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HiPower 5.0

D1.1 Specification of Use Cases

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EXECUTIVE SUMMARY

The HiPower 5.0 project develops advanced, energy-efficient power electronics for sustainable mobility. It leverages wide bandgap semiconductors like GaN and SiC to enhance electric drivetrain performance. Industrial demonstrators will validate innovations across automotive and maritime applications. Use cases include inverters, chargers, DC/DC converters, and shipboard power systems. Work Package 1 defines specifications for six use cases with stakeholder involvement. Deliverable D1.1 outlines high-level objectives, functionality, and testing requirements. These specifications guide technical development in subsequent work packages. Project impact will be assessed in WP6 and reported in future documents. This document lays the foundation for achieving HiPower 5.0's strategic goals.

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1 Introduction

HiPower 5.0 Project Overview

The HiPower 5.0 project is focused on the development of highly integrated, energy-efficient power electronics components tailored for sustainable mobility in both automotive and maritime sectors. Leveraging advanced wide bandgap semiconductor technologies—specifically gallium nitride (GaN) and silicon carbide (SiC)—the project aims to achieve significant advancements in the performance, reliability, and environmental sustainability of electric drivetrain systems.

Concept and Approach

HiPower 5.0 adopts a use-case-driven approach, designing, building, and testing industrial demonstrators that showcase the technological innovations and benefits across various transport modes. These demonstrators span multiple application domains, including:

- Inverters and on-board chargers for battery electric vehicles (BEVs)
- Integrated inverter and e-motor systems for passenger cars
- DC/DC converters for light and heavy-duty vehicles
- Power converters for electric ships

Work Package 1 (WP1): Use Case Demonstrator Requirements and Specification

The primary objective of WP1 is to define clear and comprehensive specifications for each industrial use case, involving all relevant stakeholders. In the second phase, detailed requirements will be established to ensure a shared understanding of the needs and expectations for each demonstrator. This process supports alignment with the overall project goals, the development of all technological innovations in the different work packages (WP2 to WP5), and will be additionally documented in Deliverable D1.2, which outlines technical requirements and evaluation criteria for subsequent work packages (cf. Figure 1-1).

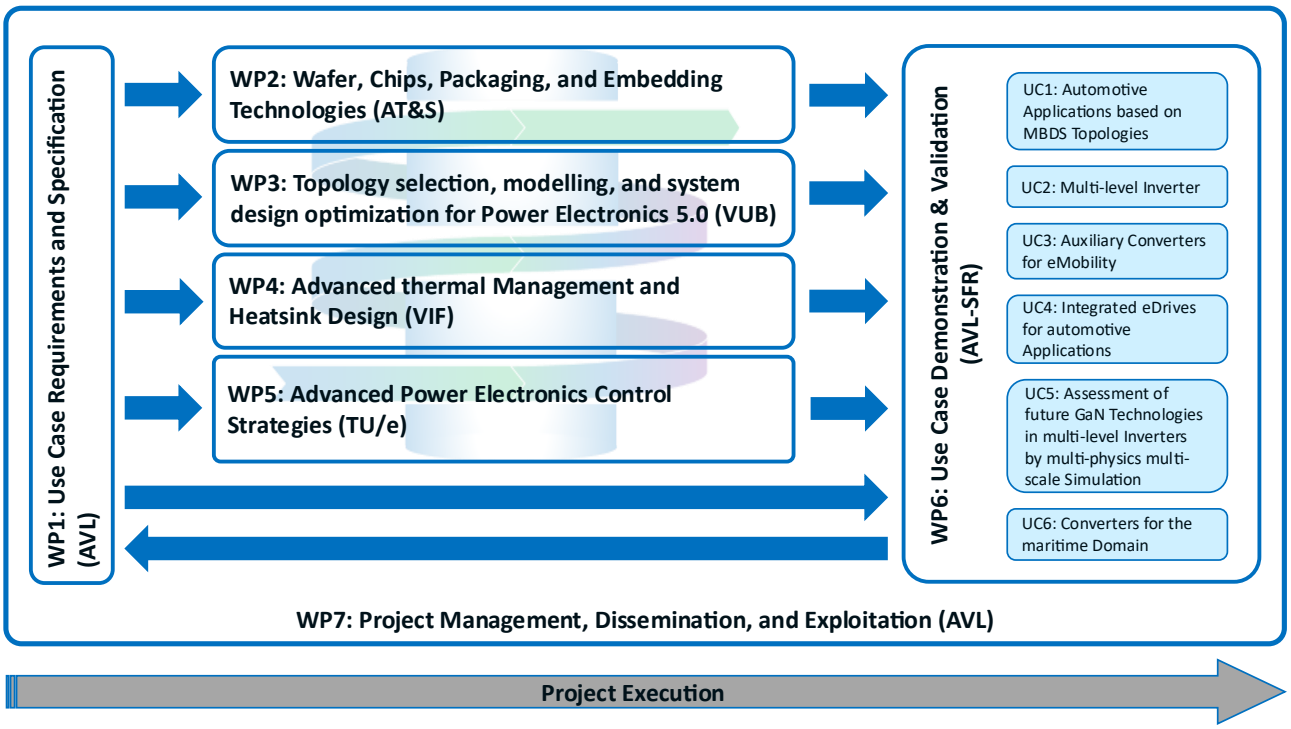


Figure 1-1: Work-package structure which reflects the logical R&D activity hierarchy

Deliverable D1.1: Specification of Use Cases

This document represents the foundational step of the project, setting the stage for all subsequent activities and ensuring alignment with project targets. Task 1.1 focuses on specifying the demonstrators for six distinct use cases (UC1 to UC6), with active stakeholder involvement. The output of this task is this deliverable, D1.1, which provides high-level specifications that will guide the technical development in other work packages. For each use case, the following elements are defined:

- Objectives and key targets
- Functional scope
- Testing procedures and test-bench specifications

These specifications serve as the baseline for detailed requirement definitions and guide future tasks and project activities.

Automotive Use Cases

- **UC1**: Develop an automotive converter using GaN Monolithic Bidirectional Switches (MBDS) topologies to achieve energy efficiency beyond 99%.
- **UC2:** Hybrid multi-level automotive Inverters
  - **UC2a**: Create a high-power hybrid multilevel inverter for battery voltages exceeding 800 V.
  - **UC2b**: Design a 400 V fusion inverter optimized for CO_2 footprint, cost-efficiency, and drivetrain performance.
- **UC3:** Auxiliary Converters for eMobility
  - **UC3a**: Build a light-duty vehicle auxiliary converter utilizing 1200 V GaN technology.
  - **UC3b**: Implement a heavy-duty vehicle auxiliary converter combining wide bandgap devices for maximum durability.
- **UC4:** Integrated eDrives for automotive applications
  - **UC4a**: Integrate an inverter into an EESM motor using GaN and SiC technologies.
  - **UC4b**: Develop an in-wheel motor with integrated inverter based on GaN MBDS technology.

Simulation & Assessment Use Case

- **UC5**: Assess future GaN technologies in multilevel inverters using multi-physics and multi-scale simulation tools.

Maritime Use Cases

- **UC6:** Converters for the maritime domain
  - **UC6a**: Design an integrated marine eDrive using SiC for compactness and high efficiency.
  - **UC6b**: Develop a modular high-power marine charging unit with advanced SiC-based system topology.
  - **UC6c**: Create a 3 kV DC source for marine applications with galvanic isolation and evaluate HV SiC packaging concepts.
  - **UC6d**: Investigate and benchmark solid-state circuit breakers for DC grids on ships using wide-bandgap (WBG) semiconductors.

Future Evaluation

The assessment of project objectives will be conducted in **Work Package 6 (WP6)** and documented in subsequent deliverables.

2 UC Specification

2.1 (UC1) Automotive Applications based on MBDS Topologies

2.1.1 Introduction

Bidirectional switches (BDS) offer the opportunity to reduce conduction and switching losses for buck-boost topologies significantly, as they enable these functionalities with current flowing only through one semiconductor. The next generation GaN technologies unlock the possibility of fundamental improvements. For motor drives, BDS enables current source inverters with no dV/dt stress for insulation and bearings and less switching losses. Lateral GaN technology is an enabler for bidirectional switches, as changing from a regular switch to a bidirectional switch only requires a second gate. This measure does not increase channel resistance, which has been the main drawback of these topologies up to now. Especially when converting AC to DC, the voltage was first boosted to a higher level and stepped down again to a lower voltage, which results in switching unnecessarily high voltages and two semiconductors for the current to flow through. With current source inverters this is not necessary anymore and conduction and switching losses decrease.
The benefits of these new possibilities are fundamental: efficiencies of 99% for applications like grid interface (PFC) and DC/DC converters come into range at lower volume and cost. This will have big impact in many application areas like renewables, automotive, industry, and IT power supply, enabled by advanced multi-physics simulations and BDS characterization that optimize CSI topologies to minimize conduction and switching losses, enhance energy efficiency, and improve power density, and allow for rapid iteration and refinement of these designs while addressing thermal management and design constraints within the twin transition framework.
This use case will work out the basics of high-frequency current inverters and will implement it as hardware prototypes, to discover unexpected obstacles in application. As the focus of the last decade's development was the voltage source inverter, knowledge must be built up from scratch and previous experience can only partly be used.

2.1.2 Use Case Objectives and Targets

This use case will investigate different current source inverter applications, and the following high-frequency current inverters will be developed:

- 22 kW 3-phase grid connecting unit for OBC and PFC
- Bidirectional DC-DC converter
- Current source inverter for auxiliary motor drive in vehicles

2.1.2.1 OBC and PFC

This application use case focuses on a 22 kW 3-phase grid connecting unit, which can act as an OBC or a PFC. New OBC topology will be investigated, using bidirectional switches (BDS) enabled by next-generation GaN technology. This will enable inverters with a minimal number of switches and switching losses. The design leverages BDS topologies to achieve high power density and efficiency while addressing thermal management, EMI/EMC, and compactness. Key targets include:

- Volume reduction by 50% compared to HiEFFICIENT demonstrator
- An efficiency of 99%
- Reduction of manufacturing costs
- Reducing energy conversion steps in the application
- Minimizing the number of power devices
- A power factor ≥ 0.99 and a THD ≤ 5%

2.1.2.2 Bidirectional DC-DC converter

The need for DC/DC converters, interfacing the traction battery with the HV bus of the vehicle, is mainly twofold:

- providing the traction inverter with a constant input voltage (strictly higher than the actual battery voltage) so that the operation of the electric machine is optimized for any battery voltage, in both motoring and regenerative braking driving modes, and
- allowing charging of the battery when connecting to a LV charging slot.

Several system architectures (positioning options with various vehicle architectures) and DC/DC converter solutions (topology and operation) will be considered to fulfil both requirements. The impact of different design choices and possible operating scenarios will be analysed and compared. The objective is to determine possible configurations that ensure proper system operation, and highlight possible limitations (e.g., efficiency, control issues, etc.) and special requirements (e.g., isolation/efficiency trade-off for implementing partial power processing).

The system shall operate with a battery voltage range of 400 to 840 V, a mainly non-isolated DC-DC converter, an inverter DC bus voltage between 900 and 940 V, and a charging interface rated from 400 to 1000 V. Compatibility will be assessed for driving modes under both motoring and regenerative braking conditions in simulation, where the converter will boost the battery voltage to the inverter DC bus or buck energy from the inverter DC bus back to the battery.

The system will also support charging of the high-voltage battery initiated from either low-voltage (optional) or high-voltage charging columns. The option of Vehicle-to-Grid (V2G) operation will also be evaluated, so that it might be compatible with both charging technologies.

The primary objective will be to define a system architecture and DC-DC converter design capable of achieving a peak efficiency of 99% across all operating modes, while still guaranteeing an average efficiency over a standard driving cycle of at least 98%. The investigation will cover the adoption of MBDS technology in this specific application as well as standard GaN HEMT or even SiC technology (depending on the actual selected architecture/topology).

2.1.2.3 Current source inverter for auxiliary motor drive in vehicles

The current-source inverter (CSI) offers several advantages over conventional voltage-source inverters (VSI); however, despite some research and prototype implementations, its use as a motor controller remains limited and has not resulted in commercial applications in the automotive domain to date. Our first objective is to understand and capture the requirements of this specific automotive application, particularly with respect to semiconductor devices. These requirements will feed into the design and development of a monolithically integrated GaN bidirectional switch with a breakdown voltage of 850 V. Supporting activities include the provision of early information on GaN BDS functionality and intended use cases, the supply of engineering samples, preliminary datasheets and simulation models for 650 V and 850 V variants as they become available and the sharing of application-level expertise through application notes and internal research findings on the use of bidirectional switches across different power converter topologies. These efforts aim to deliver a ≥850 V GaN BDS device that meets application needs, enables system development and supports future market adoption and exploitation. The maximum achievable power level of the developed system will ultimately depend on the availability and electrical characteristics of the selected hardware components.

As a second objective, a comparative evaluation between a current source inverter (CSI) and a voltage source inverter (VSI) will be performed. In the CSI architecture, reduced motor winding losses contribute to higher overall system efficiency. The replacement of bulky, cost-intensive and thermally critical DC-link capacitors—typically required in VSI topologies—with DC-link inductors enables higher power density and improved thermal behaviour. In addition, CSI architectures provide inherent short-circuit protection due to their current-source nature, making them particularly well-suited for the adoption of sensitive wide-bandgap devices, such as GaN-based switches. Since it is intrinsically filtered on phase outputs, the CSI allows working

at higher frequency without exceeding dV/dt limits to preserve motor windings insulation. Unlike VSI solutions, the use of CSI is expected to result in reduced electromagnetic frequencies even when longer motor windings are employed. The overall objective is to minimize electromagnetic interference and comply with stringent European EMC standards, while simultaneously achieving high power density and high efficiency. A key focus is to assess whether bidirectional switch (BDS) technology introduces new EMC challenges. Modern EMC simulation methods will be applied to support efficient design and results will be experimentally verified. High-bandwidth current sensing, along with optimized inductors, transformers and EMI filters, will be considered, including a comparison of the current source concept with state-of-the-art voltage source topologies in terms of DC-link implications, power density, cost and EMC performance.

2.1.3 Demonstrator: Scope and Functionality

2.1.3.1 OBC and PFC

The project implements a single-stage OBC in which grid conditioning and power-factor correction (PFC) are realized with bidirectional blocking switches (BDS). This eliminates the need for separate PFC and DC-DC blocks while improving efficiency. The BDS power electronics are complemented by additional components (sensors, filters, controllers, cooling hardware) and integrated into a testable hardware demonstrator for software development. The software will provide complete grid synchronization, current regulation, CAN communications, and a test interface for status, control, and data extraction. A fully integrated single-stage OBC will be available at the end of the project.

2.1.3.2 Bidirectional DC-DC converter

To serve as the central interface between the vehicle's charging inlet, the high-voltage battery and the electrical drivetrain, the converter needs to fulfil certain requirements. In charging mode, it needs to accept a relatively low voltage from the on-board charger (connected to the charging network) and convert it to the higher voltage of the vehicle's battery. In driving mode, it converts the variable battery voltage to a constant voltage to supply the electric drivetrain. In addition, this operating mode also demands electrical power equal to that of the drivetrain. During recuperative breaking, the converter allows power transfer from the drivetrain back to the battery. In conclusion, these operating modes require the functionality of a bidirectional buck-boost converter.
Since energy is limited in an electric vehicle and power losses increase cooling efforts, the converter needs to operate at the highest possible efficiency. A compact size of the converter is also critical for integration into the limited installation space of an electric passenger vehicle.

2.1.3.3 Current source inverter for auxiliary motor drive in vehicles

The involved partners collaborate on a comprehensive project covering the definition of specifications, design, simulation and the realization of physical prototypes for a Current Source Inverter (CSI) intended for motor control applications in the automotive sector. The performance of this CSI will be benchmarked against a reference Voltage Source Inverter (VSI), which will be identified and used as a *baseline*, with the comparison based on specific key performance indicators (KPIs), including power density and the EMC (electromagnetic compatibility) footprint. The unit shall operate in 400 V BEV/HEV environment and must be able to support peak power of 2 kW. To ease the back-to-back comparison, the CSI shall provide the same vehicle interface to the VSI.

2.1.4 Testing and Validation Specification

2.1.4.1 OBC and PFC

The testing and validation activities for the developed 22 kW onboard charger (OBC) based on novel bidirectional GaN power semiconductors are designed to ensure the technical function, to measure the real performance, and robustness across the relevant operating conditions. The system is developed using a modular hardware architecture, allowing individual functional blocks such as the AC input filter, MBDS GaN power stage, primary side, secondary side, as well as the self-developed transformer and magnetic

components to be tested and validated separately. The development of the magnetic components, including transformers with defined leakage inductance or combined inductor–transformer solutions, is highly specialized for the selected electrical topology. The magnetic components are dimensioned, designed, and prototyped by CNC machining directly from a ferrite block. The individual magnetic components are tested separately using impedance analyzers and dedicated measurement equipment for the characterization of inductive components, allowing verification of inductance values, losses, and frequency-dependent behavior prior to system integration.
The validation strategy covers also simulation, hardware commissioning, software verification, electrical performance assessment, and electromagnetic compatibility evaluation. The development process is supported by several simulation activities at both component and system level. Matlab Simulink electrical control models are used to analyze bidirectional power flow. Adapted Solutions Portunus simulation models are used to analyze switching behavior of the GaN devices, loss distribution under nominal and derated operating conditions. Simulation results are continuously validated against experimental measurements obtained from hardware prototypes at different stages of development, ensuring model accuracy, and enabling iterative refinement of the system design. The hardware commissioning is performed in a staged and risk-mitigated manner, starting from low-voltage and low-power operation and gradually progressing toward full-power operation up to 22 kW. This phase includes verification of power stage functionality, gate drive operation, sensing accuracy, and protection mechanisms, with a focus on the correct bidirectional blocking behavior of the novel GaN semiconductor devices.
Embedded software and control algorithms will be validated for stable operation, fault handling, and for transitions between charging and discharging modes. CAN communication interfaces and protocols will be tested to ensure interaction with vehicle control units.
Electrical performance validation includes efficiency measurements, power factor and harmonic distortion analysis, and characterization of the OBC over a wide operating range. In addition, electromagnetic compatibility will be evaluated through EMC measurements, including conducted emissions, to identify critical frequency ranges for filter and layout optimization. All testing and validation results are systematically documented, providing traceability between design objectives, simulation models, and experimental outcomes.

2.1.4.2 Bidirectional DC-DC converter

The validation of the proposed system architectures and bidirectional DC/DC converter solutions will follow a staged approach combining simulation, analytical modeling, and experimental verification. Initial assessment will be performed through detailed system-level and converter-level simulations to verify functionality, operating range compatibility, and bidirectional power flow under motoring, regenerative braking, and charging scenarios. Based on the selected architecture and topology, a laboratory prototype will be designed and built within the research organization and tested under controlled conditions. Experimental validation will focus on voltage regulation, power flow controllability, efficiency trends across representative operating points, and thermal behavior, in alignment with the defined voltage and power ranges. Prototype measurements will be used to validate simulation models, identify practical limitations related to control, losses, and integration, and support a comparative evaluation of semiconductor technologies and partial power processing concepts.

2.1.4.3 Current source inverter for auxiliary motor drive in vehicles

Two testing options are considered. One partner currently uses a system with two motors running against each other and a torque meter between them (maximum power 15 kW; motor 1 speed limit 8,000 rpm; developed motor speed 20,000 rpm; maximum torque 100 Nm). At the time of setup, no commercial motor capable of 20,000 rpm was available to match our developed motor, so a non-ideal pairing had to be used. A suitable commercial motor is now available and will be installed in the coming months, allowing the test bench to operate in a more optimal configuration.

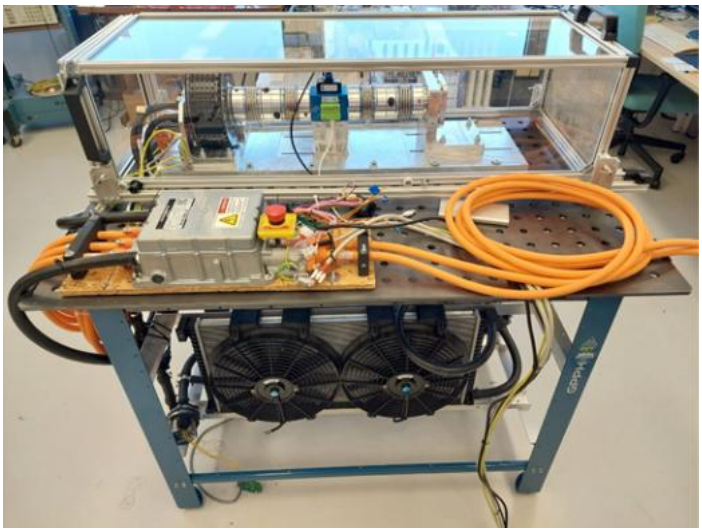


Figure 2-1: STUBA test bench for testing motors and inverters

The second option is to use services of an external lab, with a motor emulator, e.g., from AVL. Testing will start with standard static tests and then continue with double pulse tests for lower voltages. Temperature of all components will be monitored with an infrared camera. After initial, testing performance testing in torque and speed control mode will be performed.
Once validated at component level, the physical CSI prototype will undergo rigorous testing and validation in a realistic environment, thanks to a test bench provided by Politecnico di Torino. The identified target application for the demonstrator is an integrated smart actuator in the automotive chassis domain, such as active suspensions.



Figure 2-2: Actuator test bench

2.2 (UC2a) High-power hybrid multilevel Inverter (SiC and GaN)

2.2.1 Introduction

The use case will focus on the development and testing of a high-power density WBG based multilevel reconfigurable inverter with a state-of-the-art high-performance microcontroller and advanced control software. The inverter will be designed to operate with a target to increase this operating voltage as close to 1000 V as possible.
Main development areas of the inverter are as follows:

- Hardware:
- custom power stage including embedded power die,
    - smart gate driver,
    - ease of assembly,
    - optimized EMC performance, and
- Low-volume DC-link capacitor.
- Software:
    - high-performance TC4XX microcontroller,
    - field oriented control for eMotor,
    - 2-level and 3-level control for commutation, and
    - Integrated diagnostics.

2.2.2 Use Case Objectives and Targets

UC2a aims to design and manufacture a 3-level hybrid traction inverter to increase the efficiency of the inverter up to 99.5%. Compared with a two-level output, 3-level conversion will bring lower total harmonic distortion, reduced EMI and lower voltage stress on switches. In this application, UC2a stakeholders are evaluating the combination of SiC and GaN to utilize benefits of both semiconductor technologies. With this hybrid design, the objective is to use GaN for light load and balancing and keeping SiC for bulk power switching. Embedding wide-bandgap devices using ECP® technology is also going to improve thermal management and switching performance of power modules, thereby increasing overall system efficiency.
Another key goal in this use case is to investigate the use of bidirectional switches in an automotive inverter. Operational scenarios of an automotive inverter will be analyzed to determine if those can be met by bidirectional switches. On the other hand, BDS technology will be checked whether it imposes new challenges on EMC. UC2a is targeting 20% reduction in filter size while minimizing electromagnetic interference (EMI) and meeting tight European standards. EMC filter design will be also supported by AI tools
Regarding prognostics and health management (PHM), advanced machine learning methodologies for State-of-Health estimation of power electronic switches using multiple neural network architectures (CNNs, LSTMs, PINNs) with systematic hyperparameter optimization will be developed. A hybrid experimental-simulation approach will generate comprehensive training datasets through controlled power cycling tests of SiC MOSFETs and PLECS-based synthetic data generation replicating realistic automotive operating conditions.
A physics-based state-of-health (SoH) calculator is also being considered. The base is a finite element (FE) electro-thermo-mechanical simulation. The SoH calculator will be a surrogate model (neural-network-based) for the FE simulation combined with a counting method as well as a lifetime model.
Active thermal control strategies will be developed and integrated into the use-case thermal management framework, in coordination with WP5. These strategies will rely on real-time control systems enabled by digital-twin technologies or advanced sensor solutions. A further objective is the tight coordination between modulation and the cooling system, so that electrical and thermal actuators work together to keep devices within safe limits without oversizing hardware. For EV users, this enables more efficient and compact

converters with higher reliability, longer lifetime, and more dependable fast-charging and drivetrain performance.

2.2.3 Demonstrator: Scope and Functionality

The drivetrains of today's electric vehicle usually feature wide-bandgap semiconductor technology (SiC or GaN), reducing inverter switching losses to a minimum. However, another significant part of the overall electric losses in an electric vehicle's traction system is generated in the electric machine due to high-frequency currents that are caused by harmonic distortions. Since these distortions are the result of the switching pattern implemented in standard inverters, that is, alternating between two voltage levels ($U_{DC}/2$ and $-U_{DC}/2$), one possible approach is to introduce a third voltage level to reduce distortions by creating a more sinusoidal waveform that is applied to the machine windings. To achieve this functionality, different three-level inverter topologies have been proposed. For this project, the T-Type topology has been chosen, as it provides three-level functionality with a comparably low additional semiconductor count. Moreover, it is expected to benefit significantly from the use of bidirectional switching devices.
Figure 2-3 exemplarily shows one of the three half bridges of a T-Type inverter. The two additional switches (in comparison to a standard two-level voltage source inverter) are marked with Q2 and Q3, forming the so-called T-leg.

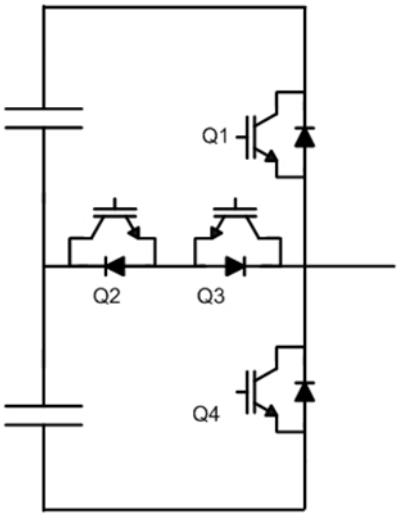


Figure 2-3: T-Type inverter topology

Using bidirectional switching devices, both Q2 and Q3 can be included in one single device, reducing conduction losses and required footprint on the power module.
Usually, switching devices in automotive traction inverters consist of a number of parallel individual switches (bare dies) to cope with the high current demands in an electric drivetrain. To achieve three-level functionality over the entire range of operation, also the additional semiconductors would need to be parallelized accordingly, leading to high space demand and cost. Since electric vehicles – like all passenger vehicles – are operated most of the time in low to medium load scenarios, it is more reasonable to dimension the T-leg switches to a limited maximum current. In those scenarios where maximum current performance is needed (acceleration, hill climb, etc.), the inverter would then be operated in two-level mode, with the T-leg switches turned off. Thus, the benefits of the three-level topology can be achieved with only a fraction of the semiconductor effort and cost.
As an efficiency improvement, a 1-2% reduction in energy consumption is expected in the WLTP cycle for the 3L compared to the 2L. An exemplary differential map of engine losses is given in Figure 2-4.

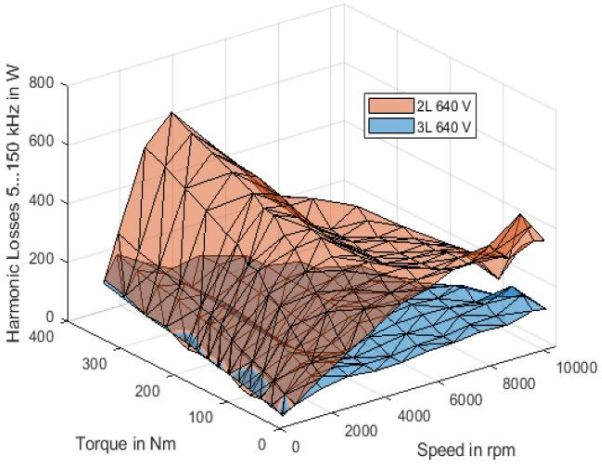


Figure 2-4: Comparison of 2- and 3-Level harmonic losses of the electric motor (Sierts, J. Allgeier, F. Stamer, "Efficiency increase of electric drives by use of multilevel inverters and permanent magnet synchronous motors", DriTev, Baden-Baden, Germany, 2024)

2.2.4 Testing and Validation Specification

To determine the efficiency of the 3L-inverter, measurements will be conducted on an electric machine test bench at Mercedes-Benz. The test bench is depicted in Figure 2-5. The performance data of the test bench can be found in Table 2-1.



Figure 2-5: E-Machine Test Bench at Mercedes-Benz

Parameter	Value
max. Speed	20000 rpm
max. Torque	680 Nm
cont. Torque	545 Nm
Maximum Power	500 kW
Continuous Power	400 kW
Maximum Voltage	1000 V
Maximum Current	1200 A

Table 2-1: E-Machine Test Bench Parameters

The machine has been adapted to the test bench, and it is possible to measure the rotational speed, torque, and AC currents and voltages using a Yokogawa WT5000. With this equipment, the efficiency of the machine can be determined. Furthermore, the DC current and voltage are measured. In combination with the AC measurement, the efficiency of the inverter can be obtained. From these two efficiencies, overall efficiency can then be calculated.
By operating the Inverter in 2-level and 3-level mode two different efficiency maps can be obtained. From this, a comparison between 2- and 3-level can be readily made. Other operating modes, such as active short circuits or idle operation, can also be tested to verify the robustness of the inverter against fault conditions. Rapid setpoint changes or step responses can be applied to the inverter to test and verify the control algorithms. If necessary, the transient behavior of the currents can be evaluated for this purpose.

2.3 (UC2b) Fusion + GaN T-Type Inverter

2.3.1 Introduction

In the current automotive market, 400 V battery systems remain prevalent, particularly in smaller vehicles. This use case investigates existing power semiconductor devices and proposes a solution to address the market need to reduce overall costs, enhancing efficiency and minimizing the CO_2 footprint. To achieve this, various power semiconductor technologies will be evaluated for their feasibility across different topologies. Additionally, a fusion inverter that integrates multiple technologies will be developed to optimize performance in this context.

2.3.2 Use Case Objectives and Targets

In this use case, a 400 V T-Type inverter will be developed. This solution will support selecting and evaluating the most suitable power semiconductor technology to best meet the needs of the 400 V vehicle class. To enable high efficiency and assess its impact on the CO_2 footprint, investigations will be carried out to include the effects of real-world driving scenarios along with implemented maximum peak power.
Additionally, to reduce electromagnetic interference (EMI) while maintaining efficiency, the integration of smart gate drivers will be studied. These smart gate drivers can potentially provide in-situ measurements that are important for monitoring the aging and degradation of a power semiconductor device. To achieve this, novel gate driving concepts will be implemented and evaluated, with a focus on their integration for commercial automotive applications.
After the completion of this project, the end user can benefit from lower cost, higher efficiency, reduced environmental impact, and improved overall system reliability.

2.3.3 Demonstrator: Scope and Functionality

In Figure 2-6, the topology of a T-type Inverter is presented. This design uses power semiconductor devices on the horizontal legs, which allow bidirectional current flow. These devices can be connected in either a common-source or common-drain configuration. The topology supports two operating modes: when efficiency is the focus, the horizontal leg is involved in the commutation, resulting in a 3-level operation. When high power is the priority, only the vertical legs are involved in commutation, forming a B6-bridge, also known as 2-level operation. When high power is the priority, only the vertical legs are involved in commutation, forming a B6-bridge, also known as 2level operation. This flexibility allows for the integration of different power semiconductor technologies in-level operation. This flexibility allows for the integration of different power semiconductor technologies in a single solution.

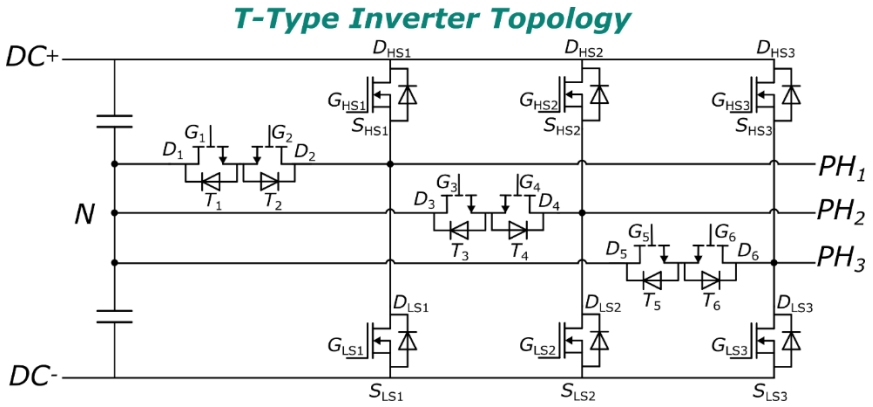


Figure 2-6: T-Type Inverter Topology

For this particular use case, the impact of different semiconductor technologies on CO_2 emissions will be analyzed. This consideration will be integrated from the start of the design process. Efficiency will be evaluated using both the WLTP drive cycle and an OEM-specific drive cycle to assess performance at different

output power levels. This approach aims to find an optimal balance between CO_2 footprint during production, customer costs, and drivetrain efficiency.
Additionally, the influence of volume on the degree of electronic embedding will be investigated. This includes incorporating additional functionality and features directly onto the PCB to achieve a favorable cost-to-size ratio. Efficiency tests on the physical prototype will be performed and compared with simulation results. A benchmark with other inverter designs will also be conducted to assess the differences between approaches.
The inverter will be controlled using a model-based approach. Control algorithms will be developed and tested with a particular focus on managing neutral-point balancing in the inverter-based approach. Control algorithms will be developed and tested with a particular focus on managing neutral point balancing in the inverter.

2.3.4 Testing and Validation Specification

For the purpose of testing, several tests are planned for use case validation.

2.3.4.1 Commutation Cell Characterization: double-pulse test

To characterize the switching behavior and loss profile of the commutation cell in each inverter leg, double-pulse tests will be performed. These tests will cover all possible current paths in the power module during switching. The measurement procedure will include capturing turn-on and turn-off waveforms, voltage overshoot, and switching energy. A preliminary test setup for a single T Bridge is shown in Figure 2-7, with the load inductor connected to the high-side switch. This will allow benchmarking of different semiconductor technologies under identical switching conditions.

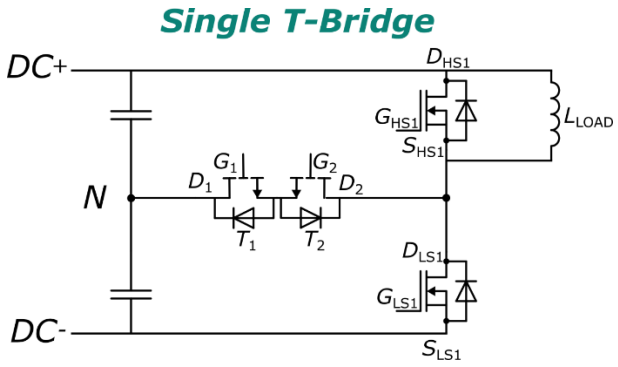


Figure 2-7: Individual T-Bridge with load inductor

2.3.4.2 System-Level Efficiency and Performance Test

The complete inverter will be validated on a motor test bench. The inverter will drive an electric machine under controlled loading conditions. Efficiency and performance will be measured using both the WLTP drive cycle and an OEM-specific drive cycle. Output torque, speed, current, voltage, and switching losses will be recorded. The test setup for this configuration is illustrated in Figure 2-8.

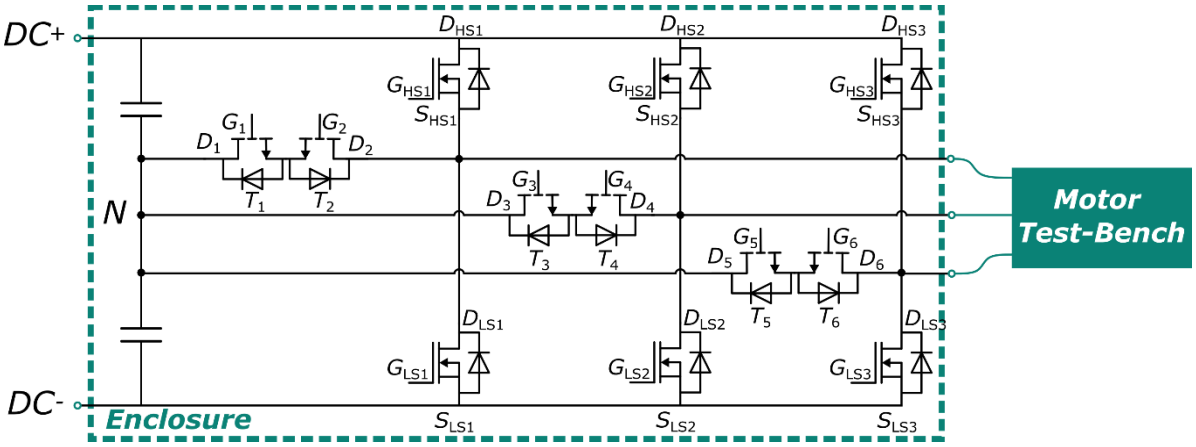


Figure 2-8: Connection to the Motor Test-Bench

2.3.4.3 Safety and Control Function Validation

These tests will ensure reliable and safe operation of the device. All implemented safety features (overcurrent, overvoltage, thermal protection) will be intentionally triggered under controlled conditions to verify the correct response. The control logic on the PCB will be evaluated for neutral point balancing performance and fault handling.

2.4 (UC3a) LD auxiliaries converter

2.4.1 Introduction

The scope of the use case 3a is to develop prototype auxiliary converters based on the next generation of power devices for 800 V HV-Box for passenger car requirements, with a focus on a bidirectional on-board charger (V2G) and integrated DC/DC converter for 12 V, using new GaN and embedded PCB Chips (general overview Figure 2-9).

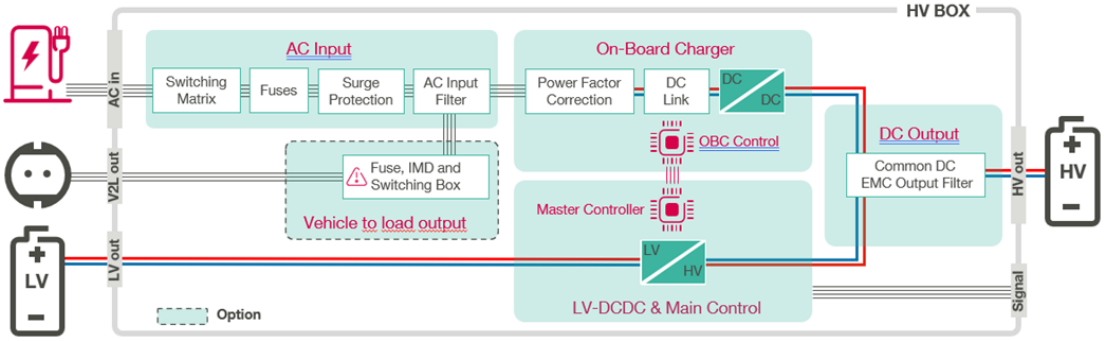


Figure 2-9: LD auxiliaries converter overview

2.4.2 Use Case Objectives and Targets

In UC3a, Schaeffler (Old Vitesco) and its partners will assess the 850 V MBDS GaN chips from Infineon as well as the 1200 V Smart discrete p-GaN Gate HEMTs provided by IMEC and the 1200 V GaN HEMTs Gate Recess from CEA, all being embedded as bare die in the PCB by AT&S. These new technologies should allow for power density above 2 kW/l, but also the capability to address the 800 V battery without having to increase the topology levels (e.g., multi-level) on the converters.

KPI UC3a	Baseline UC3a	Target UC3a
Bidirectional chip assessment for auxiliary converters	Bidirectional switches SiC	Bidirectional switches GaN
Switch technology	Silicon / SiC	GaN
Power density (kW/l)	< 2kW/l	> 2kW/l
Voltage Capabilities for 800 V battery	Silicon / SiC	1200 V GaN
Frequency	<100kHz	>100kHz
Efficiency 50-100% load	94%	96%

Table 2-2: Envisaged KPIs for UC3a

The main benefits expected for these new GaN chip technologies (1200 V and 850 V BDS) for the use case converters are efficiency conversion increasing and final product size reduction.

2.4.3 Demonstrator: Scope and Functionality

For **Use Case 3a (UC3a)**, the project will define and specify GaN based power converter topologies in close collaboration with the project partners. These specifications will enable the integration of **embedded 1200 V GaN dies into PCB based AC/DC and DC/DC converters**, including the associated EMC filtering concepts and the definition of suitable magnetic components for the different power conversion stages. The converter concepts will be fully validated through simulation to assess electrical, thermal, and EMC performance prior to hardware realization.

A key focus of UC3a is ensuring robust **thermal behavior of embedded GaN dies** through optimized cooling concepts, enabling high power density operation while maintaining reliability. The use case will therefore address critical technical challenges related to **efficiency improvement**, **reliability**, and **high-performance cooling of embedded semiconductor devices** in compact PCB assemblies.
By the end of the project, UC3a will deliver **fully designed and tested PCB converter boards**, providing experimentally validated evidence of efficiency gains, thermal performance, and integration feasibility. These results will establish a solid technological basis for further system-level integration and industrial exploitation.

2.4.4 Testing and Validation Specification

Testing and validation activities will ensure correct functionality, robustness, and performance of the developed hardware. Prior to mechanical assembly, essential hardware functions such as auxiliary power supplies, CAN communication, and PWM signal integrity will be verified to enable early detection and correction of integration issues. The prototype validation will include comprehensive electrical, thermal, and efficiency testing. **Double Pulse Testing (DPT)** will be performed to characterize the electrical behavior of the GaN dies, with a particular focus on switching energies through detailed drain-source voltage and current measurements. The measured parameters will be compared with supplier specifications to validate device performance. In addition, **$R_{DS(on)}$ variation with temperature** will be characterized, and **DC/DC operation tests** will be conducted to assess overvoltage behavior during switching. Thermal characterization will include measurements of the **junction to coolant thermal resistance ($R_{thjcoolant}$)**, followed by progressive **power testing from zero to full load**, combined with thermal and efficiency measurements.
After initial electrical validation, the system will be mechanically assembled with the PCB mounted onto the cooling plate, including verification of the complete thermal stack-up and screw fixation. **Dielectric testing** will then be carried out to ensure proper insulation and to identify any weaknesses related to PCB layout, hardware, or mechanical design. To precisely monitor device temperatures, thermal or optical probes will be implemented for **direct GaN junction temperature measurement**.
Initial powered operation will be performed in DC/DC mode in order to quantify switching-induced overvoltage. The gate resistance values for turn-on and turn-off will be optimized to limit Drain-Source overvoltage while maintaining switching performance. Final validation will consist of **full power tests**, confirming stable thermal behavior of the GaN dies and overall system performance under nominal and extreme operating conditions. The envisaged testing setup and environmental conditions will be defined to ensure repeatability and relevance for the targeted application.

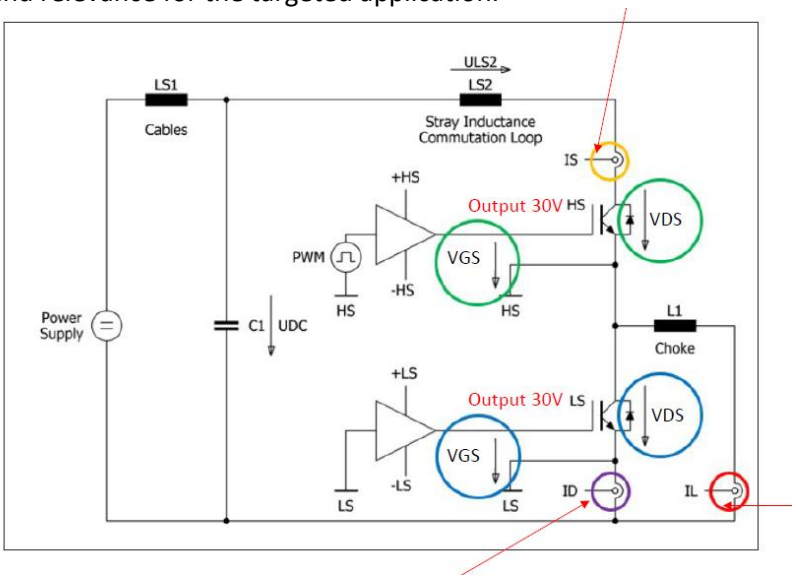


Figure 2-10: Testing set up principle for double pulse test

To perform all those tests, some specific equipment is needed:

- Adapted HV bench including protection and safety
- 15KW, AC Grid generator.
- 15kW, 800V DC supplies 15KW
- Coolant equipment with water glycol (Chiller)
- Current & voltage probes
- Double pulse test bench



Figure 2-11: Test equipment (top HV testbenches; middle: current and voltage probes; bottom: DPT test bench)

2.5 (UC3b) HD auxiliaries converter

2.5.1 Introduction

In use case 3b, the partners are working together on the developments around a DC/DC converter for heavy duty e-mobility. The focus will be on lifetime, as the durability requirements for commercial and heavy-duty vehicles are about 10 times higher than for passenger vehicles and the environmental severity is significantly higher than for passenger cars, for example due to vibrations. Auxiliary converters for passenger applications are already moving towards SiC switch technology, allowing for higher power densities and lower losses. The goal of the prototype development and validation is to demonstrate the feasibility of the next-generation WBG devices in these heavy-duty applications. The partners will contribute in power electronics, thermal management, control methods (including model predictive control), and WBG device evaluation.

2.5.2 Use Case Objectives and Targets

The expected outcome of these developments is to demonstrate the full capability of WBG technologies for auxiliary converters for heavy-duty vehicles. The expected benefits include a power density increase (O2) without compromising efficiency (O1), lifetime, and affordability of the solutions (O3). This will be heavily supported by digital tools as are in focus of O4. Specifically for commercial and/or heavy-duty vehicles, the targets comprise practical aspects like a small physical footprint, high efficiency of 97% with a power output of up to 5kW, and maximum extended lifetime of over 80.000 hours. These are critical for commercial truck applications and support the transition to zero-emission transport and logistics. Within these applications, industry standards are considered, fitting the mission objective of the product. For example, the components are chosen in such a way that safety is guaranteed in every scenario. This includes the choice for aptiv watertight plugs on the LV side and TE connectors on the HV side which guarantee safety in higher altitudes, both can be seen in the image below.

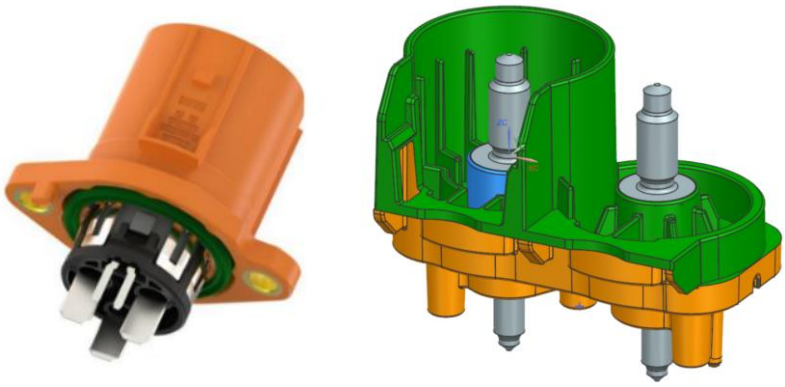


Figure 2-12: TE HV connector and aptiv LV plugs for safety and standardization

2.5.3 Demonstrator: Scope and Functionality

The UC3b demonstrator will implement a bidirectional DC/DC converter for heavy-duty e-mobility applications, designed to meet stringent durability and efficiency requirements. Key characteristics are:

- Rated power: 5 kW
- Bidirectional DC/DC topology
- Cooling: Water-cooled, using 50/50 glycol-water mix from truck cooling circuit
- Optimized for long lifetime and high-power density

Additionally, the partners will deliver research results on the topics of digital twins, WBG power devices and model predictive control for power converters. All this is to be carried out with industrial standards in mind. Based on these specifications and due to longer lead times, initial work has been done on the housing and

cooling concept using the water-cooling methods. Figure 2-13 gives an initial view of the housing and connectors, as well as the cooling channels and simulations.

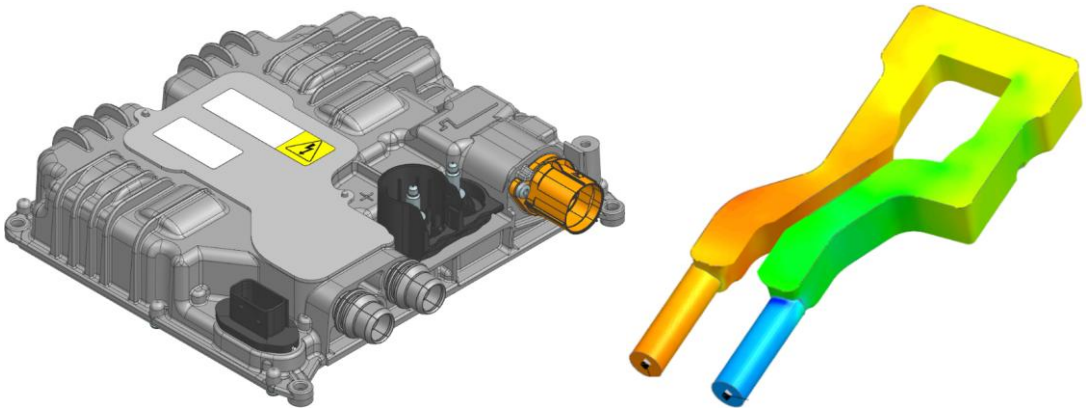


Figure 2-13: Converter housing and cooling concept and simulation

Additionally, options to broaden the scope of the architecture might include work on increasing the number of converters in parallel in the system to achieve higher voltages, as shown in Figure 2-14 below.

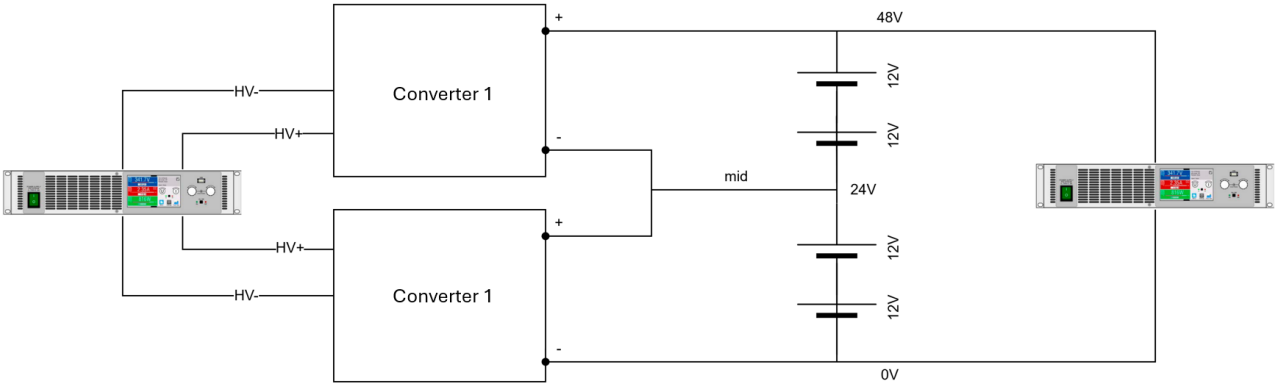


Figure 2-14: 48V parallel converter concept

2.5.4 Testing and Validation Specification

The designed and prototyped heavy-duty converter will be tested and validated on a variety of factors. To start, the prototype will be tested on electrical and functional properties. To test efficiency, the converter will be validated on a test bench with controlled input and output parameters to assess performance in a relevant environment. Furthermore, the converter will undergo lifetime testing, assessing the WBG switch lifetime. Additionally, several automotive standard test protocols will be caried out, like shock and vibration testing, climate testing (humidity and temperature) and EMC testing. All tests will be carried out in Prodrive's in-house and accredited test facilities as seen below.



Figure 2-15: Prodrive EMC lab, climate chambers, and in-house developed automatic electrical testers (AET)

2.6 (UC4a) EESM with integrated inverter

2.6.1 Introduction

Main objective of Use Case 4a (UC4a) is to develop and evaluate integrated eDrives for automotive applications, specifically focusing on an Electrically Excited Synchronous Machine (EESM). This evaluation will be conducted through a comparison of a standard permanent-magnet synchronous motor (PMSM) with two distinct power electronics technologies: a “State-of-the-Art” (SOTA) SiC based system and a novel “GaN based System”. A key aspect of this use case is the head-to-head comparison of the two different power electronics architectures driving the same rare-earth-free EESM motor. This motor architecture requires a more complex electronic drive system featuring two independent inverters: one dedicated to the stator winding and a separate one for the rotor (excitation) winding.

The GaN System specifically focuses on the following project goals:

- Improved eDrive Components
- Decrease carbon footprint: 30 % compared to a standard PMSM
- Increase driving range (distance): 2% compared to a standard PMSM
- System efficiency increase by 3% at low-torque operation, combined with improved THD
- 20% increase in power density compared to an EESM with brush (axial length reduction by the size of brush system)
- Digital tools supporting the twin transition for next-generation Wide Band Gap (WBG) technologies based eDrivetrains.

The SOTA System Baseline and Targets:

The SOTA System serves to establish a high-performance baseline against which the GaN System will be compared. Its key performance targets, based on the HiPower 5.0 Motor concept, are:

- **Peak Power:** 320 kW @ 650 V
- **Peak Torque:** 600 Nm @ 650 V
- **Estimated Motor Efficiency (for WLTC):** 96.15% (Motor only)

2.6.2 Use Case Objectives and Targets

This use case targets the development of a **next generation, rare-earth-free electric drive system** that significantly improves efficiency, sustainability, reliability, and cost competitiveness of high-power electric vehicles. The core innovation is a **320 kW brushless electrically excited synchronous motor (EESM)** combined with advanced power electronics, contactless rotor excitation, and compact two-phase cooling.
A key technological breakthrough is the replacement of conventional, wear prone slip rings with an **integrated Wireless Power Transfer (WPT) system** for rotor excitation. This contactless solution, embedded in the hollow rotor shaft, increases reliability and reduces lifetime maintenance costs.
In parallel, a **high-frequency Gan-based WPT concept** is developed to demonstrate the scalability and future performance potential of the approach.
To enable high continuous power and torque density, the project integrates **two-phase microfluidic cooling** directly into the stator and inverter. This allows a substantial reduction in cooling system volume and mass while improving thermal stability and component lifetime.
Power electronics performance is further enhanced by benchmarking a **state-of-the-art SiC 2-level inverter** against an **innovative GaN-based multilevel inverter**, providing quantifiable insights into efficiency gains and harmonic reduction.
The project delivers strong **economic and strategic benefits** by eliminating rare-earth permanent magnets, thereby reducing exposure to material price volatility and strengthening European industrial sovereignty. The

combination of contactless excitation and advanced thermal management increases system robustness and lifetime, lowering total cost of ownership.
Overall, the proposed solution directly supports European climate and sustainability objectives by reducing carbon footprint, improving energy efficiency, and avoiding critical raw materials, while simultaneously enhancing vehicle performance and industrial competitiveness.

2.6.3 Demonstrator: Scope and Functionality

A core element of this use case is the direct comparison of two distinct power electronics architectures driving the same rare-earth-free EESM motor. This particular motor, due to its nature, necessitates a more complex electronic drive system comprising two independent inverters: one dedicated to the stator winding and another for the rotor winding (excitation).

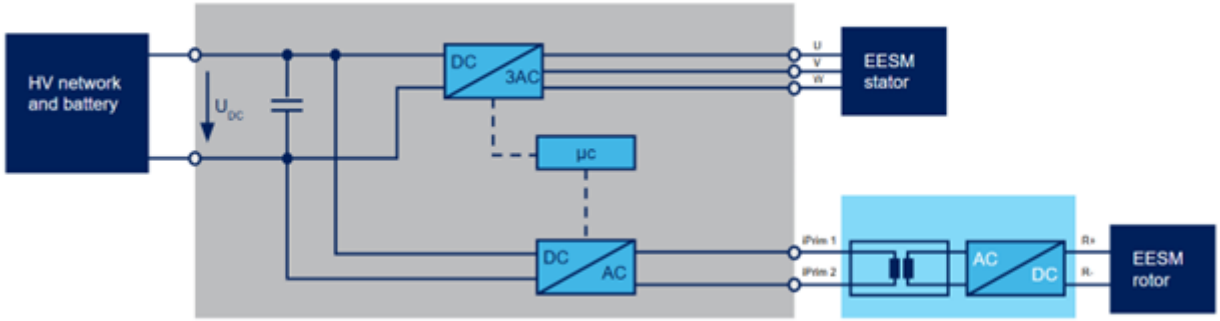


Figure 2-16: System overview to drive an EESM motor

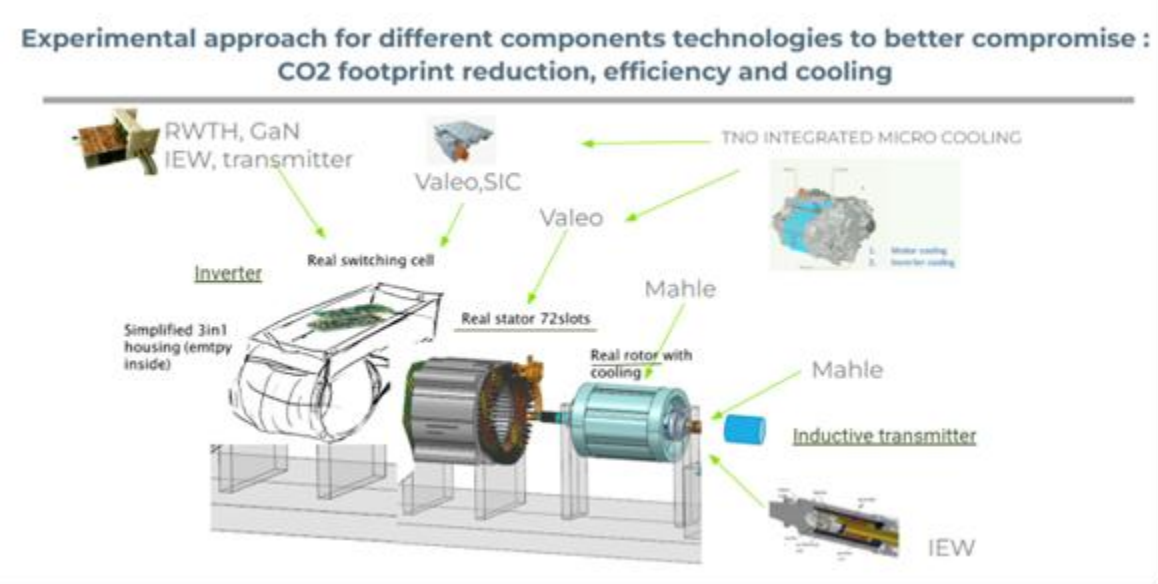


Figure 2-17: High-Level view of the developments and partner responsibilities

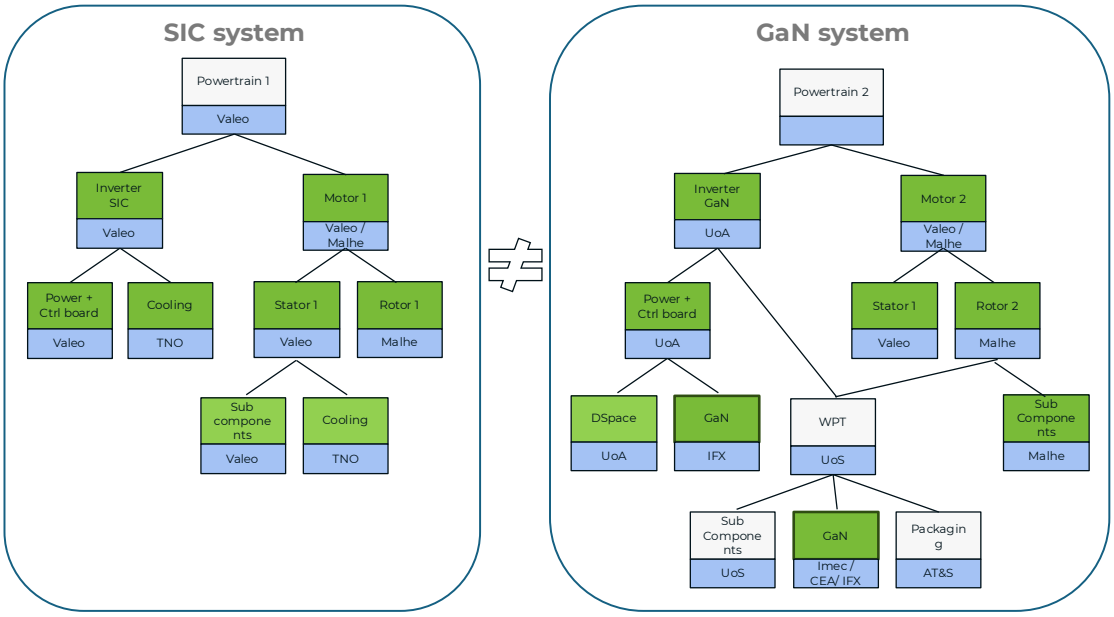


Figure 2-18: Comparison of the 2 systems divided into sub systems:

GaN-based inverters are currently not fully recognized for their efficiency advantages in the lower switching frequency range typical of automotive applications (0–20 kHz). This project addresses this gap by exploiting the **synergistic combination of a brushless EESM and GaN inverter technology**, which is expected to outperform the current state-of-the-art drive systems in key functional metrics, including efficiency, harmonic behavior, and system integration.

To eliminate wear prone slip rings, the project develops a **contactless inductive Wireless Power Transfer (WPT) system** for rotor excitation. The main technical challenge lies in transferring high electrical power within a highly compact space while effectively managing thermal loads. In parallel, a **high-frequency (>500 kHz) GaN-based WPT system** is developed to explore the technological limits and future scalability of this approach.

The high power density of the EESM and the tight integration of the inverter impose significant thermal challenges. To overcome the limitations of conventional single phase liquid cooling, the project introduces a **highly compact two-phase microfluidic cooling concept** for both stator and inverter, enabling superior heat transfer, reduced cooling system volume and mass, and improved component lifetime.

By the end of the project, Use Case 4a delivers **two fully integrated eDrive demonstrator systems at TRL 4/5**, moving beyond theoretical concepts toward experimentally validated solutions. Both demonstrators will be available for extensive testbench validation. The GaN inverter demonstrator will leverage **next-generation BDS GaN power modules** provided by the project partners, ensuring technological relevance and a clear pathway toward industrial adoption.

2.6.4 Testing and Validation Specification

State-of-The-Art (SOTA) system, which incorporates the high-power motor and SiC inverter, will be tested at a dedicated Valeo facility. This testing will be conducted on a specialized test bench specifically engineered and equipped to safely and effectively handle the high power and unique operational characteristics of this motor class. Different tests will be performed as Performance Validation, Thermal Management, Software and Control Unit Validation. Similarly, the GaN system will be tested at RWTH Aachen University facility.



Figure 2-19: Testbenches for UC4a

The first proposal for the performance test cycle is based on the **WLTP (Worldwide Harmonized Light Vehicles Test Procedure)**, defining a set of representative operating points (OPs) under motoring (M) and generating (G) conditions.

2.7 (UC4b) High-power HV integrated in-wheel drive system

2.7.1 Introduction

Use case 4b (UC4b) addresses the development of a high-power, high-voltage (400–850 V) integrated in-wheel drive system for next-generation electric vehicles, targeting mainly automotive applications and advanced mobility concepts. The use case focuses on the tight integration of a wide-bandgap (WBG) power electronics inverter (GaN/SiC) directly with an in-wheel motor (IWM), combined with a shared, smart thermal management system and advanced digital intelligence.

The motivation behind this use case stems from the increasing demand for zero-emission, energy-efficient, compact, and modular drivetrain solutions. Conventional drivetrain architectures relying on centralized motors and silicon-based inverters face inherent limitations in efficiency, power density, thermal performance, and scalability. In contrast, in-wheel motor concepts offer enhanced modularity, packaging flexibility, and vehicle dynamics, but their widespread adoption has been constrained by challenges in power electronics integration, thermal management, reliability, and lifetime.

UC4b leverages bidirectional GaN and SiC devices, advanced packaging and embedding technologies, smart sensing, AI-enabled control and condition monitoring to overcome these limitations and to include prognostic health management (PHM). The use case aims to push the technology readiness level from early prototype stages to system-level validation, demonstrating a fully integrated, intelligent in-wheel drive suitable for future high-voltage electric drivetrains.

2.7.2 Use Case Objectives and Targets

The primary objective is to design, implement, and validate a fully integrated high-power HV in-wheel motor drive system that significantly outperforms current state-of-the-art solutions in terms of efficiency, power density, and lifetime. Concerning the integration of WBG-based power electronics, this use case targets the development of a compact inverter using new (bidirectional) GaN and/or SiC devices, integrated directly with an in-wheel motor, replacing conventional silicon-based solutions. By leveraging advanced PHM, with specific sensorics and 'intelligent' components, this use case will demonstrate AI-based lifetime predictions and real-time (system-of-systems) monitoring. For this, an edge-cloud PHM framework is implemented, including in-situ GaN degradation indicators (e.g. online $R_{DS,on}$ measurement).

Technical objectives quantification and summary are provided below and presented in Table 2-3:

- High-voltage operation
  Extension of the DC-link voltage from today's ~400 V, ranging up to 850 V, enabling compatibility with future EV architectures.
- Efficiency improvement
  Increase overall system efficiency from a baseline of approximately 91% up to 93%, through optimized topologies, WBG devices, and advanced control.
- Power density enhancement
  Achieve a 5–10% increase in power density compared to existing non-integrated IWM solutions with external inverters. By reducing volume and increasing power handling.
- Lifetime and reliability extension
  Demonstrate up to 20% improvement in drivetrain lifetime (targeting ~300,000 km equivalent mileage), supported by physics-of-failure-based reliability models and mission-profile testing.

KPI UC4b	Baseline UC4b	Target UC4b
Switch technology	Silicon	GaN SoC / MBDS GaN / MBDS SiC
DC voltage	Up to 403 V	400 V – 850 V
Power	67 kW	80 kW – 100 kW
PHM (Prognostic Health Management)	Only Tj-based derating	Intelligent edge-cloud PHM strategy (in-situ $R_{DS,on}$ measurement) & secure cloud-connectivity with real-time system of systems (SoS) assessment
Power density	1.53kW/Kg	Increase by 5% - 10%
System efficiency	91%	93%
Intelligent monitoring and control	MPC, FOC	AI, NN, PHM, HMI, SoS
Reliability of motor drive	250,000 Km	Increase by 20%

Table 2-3. Envisaged KPIs for UC4b *(AI: Artificial Intelligence, NN: Neural Network, HMI: Human Machine Interface)*

After completion of the project, end users will benefit from more energy-efficient electric drivetrains, directly translating into extended driving range or reduced battery size. Also, a validated demonstrator concept for compact and modular in-wheel drive solutions, with insights enabling flexible vehicle architectures and improved vehicle dynamics. The added intelligence, lifetime models and PHM framework will show improved reliability and reduced maintenance needs. Moreover, the prototype will demonstrate enhanced safety and availability, with early fault detection and fault-tolerant control algorithms. This use case provides a future-proof drivetrain platform compatible with upcoming high-voltage EV standards and digitalized vehicle ecosystems.

2.7.3 Demonstrator: Scope and Functionality

Scope and Implementation

The UC4b demonstration consists of a fully integrated inverter–motor assembly, based on an Elaphe high-power in-wheel motor platform, augmented with a next-generation WBG inverter with a shared cooling loop (oil-based coolant) and sensing equipment.
The implementation can be structured in two main parts: the integrated hardware platform and the intelligence, control and connectivity layer.

Part I – Integrated Hardware Platform: This encompasses the design and realization of a modular inverter using bidirectional GaN/SiC devices, with topology candidates such as Voltage Source Inverter (VSI), T-Type, Neutral Point Clamped (NPC), or Current Source Inverter (CSI) evaluated through high-fidelity multi-physics simulation models. To fully integrate the developed inverter in a compact way, we focus on smart packaging and embedding of power devices and gate drivers, including integrated sensing capabilities. For thermal management of the integrated eDrive, the demonstrator includes the development of a shared cooling system for motor and inverter, potentially oil-based, with a smart heatsink embedding self-powered temperature sensors. Finally, for the planned leveraging of digital twins and intelligence, we foresee the integration of high-bandwidth, isolated sensors for voltage, current, and temperature at device, PCB, and heatsink level.

Part II – Intelligence, Control, and Connectivity: The use case demonstrator will operate with implementation of advanced hybrid control strategies, combining Model Predictive Control (MPC) with self-learning AI models to optimize efficiency and reduce device stress. It will serve as an experimental platform for the developed in-situ condition and health monitoring unit, integrated into the gate-driver circuitry. This setup will demonstrate the deployment of an edge–cloud architecture, enabling secure data transmission, AI-based performance assessment, and real-time visualization through a human machine interface (HMI) and web-based system-of-systems dashboard.

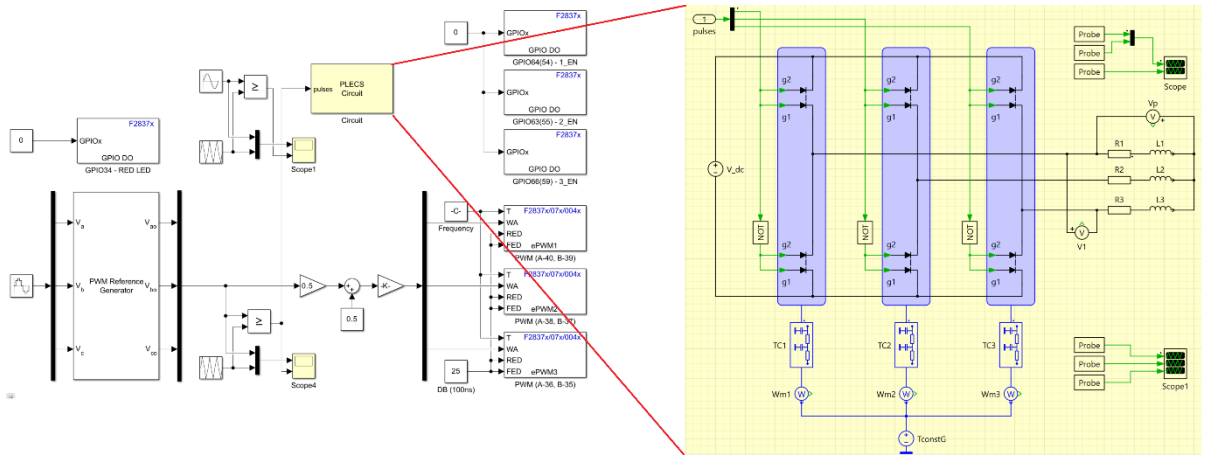


Figure 2-20: Inverter model designed in PLECS and control in Matlab

As such, this demonstration explicitly handles several key challenges:

- Thermal management under high power density and harsh in-wheel environments, including vibration and brake-induced thermal stress.
- Reliable operation of newly developed Bidirectional WBG devices under real automotive mission profiles.
- Accurate online health monitoring of Bidirectional WBG devices using indirect degradation precursors.
- Co-design of power electronics, control, cooling, and reliability within strict volume and mass constraints.

End-of-Project Features and Functionalities

At project completion, key demonstrator features and functionalities are a validated HV in-wheel drive system with integrated WBG inverter and shared cooling; AI-enhanced control with real-time efficiency and lifetime optimization; embedded and cloud-based PHM with real-time visualization of system health and performance; and demonstrated KPIs for efficiency, power density, and lifetime beyond the current state of the art.

2.7.4 Testing and Validation Specification

Validation of the UC4b demonstration will follow a multi-level testing strategy, combining simulation with test feedback loops, laboratory experiments, and long-term reliability testing. With first design models and test samples realized with the devices developed in WP2, Model-in-the-Loop (MiL) and Hardware-in-the-Loop (HiL) tests will be executed to validate control algorithms, (system) performance and digital twin simulations. The developed inverter prototype will be foremost evaluated for electrical performance, and then combined electromechanical testing is planned of the inverter–motor system under representative operating points and mission profiles. To validate the innovative cooling concepts, thermal characterization of the integrated cooling system design using embedded sensors and external measurement equipment will be performed. For PHM validation, tests will be carried out through induced degradation and fault scenarios, verifying detection, prediction, and visualization capabilities. On device level, the embedded switches can undergo reliability testing including power cycling, thermal shock, vibration tests, and mission-profile-based lifetime assessment.

The final integrated eDrive test setup and environment include a dedicated in-wheel motor test bench with controlled mechanical loading. This test bench is supplied with a high-voltage Bidirectional DC supply or Battery emulator (up to 1200 V) and programmable load conditions. The control will be implemented on a rapid control prototyping dSPACE or equivalent real-time control platform for advanced control and data

acquisition. Finally, to handle the sensors and measured data for digital twin and PHM purposes, we foresee the establishment of a secure edge–cloud infrastructure for real-time data streaming, analytics, and visualization.

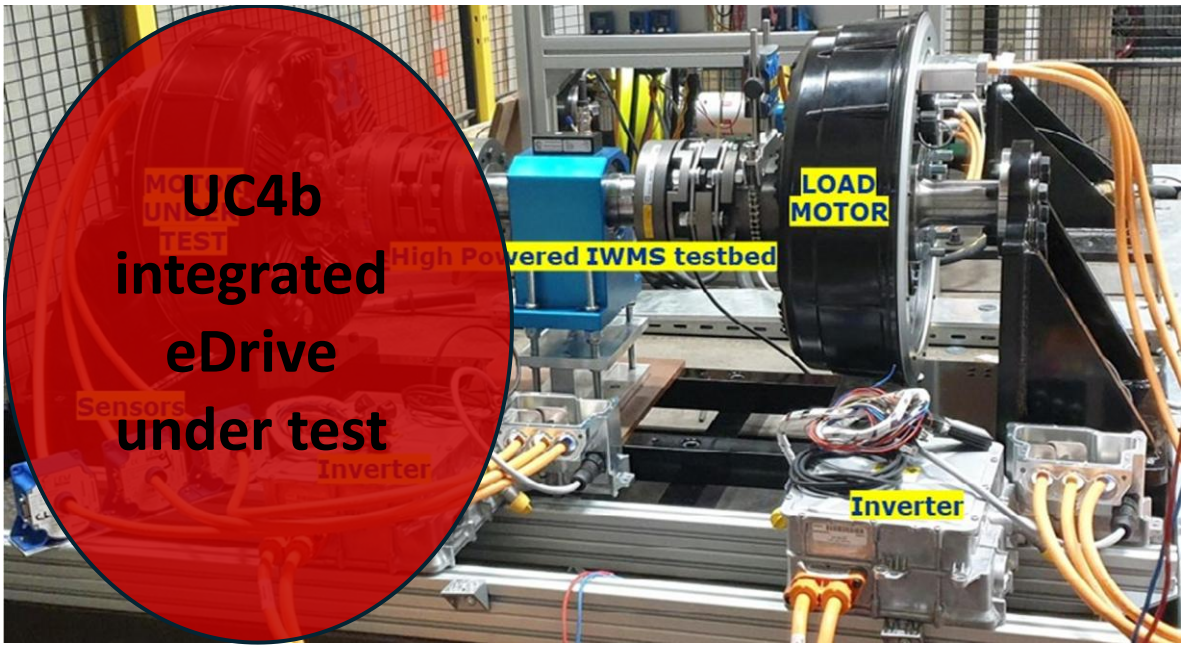


Figure 2-21: In-wheel motor system test bench

2.8 (UC5) Assessment of future GaN Technologies in multi-level Inverters by multi-physics multi-scale Simulation

2.8.1 Introduction

UC5 aims to explore the interest of future GaN technologies by using System and Technology Co-Optimization (STCO), this approach is presented in Figure 2-22. This approach has two objectives. The first one, from a system point of view, is to benchmark the potential interest of these new technologies for the system. By comparing the targeted performances of these technologies to state-of-the-art technologies, one can follow the new technologies development for their future integration. The second objective being the definition of targets for the technology itself. The system defines the requirements for the technology; one can then define a roadmap for the technology development. These two aspects will be addressed in the UC5.

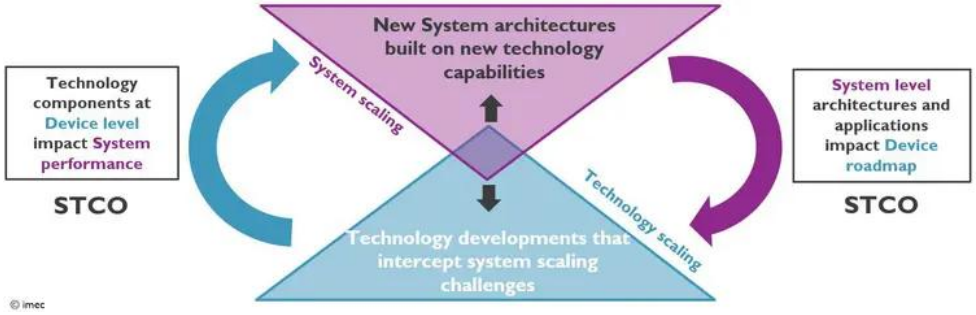


Figure 2-22:STCO Approach[1]

2.8.2 Use Case Objectives and Targets

The main objective of UC5 is to quantify, via simulation, the benefits that future generations of GaN devices can bring to EV traction multilevel inverters. For this purpose, a simulation platform will be developed in the project to explore the future performance of the system including these future GaN devices. The simulation platform will perform electro-thermo-mechanical analyses and will give performances related to a mission profile from C-segment inverter, able to drive a 150 kW class 800 V e-motor.
In this way, the most promising three-level topology candidates will be selected, and several semiconductor technologies will be compared in the same environment. Each inverter design (power module, component sizing, thermal design…) will be optimized separately and the performance of both designs will be compared to define the most appropriate one.
The main targets and Figure of Merits for the technology comparison are listed below:

- The inverter stage efficiency needs to be competitive with current EV inverters. In this way, 99.4% efficiency for steady-state 130 km/h driving conditions is targeted. Designs and component sizing will be defined according to this target without oversizing the devices to limit the environmental impact of the system.
- The ageing and parameter drift of components in the system must be low enough to allow good performance of the system after 20 years. Semiconductor junction temperature will have to be limited to ensure an acceptable semiconductor parameter drift over this period.
- Life cycle assessment (LCA) will be calculated for all the designs; this aspect will be considered to size the components to reach efficient performances by minimizing the inverter environmental impact.

[1] https://www.imec-int.com/en/articles/unlocking-system-scaling-bottlenecks-system-technology-co-optimization

2.8.3 Demonstrator: Scope and Functionality

The demonstrator developed in the UC5 will not be a physical prototype but a simulation platform to explore the design and performance of a multilevel traction inverter. As inverter electrical performance (efficiency), junction temperature of the device and inverter ageing will be compared, the simulation platform will be based on electro-thermo-mechanical simulations. The flow chart of this simulation platform is shown in Figure 2-23.

The key technical challenge is obtaining representative models to extract relevant results with acceptable simulation time. This is difficult since the time constants of the system are different (ns for electrical, ~s/min for thermal, ~days/week/month/years for mechanical one). A good agreement between Finite Element Models (FEM), Reduced Order Models (ROM) and Neural Network models (NN) will be set to optimize both simulation precision and time.

The models required for the simulation demonstrator will be developed by several partners from the consortium. Semiconductor devices, ageing/parameter drift of semiconductor devices, power module parasitics, power module thermal impedance, cooling system and ageing of the assembly (power module + cooling system) will be modeled in UC5. All models will be integrated together in the simulation platform.

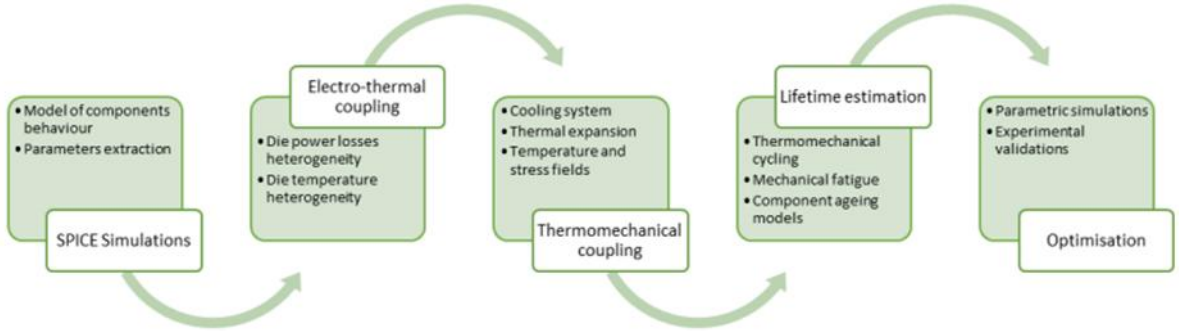


Figure 2-23: Simulation platform flow chart

2.8.4 Testing and Validation Specifications

To be confident in the simulation outcomes, the individual models will be tested and compared to characterizations and experimental measurements. Moreover, the results from the simulation platform will be compared to experimental measurements on a reduced power converter prototype. The error of the simulation platform is targeted to be lower than 10% compared to the experimental measurements.

All these model verifications and validations are critical to allow reliable results for the simulation platform. These step-by-step verifications will allow us to make fair comparisons between the predicted performance of the inverter with future GaN devices and performances of the state-of-the-art three-level inverter.

2.9 (UC6) Converters for the Maritime Domain

The maritime industry is embarking on a transformative journey with the electrification of ships. This shift is driven by the urgent need to reduce greenhouse gas emissions and the environmental impact of traditional shipping methods. Ships transport about 80% of the world's commodities. However, conventional ship drive systems, primarily powered by heavy diesel oil, produce a significant amount of exhaust gases. Ships with electric or hybrid drive systems can significantly reduce emissions and energy consumption. Moreover, advancements in battery technology are making electrified vessels more cost-effective and appealing to owners. In conclusion, the electrification of ships represents a promising pathway towards a sustainable and environmentally friendly maritime industry. As technology advances and regulatory pressure increases, we can expect this trend to continue and reshape the future of shipping. To support this trend and accelerate innovation, four different demonstrators are in focus of this use case:

- Integrated eDrive (inverter + eMotor) with different power classes,
- Charging unit for ships based on modular power stacks,
- 3 kV DC source with galvanic isolation, and
- Solid state circuit breakers for DC grids on ships.

Figure 2-24 shows a potential setup of a DC ship power system. On the right side there is the propulsion system as it will be in focus of UC6a. To charge the batteries of a battery electric ship there is the need for a grid connection at different voltage levels. During the project, a 3 kV to 1.5 kV DC conversion is assumed which is in line with the new X-MCS charging standard [CharIN X-MCS, 2025]. Therefore, a galvanically isolated DC//DC conversion is necessary to charge today's common batteries, being limited to 1500 V (UC6b and UC6c). Furthermore, solid state circuit brakers are a must to safely disconnect batteries from the DC bus in case of failures (UC6d).

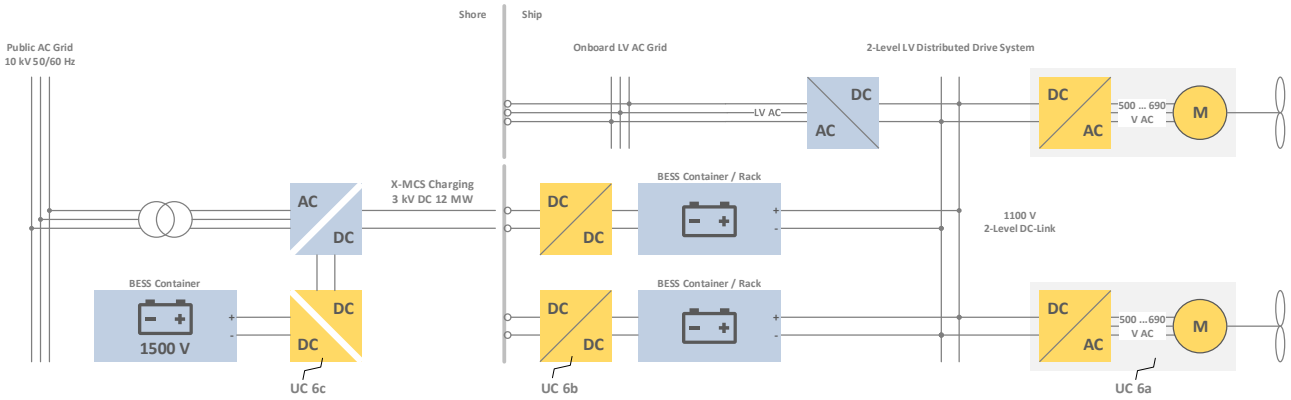


Figure 2-24: Low-voltage (LV) DC Ship Power System

In the following the single use case demonstrators are described in more detail.

2.9.1 (UC6a) Integrated eDrive for marine applications

2.9.1.1 Introduction

For electric-powered ships, the main propulsion drive—and particularly its efficiency—plays a critical role. Currently, IGBT-based inverters operating at relatively low switching frequencies are combined with permanent magnet motors. To further improve efficiency and minimize electromagnetic compatibility (EMC) disturbances, an integrated eDrive system will be developed. This system will feature an inverter utilizing Silicon Carbide (SiC) power semiconductors and an electric motor. By using SiC, the maximum system efficiency can be increased, and even more important is the significant increased efficiency during part load operation. Another aspect is an optimized volume of the integrated eDrive because of SiC-based semiconductors compared to IGBT ones. To further reduce the footprint the integration of power electronics

into the eMotor is an advantage. By integrating the SiC-based power electronic into the electric machine, extremely high efficiency, a small footprint and low electromagnetic radiations can be achieved.

2.9.1.2 Use Case Objectives and Targets

The main objective of this use case is the development of an integrated SiC-based eDrive (inverter + eMotor) for maritime applications with 1100 V DC-link and a continuous power class of approximately 350 kW. By using SiC-based power semiconductors, the efficiency under partial load (typical operation in marine application is between 20% to 30% of rated power) conditions is intended to be increased by 10%.
Furthermore, the volume of the integrated eDrive is expected to be reduced significantly due to increased switching frequencies and integration of the components. One aspect will be thereby the investigation of potential advantages of power electronics embedding for additional space reduction and increase in reliability, which will be followed in this project.

2.9.1.3 Demonstrator: Scope and Functionality

The development of the integrated eDrive focuses on the selection of two different machine concepts. Based on simulation results of at least three different concepts, two will be selected and physically implemented. Following motor types are proposed to be investigated in more detail: Permanent Magnet Synchronous Machine (PMSM), Synchronous Reluctance Machine (SynRM), and Asynchronous Machine (ASM). Furthermore, for the drive a sensorless field-oriented high-efficiency control will be developed. Compared to an e.g. Field Oriented Control, no sensors are needed, and the control shall be based on voltage and current measurements, accompanied with an observer for the orientation of the rotor.
On inverter level, AVL together with AT&S has developed a first version of a power stage with embedded 1200 V SiC dies in HiEFFICIENT project. Based on these findings, embedding concepts using SiC dies with higher voltage will be investigated and developed. The goal is that this power stack can be used up to 1300 V and significantly higher power.

Since safety and reliability are of high importance in the marine domain, redundancy needs to be considered from the beginning. Multi-Phase topologies (such as split belt machines, having six phases operated separately by different inverters) are being investigated targeting an optimal overall system performance of motor and inverter. Parallel inverters can be used to scale current and add further redundancy to ensure continuous operation on sea as shown in Figure 2-25.
Special attention needs to be put on the integration of the power electronic stacks with the machine including the corresponding EMC filter's design. Due to the planned high switching frequencies, filter size can be significantly reduced and hence the overall size of the system.
Further of importance for marine propulsion systems is an extreme low electromagnetic radiation especially in the frequency range 155 to 165 MHz, this because of being the frequency band where the emergency frequencies for marine safety are located.

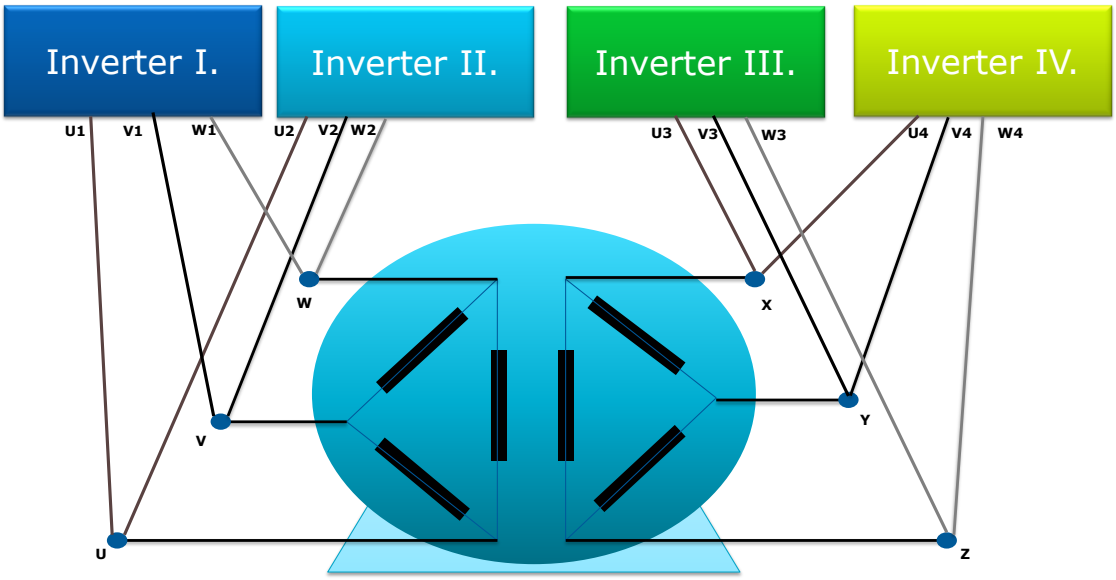


Figure 2-25: Integrated eDrive with redundancy concept

2.9.1.4 Testing and Validation Specification

The testing and validation procedure consists of two major steps. In the first step, the power electronics (i.e. the inverter modules) are tested back-to-back to analyze key characteristics such as switching behavior, performance and thermal stability in a lab environment. In this test setup (depicted in Figure 2-26) the inverters are coupled via inductors and operated in voltage and current control respectively. The second step is the testing and validation of the complete system including inverter and motor. Similarly, the test is performed in a back-to-back setup (see Figure 2-27). The two demonstrators are coupled mechanically by a shaft including torque measurement. The scope of these tests includes:

- Inverter and motor performance in the entire speed and torque range
- Validation in various ambient conditions
  - Air temperature
  - Coolant temperature
- NVH behavior
  - vibration measurement
  - torque ripple analysis
- Control performance
  - with speed sensor
  - without speed sensors
- Efficiency measurement of motor including inverter

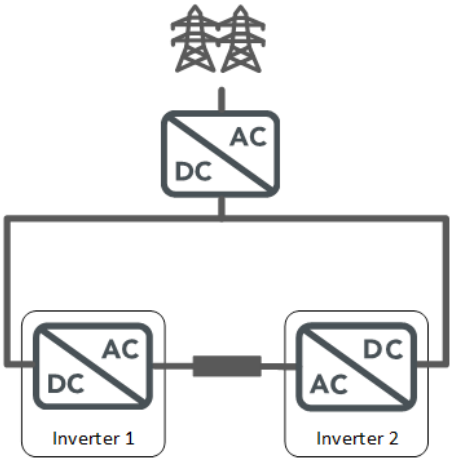


Figure 2-26: Back-to-Back test of power electronics

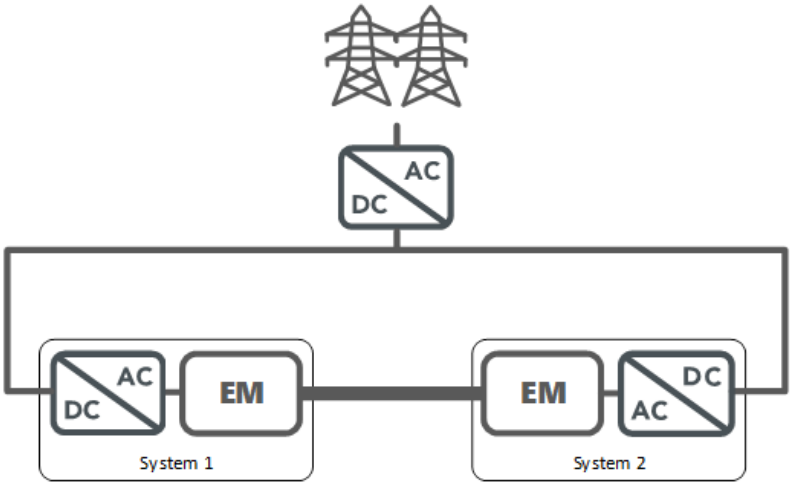


Figure 2-27: Back-to-back test setup for UC6a

2.9.2 (UC6b) Charging unit for ships

2.9.2.1 Introduction

International regulations already put strict limits on exhaust emissions of ships in harbours. Therefore, electric shore power connections have been standardised and are being implemented. Currently, these are mainly three-phase AC connections with either low voltage (LVSC) or high voltage (HVSC) shore connections. LVSC are mainly suitable for power demands up to 1 MW and are operated at 400 V, 440 V or 690 V AC according to IEC 80005-3 with connectors according to IEC 60309-5. For large ships with loads of more than 1 MW, HVSC are operated at 6.6 kV or 11 kV according to IEC 80005-1 with connectors according to IEC 62613-2. However, charging batteries on a ship with AC shore power requires additional AC to DC conversion equipment on board, which is only utilized during the charging phase. Hence, it is desirable to apply DC charging technology with the conversion equipment on the shore side. The IEC / IEEE / ISO joint working group JWG28 is working on the extension of the series of standards towards IEC 80005-4 for DC connections. In parallel, the Megawatt Charging System (MCS) [CharIn MCS, 2025] introduced by the CharIN initiative has also been adopted as a fast-charging technology for battery electric ferries. MCS has been specified for a charging power of up to 3.75 MW (3000 A at 1250 V) initially. Two extensions are being prepared to increase the maximum power to 4.5 MW (3000 A at 1500 V) with Ruggedized-MCS (R-MCS) [CharIn, 2024] and 12 MW (4600 A at 2600 V) with the proposal of Extreme MCS (X-MCS) [CharIn X-MCS, 2025], respectively. Although R-MCS and X-MCS are mainly targeted at fast charging of mining trucks with a minimum interruption of

operation, their high power levels would even be suitable as shore power connections of larger ships or fast charging of ferries. At higher DC voltages, the current rating and conduction losses of the shore connection cables can be kept lower, which makes the handling of the cable and connector much easier.
However, commercially available battery energy storage systems (BESS) for ships and stationary application are limited to voltages below 1500 V at the time of writing this specification. Therefore, it will be necessary to use a stepdown converter to connect a 3000 V DC shore charging connection to 1500 V batteries aboard the ship.

2.9.2.2 Use Case Objectives and Targets

The development goal of this use case is a power converter suitable for **DC fast charging of ships** based on modular 125 kW power converter. The charging converter solution will consist of a galvanic isolation stage, which serves as the charging converter on the shore, and a stepdown converter stage to transfer power between different voltage levels on board. These two basic building blocks are depicted in Figure 2-28.

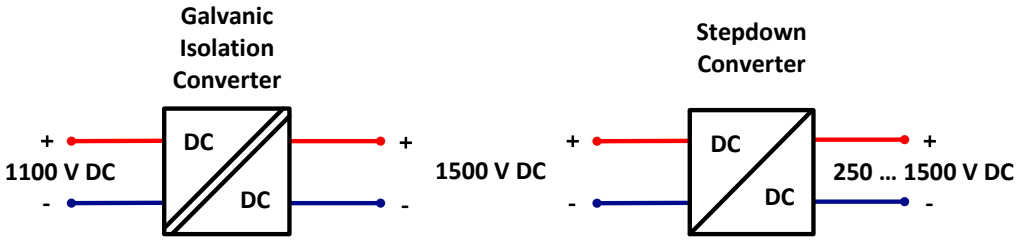


Figure 2-28: The two basic building blocks for UC6b.

The galvanic isolation converter shall not only provide galvanic isolation between shore side power systems and onboard power systems, but it shall also allow for series or parallel connection of inputs and outputs, such that a flexible configuration for conversion between different voltage levels is possible. The stepdown converter shall provide a wider output voltage range at constant power, such that the DC charging system can adapt to the variation of battery voltage between fully charged and fully discharged states.
By series connection of two conversion strings, it shall be possible to operate at up to 3000 V DC.

2.9.2.3 Demonstrator: Scope and Functionality

Within this project, the scope is to demonstrate the power conversion from low voltage AC grid (400 V or 690 V 3-phase AC) to 3000 V DC charging system voltage and back down to a battery system voltage below 1500 V. By series connection of two strings with 125 kW each, the demonstrator will be able transfer a power of 250 kW. The main challenge will be to design the building blocks for a working voltage up to 1500 V DC and to provide insulation coordination for a system voltage up to 3000 V DC under marine environment and operating conditions. The same building blocks and system topology will be used in use case 6c. Hence, more details are provided in the following section (UC6c) 3 kV DC Source.

2.9.2.4 Testing and Validation Specification

Testing and validation specifications are provided in the following section (UC6c) 3 kV DC Source.

2.9.3 (UC6c) 3 kV DC Source

2.9.3.1 Introduction

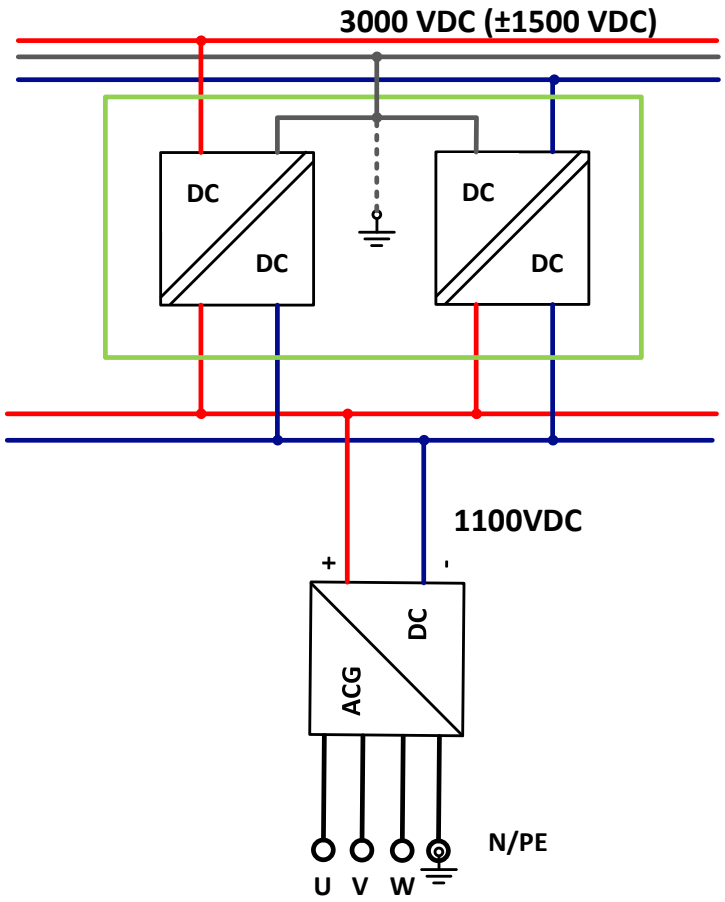
As described earlier, most modern electric ships that use a DC link for onboard energy distribution operate with DC link voltages around 1000 V (with a wide range of variation, if the DC link is directly connected to the battery). As can be seen from the MCS specification and the range of available DC breakers (listed in section 2.9.4 (UC6d) Solid state circuit breakers for DC grids on ships), DC link currents are limited to 3000 A. Therefore, the power transfer through a low voltage DC grid is limited to around 3 MW. For higher power levels, the DC link voltage must be increased.

2.9.3.2 Use Case Objectives and Targets

According to IEEE 1709-2010 “Recommended Practice for 1 to 35 kV Medium Voltage DC Power Systems on Ships” and [Khersonsky, 2011], the next voltage level is 3 kV (or ±1500 V with symmetric potential around neutral/ground potential). The goal of this use case is to design, build and demonstrate a DC-to-DC converter system for flexible conversion between a low voltage DC grid below 1500 V and 3 kV medium voltage DC grid. This shall be used to integrate low voltage systems such as battery storage systems, low voltage drives (such as in UC6a) or low voltage AC-to-DC converters into a 3 kV DC system or enable the fast charging of low voltage BESS through X-MCS (see UC6b). Furthermore, the converter system shall be suitable for the testing of 3 kV DC subsystems in laboratories or on testbeds.

The scope of this UC is to develop a 3 kV DC source/sink by connecting two 1500 V DC/DC converters with galvanic isolation in series to enable a coupling between different DC buses, e.g. 1.1 kV and 3 kV. Operation with either a grounded middle point or floating middle point shall be possible. In addition, access to the middle point shall be possible to form a three-level DC bus.

As shown in Figure 2-29, the converter system will consist of a galvanic isolation stage (indicated by the double diagonal line) and a voltage adjustment stage without isolation in order to adapt the voltage to different needs (such as testing subsystems at reduced voltage before ramping up to full voltage, or to accommodate the voltage range of a battery system).



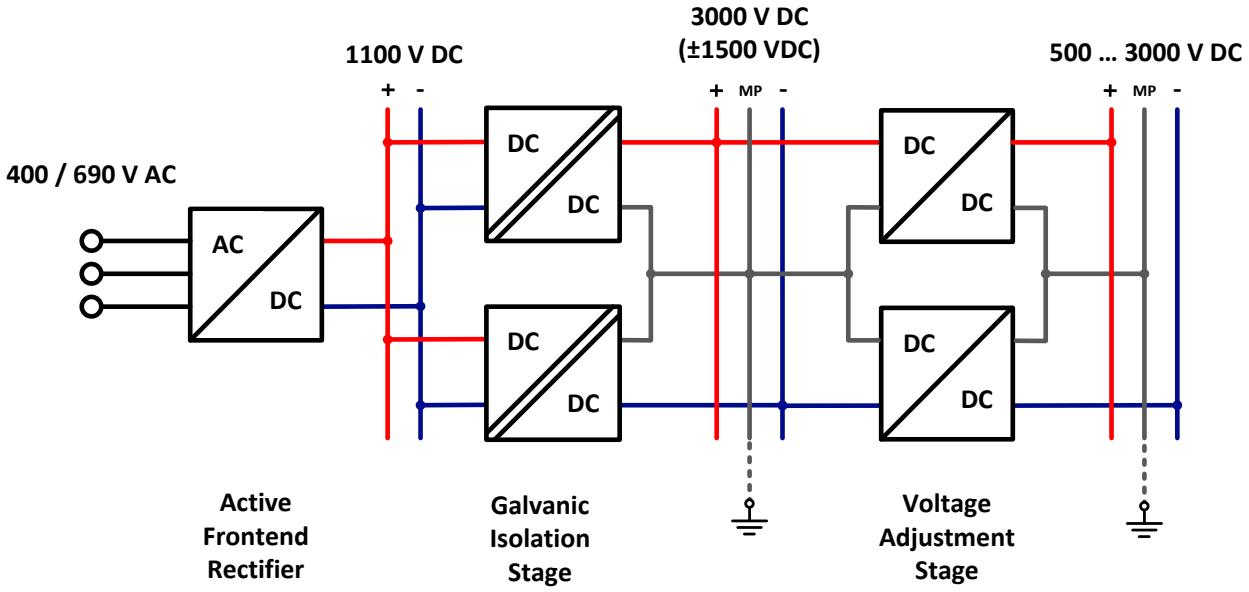


Figure 2-29: Schematic of the scope of UC6c

One of the key objectives is the investigation of the best-fitting topology and the selection of the most appropriate SiC power semiconductors. Possible options are chips with a blocking voltage between 2.3 kV and 3.3 kV. The galvanic isolation stage will be implemented with a medium frequency transformer. Another objective is to evaluate whether hard switching operation as a dual active bridge with a wider range of efficient operating points or resonant operation with higher efficiency in a narrower range is more beneficial for this use case. The voltage adjustment stage will be implemented as a bidirectional buck converter
This use case will further evaluate the potential of power electronics embedding of 2.3 kV or 3.3 kV SiC MOSFETs and shall enable the comparison with a power module-based approach. Moreover, a special investigation will be carried out on fault-tolerant control and/or modulation techniques. The target is to enhance the availability of the DC source by exploiting the multiple degrees of freedom afforded by the modular character of the topology; redundancy in switch transitions and alternative current conduction paths will be explored, employing real-time optimal control methods based on the Model Predictive Control (MPC) paradigm.
For achieving a high modularity, building blocks in the range of 125 kW are planned, which can later be stacked to reach the required power classes. Due to the 3-level architecture, the final granularity will be in steps of 250 kW.

2.9.3.3 Demonstrator: Scope and Functionality

The developments for the 3 kV DC Source, based on two 1500 V DC//DC converter modules, focus on a modular approach to switch the individual DC/DC modules in series and/or parallel to fit a wide range of applications. The work will start with a study to evaluate which switching element (2.3 kV or 3.3 kV SiC) and which design – soft or hard switching, number of interleaved parallel stages – is best for the application. The evaluation will be done with respect to technical requirements (efficiency, robustness, lifetime) and economic aspects (cost and availability of components). Therefore, different approaches will be simulated and evaluated. After deciding on the semiconductors and topology, the design of a converter system will be done. The topologies will be simulated, and the parameters and passive components will be optimized.
In the design of the modular DC Source, insulation must be designed to withstand up to 3000 V working voltage between any output terminal and ground, as the absence of a grounded midpoint can create this potential difference. This can be achieved either by fully insulating each converter for the total working voltage or by implementing layered insulation between power semiconductors, heatsinks, housings, and

reference potentials using suitable materials and cooling methods. Furthermore, a suitable auxiliary supply system must be selected. The different options need to be investigated in more detail during implementation to follow the best approach for the applications in mind.

2.9.3.4 Testing and Validation Specification

As a first step, a 2-level converter solution for up to 1500 V and 125 kW (the upper half of the target configuration) will be built up including driver circuits, protection, current and voltage measurement, and control, such that it can be tested in a low voltage laboratory. The target test setup is illustrated in Figure 2-30. The test setup will be supplied by a low voltage grid rectifier with an adjustable DC-link voltage of up to 1100 V. The galvanic isolation stage will step the voltage up to 1500 V and the voltage adjustment stage will be used to control its output current and thus the power flow and to recirculate the power back to the input DC-link. With this setup it will be possible to gradually ramp the power up to the nominal value (in forward and reverse direction) and to test the thermal performance under controlled conditions.
Furthermore, this subsystem will be tested for its dielectric withstand capability with a high voltage tester.

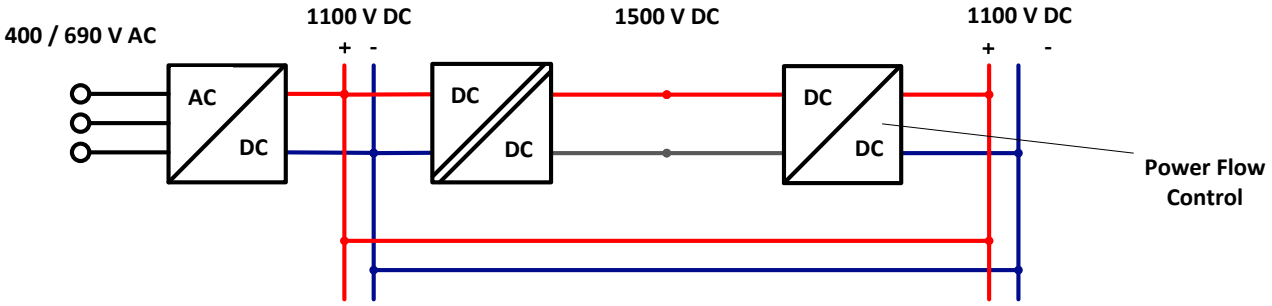


Figure 2-30: Low voltage test setup suitable for the validation of the building blocks. Voltages up to 1500 V can be tested at power levels up to ±125 kW. This setup can be operated in a low voltage power electronics laboratory.

Once the tests on the half subsystem described above are concluded successfully, the second half will be built, tested and then assembled into the full converter system in the same way. This will make it possible to build a test setup as shown in Figure 2-31, which can be operated at voltages up to 3 kV and a power of 250 kW – again in both directions. To recirculate the power from the final 3-level DC-link (on the right) back to the 2-level DC-link (on the left), another pair of galvanic isolation converters are required.
To test this demonstrator, a dedicated test laboratory is necessary to cope with voltages beyond the low voltage regime of 1500 V.

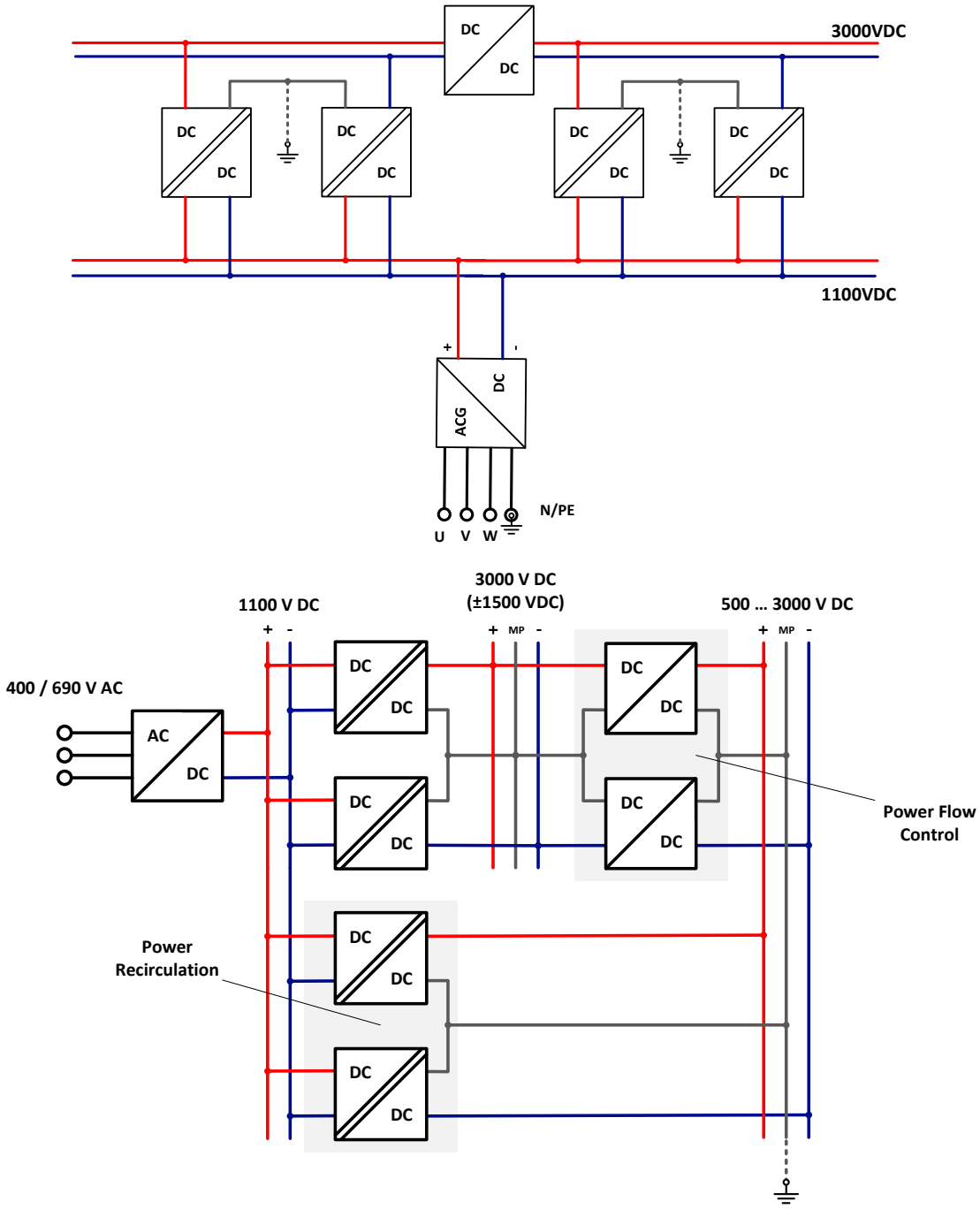


Figure 2-31: Full voltage test setup with series connection and an additional Buck Converter for wider voltage range and power flow control and a second galvanic isolation converter for power recirculation in back-to-back operation. Voltages up to 3000 V can be tested at power levels up to ±250 kW. This configuration will be built and tested in a medium voltage laboratory.

2.9.4 (UC6d) Solid state circuit breakers for DC grids on ships

2.9.4.1 Introduction

In a large number of applications, the aim is to convert the existing local AC distribution network to a DC distribution network. This is primarily due to the repeatedly proven great potential in terms of energy efficiency, resource savings, and increased security of supply. Load break switches are also required in DC

distribution networks for safety and load flow control (e.g., to prevent complete system failure in the event of electronic faults). In contrast to AC switches, very few load break switches are currently available for DC currents. This is partly because DC technology is still in the early stages of market penetration and partly because DC switches are inherently more complicated to implement, as there is no principle-based zero crossing in the DC load current. This low availability becomes even more pronounced when considering higher system voltages in the low voltage range of 1000-1500 Vdc or even low medium voltage (1.5 – 3 kVdc). However, due to the energy transition and the steadily growing demand for electrical energy in almost all relevant applications (shipboard power systems, industrial plants, fast charging parks, data centers, etc.) with large local distribution networks, a trend toward these voltage classes is already evident.
For the reasons mentioned above, the development of highly efficient DC load break switches is therefore essential. It has already been proven that these are best constructed on a semiconductor basis (mechanical switches are too slow and hybrid concepts are too cost-intensive and complex in the power range under consideration). In the literature, these switches are known as SSCBs (solid-state circuit breakers).
The focus of UC6d is on developing an SSCB for DC-based board networks on ships. In order to make the best possible use of economies of scale and accelerate the introduction of this innovative technology, spillover effects in other applications are being thought.

2.9.4.2 Use Case Objectives and Targets

The proposed solution aims to **reduce transmission losses to 70% of the current state-of-the-art**, delivering a significant efficiency improvement. It supports **fault-tolerant operation through inherent redundancy**, allowing continued functionality in the event of internal electronic failures. The design offers **high scalability in both current and voltage**, enabling deployment across low and medium-voltage applications and maximizing reuse across multiple markets. Compared to existing solutions, the concept delivers **improved reliability** while simultaneously achieving **lower overall system costs**, strengthening its competitiveness and suitability for wide-scale industrial and commercial adoption.
There are a number of applications that would benefit from a DC-based distribution network. The SSCB is an essential component in this regard, but unfortunately it is currently hardly available on the market. The development of an efficient SSCB is therefore a basic prerequisite for the realization of advantageous DC networks.

2.9.4.3 Demonstrator: Scope and Functionality

In UC6d, it is planned to realize a fully functional SSCB for dc-based distribution grids. A modular approach to the switch is being pursued to enable its use in various applications in both low and medium voltage. However, if the results of the topology study show that this modularity has an unfavorable impact on costs and performance, the focus will be shifted to medium voltage, as this is where the greatest demand is seen. This is particularly true in the field of shipboard power systems.
The biggest challenge in realizing the SSCB prototype is to build it efficiently. This means, above all, a drastic reduction in conduction losses compared to the state-of-the-art. In addition, the switch must be able to limit the overvoltages that occur when a DC current is switched off without having to use costly components.
The developed demonstrator should be capable of covering the full working range defined. This means that it must be able to switch off the DC current even in the worst-case operating point. This operating point is characterized by the maximum defined current, the maximum voltage in the DC distribution network, and the maximum defined inductance in the distribution network.
This switch-off process must meet the following conditions:

- The SSCB must not be damaged by the switching operation.
- It must be able to switch back on within a defined period of time.
- The switch-off overvoltage must be limited to a defined value.
- The definition of the overvoltage and “switch back to on time” depends on the considered use case

2.9.4.4 Testing and Validation Specification

The Testing and Validation of the system will be carried out with simulation models as well as with down-scaled hardware setup in high-voltage laboratory for experimental verification of the results.
The laboratory test setup consists of the following tools and & techniques:

- Data Acquisition Systems: High-speed recorders for event analysis.
- High Voltage Multimeters and Sensing equipment
- Function Generators: Programmable sources for voltage/current pulses
- Harmonic Analyzers: Measure harmonic distortion.
- Isolated Network Simulators: Create realistic grid scenarios.

The new topology will be compared to the existing state-of-the art products listed in Table 2-4.

	Astrolkwx	Schneider El.	Eaton	Siemens	ABB	LS
Breaker Type	AA-10411-10	PacT JDC	CJGPVS, CKDPV	HDGD	SACE Emax	Susol
Rated current	350 ~ 3000 A	30 ~ 1200 A	150~3000 A	50~1600 A	5000 A	16~1600 A
DC-Link voltage	1500 V_{DC}	500 V_{DC}	600~1000V_{DC}	600 V_{DC}	250~1000 V_{DC}	500–1500 V_{DC}
Breaking capacity	Up to 20 kA	20 up to 50 kA	1.5 to 42 kA	42 kA	65 kA	20kA to 50 kA
Amb. conditions	−10°C to 60 °C	−10°C to 60 °C	−40°C to 70 °C	−25°C to 70	−40°C to 70 °C	−25°C to 55 °C
Operation time	*8 µs*	≤30 ms	1 ms	70–300 ms	≤70 ms	≤40 ms

Table 2-4: State-of-the-art SSCB

The simulation phase will include a modeling of the MV DC Grid comprising DC sources/generators, cables, filters, connectors, DC/DC converters and various other DC loads. Such a model will enable us to capture the overall system behavior in a second-order nonlinear differential equation, which is used then for the implementation of a linearization via state feedback (LSF). This procedure is schematically depicted in Figure 2-32.

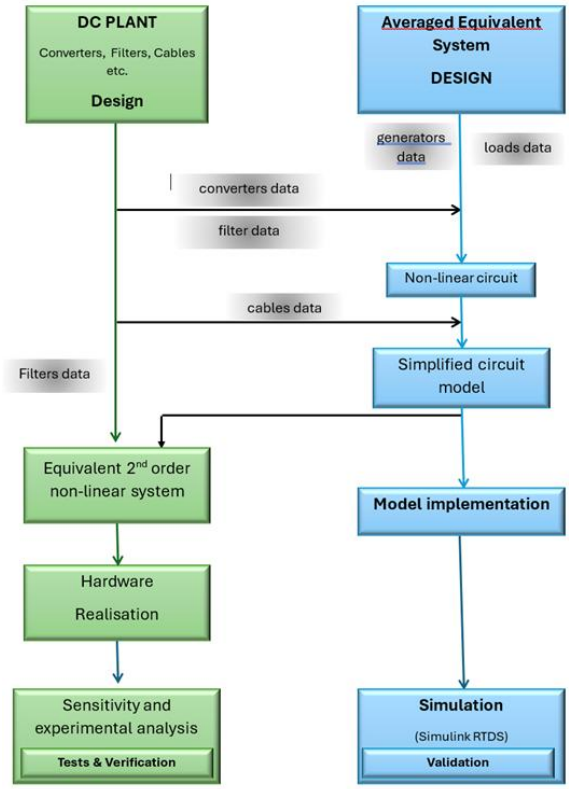


Figure 2-32: System design procedure for shipboard MVDC grids

In the second phase, a suitable electrical circuit will be designed, and prototype DC breaker will be finally realized for testing and experimental validation. Based on the structural/cost advantages as well as on reaction time and efficiency of the target DC breaker, the suitable topology will be selected. Additionally, a suitable energy absorption technique (e.g. MOV-based, capacitor-based DCCBs, hybrid MOV–Cap DCCBs) will be analysed and implemented in the prototype design.
One of the possible topologies together with current and voltage measurements is depicted in Figure 2-33.

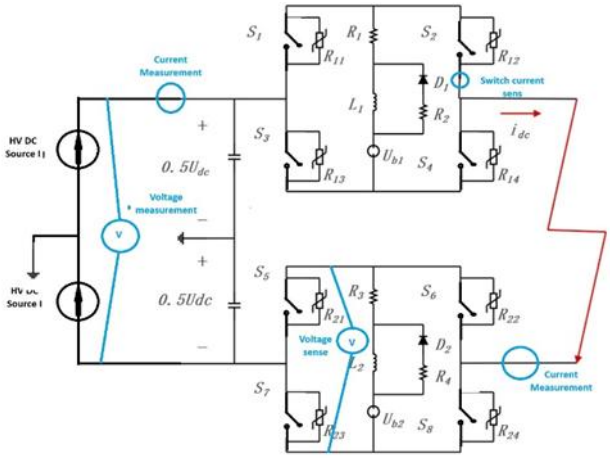


Figure 2-33: The topology of the symmetrical full-bridge SSCB

3 Terms, Abbreviations and Definitions

HiPower 5.0	Leading edge semiconductor, integration, and control system technologies for highly compact and smart edrive components towards more sustainable power electronics 5.0
AET	Automatic Electrical Testers
ASM	Asynchronous Machine
BDS	Bidirectional Switch
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicles
CNN	Convolutional Neural Network
CNC	Computerized Numerical Control
CSI	Current Source Inverter
DD	Data-Driven
DEC	Websites, patents filing, press & media actions, videos, etc.
DEM	Demonstrator, pilot, prototype, plan designs
DCCB	Direct Copper Bonding
DMP	Data Management Plan
DPT	Double Pulse Testing
EESM	Electrically Excited Synchronous Machine
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EV	Electric Vehicle
FE	Finite Element
FEM	Finite Element Models
GaN	Gallium Nitride
HD	Heavy Duty
HVSC	High Voltage Shore Connection
HEMT	High Electron Mobility Transistor
HIL	Hardware In the Loop
HW	Hardware
LCA	Life Cycle Assessment
LD	Light Duty
LSTM	Long Short-Term Memory
LSF	Linearization via State Feedback
LVSC	Low Voltage Shore Connection
MBDS	Monolithically integrated BDS

MCS	Megawatt Charging Standard
MIL	Model In the Loop
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
MPC	Model Predictive Control
NN	Neural Network
NPC	Neutral Point Clamped
OBC	On Board Charger
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
PFC	Power Factor Correction
PINN	Physics informed Neural Network
PMSM	Permanent Magnet Synchronous Machine
PLECS	Piecewise Linear Electrical Circuit Simulation
PoF	Physics-of-Failure
PU	Public, fully open, e.g. web (Deliverables flagged as public will be automatically published in CORDIS project's page)
R	Document, report (excluding the periodic and final reports)
ROM	Reduced Order Models
SEN	Sensitive, limited under the conditions of the Grant Agreement
SiC	Silicon Carbide
SoH	State-of-Health
SOTA	State of the Art
SSCB	Solid State Circuit Breakers
STCO	System and Technology Co-Optimization
THD	Total Harmonic Distortion
SynRM	Synchronous Reluctance Machine
SW	Software
V2G	Vehicle-to-Grid
VSI	Voltage Source Inverter
WBG	Wide Band Gap
WLTP	Worldwide Harmonized Light Vehicles Test Procedure
WP	Work Package

Table 3-1: Terms, Abbreviations and Definitions

4 References

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