NEWBORN - NExt generation high poWer fuel cells for airBORNe applications

WP08 – Power line

D8.21 Design report on the battery management system

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REVISION HISTORY

Revision	Date	Revision summary
0	2024-11-29	Initial issue

Table 1: Revision history

INTELLECTUAL PROPERTY

Section/Chapter/Item	Owning Entity	Nature of IP	Comments
Overall Slave BMS architecture.	PVS	Exclusive Background	
Tailoring the BMS for the NEWBORN ground demonstrator and specific adaptations made to accommodate requirements for the NEWBORN project	PVS	Exclusive Foreground	

Table 2: Intellectual property

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This document is a deliverable in the form of a report to present a comprehensive overview of the battery management system.

1.1 Objective

The objective of task T8.9 ‘Battery management system (electronics and SW)’ is to upgrade current State of the Art Battery Management System (BMS) to control the 350 kW, 800V, 100 kWh battery system developed in task T8.7 and described in deliverable ‘NE-WP08-SE-NO-DEL-800018-00’.This document is part of the outcome of task T8.9 and describes how the BMS is upgraded to control the upgraded battery pack.

The formal description of the deliverable according to Grant Agreement is “Document describing the battery management system design and its validation summary.”

1.2 Scope

This scope of this document includes a description of the BMS topology for the NEWBORN battery system, focusing on the master BMS and controller BMS and their interaction with systems that work alongside the BMS in the battery system, including the Bus-tie DC/DC converter and Battery Thermal Management System, and externally to the Power Management Control Unit.

Some of the activities performed for task T8.9 are also included in other deliverables. Where necessary, these other deliverables will be referenced, and a short summary is provided.

Excluded are details specifically about the slave BMS other than a general description about its tasks, as this is mostly based on the BMS utilised in the Pipistrel Velis Electro and has not been developed under the NEWBORN project. Also, excluded are detailed drawings of components, confidential schematics, and names of suppliers, parts or other components that could be used to determine the suppliers of materials, parts or other components of the BMS or battery pack.

2 REFERENCES

ID	Reference	Title	Revision
[1]	NS-WP01-SE-NO-DEL-100007-00	D1.7 Set of subsystem requirements documents	00
[2]	NS-WP01-SE-NO-DEL-100008-00	D1.8 System-level interface control document summary	00
[3]	NC-WP06-IN-NO-DEL-600601-00	D6.1 Energy management concept analysis report	00
[4]	NE-WP08-SE-NO-DEL-800010-02	D8.1 Electrical architecture & topology report	02
[5]	NE-WP08-SE-NO-DEL-800018	D8.18 Battery prototype design description document	00
[6]	NE-WP08-SE-NO-DEL-812023-00	D8.23 Harmonized wiring interfaces description	00
[7]	NE-WP08-SE-NO-DEL-812024-00	D8.24 Overall bonding concept	00
[8]	NE-WP08-SE-NO-DEL-800025	D8.25 Design guideline for high voltage in non-pressurized environment	Draft

GLOSSARY

BMS	Battery Management System (general)
BS	Battery System
BTDC	Bus-tie DCDC converter
BTMS	Battery Thermal Management System
CAN	Controller Area Network
CBMS	Controller BMS
FC	Fuel cell
GA	Grant Agreement
GSE	Ground Support Equipment
HV	High Voltage
MBMS	Master BMS
NEWBORN	NExt generation high poWer fuel cells for airBORNe applications
PMCU	Power Management Control Unit
SBMS	Slave BMS
SM	Safety Monitor
SoC	State of Charge
SoH	State of Health
SoP	State of Power; the maximum amount of power available
SoX	State of X, referring to health (SoH), charge (SoC), Power (SoP)
SSPC	Solid State Power Controller
SW	Software
TR	Thermal Runaway (an uncontrolled increase in temperature resulting in a hazardous situation)
WP	Work Package

3 BATTERY PACK CONFIGURATION

For the understanding of the different BMS levels and how the BMS is integrated in the battery pack, it's important to understand the configuration of the battery pack as described in deliverable [5]. Since this deliverable is marked sensitive – in contrast to this deliverable which is public – a summary of the explanation of the configuration design of the battery pack is provided below based on deliverable [5].

The NEWBORN battery system consists of two battery packs and additional components like the BTDC, BTMS, and Controller BMS, as shown in the overview of the connections in Figure 1.

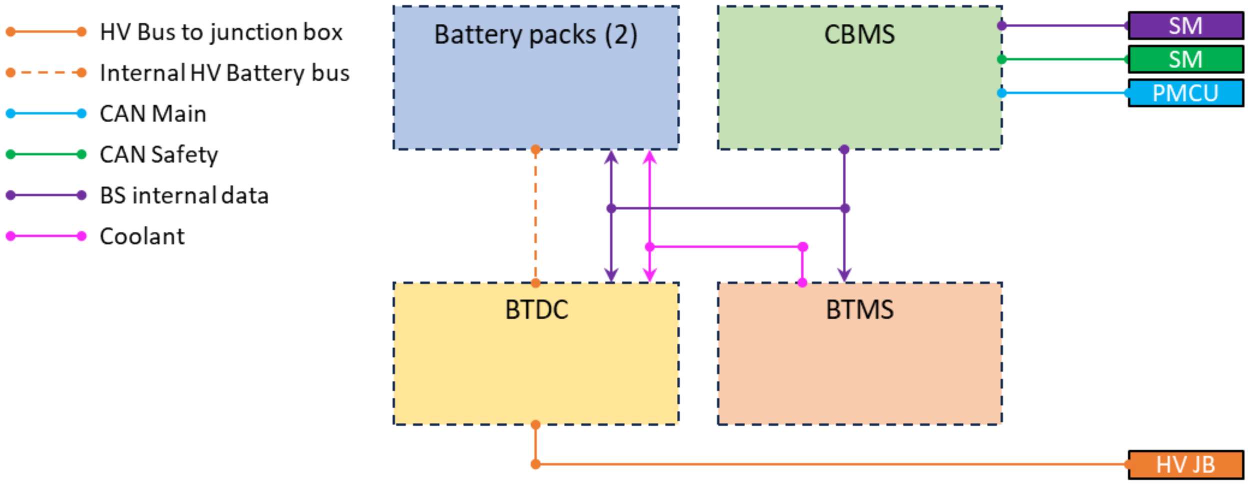

Figure 1: Overview of main connections between components

From the battery packs there is an internal HV battery bus going to the BTDC from where it is connected to the HV bus going to the junction box (traction network). The CBMS sets the droop control parameters of the BTDC based on the status of the battery pack, which is all communicated via the internal CAN network. In addition, the CBMS communicates via CAN and internal A/D lines with the BTMS for control of the thermal management of BTDC and the battery packs.

In Figure 2 is shown an overview of the battery pack topology. Each of the two battery packs consists of three battery strings connected in parallel, resulting in a total of six battery strings for the entire BS. There is also a crosslink between the two battery packs, meaning that they are in parallel connected and thus effectively the two battery packs could be considered as a single battery pack from the BMS point of view, as a difference in voltage/SoH is levelled out via the crosslink to ensure equal voltage/SoH between the two battery packs.

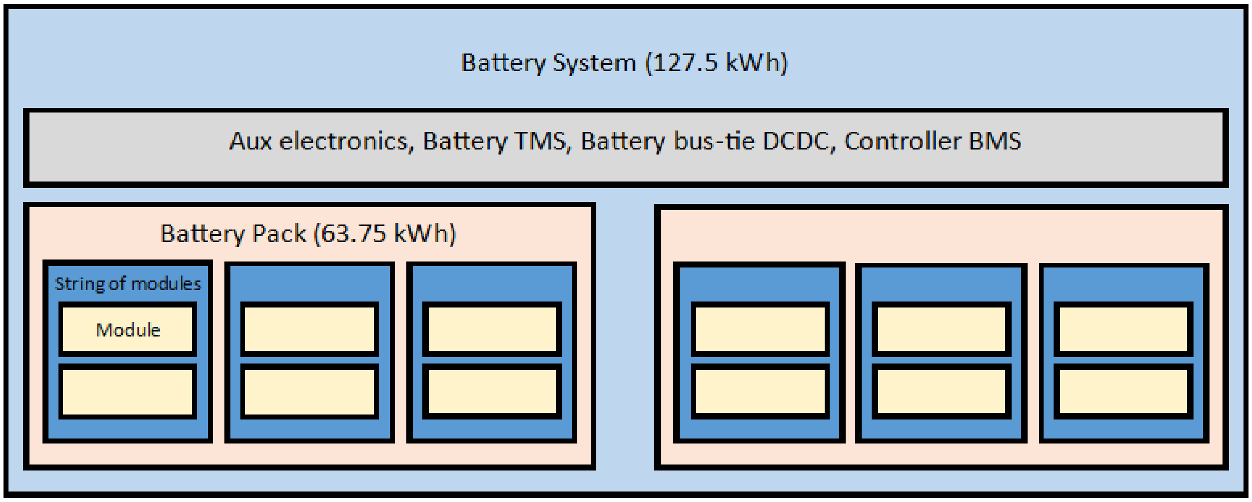

Figure 2: Overview of battery system terminology from [5]

Each battery string consists of two 400V battery modules in series, achieving the required 800V on string and pack level. All battery strings are connected to the battery bus, with the BTDC boosting the battery bus voltage to the HV bus.

4 BMS DESIGN

The BMS for the NEWBORN ground demonstrator has a hierarchy consisting of three levels:

- Lowest level: Slave BMS (SBMS)
- Middle level: Master BMS (MBMS)
- Top level: Controller BMS (CBMS)

The SBMS design is comparable to the EASA certified Pipistrel VE BMS, considering necessary changes. That is why the Section 4.1. will provide a general description of the functionality of the SBMS. Changes to adapt the VE BMS for the NEWBORN project includes modifications to enable balancing of up to 192 cells to enable 800V and reordering of the layout of the PCB to fit the NEWBORN battery modules.

The MBMS connects and synchronises two SBMSs to ensure that not only the cells are balanced within each module, but also that both modules in series are balanced between each other. Other tasks of the MBMS are to determine the SoX parameters based on the SBMSs from the two modules, and forwards information between CBMS and SBMS.

The CBMS is the highest level of control within the BS. Based on the status of the battery packs and required power it controls the BTDC. In addition, it controls the BTMS as well to ensure the BTDC and battery packs operate within their operating range.

4.1 Slave BMS summary

The SBMS is a critical component in the architecture of modern battery systems, including for battery systems used in (Hybrid-) Electric aircraft. The SBMS operates under the direction of a MBMS, which it communicates with to coordinate tasks and ensure the overall health and efficiency of the battery pack. The primary function of a SBMS is cell balancing, which involves equalizing the charge across all cells in the module to maximise capacity and prolong the life of the cells.

In addition to cell balancing, the SBMS is responsible for measuring critical parameters such as the cell voltage levels, the charging and discharging current, and the temperature inside the battery modules. These measurements are vital for SoX calculations, and to make decisions regarding charging and discharging of the battery pack. The SBMS also operates the contactors for connecting and disconnecting the battery to the HV battery bus, based on commands from the MBMS, CBMS or if an anomaly detected by the SBMS itself. Control of the contactors includes the pre-charge contactor, which prevents a current spike on the battery due to a sudden load to charge all capacitors in the system, potentially damaging components.

Safety is paramount in the design of a SBMS, and it includes a fuse to protect against overcurrent conditions. The SBMS continuously monitors for fault conditions, such as overvoltage, undervoltage, overtemperature, or communication failures, and will respond accordingly. This ensures that the battery operates within its safe operating area, preventing conditions that could lead to reduced performance or safety hazards.

The decentralized nature of this system, with multiple SBMS units operating autonomously yet in communication with the MBMS and CBMS, allows for a scalable and modular design. This simplifies the system and allows easy scaling up or down the number of strings based on the aircraft requirements and improves maintainability and replacement of (part of) the battery system.

4.2 Master BMS

Master BMS takes middle place in the hierarchy of managing batteries and communicates with SBMSs and CBMS. The MBMS is in charge of forwarding data between CBMS and SBMS and to ensure the two SBMS modules are balanced by sharing SoC and voltage data between them. The MBMS shares all SoX data with the CBMS.

Data shared between SBMS and MBMS is used for determining SoX parameters; SoC, SoH, and SoP.

- SoC data is collected by both SBMS and MBMS (on string level) and then used to determine the SoC for the entire string.
- SoH is determined by SBMS on module level. The MBMS merges SoH data of two modules together to determine the SoH on string level.
- SoP is based on SoC in combination with other parameters from the battery module, collected by the SBMS. This includes both peak power and long-term power.

In Figure 3 is shown an example how balancing between the modules is done.

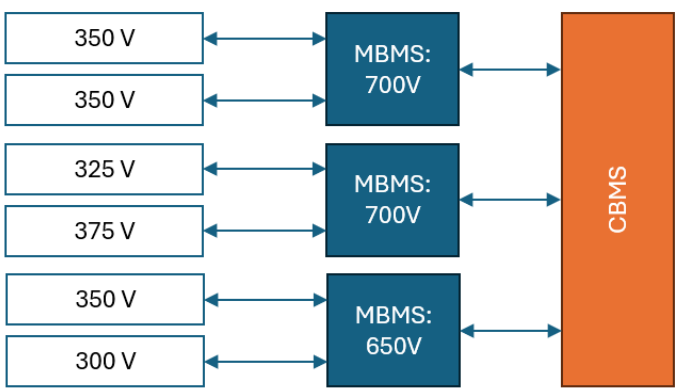

Figure 3: Example of balancing by MBMS

In this example, two strings are at the state of 700V and one string is at 650V. During startup and charging of the system, all MBMSs share their string voltage with the CBMS. Next, the string with the lowest voltage will be connected to the battery bus first, so it can be charged to the next lowest voltage, 700V in this example.

However, charging to 800V on string level would pose a risk as not all modules have the same voltage, risking overvoltage on some modules. Hence, to balance two modules within a single string the MBMS communicates with the two SBMSs it's connected to. The MBMS oversees voltage levels and SoC on string level and controls the two SBMSs to ensure equal voltage levels between the two modules across the entire string.

Once all strings are connected in parallel to each other and all modules are balanced, the full voltage/SoC operating window can be used for charging and discharging.

4.3 Controller BMS

The Controller BMS, or CBMS, plays a central role within the BS control. Based on data retrieved from the MBMSs, the CBMS controls the BTDC to regulate charging and discharging of the battery pack. It also controls the BTMS to ensure both battery packs and BTDC operate within their specified operational range.

In addition to the top-level control of the BS, the CBMS is also responsible for the communication with the PMCU via the CAN main line, and to provide status updates of the BS via the CAN safety line. Data transfer is done by CAN and optional discrete signals, to provide redundancy and reliability for communication, as stated in "Interface isolation and grounding, Design guidelines".

In Figure 4 is shown the configuration of the battery system, including battery modules, CBMS, BTDC, and BTMS. Specific details regarding redundancy of aviation applications have been simplified to a single CAN network. When this system would be integrated in an aircraft like the Miniliner, additional effort will be dedicated to ensuring redundancy and preventing common failure modes.

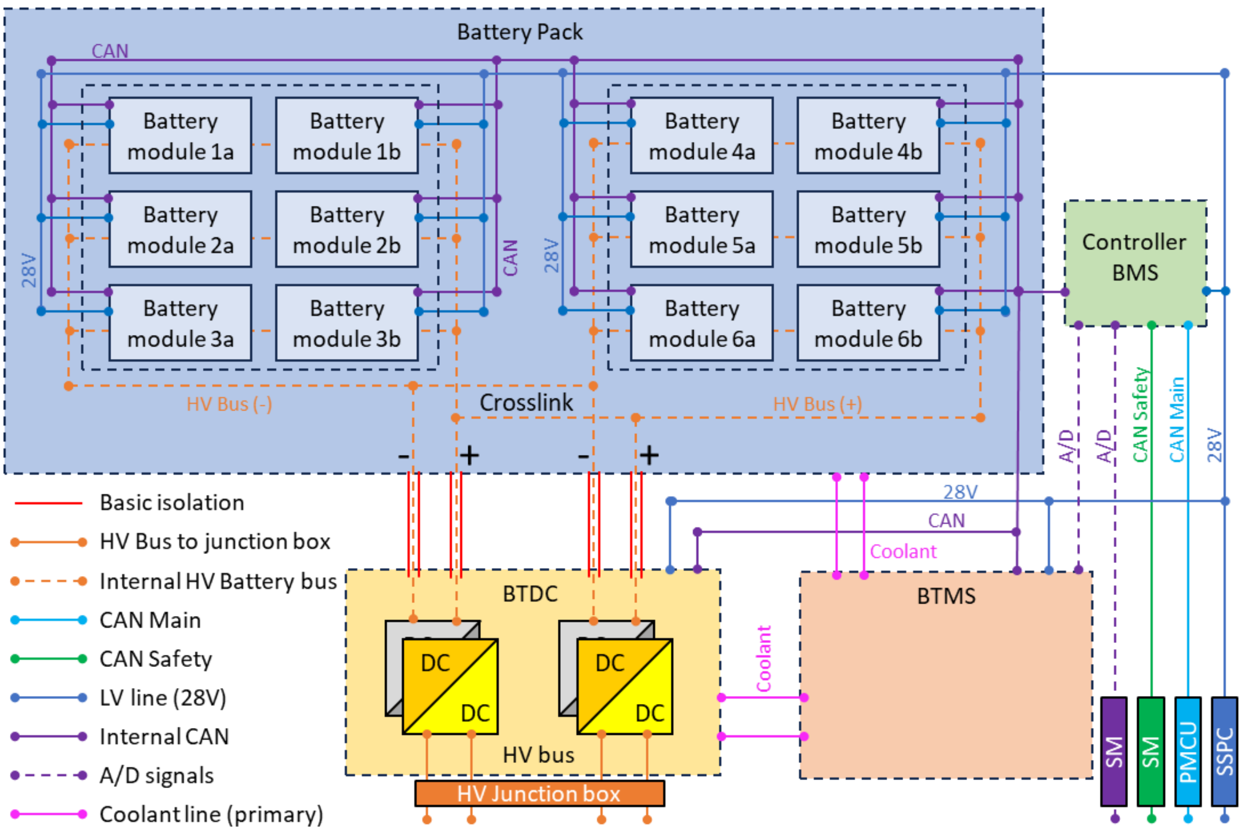

Figure 4: Configuration of NEWBORN Battery System

There are a total of six strings, where the number of the module refers to the specific string number. String number 1, 2, and 3 are part of the first battery pack, and string number 4, 5, and 6 are part of the second battery pack. Each string consists of 2 modules, indicated with an 'a' or 'b' following the string number.

Parallel connection between the strings is done only at string level, not on module level. The SBMS is responsible for the actual balancing of the cells, the MBMS ensures two modules are balanced equally while the CBMS is responsible for initial balancing during startup and connecting the strings in the right order to the battery bus during charging.

Referring to Figure 3 from section 4.2, while cell balancing is performed by SBMS and MBMS, it's the CBMS that determines the bottom string should be connected to the battery bus first, start charging to 700V, and then connect the other two modules to prevent current surges by connecting the three strings all at once, with a 50V difference between the strings.

The HV bus of the battery is connected to the BTDC, which boosts the voltage to the required voltage for the HV bus. The control of the BTDC for setting the HV bus voltage is based on a droop control of which the parameters are continuously updated by the PMCU and CBMS. More details about the control of the BTDC and HV bus voltage can be found in deliverable [3] section 4.3. The BTMS is controlled by the CBMS and provides cooling to both the battery pack and the BTDC.

4.3.1 Electrical interfaces Controller BMS

In figure Figure 5 is shown the signal network from the CBMS to the other subsystems within the BS. There are a total of six MBMSs, where each MBMS communicates with two SBMSs. The BTDC are controlled solely by the internal CAN network, and the BTMS uses a combination of CAN and discrete signals.

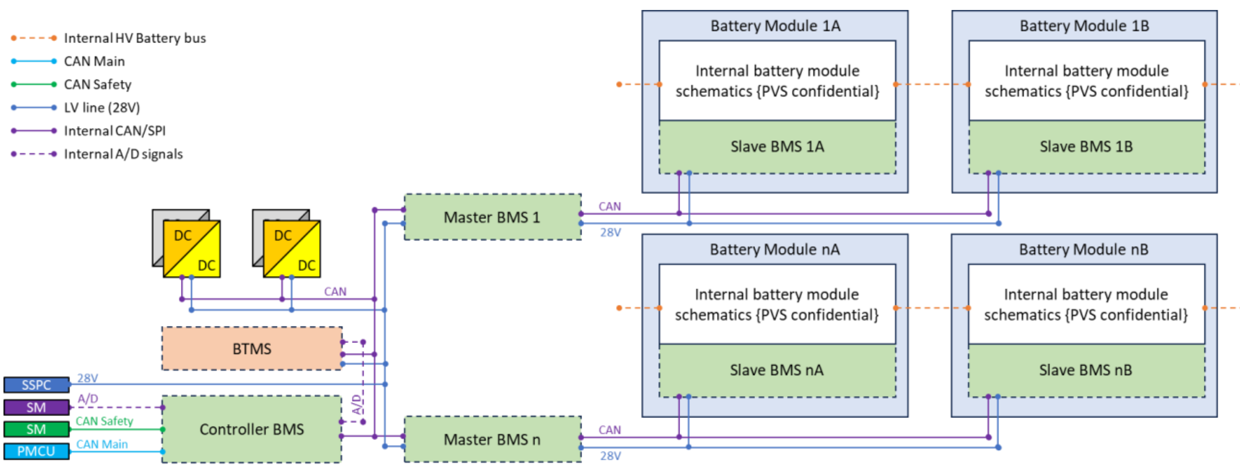

Figure 5: CAN network of CBMS within BS

4.3.2 Controller BMS and Power Management Control Unit interactions

The Power Management Control Unit, in detail addressed in the deliverable [3], is the logic of power demand split between BS and FC. The PCMU and CBMS communicate via the CAN Main line, as shown in Figure 4. Based on the desired power level set by the PMCU, the CBMS controls all subsystems related to the BS (BMS, BTDC, BTMS) to provide the requested power within the safe operating limits of the BS. The CBMS does not directly change the power setting of the BTDC, instead, it adjusts the droop control parameters of the BDC.

One of first interactions between CBMS and PMCU is Power-up BMS sequence. CBMS reports battery state via CAN to PMCU until it's 'ready for HV discharge'. PMCU is responsible for commanding CBMS to connect battery to HV bus, after the pre-charge of the HV bus is completed.

The PMCU also determines battery mode, among power target, while CBMS reports its status, actual power, temperature, maximum instant and long-term power, maximum and nominal capacity, SoC, SoH, and availability of strings. Besides these, PMCU could exchange discrete signals with CBMS for the sake of redundancy and reliability, according to “Interface isolation and grounding, Design guidelines”.

4.3.3 Controller BMS and Master BMS interactions

The main interaction between the CBMS and MBMS is related to forwarding SoX data from SBMS and MBMS of each string to the CBMS. This data is essential to the CBMS for controlling of the BTDC as this provides the maximum safe operating limits of the battery pack and ensures the battery pack charging/discharging power remains within its safe operating window. The communication protocol between MBMSs and CBMS in this stage is to be determined.

During the startup sequence, the CBMS oversees voltage levels provided by MBMS and ensures string voltage levels are equal before connecting it to the battery bus. If the deviation in string voltage is too high to allow connecting all strings, the CBMS commands which string is connected to the battery bus and controls charging rate until all strings can be connected to the battery bus.

4.3.4 Controller BMS and Bus-tie DCDC converter interactions

As mentioned in paragraphs 4.3.2 and 4.3.3, based on HV bus power requirements from the PMCU and SoX parameters of the battery pack, the CBMS controls the BTDC to balance the HV bus and provide additional power when needed.

During normal operation conditions the desired droop control parameters level set by the PMCU should be forwarded by the CBMS to the BTDC. In case of degraded performance of the battery pack and a desired power level from the PMCU exceeding the safe operating limits of the battery pack, the CBMS shall adjust the power level to the maximum allowable power level within the safe operational range with respect to voltage range, temperature range, and maximum power/current draw.

The CBMS should prioritise the health and safety of the battery packs, unless this threatens the safety of the aircraft. This is based on control laws determined in WP6 of the NEWBORN project. For example, in case of emergency where a power boost from the batteries is needed – resulting in undervoltage of the battery cells – to safe the aircraft, the CBMS shall prioritise providing the power boost over the potential risks caused by undervoltage.

4.3.5 Controller BMS and Battery Thermal Management System interactions

The main components of the BTMS controlled by the CBMS are activating the coolant fluid pump, and activating ventilators to simulate airflow over the radiators during the ground demonstration.

In addition to the fluid pump and ventilators, there are several sensors integrated which communicate over CAN to the CBMS. These sensors include:

- Differential pressure sensors
- Flow meter

These sensors are used to validate the system is working and to check there is no leakage in the coolant loop.

Prior to the ground demonstration, the GSE (Ground Support Equipment) will be used the precondition the battery to its ideal temperature range. For this, the CBMS will collect data from the MBMS about the thermal status of the battery pack to indicate thermal conditioning needs.

4.3.6 Controller BMS and Safety monitoring interactions

The CBMS has the responsibility to collect the operational status of all subsystems within the BS and communicate this data to the Safety monitoring. All operational condition and safety monitoring related data within the BS is collected by an internal CAN network and/or discrete A/D lines.

In case of failure of the CBMS there is a discrete signal from the CBMS to the safety monitor which provides the status (failure/no failure) to the safety monitor.

5 PROGRESS AND CONCLUSION OF BMS DEVELOPMENT

Chapter 5 of this deliverable will be updated after completion of final BMS design to include the validation report of the BMS.

The design phase of the BMS design is nearing completion. Based on the topology of the BS and specifications for the NEWBORN ground demonstrator, a three-level BMS has been developed including:

1. Slave BMS for cell balancing and sensing within the battery pack
2. Master BMS for balancing two modules in series, collecting SoX data
3. Controller BMS for collecting all battery pack data and control of BTDC and BTMS

This phase has involved extensive simulations and validations to guarantee that the design is robust, efficient, and capable of handling the high-power demands of the battery pack design as described in deliverable [5].

Following the completion of the design, the next step involves sending the design to production for the first prototype. This stage is critical as it transitions the project from theoretical design to tangible implementation. This phase will also include rigorous testing of the prototype to validate the design, ensuring that all components function as intended.

After successful validation of the prototype, the BMS will be implemented in the BS. The implementation is crucial as it confirms the system's readiness for deployment in the NEWBORN ground demonstrator. The successful integration and testing of the BMS will pave the way for its use in high-power applications such as hybrid-electric commuter aircraft.