if a measurement is to be made using another isolation resistance tester

– The battery is only to be measured in the warm state (operating temperature reached); the Battery Management System (BMI) is to be disconnected from the battery by an authorized person (removing the BMI prevents wrong measurements due to measuring the internal isolation of the BMI).
Please be sure that the isolation resistance tester can be safely used at the battery DC voltage
– A DC voltage of 500 V is applied with charging polarity
(i.e. + to + / - to chassis and - to - / + to chassis).
– The current is limited to 2 mA.
– The resulting resistance must be at least 10 MΩ. (>50 MΩ at delivery of a new battery)

Recommended isolation resistance tester:

Megger BM200 Avo International

A standard DDM Voltmeter could give some indications
The battery is only to be measured in the warm state
Please be sure that the Voltmeter can be safely used at the battery DC voltage

The measure of the DC voltage between the battery poles and the battery chassis should show a fast decreasing voltage, as for a small capacitor that will discharge on the input resistance of the DDM meter. The measure a fixed voltage is indicative of a loss of the electrical insulation.
The measure on both the battery poles + to -, + to chassis and - to chassis, together with the characteristic of the meter, could help to estimate the defect.
Please coordinate and report all the measurement to FZ Sonick.

For your safety, if a ZEBRA® battery shows an internal ISO error, the battery must be taken out of service and cooled down. It is necessary to coordinate with FZ Sonick the return of the battery for evaluation and repair. Trying to operate a battery that showed an internal ISO error can be dangerous.

9. SAFETY AND EMERGENCY ACTIVITY FOR ZEBRA® BATTERIES

9.1 SAFETY CONSIDERATIONS

Please always take in consideration that a battery can store a relative large amount of electrochemical energy and consider that if any energy is released or dissipated in an uncontrolled way can arise in possible danger.

A ZEBRA® battery is a high temperature battery; the normal operating temperature for the cells is in the range 260-360℃.

The battery enclosure has a good thermal insulation thanks to the vacuum between the inner and the external box, and in normal condition a ZEBRA® battery will dissipate from the battery case some thermal energy (60-190 W), depending on the battery type.

In fault conditions, for example in case of crash, penetration of objects or a major fault inside the battery, a ZEBRA® battery will not explode, but the battery could heat up internally and occasionally shows hot spots higher than 500 ℃ on the external case or in the air hoses.
Small flames have been occasionally observed in heavily damaged batteries with damaged box.

In case of fault press the emergency button, if available: the operation will remove the power supply of the main contactors of the BMI.

As ZEBRA® batteries are hermetically sealed; the contact with internal hazardous material is highly improbable.
During the normal operation, there is no generation of gases and there are no surfaces with high temperatures.
Please pay attention to the proper dissipation of the cooling air that can reach temperature higher than 350℃ when the fan is activated.

Depending on the model, a ZEBRA® battery can have a dangerous DC voltage: it is necessary to adopt all the precautions to avoid electrical shock and damage to the external case.

ZEBRA® battery safety is based on:

1. Electronic control unit: this stops charge and discharge if the conditions are not safe.
2. Mechanical protection: the stainless steel case does not allow access to the internal components.
3. Structure of the cell: the sealed mild steel case does not allow the release of active materials.
4. Chemistry of the cell: in case of breakage of the ceramic tube, the cell will react internally, producing safe, neutral products.

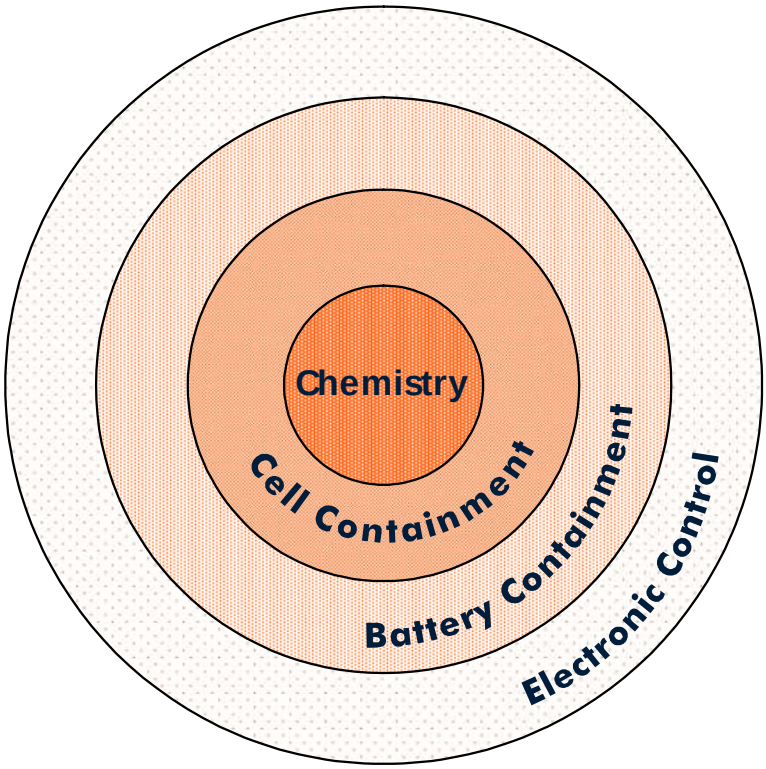


Figure 20: *ZEBRA® battery safety concept*

9.2 BATTERY FIRES

In fault conditions, for example in case of crash, penetration of objects or a major fault inside the battery, a ZEBRA® battery will not explode, but the battery could heat up internally and occasionally shows hot spots higher than 500 ℃ on the external case or in the air hoses.
Small flames have been occasionally observed in heavily damaged batteries with damaged box.
Sodium is highly reactive and flammable.

In case of fire, if possible, let the battery burn out and self extinguish. The cool down of a battery could require several hours.

If not possible, dry sand, soda ash or extinguishing agents for burning metals are recommended.
Please refer to the enclosed safety data sheet.

9.3 DANGEROUS MATERIALS

Metallic Sodium is highly reactive and flammable; it reacts with water releasing Hydrogen. Exposure may cause severe caustic burns to the skin and eyes.
The Sodium aluminium tetrachloride is corrosive and can react heavily with water.
ZEBRA® batteries with a damaged external case must be managed with gloves and respiratory protection: the internal components can maintain high temperature for a long period of time, dangerous voltages can be present and leakage of corrosive materials can occur.

9.4 RELEASE OF GAS IN CASE OF FAULT

In case of faults it is possible that high temperatures inside the battery could result in the opening of some cells, with a possible release of gas, mainly HCl.

9.5 CONCLUSIVE NOTES

ZEBRA® batteries have been tested under crash, penetration tests, water immersion and fire situations. In these cases no dangerous situations have occurred.
ZEBRA® batteries have also been tested with an external electrical short circuit and even in this case no dangerous situations have occurred. Detailed safety test reports are available.

Figure 21: Crash test at 50Km/h

9.6 IMPORTANT SAFEGUARDS

All safety instructions must be read carefully and must be fully understood, before attempting to use a ZEBRA® Battery. Contact FZ SONICK for any question.

The safety instructions have been classified according to the seriousness of the risk, as follow:

Danger: "Danger"indicates the existence of a hazard that could result in death or serious bodily injury, if the safety instruction is not observed.

Warning: "Warning"indicates the existence of a hazard that could result in bodily injury, if the safety instruction is not observed.

Caution: "Caution"indicates the existence of a hazard that could result in property damage, if the safety instruction is not observed.

9.7 DANGER

Danger: Never disassemble the battery pack, as that could cause expose to high voltage or to high temperature and leakage of molten salts which my be corrosive

Danger: Never short-circuit the main battery pack by either accidentally or intentionally bringing the terminals in contact with another metal object. This could cause personal injury or a fire, and could also damage the battery pack.

Danger: Never hammer a nail into the battery pack. Never hit a hammer on the battery pack.

Danger: The battery must be operated with the dedicated battery controller. A battery without the battery controller could cause the exposure to dangerous voltages.

9.8 WARNING

Warning: If you ever detect excessive heat, discoloration of the battery surface, deformation or anything unusual of the battery pack, do not use it, remove it and contact FZ SONICK.

Warning: If you ever detect a *plopping* noise from the battery pack, remove it as soon as possible because of a risk of overheating.

Warning: Never delete, by using ZEBRA® monitor, an INTERNAL ISO ERROR detected by the BMI and not substitute a BMI that detected an internal iso error to continue to operate the battery (without FZ SONICK technician authorization). A battery with an internal ISO error must be let cool down and removed from a vehicle. The battery should be packed for transport when cold and if possible not charged. Using a battery after the detection of an internal ISO error can result in dangerous situation.

Warning: Never dispose used battery packs with other ordinary solid wastes. The battery must be returned to FZ SONICK or to a collection point determined by FZ SONICK for a correct recycling. Please contact FZ SONICK for details. If the battery controller is removed, protect the metal terminals with insulating tape, in order to prevent accidental short-circuiting or contact with potential dangerous voltages.

9.9 CAUTION

Caution: Never throw the battery pack into a fire.

Caution: Always confirm that the battery pack is compatible with your system before installing the battery pack.

Caution: Never expose the terminals of the battery pack to any other metal object. Whenever transporting it, pack the battery in the proper package.

Caution: The battery must be operated by the dedicated battery controller. Never try to charge or discharge a ZEBRA® battery without its controller. Any maintenance operation or measure on the battery pack must be performed only by trained personal.

Caution: A battery with an open or a heavily damaged case should be stored in open air and protected against water.
Battery with a heavily damaged external case should be wrapped with polyethylene sheets before of the packing, to avoid the risk of release of material or smell.

Caution: If any part of the human body may accidentally contact with a leakage from the battery pack, immediately wash with use large amounts of water. Remove any liquid that has contacted your clothes by washing them immediately with water.

10. MATERIAL SAFETY DATA SHEET

MATERIAL SAFETY DATA SHEET

According to European Regulation n. 1907/2006

Issuing date: 12.04.10 ***Reviewed date on: 12.04.10***

Trade name: ZEBRA® Battery

1. Identification of substance:

Identification: Batteries containing sodium
Trade name: ZEBRA Battery
Nickel / Sodium Chloride Traction Battery
Utility: Electric pile
Manufacturer: FZ Sonick SA
Via Laveggio 15
6855 Stabio (TI) Tel.: 0041-(0)91-6415311
Switzerland Fax- 0049-(0)91-6415333

Emergency contact: 24 hours emergency:
North America: Europe:
Contact-. CHEMTREC TUIS Emergency telephone
001 (800) 424-9300 0049 (621) 6043333

e-mail of the technician: cristiano.martinato@fzsonick.com

2. Hazards identification

The Zebra batteries are hermetically sealed and vacuum packed.
The battery under standard conditions of use is not dangerous for the user.
Severe mechanical damages of the battery or a short circuit can cause the failure of the battery with the emission of potentially corrosive and/or toxic substances for inhalation, ingestion and contact, possible generation of flammable gas and eventually fire.

3. Composition/information on ingredients

Potentially dangerous Constituents	**% by Weight**	**CAS**	**EINECS**	**TLV (mg/m^3)**	**Symbols**	**R Sentence**
Nickel (as metallic Ni)	9*-13	7440-02-0	231-111-4	1.5	Xn	R40 R43
Sodium (Na)	2-5*	7440-23-5	231-132-9	Not defined	F, C	R14/15 R34
Nickel Chloride ($NiCl_2$)	5-13*	7718-54-9	231-743-0	0.05	T, N	R49-38-61-68-23/25-42/43-48/23-50/53
Sodium fluoride	< 0,5	7681-49-4	231-667-8	2.5	T	R25-32-36/38

Aluminium	< 0,1	7429-90-5	231-072-3	10	F	R10 R15
Nickel sulphide (as Ni_3S_2)	< 0,7**	12035-72-2	234-829-6	0.1 (as Ni)	T	R49 R43 R48/23 R68 R50/53
Sodium Iodide	< 0,1	7681-82-5	231-679-3	10 3 inhalable dust	Xi	R36/37/38 R42/43
Sodium Aluminium Chloride ($NaAlCl_4$)	13	7784-16-9	232-050-6	2 (as Al) 7,5 (C) as HCl (decomposition)	C	R14 R34
Ceramic fibres	< 0,5	142844-00-6	266-046-0	0,2 ff/cm^3	T	R49

*% present during charged state
** theoretical maximum % generated during battery use.

4. First aid measures

General information:
Go immediately away from the danger area

- After inhalation:
Seek medical treatment.

- After skin contact:
Drench affected skin with plenty of water, then wash with soap and water and seek medical treatment.

- After eye contact:
Immediately wash out with plenty of water and continuing the treatment until medical assistance is provided.

5. Fire-fighting measures

Keep public away from danger area. Keep upwind and use selfbreathing apparatus.
Notify police and fire brigade as soon as possible.

NOT USE water to extinguishing fire or washing spilled chemical substances from the battery.
NO smoking.

Extinguishers allowed:
Extinguisher Class D,
Powder or dry sand,
Sodium carbonate,

Extinguishers forbidden:
Water
Carbon Dioxide, CO_2 extinguishers
Extinguishing halogen agents

Personal protection:
Selfbreathing apparatus
Protective clothing

6. Accidental release measures

The spilling of chemical substances contained inside the battery can happen only in case of a battery damage causing the breaking of all the multiple cases present in the battery.

Caution measure for people:
Wear protective clothing: Selfbreathing apparatus or protective mask with filter against acid as and powder (ABEKP3)
Goggles or face shield
Protective gloves.

Keep away the not equipped people

Intervention equipment
Shovel
Broom
Vacuum cleaner with high efficiency filters
Sand or other absorbent.

Actions to do:
Any action has to be done only if there are no risk for people.
PROTECT against water,
CONTAIN or COVER spilled substance with dry sand or dry earth
Collect powders and adsorbed liquids avoiding dust clouds and convey in sealed plastic box to dispose as potentially toxic material

NEVER USE WATER

7. Handling and storage

HANDLING
- Instruction for a safety handling:
  Handling with care and caution, avoid always that the items come in contact with water
  Terminals should not be put in short circuit
  Do not punch or damage the battery case.

STORAGE
- Storage place requirements:
Keep in dry area, away from heating sources and with temperature between – 40 and +50 ℃

- Packaging:
  The batteries can be shipped unpacked or in wooden crates.

- Storage class:
  not defined

8. Exposure controls/personal protection

Control of the professional use:

In standard conditions of use, the battery does not need any individual protection measure for the exposure to chemical agents.

9. Physical and chemical properties

ZEBRA Battery

Solid object composed by a metal casing completely closed, which completely includes the chemical substances potentially dangerous.

Shape: cubical
Color: metallic
Smell: no one
Using temperature Range: -40 □ +50 ℃
Energy density: 100 □ 125 Wh/kg
Instantaneous power: 150 □ 180 W/kg

10. Stability and reactivity

The battery is stable under standard conditions of use.

11. Toxicological information

The intact battery does not permit any contact between the chemical products and the external environment.

12. Ecological information

The intact battery does not permit any contact between the chemical products and the external environment.
For any qualitative information about the chemical products see point 3.

13. Disposal consideration

Do not dispose together with household waste materials
Do not burn

Return to the producer company FZ Sonick SA in Switzerland for the dispose and the recycling.

14. Transport information

UN number:	**3292**	"Batteries or cells containing sodium"
Class:	**4.3**	"Water reactive substances" In contact with water produces flammable gas
Packing group:	II	Materials of medium danger
Packing instructions:	433	for air shipment
	P408	for road shipment
	IMDG	for sea shipment
Kemler nr:	not identified	
ERG:	4W	
Particular caution:	Protect from humidity and water	
	Handle with care	
	Do not overlap	

Transport classification conforming to the following specific regulations:
for road or rail transport ADR/RID (SDR)
for air transport IATA
for sea transport IMDG.

For road transport, ADR dispositions only if the gross weight for each transport unit is > 333 kg (Category 2, tabel 1.1.3.6.3 ADR 2007).
During air transport: use only cargo flight

-Conforming to the regulations the batteries or cells are transported:
cold with the sodium at the solid state
labeled and packed conforming to international rules (ADR, IATA, IMDG)
the batteries should be transported not charged (state of charge 0%).

- Batteries and cells must consist of hermetically sealed metal casings which fully enclose the dangerous goods and which are so constructed and closed as to prevent the release of the dangerous goods under normal conditions of transport.

15. Regulatory information

The transport of sodium batteries is regularized by the Organization of United Nations.

Regarding the regulations "**A.D.R. Agreement and complementary rules about dangerous goods**" – Number 7 – 2002, Chapter 1.1 "Application field and applicability" Tab. 1.1.3.6.3, Sodium batteries could be or not be under ADR regulations. If the gross weight for transport unit is < 333 kg (Category 2), the transport should not be declared as ADR.

Regarding the **IATA** regulations, International Air Transport Association – 42nd Edition – 2001 – List of Dangerous Goods, Batteries containing sodium Do not have limit for the sodium contents.

Regarding the instructions **1999/45/CE and 2001/60/CE** concerning the classification, packaging and labeling of dangerous compounds, it's applied the Art.12 "Exemption from labeling and packaging requirements", since the sodium batteries, as they are put on the market, do not present any risks of chemical-physical nature or any risks for health or for environment.

16. Other information

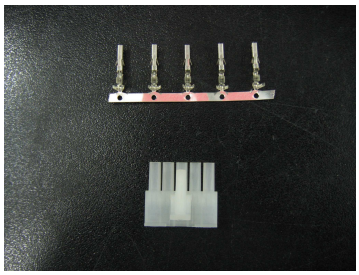
- All data are indicating on our present knowledge basis.

APPENDIX A: Cell's operation parameters table

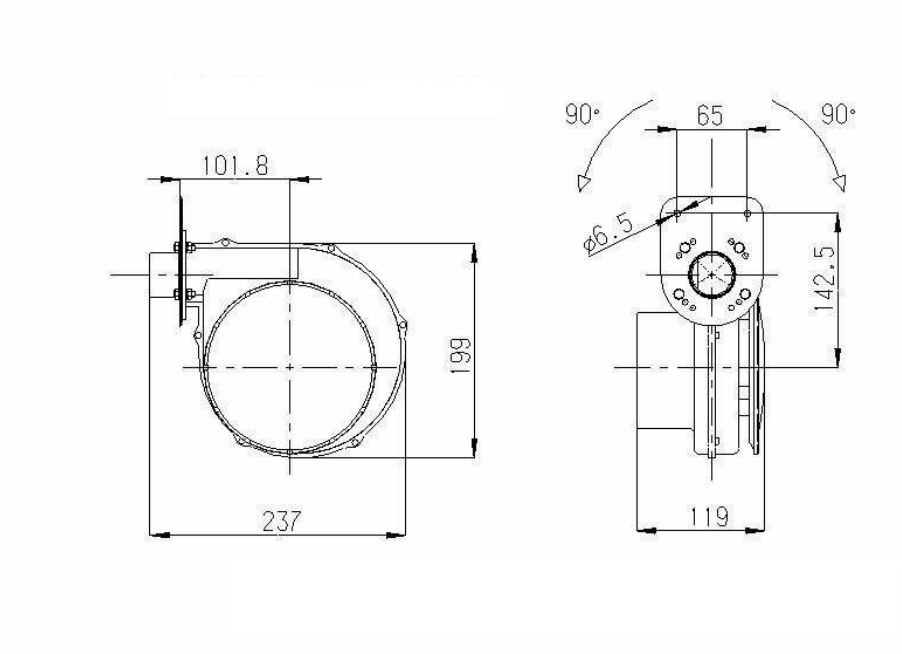
Cell type:	**ML3C**	**ML3P**	**ML3X-38**	**ML3X-32**	**ML8P**	**ML/8x**
End of charge resistance	180mohm	180mohm	180mohm	180mohm	180mohm	180mohm
End of charge current min	240mA	240mA	240mA	240mA	240mA	240mA
Current short	270A	270A	270A	270A	115A	115A
Current max fastcharge	30A	0A	0A	0A	0A	0A
Current max fastcharge (red)	2A	0A	0A	0A	0A	0A
Current max charge (normal ch)	**10A**	**6A**	**10A**	**10A**	**4A**	**4A**
Current max charge (red)	2A	2A	2A	2A	1A	1A
Current max discharge	**117A**	**117A**	**117A**	**117A**	**70A**	**70A**
Current max discharge (red)	20A	20A	20A	20A	10A	10A
Current max regen braking	**30 or 60A**	**30 or 60A**	**30 or 60A**	**30 or 60A**	**25A**	**25A**
Current max regen braking (red)	10A	10A	10A	10A	8A	8A
Voltage short	1,3V	1,3V	1,3V	1,3V	1,3V	1,3V
Voltage max fastcharge	2.70V	N.A	N.A	N.A	N.A	N.A
Voltage max generator (HEV, up to 70% SOC)	**2.7V**	**2.67V**	**2.67V**	**2.7V**	**2.67V**	**2.67V**
Voltage max charge (normal ch)	**2.67V**	**2.67V**	**2.67V**	**2.67V**	**2.67V**	**2.67V**
Voltage min discharge	**1,7V**	**1,7V**	**1,7V**	**1,7V**	**1,7V**	**1,7V**
Voltage max regen braking (EV)	**2,9 or 3,1V**	**2,9 or 3,1V**	**2,9 or 3,1V**	**2,9 or 3,1V**	**2,9 or 3,1V**	**2,9 or 3,1V**
Voltage max regen braking (HEV)	**2,9V**	**2,9V**	**2,9V**	**2,9V**	**2,9V**	**2,9V**
Nameplate capacity	32Ah	38Ah	38Ah	32Ah	25Ah	25Ah

Table 2: Cell's operation parameters table

APPENDIX B: ZEBRA® fan cooler

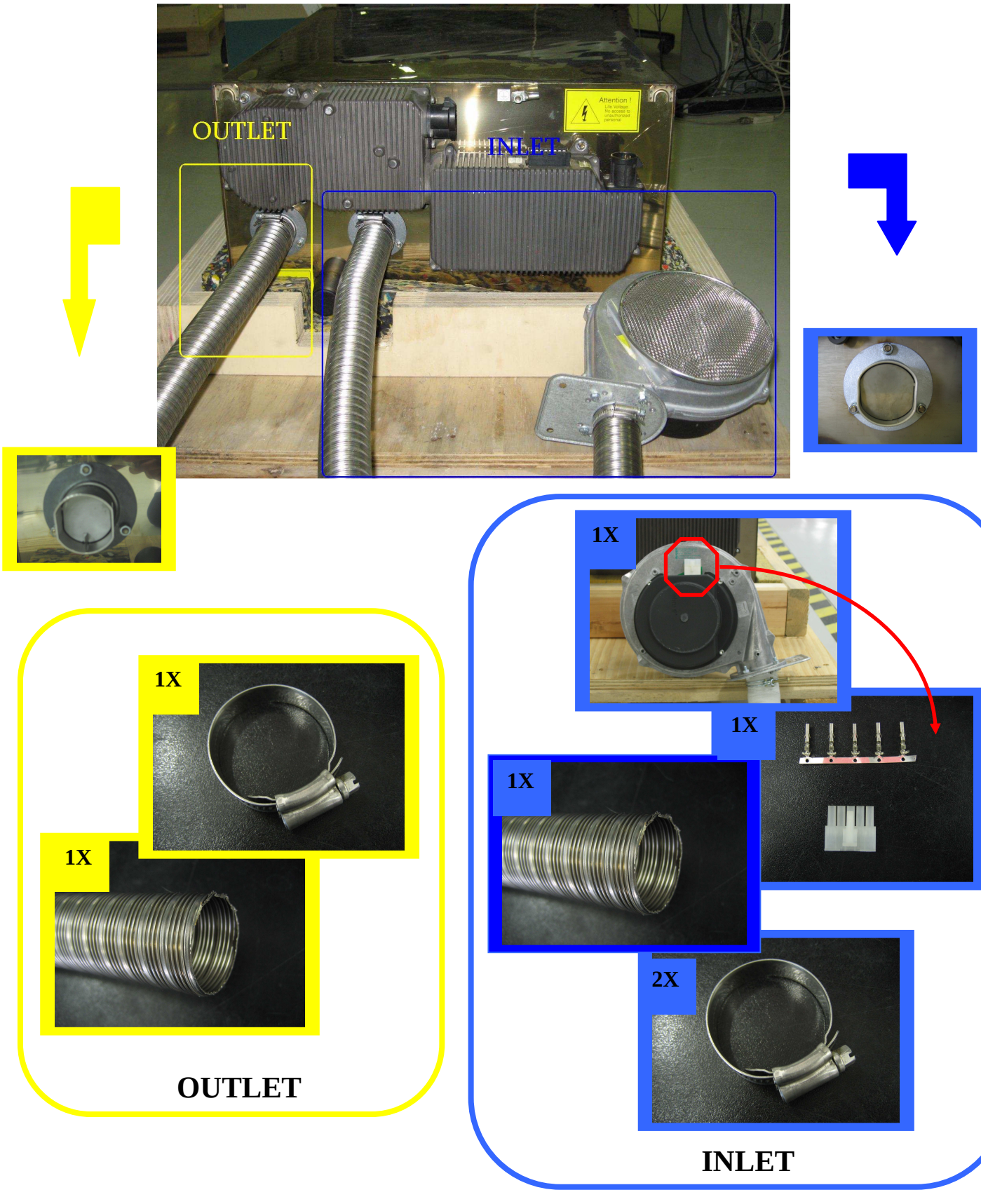
	**Fan Cooler set** Type Cooling Fan Set 12V Id.Nr. 30X00066 Type Cooling Fan Set 24V Id.Nr. 30X00067
	**Fan Cooler connector 12V/24V** Id.Nr. 30X00074

Dimension : 237 x 199 x 119 mm, weight :1.7 Kg



ZEBRA® battery hose (30X00080)	flexible inox metal hose, internal diameter=40 mm for both air inlet and outlet

APPENDIX C: Hose set mounting



APPENDIX D: Thermal management on old battery configuration

Heating set point

The heating set point depends on the operating mode and on the cell type:

DISCHARGE and PARK mode	270 ℃	ML3C and ML3P TYPE cells
CHARGE mode	270 ℃	ML3C TYPE cells
CHARGE mode	290 ℃	ML3P TYPE cells

After the end of charge the temperature set point will be 270 ℃

In special applications the heating set point can be different, for example for small batteries with P type cell the typical temperature set point is 297.5 ℃ for all the operation modes.
The AC heater keeps the temperature to the heating set point with a hysteresis of +/- 3.5 ℃.
The DC heater keeps the temperature to the heating set point with a hysteresis of +/- 2.5 ℃.

Temperature Operating Range

DISCHARGE mode:
The discharge is allowed for temperatures between 260℃ and 360℃ for both C and P type cells.
A power reduction algorithm is applied if the temperature is higher than 340℃: the reduction applies to current max charge and current max discharge and includes full reduction for temperature higher than 350℃ and a linear reduction between 340℃ and 350℃.

CHARGE mode:
Upper limit
for both C and P type cells the charge, and fast-charge for C type**,** is NOT allowed if the temperature is higher than indicated in the **upper red** line on the graph illustrated below. Fast-charge is not allowed if the gradient of the temperature is higher than 5.5℃/min.
Lower limit
For C type cells, the normal charge, including fast-charge is NOT allowed if the temperature is lower than 260C
For P type cells: the normal charge, is NOT allowed if the temperature is lower than the linear limit between 270℃ and 285℃.The first char ge after a thermal cycle, is allowed at a minimum temperature of 285℃.
The same applies for the HighTemperatureSetpoint configuration that can be applied for some specific applications.

The BMI will consider a thermal cycle if the battery temperature is increased from 160℃ to 260℃.
The reduction of charging current for balancing is not applied for P type cells.

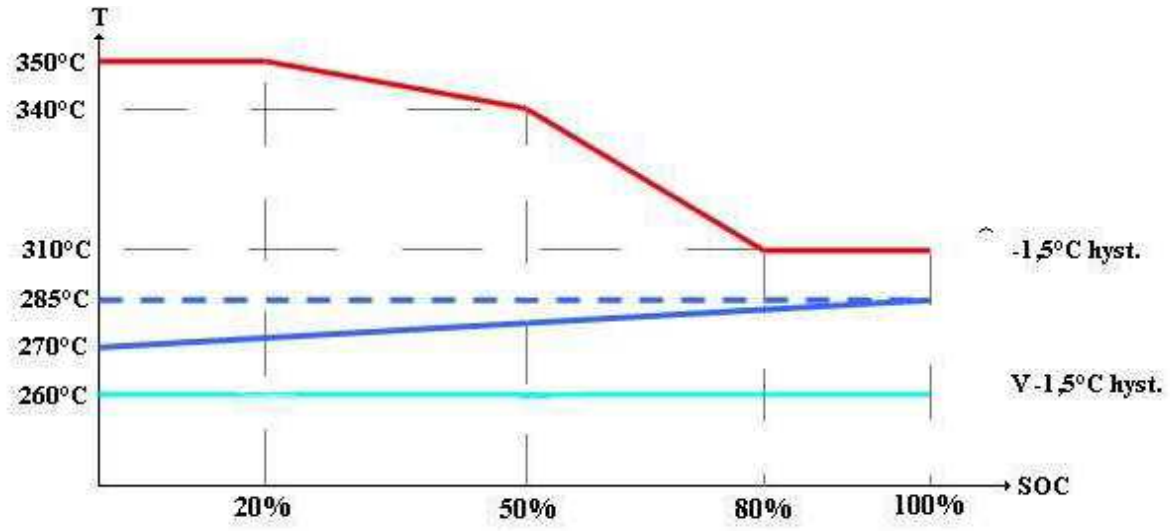


Figure 22: Upper and lower limits for charge

Battery Cooling

Depending on the model, a ZEBRA® battery can be air cooled. Each battery requires a dedicated cooler, supplied by FZ SONICK (see Appendix B). The fan is automatically activated by the BMI battery controller when necessary.

CHARGE mode: The fan is active if the temperature is above the upper blue line:
340 ℃ - 302.5 ℃

FASTCHARGE mode: The fan is active if the temperature is above the lower red line:
320 ℃ - 302.5 ℃

PARK mode: By default the fan is off to avoid discharge of the vehicle 12/24V battery.
In special applications the cooler could be operational.

EMERGENCY mode: The fan is off if the BMI sets an emergency error, the fan test can then be activated.

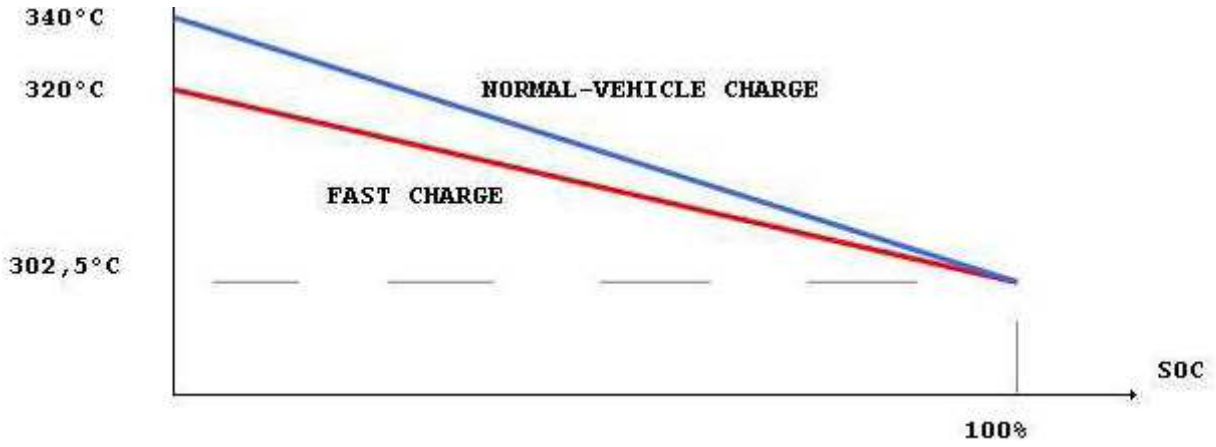


Figure 23: Fan operation in normal charge and fast charge.

DISCHARGE mode:

The fan is active if the temperature is above a line (depending on temperature gradient) contained between the two lines. (±2, 5℃ hysteresi s).
Some limits could be adjusted by the user via diagnostic software. In special application the cooling set point can be different.

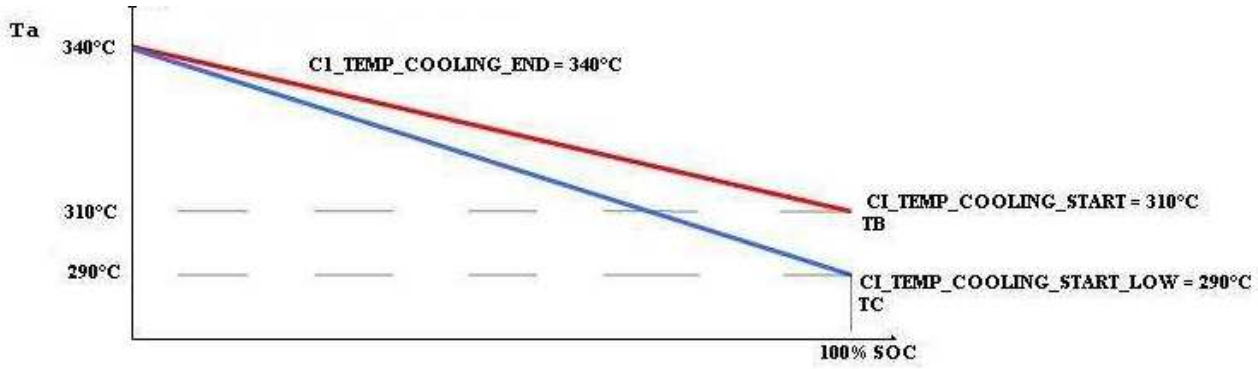
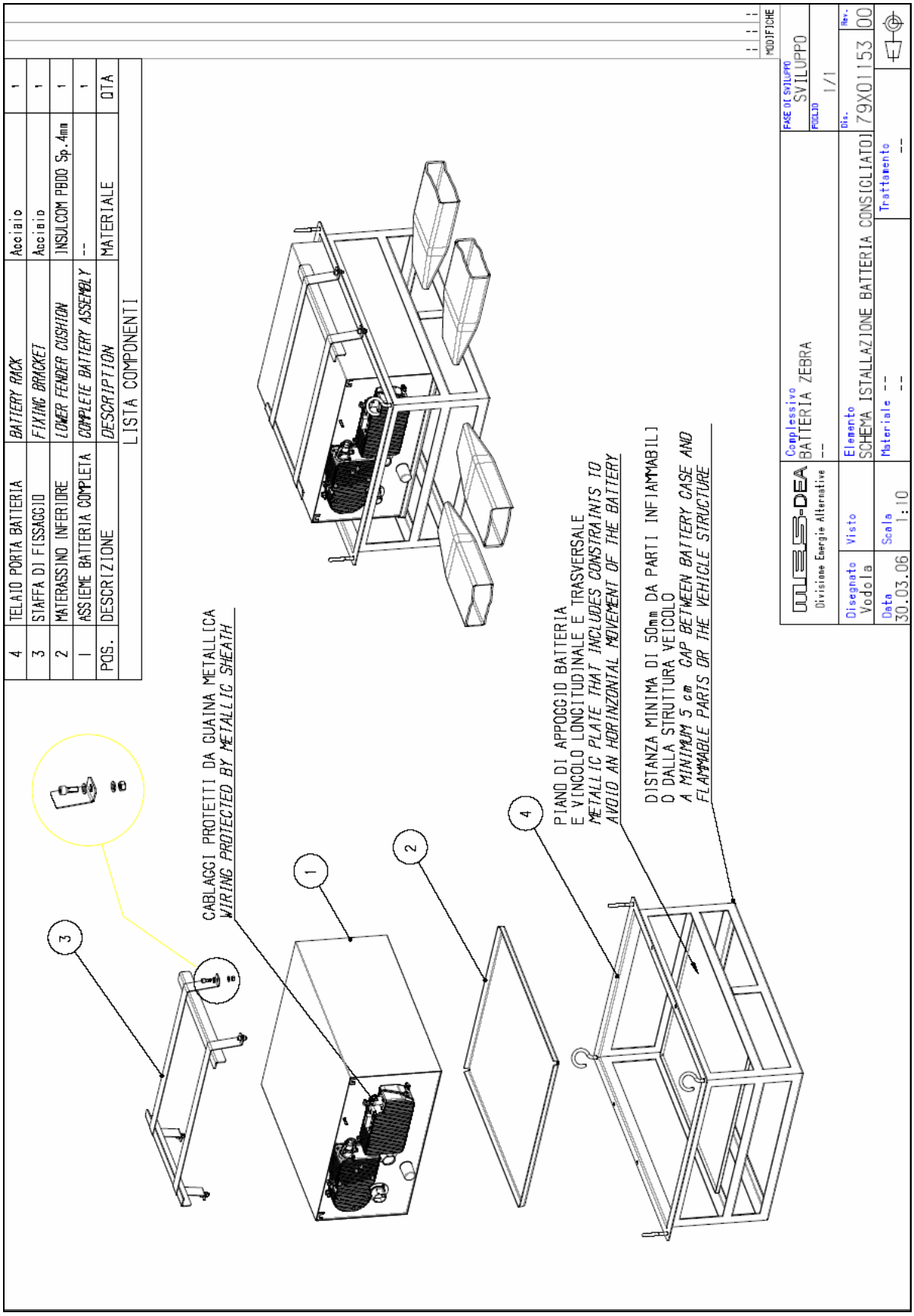


Figure 24: Fan operation in discharge model.

APPENDIX E: Mounting example: Battery rack, typical for bus application



APPENDIX F: Mounting example: Battery containment box, typical for car application