The EU project HELIOS – Improvement of BMS functionality

Tomas Jezdinsky
ECI – European Copper Institute, Brussels, Belgium

Markus Schweizer-Berberich
Vitesco Technologies, Berlin, Germany

Juan Alberto Romero Baena Vitesco Technologies
Vitesco Technologies, Regensburg, Germany

Philippe Grass,
Vitesco Technologies, Regensburg, Germany

Tobias Braun
Vitesco Technologies, Regensburg, Germany

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1 Abstract

"HELIOS" is an acronym for High-performance modular battery packs for sustainable urban electromobility services. The HELIOS project funded by the EU Commission under Horizon2020 aims to create a new concept of hybrid, modular and scalable battery pack for a wide range of use cases, to be adapted for improved EV range and/or fast charging time according to different use cases, combining high-energy and high-power cells to achieve ambitious goals. Applying a holistic approach, the HELIOS project investigates optimal eco-designs and advanced processes to demonstrate innovative, lighter and eco-friendly EV battery packs as effective models for urban electromobility, and in addition facilitates the reuse in 2nd- life energy storage applications and easier recycling at its End of Life, contributing to a circular and sustainable supply chain in the EU.

2 Introduction – HELIOS concept

The HELIOS project (4 years, 2021 - 2024) will develop and integrate innovative materials, designs, technologies and processes to create a new hybrid concept of battery modules. An adapted configuration and combination of these hybrid modules will offer - other than the current "one-for-one application" approach of most EV OEMs - a new smart, modular and scalable battery pack for a wide range of EV vehicles from small city cars to full-size E-Buses.

The project consortium consists of 18 partners, involved in main tasks as

- Cell selection for a hybrid high-power – high energy module
- Cell testing and evaluation
- Mechanical & electrical design of the battery modules
- Thermal management
- BMS and multi-sensor integration
- Power electronics & control strategy
- Digital twins and IoT fleet management SW platform
- Battery pack for 2nd life stationary storage solutions
- LCA and LCC analysis, assessing the recycling impact after EoL
- Integration & Testing of the battery pack demonstrator on demo vehicles, using 350kW super-fast charging
- Dissemination and exploitation of key project results

HELIOS project partners comprise academia, research institutes, automotive system supplier, one Bus OEM, IoT experts and one industry association. The following simplified scheme (Figure 1) shows the integrated technologies, designs and processes as well as the main partners involved in each area:

For more details on the partners and their tasks in the project, please see: www.helios-h2020project.eu

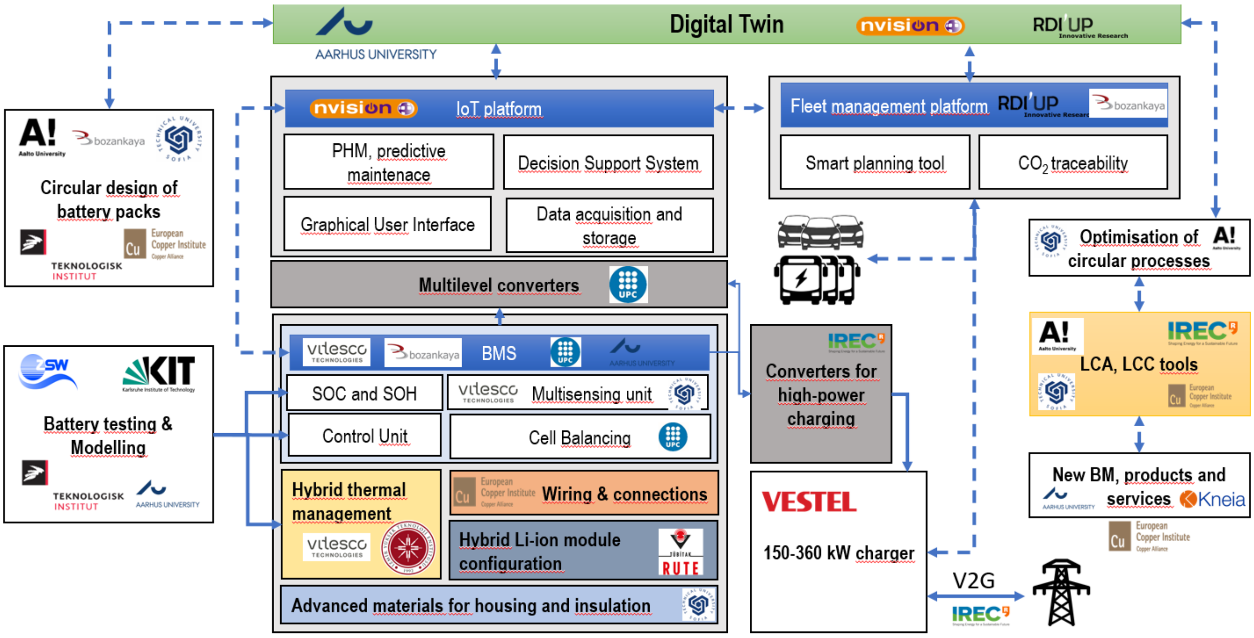

Figure 1: Scheme of the technologies, designs and processes developed under the HELIOS action and main partners, only a short overview on the major tasks.

To accelerate the mass market take-up of Battery Electric Vehicles (BEV), it will be necessary to increase the energy and power density of battery packs and to reduce weight and package space in order to improve driving range and decrease overall car weight. Therefore, the HELIOS projects will develop an innovative hybrid battery module combining high-energy and high-power cells to achieve ambitious goals.

Energy transfer between the different parts of the hybrid battery is achieved by intelligent power electronics embedded in the Battery Management System (BMS). By this, improved power capability combined with high energy is possible.

3 System overview

3.1 Project KPIs

The HELIOS project will create a new concept of standardized, modular and scalable hybrid battery pack, adaptable for different EV use cases. This more common approach should address both performance and safety requirements, as a competitive advantage for the entire battery value chain against the singular battery pack solutions each vehicle OEM is developing by its own today.

Helios has set ambitious objectives for its modular battery pack solution:

- Increase the energy density of Li-ion battery packs with a reduction of 30% in weight and 20% in volume, improving the overall performance of urban electromobility fleets.
- Enhance ultra-fast charging with minimum degradation, by optimizing the thermal management system and power electronics, targeting a roundtrip efficiency above 90% and a 25% shorter recharging time
- Extending EVs calendar life of 20 years, with a target of around 300,000 km in real driving

The LCA and sustainability analysis in HELIOS will improve circular economy processes within manufacturing, assembling, disassembling and recycling, and validating new functionalities and applications for second life batteries.

IoT, digital twin and fleet management platform are innovative approaches providing:

- Advanced monitoring and visualization in real time
- Communication between physical and virtual systems (sensor data exchange)
- Recommendations for improved BMS controls to enhance performance and lifecycle

These digital approaches should reduce CO_2 emissions associated to operating Electric Vehicles (EV) by optimizing recharging schedules and tracing the carbon footprint of EV fleets, thus improving the overall fleet sustainability.

The technologies, designs and processes developed during the HELIOS actions are integrated for manufacturing different battery packs installed into existing vehicles for validating their performance, lifetime, ultra-fast charging compatibility, safety, modularity and scalability. First, a single battery pack of ~20 kWh with increased energy density is developed and integrated for a small city EV (Mitsubishi i-MiEV) available at the laboratories of the Aarhus University School of Engineering. Second, the system is scaled-up by using several modules for developing a larger battery pack of ~225 kW for its integration in a S-10 e-Bus provided by Bozankaya. Table 1 reflects the specifications of the vehicles before and after the HELIOS action.

Parameter	Mitsubishi i-MiEV	HELIOS small EV	S10 E-BUS	HELIOS E-BUS
Traction battery	20kW Li-Ion	20 kWh HELIOS battery packs	225kW LFP	225 kWh HELIOS battery packs
Output power	50 kW	50 kW	250 kW	250 kW
Charging time	30 min	< 6 min	from 3h -7h	< 45 min
Charging power	Chademo (max 62.5kW, up to 125A)	180-360 kW, HELIOS charging	up to 80 – 180kW	Up to 360 kW, HELIOS charging

Table 1: HELIOS KPI goals vs the existing vehicles performance data.

3.2 Cell selection & Hybridization concept

Various and sometimes contradicting parameters must be considered in the design of the EV battery pack. Parameters are driving range, power capability for acceleration and regenerative braking. Also, fast-charging, lifetime, weight, volume and cost are relevant. Cells are mostly fixed in their characteristics. Hence within HELIOS we stick to today's commercially available EV battery cells. By mixing High-Energy (HE) and High-Power (HP) Lithium-ion (Li-ion) cells as a hybridization approach, it is possible to increase design flexibility for a wider range of EV applications.

A scoring system, based on weighing equations for the relevant parameters such as gravimetric and volumetric energy density, charge rate, costs, logistic considerations and others, helped to select an optimized combination of HE and HP cells [1]. The cell parameters are listed in Table 2. Obviously, this final selection is a compromise based on today's available options. Plus, we need to look for some adapted combinations for our prototype demonstrators (small city EV and full-size E-Bus) to focus selectively on some KPIs in each.

Cell Type	High Power	High Energy
Company name	Toshiba	Farasis
Product Name	SCIB 20 Ah	IMP14294105P73B
Cell chemistry	LTO	NMC
Rated/ Nominal capacity	20 Ah	73Ah
Nominal Voltage	2.3 V	3.65 V
Gravimetric energy density	84 Wh/kg	280 Wh/kg

Table 2: Overview on high power and high energy cells selected for HELIOS project.

Using a combination of different battery cells in HELIOS is an effective strategy to improve energy and power capabilities and lifetime, allow a more flexible operation and optimize the dimensioning for different use-cases. Cells with high power density are then employed in high performance (hence high power needed) driving cycle conditions and cells with high energy density contribute to increase the driving range (hence energy needed).

The HELIOS approach of combining a certain number of HE and HP cells in modules in parallel and then connect in series, with the necessary DC-DC converters in between will allow to configurate adapted battery packs based on number of HE and HP modules for a specific use case a/o a well-defined range of vehicles. At present, in that early stage of the HELIOS project, the exact configuration options are still under evaluation regarding issues on performance, ease of manufacturing, ease of disassembly and recycling and obviously final cost per vehicle in mass production.

4 BMS with scope on wireless communication

4.1 BMS general concept and functions

The Battery Management System (BMS) is the part which makes a potentially hazardous energy storage system safe and operable. Therefore, the BMS monitors the voltages, currents and temperatures of the battery system and triggers relevant measures to keep the battery inside of the pre-defined limits. State functions are calculated and communicated to the vehicle for consideration in the operation profile. Such state functions are State of Charge (SoC), State of Health (SoH), which is sometimes split into State of Function (SoF) or State of Power (SoP), and State of Safety (SoS).

4.2 BMS concept balancing

For optimal capacity or energy utilization all cells must have the same level of self-discharge, capacity, or power. Unfortunately, cells show already some initial deviation in these parameters. With aging, these deviations become even larger due to material or operational differences. Thus, balancing algorithm on the BMS (see Figure 2) must keep cells in battery as close together as possible to maximize storage capacity and to avoid accelerated aging when hitting dis-/charging limits by different cells from the deviation bandwidth.

	Passive	Active	Power
Principle	Energy dissipation	Charge transfer and energy retention	Power redistribution
Components	Switched Resistor	Switched energy buffer	Power electronics and switches
Status	Typically implemented e.g. automotive, 3C	Sometimes implemented e.g. stationary	Often proposed in different variants
Power path	via cell	via cell	via power electronics
Target for Equilibration	Self discharge SOC = 100%	Capacity differences 100% capacity utilization	Impedance differences 100% capacity utilization @ power
Cost	low	medium	high

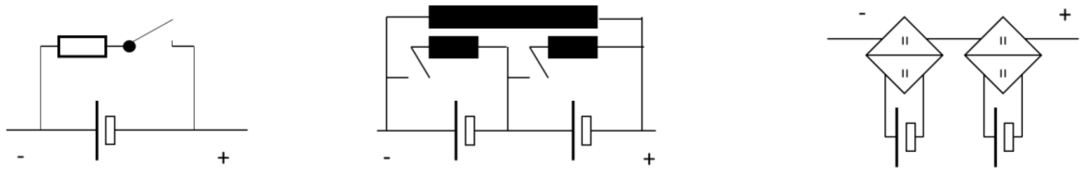

Figure 2: Overview on different balancing and compensation concepts.

- Passive Balancing is state of the art in mass market application today. In case of extended self-discharge this is a low-cost way to bring cells with high SoC to those with low SoC to maintain the full charging potential and thus capacity utilization. Simple systems start balancing just when the first cell reaches the end of charging limit and bypass the charge. More sophisticated systems define the trigger from the open circuit voltage as function of the SoC or the efficiency of the cells and calculate the time for balancing to reach the same operation relevant SoC point. In this case balancing can be done during rest or operation of the battery as well. The balancing circuit is typically designed for several tens to a few hundred mA, but is mostly limited by the power loss and heat dissipation of the electronics close to the cells
- Active balancing targets for the compensation of capacity deviations. Via a separate buffer (capacitor, inductor, battery cell), charge is transferred from “strong” cells to “weak” cells. Normally the weakest cell would limit the discharge. The remaining charge of the strong cells would not be used. But by active balancing this capacity can be additionally utilized. Active balancing is much more efficient and heat dissipation is not the limiting factor. The optimal design would be led by the operational profile but could result in high currents and high implementation costs. This is the reason why it is typically limited to several hundred mA to a few Amperes.
- Power balancing and dynamic reconfiguration capabilities are further options and help compensating differences in the resistance or power of the cells. Additional power electronics is used to support or bypass weak cells or modules according to the requirements of the operation profile. The power path doesn’t go through the cells as in option 1 & 2 but goes (at least) partly through the power electronics. This is the most expensive way of implementation because the power electronics must fulfill the maximum current/power requirement of the application.

While the first two options are normally considered as part of the BMS, the 3rd option goes beyond this and becomes more a topic of integration of power electronics, which is often used in the powertrain as converter or inverter, into the battery system architecture. The HELIOS project extends this 3rd option into a 4th one by intentionally introducing two different types of cells which deviate in capacity/energy and resistance/power. Energy transfer between both arrangements is done with power converters. This setup is called a hybrid-battery and tuning of the battery to the requirements of an application becomes possible with of-the-shelf battery cells. The design and the level of integration of the power electronics into the BMS is one topic of the HELIOS project.

4.3 BMS Concept wireless

Small batteries are equipped with a monolithic single board BMS and communication between the cell monitoring and the central micro-processor is established via e.g. UART, directly on the PCB. Large automotive or stationary battery systems could contain hundreds of cells in series connection establishing batteries with several hundred Volts. Two directions of battery architecture are currently discussed. For many years it has been common sense that the battery is split into modules. This is easier for manufacturing and in the ideal case the voltage of a module is less than 60V[1] and no isolation is necessary regarding electrical shock. However, precautions are still necessary to prevent short circuits and arcing. For such concepts also the BMS is preferably modular. This means that the Cell Monitoring Units (CMU) are on separate PCBs. Mostly the size of the CMU is designed according to the number of cells in the module. Battery monitoring chips which can measure different number of cells (6/12/14/16/18/24) are available from various suppliers. Those CMUs can be stacked and have an isolated communication to the Battery Management Controller (BMC). Different wired communication standards are possible (Daisy Chain, iso-SPI, UART, CAN, I^2C). A setup, easier to assemble, uses a wireless communication. Different communication techniques are compared in Table 3. Costs of an alternative setup compared to the wired state-of-the-art solution must be balanced against savings of e.g. cables, connectors, or isolation of the many CMUs of the battery. More savings are possible on the system level.

Protocol	Wired	RF Wireless	Optical Wireless	Powerline
Benefits	• Cheap • Secure if no direct access • High speed	• Robust: no connector or cable issues • Theoretical data rate up to wired iso-SPI solution • Flexible and scalable • Intrinsic galvanic isolation	• Reliable with light guide • Low cost with direct light • Intrinsic galvanic isolation	• No additional wire for communication. Usage of bus bars. • High data rate
Gaps	• Low Robustness • No protection if access to cable	• Expensive • Security measures mandatory • Perturbation by metal • Extinction by reflections	• Low robustness either at connection or due to dust • Moderate costs • Direct line or expensive light guide	• No galvanic isolation • Adaptation for specific HV bus bar architecture • EMI cable bounded • COM modules necessary
Comments	• Baseline	• Examples: WiFi, NFC, RFID, BT, ZigBee • Cost balance by TCO	• Easier cost balance by TCO	• Cost balance by TCO • Chip solution not automotive, yet • In home applications established • Up to ~30MHz
Rating	+	+	**0**	**0**

Table 3: Comparison of different communication techniques.

New trends are cell-to-pack or cell-to-chassis designs. With such concepts, battery manufactures safe the mechanical components for the modules, and energy density and costs of the battery can be improved. Without a modular concept for the battery, it is not necessary to have a highly modular CMU concept. In this case a centralized BMS might be sufficient, or a larger domain CMU covering much more cells than usually in a modular approach to keep the sensing lines short.

The HELIOS concept is a highly modular approach, why also modular CMUs and a communication with less assembly effort between the CMUs and the BMC make sense. The different communication solutions mentioned in Table 3 show pros and cons regarding bandwidth, number of knots, cost, reliability. In the specific case we have selected 2.4GHz RF communication as the technology of choice. Meanwhile also chip suppliers see an opportunity in this application and develop wireless communication chips specifically for application in batteries. Mostly it is based on Bluetooth technology, but proprietary protocols overcome the limitations of standard BLE in specific battery applications (e.g. number of knots). There are some suppliers which have in their portfolio both, battery monitoring chips and wireless communication chips and both are designed for communicating with each other without additional adaptation. Thus,

[1] Extra low voltage directive: $\leq 50V_{AC}$ and $\leq 120V_{DC}$ is considered as harmless for adults. Reduced values of $\leq 25V_{AC}$ and $\leq 60V_{DC}$ are considered safe even for children and animals and no isolation is necessary [2]. Product Safety Directive (2001/95/EC) [3] covers consumer goods $\leq 50V_{AC}$ and $\leq 75V_{DC}$ which is below the definition of the Low Voltage Directive (2014/35/EU) [4] which applies to the range between $50V_{AC}$ / $75V_{DC}$ and $1{,}000V_{AC}$ / $1{,}500V_{DC}$. IEC 60479 describes the “Effects of current on human beings and livestock” [5] and is the base for the voltage standards.

implementation effort is reduced. Such combinations are available e.g. from Texas Instruments (BQ796xx/CC2662) or Analog Devices (ADBMS68xx/ADRF88xx).

4.4 Feasibility of wireless communication in battery environment

Two important points were addressed to understand the feasibility of the RF technology in the battery environment: cost and reliability by free radiation of the signal.

Currently we see slightly higher costs on the BOM side. The costs for the communication chip, the additional power supply, the antenna and the larger PCB are not completely compensated by the removal of wires and connectors, galvanic isolation and EMI measures. Figure 3 illustrates the adders and savings in the BMS architecture.

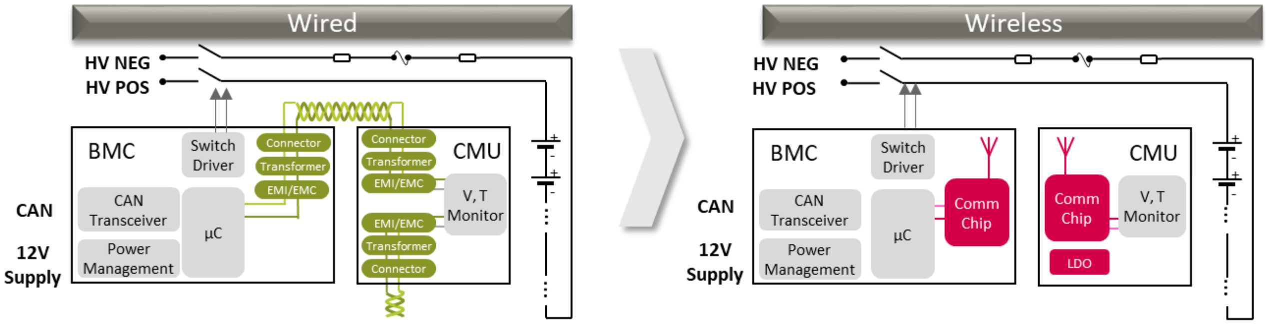

Figure 3: Simplified BMS architecture: wired (left) and wireless (right) communication between the CMU and the BMC.

More savings can be identified on the battery system level due to a wireless communication and each partner in the value chain should be open to look beyond the own business case to reduce the overall costs of batteries.

- Battery production becomes simpler. No connectors need to be placed. Modules need not be connected for end of line measurement. Slightly reduced labor cost is possible due to removal of ~15sec working time per cable and connector.
- The design becomes more flexible. No harness needs to be designed and tested for a new battery. Development cost can be reduced. Especially, if more different battery designs are developed the better the situation would become for the wireless solution.
- The energy density can be increased. The space for the harness and for placing the connectors can be removed or filled with additional cell volume. An estimate of 2% seems reasonable and cost reduction is in the order of 10% of the housing cost necessary for this 2% of capacity volume.
- It is expected that recalls due to connector failures become obsolete. With 60ppm connector failures, significant following cost for pick-up, service and spare parts can be avoided by wireless communication.
- Assembly of the communication line of modules in case of a general service needs labor time. Wireless communication avoids these costs. This is a benefit according to the failure probability of a pack.
- Some quality aspects become simpler. Cell data are available all the time and presorting of modules could be done easily. This improves the quality of the battery pack. Cells with less quality (and therefore lower costs) could be accepted and lead to modules in several grades. Also, earlier quality checks might be possible because more data are available. We see this as an opportunity but learnt that OEMs have tight specifications which are/must be fulfilled by the cell manufacture. A change in this approach can't be expected today but might be an opportunity in the future for further cost reduction.
- Larger benefits are seen in warehousing. Spare parts of batteries must be stored, especially after end of production of the batteries. Quality checks of these batteries are time consuming and costly and can be avoided by wireless communication. But OEMs see here limited use. This issue is addressed by tight specifications again, but the approach could change if wireless communication proves its value.
- The additional microcontroller of the wireless chip allows implementation of a battery passport on the module level which could result in benefits for maintenance and 2nd life applications as individual tracking of battery modules become possible.
- And finally, the largest benefit is in 2nd life concepts, as most of the arguments already mentioned apply together. Of course, the question is how many batteries of a program would finally go into a 2nd life application. Often OEMs currently don't address this topic as part of their own value chain, hence other stakeholders could profit and make the concept of EVs and batteries more viable and cheaper.

One concern regards wireless communication is how reliable the wave propagation and signal transfer are in the environment of batteries. Often packs have a metal housing and modules contain a high amount of metals, e.g. copper and aluminum foil of the electrode current collectors or the aluminum of the cell housing. This could result in shielding, or in reflections and extinction of the wave. First tests show a need for some countermeasures, but not a general blocking point.

The RF antenna and the wave form were simulated with ANSYS-HFSS and HW antenna matching was conducted. With this a voltage standing wave ratio of less than three was achieved for the whole Bluetooth frequency range. The return loss was around -10dB. The 3D radiation field measurement showed good correlation with the simulation.

Testing of the BMS in a real battery environment was done by applying CMUs and an extension board (as emulator of the BMC) inside of an BMW i3 battery housing with metal boxes representing the battery modules. Depending on the test, different locations were chosen for the CMUs.

The transmission and reflection of the wave inside of the battery housing was simulated. Due to the metal housing and the reflections, standing waves can occur with knots and low signal at certain locations as shown in Figure 4. This would result in missing communication at that location. The transmission coefficient was measured with different antenna orientation and for the different CMU locations. The impact on the signal transmission is shown in Figure 5.

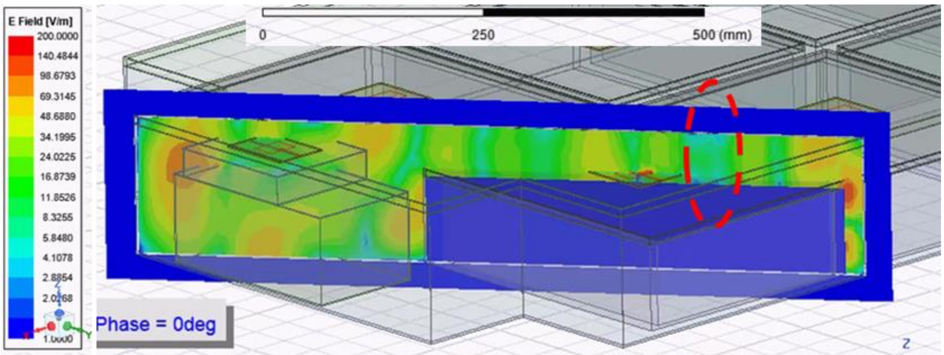

Figure 4: Generation of standing waves by reflection of the RF wave inside of the battery housing.

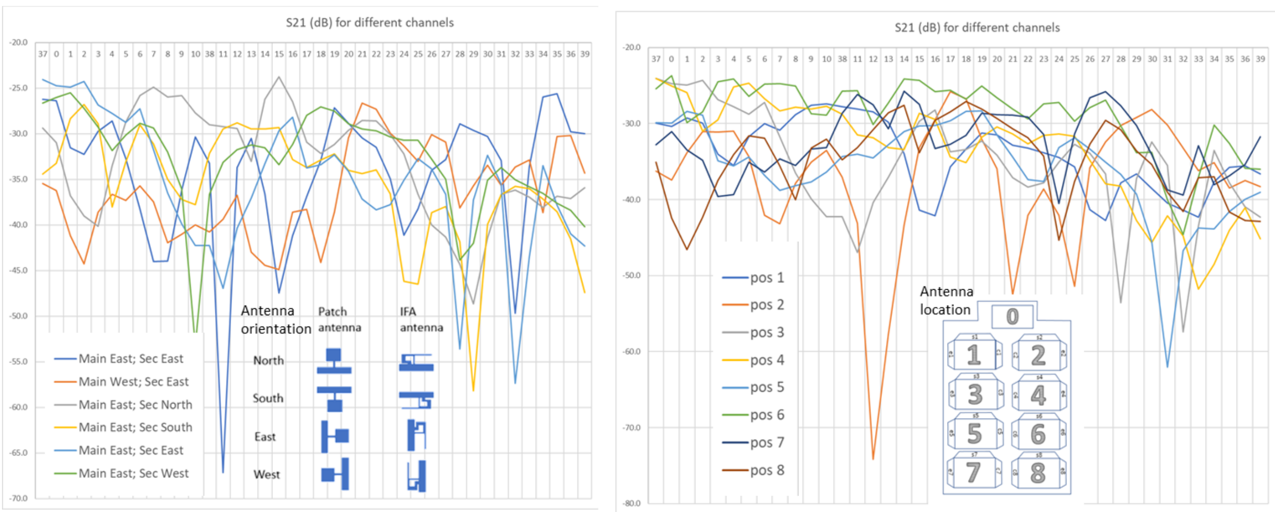

Figure 5: Transmission coefficient for different locations and antenna orientation.

These drawbacks can be overcome by using a different frequency for which the knots would occur at a different location. With this, frequency hopping and retransmission of the data is possible and reliable communication can be established within 5 retransmissions and in this case approximately 100ms time frame. The following cases were proven for a setup of 4 CMU with the number and the overall occurrence of re-transmissions in brackets:

- Closed battery housing, (1, 0.1% of messages)
- CMU outside the closed battery housing (3, 5% of messages)
- Open battery with heavy interference by scanning Bluetooth device close by (5, 15%)
- Closed battery with some interference by scanning Bluetooth device close by (2, 7.1%)
- Closed battery and CMUs shielded by additional metal plate or by positioning between modules (2, 6.8%)

The total time frame depends on the number of super-frames necessary for transmitting all data, the number of knots and the defined number of retransmissions to compensate for communication failures. A detailed timing table is necessary to fulfill the requirements of functional safety. Wireless communication can't achieve the same transfer frequency as wired communication, but it is questionable if the 10ms update rate, which are established for wired communication today, is necessary in all cases. Also, different chip suppliers have different solutions regarding the communication protocol which are more or less beneficial. Additionally, there is a microprocessor available with the wireless communication chip on each CMU which can be used for some preprocessing of the data. New functions might become possible which can compensate for the slower data transfer.

5 Sensorics with scope on thermal runaway detection

5.1 Thermal runaway behavior

Vehicle battery cells with a flammable electrolyte can under certain circumstances bear the risk of a thermal runaway. This can turn into hazardous situations for the passengers of a BEV or generate huge material damages to other vehicles or buildings.

A thermal runaway can be initiated by external factors or by internal malfunctions: Internal malfunctions may be caused by production failures of the cell or also e.g. by dendrite growth while charging, which can damage the separator layer, and hence produce internal short circuits. External factors can be mechanical abuse like stress or shocks applied to the battery housing. These shocks may damage the contacts between the single battery components and initiate short circuits. Also, electrical abuse by charging or discharging the battery over its limits can be the initial trigger to a runaway. Thermal abuse issued by unfavorable battery thermal management may also lead to thermal runaway or even support propagation of thermal runaway from cell to cell once started.

Cell ageing influenced by the number of load and unload cycles, and perhaps combined with other misuses may lead to similar runaway behavior as described before, or cell degradation with gas venting without cell thermal event. The gas composition occurring during this phase might also be relevant for the safety of the vehicle in case the lower explosion limit is exceeded.

Independently of the initiation, the runaway can start immediately or time delayed (hours or days after the trigger).

Figure 6 shows an overview of the thermal runaway propagation from initiation and start of the runaway until when the hazardous situation for passengers occurs. The heat released by the first cell's runaway event is the trigger for its neighbor cells to start thermal runaway too. This chain reaction continues until the whole battery is set on fire. The time elapsed between the first cell's runaway and a hazardous situation for the EV passengers is highly variable, depending either on the package topology or the design of the battery (e.g. cell separators), or depending on unfavorable situation (e.g. state of charge, remaining misuse).

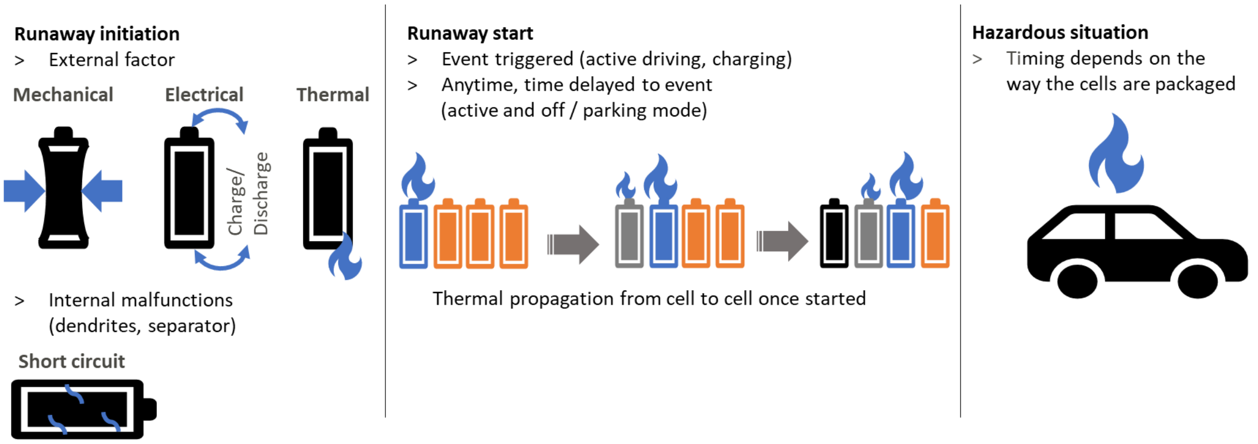

Figure 6: Overview of thermal runaway propagation

Latest "Global Technical Regulations – GTR No.20" require a warning signal five minutes before any fire, explosion, or smoke in the car cabin to protect the passengers. This warning requirement is limited to an "active driving possible mode". In case the transmission mode is set to "neutral" or even more important, in the "parking" mode, or when the battery is charging, runaway detection is not requested by the GTR´s warning requirement [6]. In order to comply with the GTR and known field problems occurring mostly while parking, HELIOS investigates concepts acquiring further physical values in a stand-alone Multi-Sensing-Unit (MSU), capable to detect early signs of cell runaway and wake up the BMS for further analysis and final decision to inform the user (Figure 7).

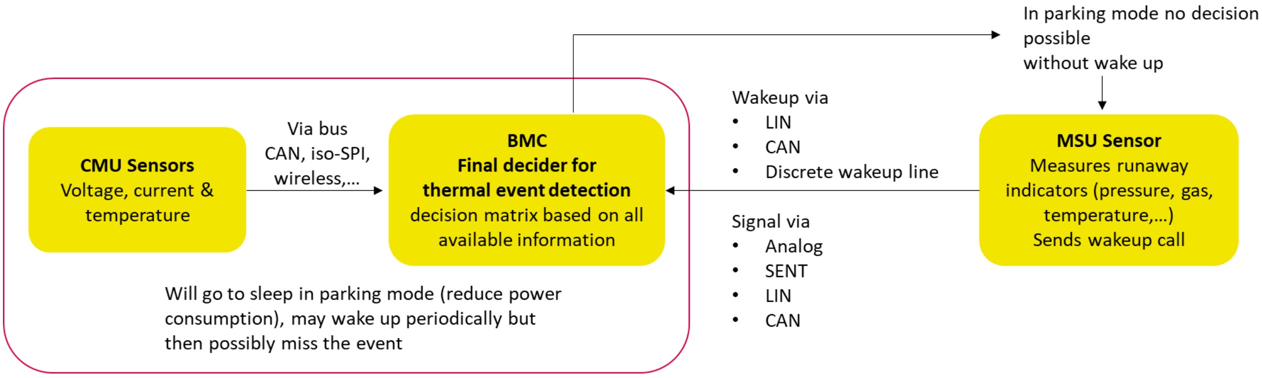

Figure 7: Interaction of multi-sensing unit with battery management system.

5.2 Possible sensors for runaway detection

Reliable sensors for detection of a thermal runaway must capture, physical effects during a runaway. Figure 8 illustrates the time sequence of a thermal runaway for pouch and prismatic/cylindrical cells.

The graph on the left shows the typical time sequence for pouch cells. Chemical reactions inside the cell lead first to an increase in surface tension (cell inflation) which could be measured at a very early stage by a strain sensor. When the cell starts to vent through micro cracks, the strain is reduced to a lower level while the cell is emitting gas into the battery pack. This low gas concentration could be an additional early indicator for a runaway, detectable with an appropriate gas sensor. Finally, when the cell runaway occurs, the cell turns to short circuit and the voltage drops to zero (invisible in park mode while BMS is asleep). The cell housing explodes, characterized instantaneously through high pressure and temperature relief and a second emission of gas increasing tremendously the concentration inside the battery case.

The graph on the right shows the time sequence for prismatic/cylindrical cells. The sequence of occurrence of strain, gas, pressure and temperature is similar to pouch cells. But the time between the different steps is shorter due to the mechanical properties of the cell housing.

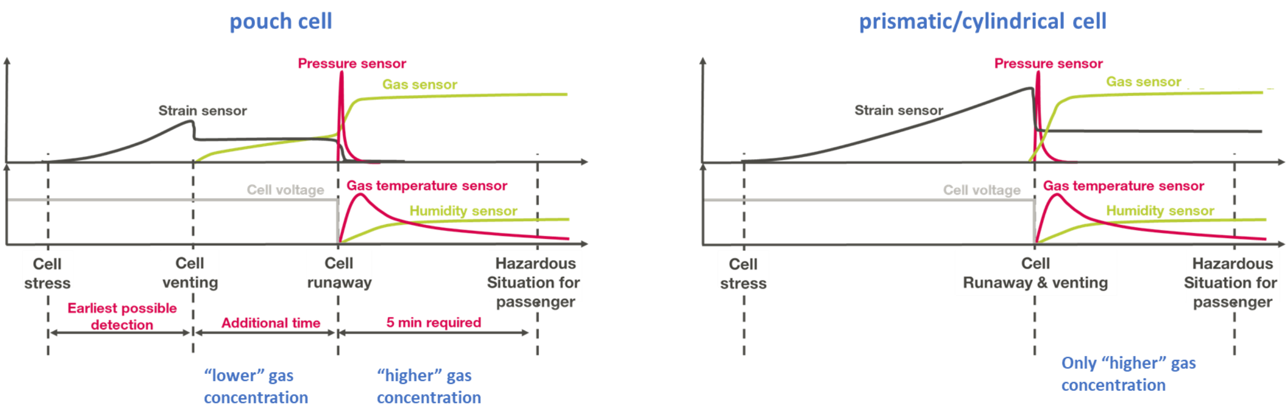

Figure 8: Time sequence of a thermal runaway for pouch and prismatic/cylindrical cells

As conclusion, the thermal runaway event can be detected with different measures (pressure, gas, strain, etc…). One of the goals of the HELIOS project is to explore what measuring principle or their combinations detects runaway with the highest reliability over lifetime and the lowest cross sensitivity to external noise leading to false detection.

6 Conclusion and Outlook

The HELIOS project at present is still at a relative early stage of coordinating the various design and engineering strings towards our final prototypes. After defining the hybrid configuration of the battery modules and the adapted combination of different number of modules for our two demonstrator prototypes, we are now in the middle of the design optimization phase and in parallel doing some testing matrix on cell level.

The next step will be the simulation of performance, the manufacturing and specific testing of the real prototypes. The mechanical and electrical integration of the battery packs in our two use cases is finally planned for 2023. In parallel the development of our software for the digital twin and the fleet management platform will be streamlined. The achievements of HELIOS will be shown and validated in 2024 in two demonstrators: a small city EV and a full-size E-Bus.

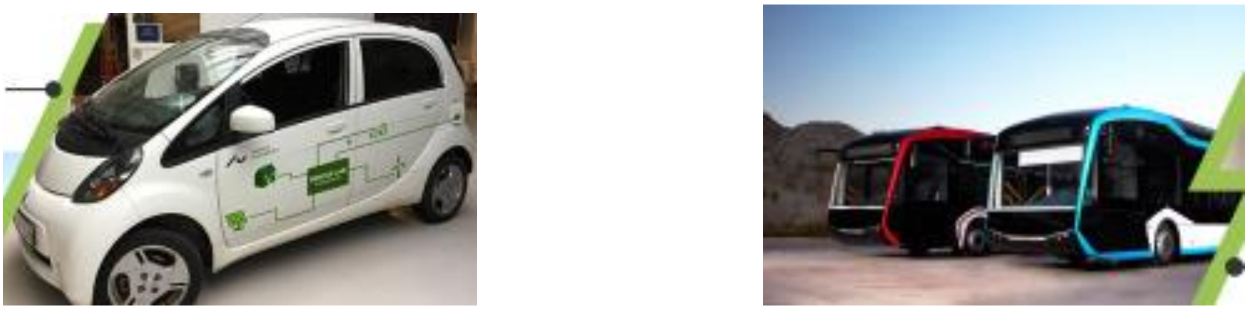

Figure 9: Demonstrator vehicles. Mitsubishi iMiEV of Aarhus university (left) and S10 bus of Bozankaya (right).

HELIOS partners will provide solutions to demonstrate the behavior of our hybrid battery pack solution with 360kW super-fast charging station technology. Table 4 finally gives an overview on the 4-year journey of HELIOS from start to end point with the related technology readiness levels (TRL) regarding aspects of this present paper- of course, HELIOS will include many others.

Technologies involved in HELIOS (some examples only)	**TRL at month 1**	**TRL at month 48**
Hybrid module configuration battery packs, integrating HE & HP cells	4	7
Improved state estimation methodologies for SoC and SoH	4	6
Development of BMS with enhanced functionalities for state estimation and connectivity	5	7
MSU integrated in the BMS for measurement of multiple parameters	5	7
Gas sensor for early detection of thermal runaway	3	5

Table 4: Definition of maturity of HELIOS components presented in this paper.

7 References

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