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The ECOCHAMPS project boosts the introduction of hybrid powertrained commercial vehicles and passenger cars. ECOCHAMPS does this by developing technologies that improve vehicle performance, comfort and functionality, lead to less CO_2 emissions and reduce costs at the same time. The project has shown five hybrid powertrains that are applied in five different vehicles, from a small and a medium sized passenger car to a van, a city bus and a heavy duty truck.

For hybrid commercial vehicles, a cost reduction has been achieved by using the Modular System and Standardization Framework (MSF). The MSF is a new pre-standard framework that recommends technical standards for hybrid electric drivetrain components. This provides planning certainty for suppliers, supports competition and scalability, resulting in a significant cost reduction for hybrid components and vehicles.

While light duty components have the advantage of potentially high quantities, production numbers of heavy-duty vehicles are comparably small. Within this context, establishing standards and norms especially for heavy and medium duty vehicles are a reasonable approach to increase the quantities across different OEMs and decrease the component prices in turn. Therefore, ECOCHAMPS proposes a pre-standard framework, the Modular System and Standardization Framework (MSF), for drivetrain components and electrically driven auxiliaries.

In a first step, requirements were identified for each component, which might have a significant impact. In subsequent experts workshops the most beneficial and feasible requirements were selected for the standardization proposal process of ECOCHAMPS. Next to the component specific requirements so-called system level requirements were identified, which have an impact on all driveline components considered in the project. In detail these are:

- system voltage levels,
- ASIL classification,
- Environmental conditions,
- DV-Testing,
- Electromagnetic compatibility (EMC) and
- Noise levels.

These requirements as well as the component specific requirements are expected to provide a reasonable cost saving potential, as soon as they are standardized.

Throughout the project, new findings from component development and integration into the demonstrator vehicles as well as feedback from an external mirror group were looped back and taken into consideration for the final version of the MSF.

In the applied standardization process, existing standards were used to an extent possible. The development of the MSF aims to provide:

- planning certainty for suppliers,
- support of commercial competition and scalability as well as
- significant cost reductions for hybrid drivetrain components and vehicles in the mid-term.

To support these aims, ECOCHAMPS publishes the final MSF via the European Council of Automotive R&D (EUCAR) as well as to national standardization committees.

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Introduction

1.1 Overall targets of the ECOCHAMPS project

The ECOCHAMPS project developed new compact, low weight and robust hybrid powertrain components for light, medium and heavy-duty road vehicles. Therefore, hybrid electric components were developed and implemented in cost optimized, efficient powertrains with improved functionality and performance, comfort and functional safety. The targeted readiness level is TRL7. The emission levels was expected to be well below Euro 6 or Euro VI, respectively.

The main objectives of the ECOCHAMPS project are to:

- Devise a modular pre-standard framework, e.g. standards for electric hybrid drivetrain components and auxiliaries for commercial vehicles – the Modular system and Standardization Framework (MSF),
- Develop a set of electric hybrid components in conformity with existing standards for light duty vehicles or existing standards and MSF for heavy duty vehicles to an extent possible,
- Develop optimized drivelines to TRL7 for the following vehicle classes: light, medium and heavy duty commercial vehicles as well as busses,
- Demonstrate key innovations in two light duty and three commercial vehicles at TRL7,
- Assess the technology development in terms of its efficiency, cost effectiveness, weight and volume.

Compared to the best in class full hybrid vehicles on the market in 2013, ECOCHAMPS will:

- Improve powertrain efficiency by up to 20 % during representative operation,
- Reduce powertrain weight and volume up to 20 % and
- Reduce hybrid vehicles costs, targeting 10 % maximum cost premium compared to conventionally propelled vehicles.

To achieve these objectives regarding the MSF, the following three-step-approach was followed:

1. Develop a modular pre-standard framework called the Modular System and Standardization Framework (MSF).
2. Develop electric hybrid drivetrain components and auxiliaries to TRL 6 or 7, realizing synergies between the needs of all vehicle classes in conformity with LV123 for light duty vehicles or, based on the MSF, for heavy duty vehicles as far as possible.
3. Assess the outcome of the hybrid component integration in the vehicles and provide updated recommendations for standardization.

1.2 The Modular System and Standardization Framework (MSF)

1.2.1 Benefits of standardization

In the following section, the benefits of standardization are described, including the participation in the pre-standardization process. Subsequently, this document describes the results of this process.

Standardization is able to reduce or even eliminate market barriers, if market players agree to the same standard. Products and services are produced and operated more efficiently due to scaling effects and higher levels of automation within the production processes. For these reasons, standardization has the chance to reduce component costs for hybrid commercial vehicles significantly and provide a common basis to compare quality, performance and safety requirements. Finally, also an improved compatibility between the market participants can be achieved, which potentially increases competition and leads to decreased prices as well.

For the research and innovation project ECOCHAMPS the following standardization can increase the impact of the project on market, industry and society, especially beyond the duration of the project itself. Thus, an early involvement in the standardization or adaption of pre-standards can shift the competitiveness.

1.2.2 Definition of the MSF

The Modular System and Standardization Framework (MSF) is a modular framework that recommends standards for electric drivetrain components and auxiliaries for medium duty and heavy duty vehicles including busses. The standardization proposal includes requirements like:

- voltage levels,
- mechanical interfaces and
- electrical and communication interfaces.

The MSF proposes standards on a component level. Therefore, standards that already have been developed for hybrid passenger cars could be used as a basis to an extent possible. The benefits for heavy-duty vehicles provided by the MSF development will be:

- planning certainty for suppliers,
- the support of commercial competition and scalability,
- shortening of development and qualification cycles, and
- significant cost reductions for hybrid drivetrain components and vehicles in the mid-term.

The ECOCHAMPS consortium intends to make the MSF available via the European Council of Automotive R&D (EUCAR). Furthermore, it is planned to communicate the MSF standardization proposals to national standardization committees.

1.2.3 Method and process

During the project several steps have been made to develop the first MSF draft. Table 2-1 and Figure 2-1 outline the process that has been followed.

Table 2-1 Method of MSF development

Step 1: Creating template with requirements for each component
Definition of requirements for each component in expert consortium. Result of the discussions was a template for each component that summarized the requirements. Suppliers filled out templates with requested values, ranges, definitions, norms etc. for the four different vehicle classes, e.g. • light duty (3.5 t – 8.0 t), • medium duty (7.0 t – 25.0 t), • heavy duty (25.0 t – 40.0 t) and • busses. That way the requirements asked by different OEMs could be discussed on an anonymized basis.
Step 2: Analysis of feasibility and benefit
In special sessions potential parameters for standardization/modularization have been identified for each component as follows: • Each partner proposes the ten most beneficial requirements from their individual perspective. • The chosen requirements are sorted into a matrix considering benefit vs. feasibility of standardization. • The requirements in the matrix are evaluated for their potential of generalization towards other components and modularization. See the template in Figure 2-1 and Appendix B for the matrix of each component. Furthermore, several requirements that should be discussed on a system/cross component level have been identified (see Appendix C): • Electromagnetic Compatibility (EMC) • Environmental conditions • ASIL-Classifications • Voltage levels • DV-Testing

Step 3: Determine requirements for standardization

Based on the results of step 2 the following process was followed for each component:
• Based on expert's opinion each requirement was evaluated. The best candidates were selected for the subsequent standardization discussions.
• Afterwards, for each requirement the scope of standardization was discussed and a requirement owner was announced
• Subsequently, each requirement owner developed a proposal for a standardization of its requirement. For the proposal the expert:
  ○ Used the templates that have been filled out by the suppliers in step 1,
  ○ discuss the proposal with in-house experts and other experts of the ECOCHAMPS consortium.
Afterwards, the requirement owners presented their standardization proposals to the expert consortium for refinement.

Step 4: Elaborating the standardization proposal
In dedicated sessions the standardization proposals of each component were discussed to find common understandings and agreements. A proposal may still have several options. Furthermore, few requirements identified in step 2 were skipped later. The MSF documents the reasons for skipping. Cross component requirements were discussed in overall group sessions.

Table 2-2 summarizes the steps towards the final MSF.

Table 2-2 Method of MSF finalization

Step 1: Component development according to the MSF draft by suppliers
The following predefined hybrid components are developed and provided for integration into the targeted demonstrator vehicles according to the MSF requirements: • High voltage battery system for HD trucks • High voltage battery system for MD trucks • DC/DC-Converter for low voltage onboard supply for MD and HD trucks • Electro-hydraulic power steering for HD trucks and city bus • Electric air compressor for HD trucks and city bus
Summary report on component development Suppliers evaluate the component development including: • a detailed description of each component, • the assessment of component conformity with LD standards and the MSF, • component test results of standard functional- and performance tests, • benefits by implementation of MSF requirements, • a first assessment of potential MSF impact on development cost as cost premium indication as well as • a short summary for each component.
Step 2: Final assessment
The assessment method and scenario are presented to and aligned with the OEMs and suppliers. Based on this feedback an assessment template for each component and vehicle was filled out by the responsible partners.
Final inputs for MSF assessment The component experts provided their figures. Those were collected, analyzed and finally expressed in respective anonymized diagrams. Since ECOCHAMPS deliverable D2.5 is public, compliance rules need to be respected.
Step 3 : External review of the MSF
The draft of the MSF was sent to external reviewers and the mirror group, including standardization bodies, organizations involved in standardization processes and external companies. The valuable feedback of those external reviewers is included in the final MSF proposal.
Step 4: Including the assessment and review into the MSF
The results from the internal assessment, as well as the external reviews are used to enhance the MSF draft. Furthermore, the component development report is taken into account anonymously.

The results of the standardization discussions of Task 2.1 of the ECOCHAMPS project are presented in Chapter 2, which is divided in:

- Subchapter 2.1 for system based/cross component requirements and in
- Subchapters 2.2 - 2.8 for requirements on component level.

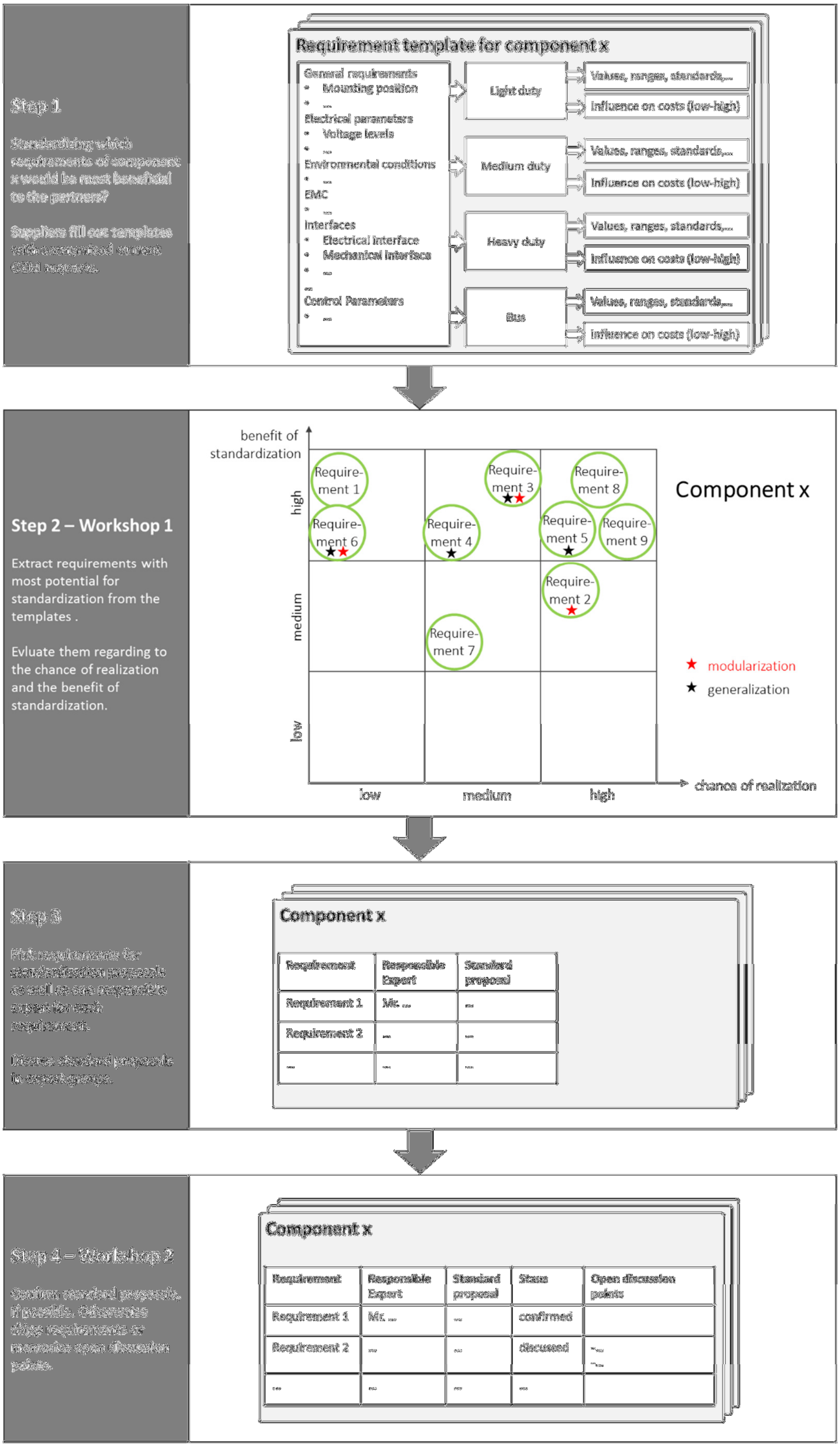


Figure 2-1 Determination of requirements that should be standardized and development of standard proposals.

1.2.4 Feedback method

Very early in the definition of the ECOCHAMPS project, the partners concluded that it would be very beneficial for the activities of work package 2 to get further external feedback for the standardization proposals that would be defined in the project. The main motivation for this was to get a feedback as broad as possible concerning standardization proposals, where every entity interested in the activity should be able to contribute, and that as many opinions as feasible could be integrated into the standardization framework.

Therefore, it was proposed to set up a mirror group within the project consisting of interested parties (non-profit organizations and companies) who would be able to provide their input to the standardization proposals without actually being part of the project.

The feedback of following parties has been received and contributed to this document:

- Asociación Española de Normalización (UNE)
- TÜV Nord Mobilität GmbH &0 Co. KG
- Vrije Universiteit Brussel (VUB)
- fka Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka)
- GIF Entwicklungsgesellschaft mbH (GIFe)
- Welfers Consulting
- FEV Europe GmbH Aachen (FEV)

In order to get a holistic view from various perspectives, the feedback is integrated as received by the mirror group members. That way standardization bodies get both, the opinion of suppliers and OEMs involved in the project as well as third party feedback with different backgrounds.

1.2.5 General feedback

This section provides the general feedback of the mirror group that is not directly linked to a specific standardization proposal.

1.2.5.1 General feedback UNE

UNE, as the Spanish national standardization body, member of the European (CEN, CENELEC, ETSI) and International (ISO, IEC) Standards Organizations, and with a large experience participating in European research and innovation projects, has been asked by the ECOCHAMPS consortium to revise and comment the draft document MSF.

As a first general impression, the document is very complete and goes to a relevant level of detail. It is a good initiative and is seen as valuable information for the light and heavy-duty road vehicles sector.

Regarding the concept of standardization, two sides have to be considered. The first one is the knowledge and use of existing standards. This aspect has been strongly considered in the document and it can be considered correctly approached.

The second side is to contribute to the generation of new standards. Moreover, this is important when a lack of standards is identified, in this case in the field of heavy-duty road vehicles. So, it is encouraged that the consortium gets in contact with the relevant standardization technical committees, especially ISO/TC 22 in this case, to provide information, raise the discussion and promote the inclusion of these aspects in their future standardization work program.

1.2.5.2 General Feedback TÜV Nord

To increase the market penetration of hybrid vehicle applications the development of cost efficient components is one of the key drivers. Modularization and standardization are indispensable to decrease development time and to gain scale effects to significantly lower costs.

ECOCHAMPS focuses exactly on those issues by using the public platform of a European funded project. This fact distinguishes ECOCHAMPS compared to other standardization activities, which are in many cases non-public. The ECOCHAMPS consortium intends to make the final Modular System and Standardization Framework (MSF) available via the European Council of Automotive R&D (EUCAR). It is also planned to communicate the MSF standardization proposals to national standardization groups and committees.

Beside the standardization work the relevant components shall be developed, manufactured and integrated into prototype vehicles. The practical experience gained from this exercise finally is the real benefit of the project compared to projects with only theoretical focus.
The involvement of suppliers and research institutes beside the vehicle manufacturers is essential for the success of this project.
TÜV NORD, as an active member of several standardization work groups, absolutely supports the idea of ECOCHAMPS and eagerly awaits the final results of this project.

1.2.5.3 General feedback Welfers Consulting

The task to review and comment the project paper "Modular System and Standardization Framework - MSF" of the EUROPEAN COMMISSION ECOCHAMPS project on hybrid electric components for Hybrid Light and Heavy Duty Vehicles has provided a very interesting insight into an important work package which is able to influence the future of the development of hybrid powertrains for road vehicles in Europe in a very positive way.
For me personally with approx. 30 years of experience in the EE engineering for light and heavy-duty CVs it was a pleasure to look at a project that is aiming to provide a framework of standards, which will eventually enable cost-down and at the same time quality improvements for components to be used in hybrid propulsion systems. This certainly will help to move hybridization of road vehicles much faster in the future.
During my own history of working at a heavy truck and bus manufacturer, I have witnessed many difficulties in bringing hybrid and/or electric vehicles into production because of a complete lack of off-the-shelf available components, which were ready to be deployed to applications in heavy commercial vehicles. Basically, everything had to be developed from scratch with huge development costs – unfortunately very often only for very small production volumes. It is my strong believe that the work carried out in this project will improve this situation significantly.
In the following, I have been focusing on those areas where I could apply my own personal experience in particular from my recent more than 10 years in the heavy commercial vehicle EE domain. Therefore, not every paragraph is discussed in detail.
One positive aspect of this project is the fact that it is not jumping directly into a discussion of specific characteristics for components and devices but that it starts on the requirement level (Chapter 1.2.3, Figure 2-1) and that it also considers all important methods (e.g. Functional Safety, DV testing, EMC, Noise assessment etc.). The requirements-based approach allows an early assessment of expected benefits from standardization as well as a structured proceeding for the following workstreams.
In total, the document provides a well-worked out approach to standardization of components for hybrid propulsion systems in the targeted vehicle classes. Sound recommendations have been formulated or the next steps forward have been described well. Important things like e.g. the desirable examples for ASIL, the standardization of CAN signals for the new functions in a hybrid system, the broader roll-out of LV123 need to be developed further to turn the ECOCHAMPS standardization activities into a real success. Given that the missing elements towards a comprehensive standardization of all aspects will be completed, the here documented framework will become a useful basis for an efficient development of high quality hybrid powertrains.

1.2.5.4 Miscellaneous

In addition to the feedback above the company Knorr-Bremse provided feedback for air compressor requirements and Spheros was involved in the discussion about potential modularization approaches for air conditioning systems for buses and trucks. The feedback of both companies is included in the outcome of the respective components.

2 Results

2.1 System based requirements (cross component level)

2.1.1 Voltage-levels

Definition of requirement scope

The scope of this requirement is to define voltage levels on system level, since all components considered in the MSF depend on it.

Standardization proposal

In order to meet the demands of the vehicle classes, light-, medium- and heavy duty vehicles and busses, two voltage levels are proposed for standardization, see Table 2-1 and Table 2-2.

Table 2-1 Options for standardization proposal for voltage levels on system basis.

Option nr.	Option description	Comment
1	Voltage levels according to Table 2-2	

Table 2-2 Defined voltage levels.

Voltage range		Low HV [V]	High HV [V]
Overvoltage	V_{Peak}	500	920
Limited operation	V_{DC}	450 - 470	850 - 870
Full operation mode	V_{DC}	250 - 450	500 - 850
Limited operation	V_{DC}	150 - 250	400 - 500
Undervoltage	V_{DC}	≤ 150	≤ 400

Conclusion

Within a dedicated cross component working group for voltage levels, the experts agreed on the two voltage levels of Table 2-2 for future hybrid commercial vehicles and bus applications. While the Low HV (first column) is in line with LV123[1] the High HV (second column) is a proposal that goes beyond LV123 and is intended for high power commercial vehicle applications like e.g. fully electric trucks or busses.

2.1.2 ASIL-classification

Definition of requirement scope

The scope of this requirement is to come to a common understanding on ASIL-classifications (Automotive Safety Integrity Level). In general, the ASIL-level highly depends on the system topology and is determined by a hazard analysis and risk assessment (HARA), which is performed application specific. ASIL-levels are defined for functions of the system/component, not for a component or the system itself. It would be beneficial to pilot selected hybrid electric drivetrain functions and elaborate the ASIL of those in order to provide a reference.

Standardization proposal

The following conclusions can be stated so far:

- For most functions of a hybrid electric drivetrain ASIL B might be sufficient.
- There may be functions that require a higher ASIL-level. These function need to be identified by a structured HARA process.
- ASIL B may not be applicable for pure electric vehicles.

ASIL-levels are proprietary information of each OEM and smart solutions are competitive advantages. Hence, it is a common understanding that finding an agreement on ASIL-levels may be hard to achieve. Nevertheless, a

[1] LV123 has been worked out between German OEMs (Audi, BMW, Daimler, Porsche, VW) to describe electrical requirements and tests of HV components. The entire document is only available for the participating companies.

suggestion is to pick few crucial functions of an electric drivetrain like *accelerate the vehicle according to the driver demand* or *turn off the e-driveline* as pilots and discuss them in the respective standardization bodies.

Mirror Group Comment:
With regard to ASIL it is rightfully stated that these are defined for functions of a system but not for the system itself. […] It is stated correctly that determination of ASIL for different functions is proprietary for each OEM, however, as suggested some pilot functions should be investigated by an appropriate HARA to provide state-of-the-art references for later assessments of similar functions. This would be useful in particular for functions of the HV Battery Systems including but not limited to the Battery Management System (BMS) as outlined on page 16.

Conclusion
Finding a common understanding for ASIL-classification is hard to achieve. Still, during the term of the project, the partners tried to find an agreement for single functions. Therefore, Daimler, Fraunhofer and JMBS propose the following proposal for several functions of a High-Voltage Battery System.

In future discussions the following remarks shall be considered for the High-Voltage Battery System. The scope of ISO26262 is as follows:

- ISO 26262 is intended to be applied to safety-related systems that include one or more electrical and/or electronic (E/E) systems and that are installed in series production passenger cars with a maximum gross vehicle mass up to 3,500 kg. ISO 26262 does not address unique E/E systems in special purpose vehicles such as vehicles designed for drivers with disabilities.
  Systems and their components released for production, or systems and their components already under development prior to the publication date of ISO 26262, are exempted from the scope. For further development or alterations based on systems and their components released for production prior to the publication of ISO 26262, only the modifications will be developed in accordance with ISO 26262.
- ISO 26262 addresses possible hazards caused by malfunctioning behavior of E/E safety-related systems, including interaction of these systems. It does not address hazards related to electric shock, fire, smoke, heat, radiation, toxicity, flammability, reactivity, corrosion, release of energy and similar hazards, unless directly caused by malfunctioning behavior of E/E safety-related systems.
- ISO 26262 does not address the nominal performance of E/E systems, even if dedicated functional performance standards exist for these systems (e.g. active and passive safety systems, brake systems, Adaptive Cruise Control).
- An revised version of ISO 26262 will be published in 2018. This version will also apply to vehicles with a gross vehicle mass of more than 3,500 kg.

The scope of ISO 26262 limits the hazards considered to those relating the Battery Management System (BMS) as this is the only electronic system and it does not address a number of the possible hazards (like electric shock, fire, etc.). For reference a full list of potential hazards from a typical high voltage (> 60 V) li-ion battery pack is:

- **Electric shock**
  No support needed by BMS - justification ECE reg. 100.
- **Cell venting due to internal short circuit** (e.g. manufacturing defect, dendrite growth, physical damage (crash, etc.))
  No support possible by battery management system (BMS) - must be covered by cells/pack design. This is the most likely hazard in a typical automotive battery pack.
- **Cell venting due to too high temperature**
  Can be partly supported by BMS, but ultimately must be covered by cells/pack design. Cell voltage, current and temperature provide a degree of redundancy for the protection provided by the BMS.
- **Power to vehicle HV bus not provided when requested**
  This is a vehicle level issue as "off" shall be a safe state for the pack. This case may also include other hazards like e.g. power to HV bus when not requested or too high/too low power on HV circuit.
- **Inability of battery pack to accept power from vehicle when requested**
  This is a vehicle level issue as "off" shall be a safe state for the pack.
- **Charging**

Charging is a vehicle level issue that may cause functional safety requirements for the BMS.

- **Water ingress** (electrolysis giving flammable gas)
  Vehicle/pack/cell level issue. Does not impact the BMS
- **Magnetic field** (due to high currents - applies to wiring outside of pack as well)
  Vehicle/pack level issue. Does not impact the BMS
- **Fire**
  Vehicle/pack/cell level issue. Does not impact the BMS
- **Weight**
  Vehicle/pack/cell level issue. Does not impact the BMS

The ASIL determination method used is the Hazard Analysis & Risk Assessment (HARA) described in ISO 26262-3.

Mirror Group Comment:
For an ASIL-classification of the High Voltage Battery System ISO 12405 "Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems" Parts 1 to 3 should be considered. A list of potential hazards, as briefly introduced above is a part of ISO 12405-3 as well.

Standardization proposal for the High-Voltage Battery System
Using publically available xEV incident data and sales data it has been determined that there have been 33 incidents worldwide resulting in 3 deaths (https://en.wikipedia.org/wiki/Plug-in_electric_vehicle_fire_incidents) (state November 2015). The death rate is about 10 times lower than conventional vehicles on a per miles driven basis. This data is used in options 1 & 2 below.

Table 2-3 Options for standardization proposal for ASIL-levels of the High-Voltage Battery System.

Option nr.	Option description	Comment
1	Use ISO 26262 on a case by case basis.	Using standard data for incidents and hazards (see above) provides a degree of consistency.
2	Using all (33) incidents recorded, giving S3/E1/C2	This gives an ASIL of QM assuming the packs are similar to existing packs.
3	Using the hazard with the highest exposure and lowest controllability (e.g. unattended charging), results in • Severity = 0 (S0) • Exposure = 4 (E4) and • Controllability = 3 (C3). As no injuries have been reported due to charging issues and S0 results in less than 10 % probability of injury.	This gives an ASIL of QM assuming the packs are similar to existing packs.
4	Use ECE reg. 100 "Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train" to define the required level of safety.	This is a legal requirement for vehicle type approval, but it does not define hazards in terms of ASIL's. It does define the minimum level of safety required for a system to be legally used.
5	Use a previously published analysis e.g. "System safety and ISO 26262 Compliance for Automotive Lithium Ion Batteries", 2012 IEE Symposium on Product Compliance.	This proposes a range of ASIL's from QM to ASIL-D for different hazards. Note these ASIL's apply to the pack, not the BMS.
6	Use SAE J2980_201505 "Considerations for ISO 26262 ASIL Hazard Classification" as a basis for ASIL determination.	This only covers collision related hazards and is not xEV or battery specific.

Mirror Group Comment:

The proposed option 5 might be replaced by ISO 12405-3 “Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems -- Part 3: Safety performance requirements”.

Conclusion

The types of hazards and their severity and controllability significantly depend on the actual cells used (details of chemistry, packaging etc.) and the application so it is not possible to standardize the ASIL levels in general. JMBS’s recommendation is that option 1 is taken for ASIL determination, and option 4 is taken for “functional safety”.

2.1.3 Environmental conditions

Definition of requirement scope

Environmental factors for a vehicle can be climatic conditions, vehicle use conditions and operating mode, supply voltage, mounting locations of components in vehicles etc. Since norms for environmental conditions already exist, the objective is to find a common agreement on existing standards and norms applicable to medium and heavy duty vehicle applications.

Standardization proposal

The standard proposal refers to existing ISO norms for low weight and high weight components, see Table 2-4.

Table 2-4 Options for standardization proposal for environmental conditions.

Option nr.	Option description	Comment
1	The following norms should be fulfilled: • ISO 16750 for low weight components ≤ 5 kg • ISO 19453 for high weight components > 5 kg	

Conclusion

Regarding the environmental conditions it was decided to use ISO 16750 for low weight components and ISO 19453 for heavier components. ISO 19453 was still in progress during component development in ECOCHAMPS and only accessible to members of the ISO-Group. The norm was finally published in March 2018.
ISO 19453 has been proposed to ECOCHAMPS and thus is considered in the MSF standardization process. These norms should be applied whenever possible.

Mirror Group Comment:

The aspects of Environmental testing, DV-Testing and Electromagnetic Compatibility outlined in chapters 2.1.3 - 2.1.5 refer to the relevant standards, which are widely used already. It is highly recommended that in particular for these cost sensitive disciplines the adherence to already established standards should be preferred to avoid costly and probably time-consuming new developments in these areas.

2.1.4 DV-Testing

Environmental conditions are a subchapter of DV-testing. Thus, DV-Testing shall be discussed after the environmental conditions have been defined. Table 2-5 shows norms, standards and test that should be considered for further discussions.

Table 2-5 Options for standardization proposal for DV-Testing.

Option nr.	Option description	Comment
1	Refer to ISO 20653, DIN 75220, EN 61810-1, EN ISO 9227, ISO 6469-3, ISO 12103-1, ISO 20653, EN ISO 527, EN 20105-A02, and LV 124	

2.1.5 Electromagnetic Compatibility (EMC)

Definition of requirement scope

Electromagnetic compatibility considers interference immunity of components as well as their emitted electromagnetic emissions. The scope of this requirement is defining the relevant parameters for standardization of electromagnetic compatibility and finding an agreement on thresholds for these parameters among the ECOCHAMPS partners.

Standardization proposal

ECE R10 describes the basic immunity to interference and emissions. It requires no disturbance of the driving behavior of the vehicle itself as well as of other vehicles and radio devices including AM/FM receivers. An internal OEM norm with focus on product quality, reliability and safeguarding the product liability was provided. Herein immunity of the vehicle against a field strength of 150 V/m in a wide frequency range is required and already agreed between several OEMs. The basis for that is the limit of 70 V/m for the exposure of people to electromagnetic radiations. Considering some reflections that may double the field strength values up to 140 V/m can be reached.

Major difference in requirements result from different measuring methods, different ambient conditions (e.g. properties of anechoic chamber) and different vehicle types (passenger car, truck and bus).

Table 2-6 Options for standardization proposal for EMC requirements on system basis.

Option nr.	Option description	Comment
1	The following norms can be referred for EMC specifications of LV-boardnets • ECE R10 • ISO 7637 • ISO 10605 • ISO 11451 • ISO 11452 • ISO 16750-2	

Conclusion

A common understanding on EMC thresholds could be achieved by harmonizing:

- the immunity with a field strength of 150 V/m in the frequency range of 20 MHz – 2 GHz as well as
- the conducted and radiated emission levels of the components in the frequency range of 30 MHz – 1 (2) GHz.

Furthermore, the following questions remain unclarified:

- Since LV- and HV-components are installed in the vehicles, influencing each other: Do we need to distinguish between the voltage levels of on-board power supply (low voltage/ high voltage) for the specification of EMC-thresholds?
- Are the thresholds defined on component or vehicle level (e.g. interference immunity)?
- Is there a reference for the agreement between OEMs regarding the immunity of the vehicle against a field strength of 150 V/m in a wide frequency range?

To reach these goals and answer the questions, a future discussion between the standardization bodies and the EMC experts of the involved partners is needed.

2.1.6 Noise levels

Since hybrid vehicles contain a combustion engine, defining noise levels for the electric components is not necessary due to their relatively small impact on overall noise. However, a discussion about noise levels will become important for pure electric vehicles. Looking beyond the scope of the ECOCHAMPS project, Table 2-7 gives some references that should be considered in future debates.

Table 2-7 Guidelines for discussions about noise levels.

Option nr.	Option description	Comment

1	**European bus system of the future (EBSF)** Interior noise: • Driving noise at 50 km/h must not exceed 70 dB(A) at the driver's ear height (measuring method in accordance with ISO 5128) • Noise level at low idle must not exceed 55 dB(A) • Noise level of the ventilation in the lowest fan position must be ≤ 61 dB(A) at the driver's ear height, and in middle fan position ≤ 70 dB(A). • Noise types with distinctive tonal characteristics (clattering, grating, squeaking etc.) must be avoided • The radio transceiver volume must automatically adjust to the noise level at the driver's workplace by means of automatic gain control, optional selective radio (with pre-announcement signal)
2	**VDV 236: ‚Klimatisierung von Linienbussen'** Interior noise: • ≤ 68 dB(A) at the passenger's ear height (measuring method in accordance with ISO 5128) Outer noise • VDV-Schriften Nr. 230 /14/ and 231 /15/ (measuring method in accordance with ISO 362 /12/ and 5130 /13/)
3	**ECE-R 51: ‚Stationary Noise Testing of Advanced Technology Vehicles'**
4	**PIEK-Keur:** Methods of measurement for peak noise during loading and unloading (June 2015)
5	Vehicle/Truck Pass-by Noise Testing

Mirror Group Comment:
Regarding standardization/requirements on noise levels, it is stated correctly that a discussion about the aspects of noise emissions of hybrid and electric vehicles will become important. This will not just be a question of lowering noise emissions in urban areas but will need also an assessment of possible road safety implications, which goes beyond the scope of the ECOCHAMPS project.

2.2 High voltage battery system

Scope of component
The scope of this component is high voltage traction batteries for hybrid commercial vehicles.

2.2.1 Specification of power requirements

Definition of requirement scope
The scope is a standardization of test procedure to be able to compare battery packs and/or cells with the possibility to scale to battery pack level (related to ISO 12405-1:2011(E) 17pp).
Preliminary data are:

- Life time operation range for cell voltage,
- Life time operation range for pack voltage,
- State of charge (SoC) high, SoC low,

- Temperature low (definition necessary for determination of minimum power ability dependent on temperature, e.g. 90% SoC and 10% SoC at 10°C)

Mirror Group Comment:
ISO 12405-1 “Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems - Part 1: High-power applications” is for high-power and ISO 12405-2 “Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems - Part 2: High-energy applications” is for high-energy applications. The life-time operation range for cell voltage is part of IEC 62660-1.

Standardization Proposal
Table 2-8 shows the standardization options for power requirement specification elaborated in WP2. For a minimum option 1 is mandatory. The other options can be considered as migration path for improving the standard step by step.

Table 2-8 Options for standardization proposal for power requirements of the High-Voltage Battery System. (BoL: begin of life; EoL: end of life; C: nominal capacity BoL; SoC: rated capacity as percentage of C)

Option nr.	Option description	Comment
1	Charge and discharge current pulses BoL (begin of life) (25°C cell temperature, SoC, t)	Different time length of current pulses to be able to calculate power ability of the pack and to determine internal resistance (SoC: 25%, 50%, 75%, t: 2s, 10s, 30s).
2	Charge and discharge current pulses at lower temperature T (BoL)	T=10°C, T=0°C cell temperature to determine power ability due to different resistances at different temperatures assuming allowed resistance growth
3	Determination of charge power ability at SoC high BoL (25°C and temperature low, t)	Different time length of current pulses to be able to calculate power ability of the pack and to determine internal resistance (SoC high, t: 2s, 10s, 30s)
4	Determination of discharge power ability at SoC low BoL (25°C and temperature low, t)	Different time length of current pulses to be able to calculate power ability of the pack and to determine internal resistance (SoC low, t: 2s, 10s, 30s)

Conclusion
ECOCHAMPS proposes to use option 1 and 2 for standardization with focus on power capabilities. Both options will need additional data like e.g. C-rates of 1, 2, 5, 10 for the current pulses.

In addition to the power specification an aligned aging specification would save validation efforts. In future preferably a load profile (power per time) is added which focuses on aging and life time with the goal of aligning the control strategy to the battery capabilities. This load profile should be common and artificial.

2.2.2 Specification of energy content

Definition of requirement scope
The scope is a standardization of test procedures to be able to compare battery packs or to compare cells with the possibility to scale to battery pack level (related to ISO 12405-1/2).
Preliminary data are:

- Life time operation range for cell voltage
- Life time operation range for pack voltage
- SoC high BoL, SoC low BoL
- allowed (assumed) capacity fade
- SoC high EoL, SoC low EoL

Mirror Group Comment:
These preliminary data items are aspects related to the cells and therefore under the responsibility of IEC 62660-1.

Standardization proposal
Table 2-9 describes the proposed options. Option 1 is mandatory for standardization. The other options can be considered for more advanced approaches.

Table 2-9 Options for standardization proposal for the energy content of the High-Voltage Battery System. (BoL: begin of life; EoL: end of life; C: nominal capacity BoL; SoC: rated capacity as percentage of C)

Option nr.	Option description	Comment
1	Full energy content	Full charge (SoC 100%) of battery pack, 1C full discharge (SoC 0%) of battery pack at 25°C
2	Usable energy content	Charge of battery pack to SoC high BoL, 1C discharge of battery pack to SoC low BoL at 25°C
3	Usable energy content at lower temperature	Charge of battery pack according to SoC high EoL and assumed capacity fade at 25°C, 1C discharge of battery pack to SoC low EoL at 10°C (higher resistance due to lower temperature)
4	1C energy window definition	Charge 1C until upper voltage limit is reached; This is considered as SoC high; discharge 1C until lower voltage is reached (this is SoC low) @ 25 degree Celsius

Conclusion
ECOCHAMPS proposes to use option 1 for determining the full energy content of battery pack or cells at begin of life (BoL) at 25 degree Celsius. This option covers option 2 as well except for some additional heating at low SoC, due to higher energy turnover (discharging from SoC 100% vs. from SoC high). Especially for hybrids, the focus of the MSF, battery performance at lower temperatures is less important because the combustion engine usually heats the battery. Hence, option 3 is omitted within ECOCHAMPS but might be an option for future augmentations.

The specification of the 1C-energy window described in option 4 can be tested without customer specific input. ECOCHAMPS proposes to define this window in the MSF since it significantly improves comparability of battery cells and packs.

JMBS provided US ABC and Freedom Car, these are probably good starting points for defining a common full charge method.

Mirror Group Comment:
Because the current rate for determining the full energy content is not considered yet, the battery manufacturer shall define the current rate.
The importance of battery performance at low temperatures cannot be stated in general, but depends where the battery is integrated.

2.2.3 Minimum set of CAN signals

Definition of requirement scope
The intention is to define a minimum set of CAN signals, which is the common basis for operating traction batteries.

Standardization proposal
ECOCHAMPS proposes to focus on J1939 as a standard for communication within commercial vehicles. This standard currently provides only one traction battery related signal. According to J1939DA_201408 this is:

- Hybrid Battery Pack Remaining Charge (SPN 5464) indicating the hybrid battery pack remaining charge. 0% means no charge remaining, 100% means fully charged.

ECOCHAMPS proposes to augment J1939 by additional traction battery related signals. In detail these are:

- Battery Voltage (measurement, max./min. allowed),
- Battery Current (measurement, max. allowed charging/discharging),

- Capacity of fully charged battery,
- Battery state of charge,
- Battery state of health,
- Max. charge/discharge power (1s, 10s, 30s),
- Contactor Status (Open/Precharging/Closed/Precharge failed),
- Cell voltages (maximum/minimum/average; max./min. allowed),
- Battery shutdown request (5s in advance before battery opens the contactors),
- High Voltage interlock status (pass, fail),
- Cell temperatures (maximum/minimum/average; max./min. allowed),
- Battery cooling inlet and outlet temperature,

Furthermore, a supplier provided a list of minimum CAN signals regarding availability status and battery performance, see Table 2-10.

Mirror Group Comment:

The basis of the signals battery state of charge and battery state of health is not defined. The CAN signals provided by the supplier are not standardized, yet.

Table 2-10 Minimum set of CAN signals for the High-Voltage Battery System.

Signals	In	Out
Minimum set of CAN signals considering the availability status	• Wake up (Hardware, CAN) • Energy request (system control, contactor control) • Crash • Shut down	• Isolation status (resistance) • High-Voltage Interlock Loop (HVIL) status • Contactor status (open/close) • Precharging status
Signals that need to be considered, if the system has an on board charger	• Status • Fast charge procedure • Diagnosis options such as ○ Engine speed ○ Ignition status ○ Vehicle speed ○ Odometer (ODO) ○ System time ○ Diagnosis available	• Contactor switch cycles remaining
Minimum set of CAN signals considering the performance of the battery		• Actual battery voltage • Actual battery current • Min., max. (average) cell voltage and temperature • Actual State of Charge (SoC) (minimum, maximum) • Predicted performance ability State of Power (SoP) (charge/discharge) – Power or current and voltage limits, time horizon (2 s, 10 s, 20 s, continuous) • State of Health (SoH) (not

		necessary if SoP ok) • Optional: Actual energy content (charge, discharge)

Conclusion
Today, hybrid vehicles are common in the passenger car segment but not in commercial vehicle applications. This is reflected by the widely spread commercial vehicle bus J1939 that currently provides only a very limited set of traction battery related signals. The proposal of ECOCHAMPS is to augment J1939 by the signals named above. This list is aligned with the European project *Transformers* which in parallel investigates hybrid on demand drivetrains for commercial vehicles.

Mirror Group Comment:
The definition of required CAN signals is an important piece of work. The wide spread standardization of CAN communication in SAE J1939 is certainly a strength in the heavy CV industry and it is necessary to maintain the CAN signal database according to the growth of functional and system requirements. It is important to join forces with other related projects to get the listed CAN signals (and probably some more) standardized within J1939. This also applies to the necessary standardization of signals for the DC/DC-Converter integration (chapter 2.5.6).

2.2.4 High voltage testing

Definition of requirement scope
The scope is the electrical safety test of traction battery packs.

Standardization proposal
ECOCHAMPS identified a comprehensive collection of existing ISO standards that covers the main issues for HV testing of rechargeable energy storage systems (RESS). Hence, ECOCHAMPS proposes to refer to the following set of norms:

- ISO 6469: Electrically propelled road vehicles - Safety specifications
- ISO 12405: Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems (ISO 12405-1 High-power applications and ISO 12405-2 High-energy applications)
- ISO 16898: Electrically propelled road vehicles - Dimensions and designation of secondary lithium-ion cells
- ISO 18300: Electrically propelled road vehicles - Specifications for lithium-ion battery systems combined with lead acid battery or capacitor
- IEC 62660-1: Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 1: Performance testing

Table 2-11 shows the concluded standardization proposal.

Table 2-11 Options for standardization proposal for the rechargeable energy storage system.

Option nr.	Option description	Comment
1	Use ISO 12405-1 for high-power applications and ISO 12405-2 for high-energy applications for lithium-ion batteries	

Conclusion
The ISO norms named above already cover high voltage testing of battery systems comprehensively. ECOCHAMPS will not propose additional contents. The ECOCHAMPS partners agreed on ISO 12405 for high voltage testing of lithium-ion traction batteries.

2.2.5 Modularity and architecture

Definition of requirement scope

Scope is to define units of a modular battery system for commercial vehicles consisting of several battery cells, which can be combined to traction batteries by connecting one or more modules.

Standardization proposal

Option 1 in Table 2-12 proposes to establish a modular battery unit – a so-called battery pack, which serves as a building block for actual traction batteries. These battery packs shall incorporate interfaces, battery disconnect unit, battery management system, a crash and safety interface and a ground connection.

Mirror Group Comment:

A definition of the terms battery module, battery pack and battery system is recommended. The so-called battery packs (incorporating interfaces, battery disconnect unit, battery management system, a crash and safety interface, and a ground connection) are a system according to ISO 12405-1.

Table 2-12 Options for standardization proposal for modularity and architecture of the High-Voltage Battery System.

Option nr.	Option description	Comment
1	The modular unit of a battery system (battery pack) for commercial vehicles shall consist of: **Interfaces:** • LV plug including 1x CAN transceiver, KL15, KL30, KL31, (crash signal) • HV plug (traction net) • Coolant plug (for liquid cooled systems) **Battery Disconnect Unit:** • Devices for redundant breaking of main current • Precharge circuit • Sensor to monitor module voltage **Battery Management System:** • Monitoring of temperature, current and cell-voltage • Balancing of cells **Crash safety signal interface (one of the following options):** • CAN Crash signal • KL30C • Analogous input for direct readout of ignition wire **Ground connection**	The modular battery has strong relations to standards for minimum set of CAN signals and voltage ranges

Conclusion

A parallel and/or series connection of fully equipped battery packs including all devices according to option 1 in Table 2-12 is considered as the final modularization step.

As an intermediate step towards this final solution ECOCHAMPS proposes to use battery cells common for passenger car applications as a base-level common building block. Due to their high quantities, these cells are highly preferred for commercial applications since this approach reduces battery costs significantly.

Based on these cells so called cell modules are proposed – a series and/or parallel combination of cells including a module controller measuring cell temperatures and voltages and balancing cells in series connection. These cell modules are suitable for series connection of these cell modules up to a certain voltage limit. This voltage limit is a design parameter because the cell modules have to withstand this limit voltage.

For a parallel connection of cell modules issues like e.g. reduced lifetime and inter-module balancing have to be solved.

Mirror Group Comment:
Different battery cells are common for passenger car applications, namely pouch, cylindrical or prismatic. The proposed aggregation of battery cells to cell modules and the serial connection of the latter is status quo and lacks a novelty.

Mirror Group Comment:
Battery modularization is an important aspect for the cost efficient design of complete battery packs. In particular, the definition of standard battery modules consisting of defined numbers of battery cells is an important prerequisite for efficient building blocks for vehicle specific battery packs. A collaboration of major suppliers of battery cells to specify key parameters for future battery modules is therefore very desirable.

2.2.6 Installation space and mounting position

Definition of requirement scope
The scope is to define a common installation space (box space) and a mounting position for traction batteries comparable to standard fuel tanks.

Standardization proposal
A standardized installation space would have great impact on traction battery costs for commercial vehicle applications. Suppliers could optimize their packs for the space defined. Furthermore, scaling effects would reduce battery costs.

Table 2-13 Options for standardization proposal for installation space and mounting position of the High-Voltage Battery System.

Option nr.	Option description	Comment
1	Different shapes of packs are defined	Probably easiest option to achieve affordable of the shelf-product that OEMs need to adapt their vehicle
2	Collect installation spaces from OEMs and find the largest common denominator (per vehicle class – light/heavy/medium)	OEM support is required
3	Standardize modules only instead of complete traction battery pack installation spaces	This option gives the OEM more flexibility to adapt their vehicle

Conclusion
ECOCHAMPS concluded that the installation space definition highly depends on the modularization concept. Further results regarding installation space are more likely, if a traction battery modularization concept is agreed among the stakeholders (see 2.2.5).

2.2.7 High-Voltage DC residual ripple

Definition of requirement scope
The intention is to define a common requirement set for high-voltage DC residual ripple, the battery has to withstand.

Standardization proposal
Currently the ISO working group ISO/AWI PAS 19295: *Electrically propelled road vehicles - Specification of voltage sub-classes for voltage class B* is developing voltage class specifications for electrically propelled road vehicles. This includes high-voltage residual ripple definitions as well.

Conclusion
ECOCHAMPS decided to support the actions in ISO/AWI PAS 19295. A parallel suggestion for high-voltage residual ripple will not be developed.

2.3 Electric Motor/Generator (EMG)

Scope of component
The scope of this component is the electric machine itself without any power electronics. Subsequently, the most relevant standardization parameters in terms of feasibility and standardization benefit are described and specific suggestions for standardization are proposed.

2.3.1 High-Voltage testing

Definition of requirement scope
The high voltage capabilities of EMGs need to be tested to fulfill OEM specific requirements. Standard tests will reduce testing time and testing efforts for the supplier and has in turn a significant potential for reducing development costs.

Standardization proposal
Currently, there are no public standards that define common tests and values for high voltage testing of EMGs. Hence, according to Table 2-14 the first option is to develop a new standard, which requires a joint long-term action of several OEMs and suppliers.

The second option is to use the existing norm LV 123 "*Electrical characteristics and electrical safety of high voltage components in road vehicles; Requirements and tests*". Currently, this norm is only available for participating German OEMs.

Table 2-14 Options for standardization proposal for high-voltage testing of the EMG.

Option nr.	Option description	Comment
1	Electrical safety and HV safety	Very high efforts from several OEMs and suppliers are required to elaborate a new standard.
2	Agree on LV123 "Electrical characteristics and electrical safety of high voltage components in road vehicles; Requirements and tests" as a common standard for high-voltage testing of electric machines	The LV 123 norm is currently only available to participating German OEMs.

Conclusion
ECOCHAMPS suggests to start negotiations with the owners of the standard with the goal to disclose the contents relevant for high voltage testing at least within Europe. This would strengthen both European commercial vehicle OEMs and European suppliers by a significant cost reduction.

<u>Mirror Group Comment:</u>
Regarding High-Voltage testing of Electric Motor/Generators it is correctly stated that there are no directly applicable standards available. Standardization in this field is certainly required to reduce development costs and also to increase quality and reliability of such components in the field. The application of the already available LV123 standard to the wider EU community of suppliers and OEMs should be the preferred solution. A new standard beside LV123 would longer-term increase costs for the partners in today's LV123 group, too.

2.3.2 Specification of power requirements

Definition of requirement scope
The power requirement specifies the power capabilities of the EMG. These values are given for selected voltages, durations and speeds for motor and generator mode.

Table 2-15 Options for standardization proposal for EMG power requirements.

Option nr.	Option description	Comment
1	Definition of continuous power and peak power in motor and generator mode. Define min. duration and min. voltage for both. Define rated and max. speed.	

Standardization proposal

Power requirements for EMGs are specified differently by different OEMs and for different applications. There is no common understanding e.g. on the requested durations of continuous and peak power. Suppliers have to test the requested values individually.

According to Table 2-15 ECOCHAMPS proposes to define several continuous and peak power ratings separated into motor and generator mode by specifying the minimum duration and the minimum voltage for both modes. Even though the EMG design will vary e.g. due to mounting position the power rating requirements will remain the same. This results in the following power requirement scheme:

Table 2-16 Power requirement scheme for the EMG.

Power requirement	Voltage	Duration
Peak motor power	minimum voltage of respective range	1 s
Short term motor power	minimum voltage of respective range	10 s
Medium term motor power	minimum voltage of respective range	60 s
Continuous motor power	minimum voltage of respective range	1 h
Peak generator power	minimum voltage of respective range	1 s
Short term generator power	minimum voltage of respective range	10 s
Medium term generator power	minimum voltage of respective range	60 s
Continuous generator power	minimum voltage of respective range	1 h

Conclusion

The proposed power requirement specification elaborated within the ECOCHAMPS project needs to be discussed by standardization organizations and revised if necessary.

2.3.3 Minimum Lifetime Requirements

Definition of requirement scope

Lifetime requirements specify the timespan the EMG should at least operate under predefined conditions.

Standardization proposal

Lifetime requirements are great cost drivers especially due to the long lasting tests connected to the verification. A single individual test can last for several thousand hours. A common understanding on lifetime requirements would reduce the testing efforts significantly since not all different OEM specifications have to be tested individually.

The standardization options discussed within the project are shown in Table 2-17. An important result is that load spectra are preferred over a direct specification of required mileages and/or operating times. This is mainly because the mileage does not cover the different loads due to different applications (e.g. fully electric, hybrid) and operating strategies (e.g. predictive, non-predictive) even for the same vehicle classes and connected mileage requirements. Hence, ECOCHAMPS agreed that mileage is not suitable for lifetime specification.

Table 2-17 Options for standardization proposal for minimum lifetime of the EMG.

Option nr.	Option description	Comment
1	Define 3-4 typical drive cycles (highway, inner city etc.) and their share; OEM derives the EMG load spectrum based on application (hybrid, fully electric etc.) and vehicle class	Load spectrum derivation option 1
2	Define standard building blocks for a load spectrum OEMs build their load spectrum based on these blocks	Load spectrum derivation option 2
3	Supplier defines lifetime classes; OEM selects class based on application specific load spectrum	Load spectrum derivation option 3
4	Directly define mileage or operating time	

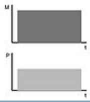
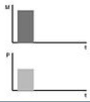
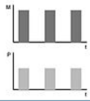
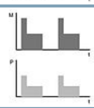
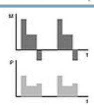
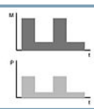
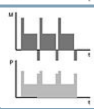
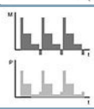
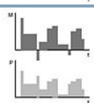
Mileage: • 750 000 km city bus • 1 200 000 km heavy duty • 500 000 km medium duty Operating time: • 35 000 h city bus • 22 000 h heavy duty • 15 000 h medium duty • 8 500 h light duty truck Cold start cycles: 10 years, 6 days a week, 2 cold starts a day (city bus)

Mirror Group Comment:

The figures in the table above should be checked. Especially the mileage of the city bus could be underestimated and is rather in a range between 1 000 000 km and 1 500 000 km. Furthermore, the mileage of medium duty vehicles seems to be overestimated.

Due to the high diversity of lifetime requirements ECOCHAMPS proposes a modular and configurable approach instead of defining a fixed set of application specific values. According to option 2 in Table 2-17 standardized load spectrum building blocks are preferred. These building blocks can be used to configure a certain lifetime requirement. ECOCHAMPS propose to use the norm EN 60034-1 "*Rotating electrical machines – Part 1: Rating and performance"* as a starting point. This norm already defines ten duty types S1 to S10 according to Table 2-18. A combination of these duty types can be used to define the minimum lifetime requirements.

Table 2-18 Duty types according to IEC 60034-1

Duty type	Description	
S1	Continuous running duty	
S2	Short-time duty	
S3	Intermittent periodic duty	
S4	Intermittent periodic duty with starting	
S5	Intermittent periodic duty with electric braking	
S6	Continuous-operation periodic duty	
S7	Continuous-operation periodic duty with electric braking	
S8	Continuous-operation periodic duty with related load/speed changes	
S9	Duty with non-periodic load and speed variations	
S10	Duty with discrete constant loads and speeds	

This approach enables test extensions if an OEM requirement is more demanding than a basic test, which was already performed. The new test does not have to start from the beginning. Instead it is only necessary to run through the building blocks and cycles that go beyond the basic test. A second option for the supplier is to run several comprehensive tests for the component and cross check if the OEM requirements are already fulfilled.

Conclusion

Standardized load spectrum building blocks are a promising approach to reduce the high test efforts for EMG lifetime testing. Further research is necessary to identify the key lifetime factors by using e.g. existing data. Within the ECOCHAMPS project the involved OEMs and suppliers need further joint discussion in order to improve the related knowledge and to propose a first set of load spectrum building blocks e.g. based on EN 60034-1.

<u>Mirror Group Comment:</u>

The proposed approach of using defined standard building blocks for a load spectrum is promising. This can help to avoid discussions around single parameters, e.g. just mileage only, and it makes it possible to efficiently combine requirements for a particular application.

<u>Mirror Group Comment:</u>

The proposed standard blocks yield a huge benefit if an aging model is applied (e.g. S4 with 200 Nm/10 s and 100 Nm/60 s means 0.1 % aging). In such a case, if the blocks were put together it would be very fast to calculate the lifetime expectation without extra testing for the specific application.

2.3.4 Housing and mechanical interface

Definition of requirement scope
The scope of this requirement is the housing and the mechanical interface of the EMG, which especially includes EMG mounting flange and the shaft.

Standardization proposal
The EMG housing and the mechanical interface are highly dependent on OEM specifications as well as application and vehicle type. Furthermore, several other parameters influence the housing of the EMG. Some examples are:

- position of the EMG according to application (P0 – P4 hybrid drivetrain architecture),
- diameter of the clutch bell-housing which depends on the torque that needs to be transmitted,
- the speed level of the EMG since e. g. P2 drives typically operate at lower speeds than P4/EV drives.

SAE J 617 – *"Engine Flywheel Housing and Mating Transmission Housing Flanges"* defines flange geometry between clutch bell-housing and motor flywheel housing. It also locates the crankshaft flange face or the transmission pilot bore (or pilot bearing bore) stop face in relation to housing SAE flange face. For different maximum torques the norm describes suitable housing specifications (SAE 1 to SAE 6, which define diameters of the flange as well as number and size of the bolts). In principle this norm can be used to design a modular EMG for P1 and P2 applications. But for component cost reasons gearbox and EMG are usually designed as a single unit instead of modular components. Within this context SAE housing flanges can provide a common basis for a set of EMG rotor diameters for P1 and P2 applications.

Regarding the torque transmission from drive shaft to clutch as well as from clutch to gearbox input shaft basically two suitable norms exist:

- SAE J 499 – spline shaft connection between clutch and drive shaft or gearbox input shaft
- DIN 5480 – splined joints with involute flanks between clutch and drive shaft or gearbox input shaft

Conclusion
Due to the high variety of EMG applications in hybrid drivetrains ECOCHAMPS concludes that the chance of realizing a housing and mechanical interface standard that goes significantly beyond the standards described above is comparably low.

<u>Mirror Group Comment:</u>
Apart from the housing standard SAE J 617, existing ISO standards should be checked as well, if those can be augmented.

2.4 Inverter EMG

Scope of component
The scope of this component is the inverter for the electric machine that converts DC power in general provided by rechargeable energy storage systems (RESS) to 3-phase AC power and vice versa. Subsequently, the most relevant standardization parameters in terms of feasibility and standardization benefit are described and specific suggestions for standardization are proposed.

2.4.1 Minimum lifetime requirements

Definition of requirement scope
Lifetime requirements specify the timespan the inverter should at least operate under predefined conditions.

Standardization proposal
Minimum lifetime requirements are important design parameters for power electronics. A specification of a minimum set would provide a lifetime base-line for future developments.
Due to the comparably low number of inverters in commercial vehicle applications ECOCHAMPS highly prefers a two-step approach in order to keep the component cost reasonably low. In a first migration step it is proposed

to use passenger car components (option 1 in Table 2-19). The higher lifetime requirements for commercial vehicles can be achieved by adapting the operation conditions. For example an adapted cooling water profile can double the lifetime of power electronics. This is still not enough for full lifetime of long haulage vehicles but provides lifetimes suitable for all other vehicle classes like e.g. distribution trucks.
This standardization approach is directly linked to proposals for:

- Cooling system, temperature ranges and durations (Section 2.4.2) and
- Ambient temperature ranges and vibration requirements (Section 2.4.3).

In a second migration step a full lifetime requirement according to option 2 in Table 2-19 is proposed.

Table 2-19 Options for standardization proposal for lifetime requirements of the Inverter EMG.

Option nr.	Option description	Comment
1	Proposal for inverter lifetime requirements • 15 000h active • 800 000 km • 7.5 Years	Typical long haul CV requirements regarding lifetime are 30.000 h active 1.6 Mio km, and 15 years; hence with option 1 it is not possible to have a single inverter for long haul CVs but option 1 provides modularity for different CV classes
2	Proposal for inverter lifetime requirements (full CV lifetime design) • 30 000h active • 1 600 000 km • 15 Years	This would result in new inverter design; which is over-engineered for vehicles with less lifetime; this results in low numbers and a higher price in turn

Conclusion
ECOCHAMPS concluded that option 1 will be proposed as a midterm solution (migration step) for minimal lifetime requirements. In addition option 2 serves as long term proposal for full-lifetime CV applications. For the second option new inverter designs will be necessary. Hence, scaling effects can be less attractive due to the focus on the commercial vehicle market.

<u>Mirror Group Comment:</u>
The situation regarding the minimum lifetime of power electronics/inverters is obviously more complex than for the Electric Motor/Generator (EMG). Therefore, the proposed two-step approach (see Table 2-19) is a pragmatic way out. In the longer term, an approach that uses pre-defined load collectives, such as for EMGs, could probably enable more efficient development.

2.4.2 Cooling system, temperature ranges and durations

Definition of requirement scope
Scope of this requirement is to define a standard for temperature ranges and durations as baseline for future inverter designs.

Standardization proposal
Coolant temperature ranges and durations are an important design parameter especially for lifetime. Agreeing on standard ranges and durations would enable high scaling effects and significant development cost reductions e.g. for lifetime testing. Table 2-20 and Figure 2-1 introduce the ECOCHAMPS standardization proposal in detail. This proposal enables the usage of passenger car inverters with a significantly increased lifetime and attractive scaling effects.

<u>Mirror Group Comment:</u>
Besides the coolant temperature ranges and durations, the thermal design influences also the lifetime.

Table 2-20 Options for standardization proposal for cooling system, temperature ranges and durations of the Inverter EMG.

Option nr.	Option description	Comment
1	• Water cooling with G40 H2O mix 50:50 should be the standard	

• Component should allow vacuum filling of cooling circuit • Pressure drop @ flow rate @ temp. for a given media should be defined, proposal is: 200 mbar @ 5 l/min @ 25 °C • Maximum pressure in cooling circuit shall be 3.5 bar • A first suggestion for temperature ranges and durations is summarized in Table 2-21 • In a range of -40° to 60°C full power operation should be possible (derating above 60°C)

Conclusion
The proposed cooling system as well as the temperature ranges and durations are a first proposal that enables the adaption of passenger car inverters for commercial vehicle applications with reasonable efforts. This proposal needs to be discussed by the OEM of the ECOCHAMPS project. If an agreement can be achieved especially on the proposed reduction of the temperature profile, an economically reasonable transition from passenger car to commercial vehicle application is achievable.

Table 2-21 Proposal for temperature ranges and durations

Cooling water temperature	%	hours
-40 °C … -20 °C	4.0	600
-20 °C … 25°C	15.0	2 250
25 °C … 55 °C	30.0	4 500
55 °C … 60 °C	50.0	7 500
60 °C … 65 °C	1.0	150

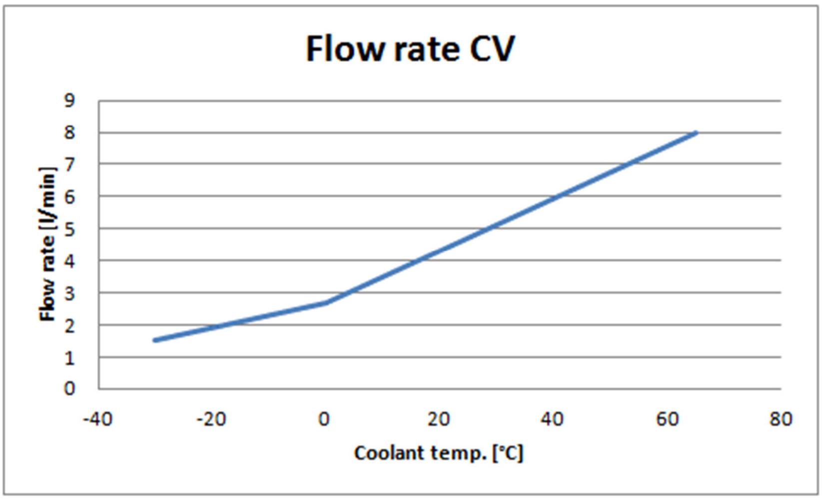


Figure 2-1 Typical dependence of flow rate vs. temperature.

2.4.3 Ambient temperature ranges and vibration requirements

Definition of requirement scope
The scope is to agree on common temperature ranges and vibration requirements for EMG inverters in commercial vehicle applications.

Standardization proposal
Ambient temperature ranges and vibration requirements are directly linked to the mounting position of the component. These mounting positions and the specific temperature ranges and vibration requirements are standardized in ISO 16750. The reasonable options for mounting EMG inverters are summarized in Table 2-22.

Table 2-22 Options for standardization proposal for ambient temperature ranges and vibration requirements of the Inverter EMG.

Option nr.	Option description	Comment
1	Mounting position is engine • Vibrations, temperature ranges and pollution are defined by engine mounting position according to ISO 16750 • The IP class remains unaffected and shall be IP67 & IP6K9K.	Currently not feasible (technologically)
2	Mounting position is chassis • Vibrations, temperature ranges and pollution are defined by chassis mounting position according to ISO 16750 • The IP class remains unaffected and shall be IP67 & IP6K9K.	

Conclusion
ECOCHAMPS concluded that engine (option 1) and chassis (option 2) are the only reasonable mounting positions for EMG inverters in commercial vehicles. Other mounting positions are not considered. The temperature ranges and vibration requirements for the considered mounting positions shall be according to ISO 16750.

2.4.4 Minimum drive cycle/lifetime requirements

Definition of requirement scope
Lifetime requirements specify the timespan the EMG inverter should at least operate under predefined conditions.

Standardization proposal
Lifetime requirements are great cost drivers especially due to the long lasting tests connected to the verification and testing. A single individual test can last for several thousand hours. A common understanding on lifetime requirements would reduce the testing efforts significantly since not all different OEM specifications have to be tested individually.

The lifetime requirement of the EMG inverter is directly linked to the lifetime requirements for the EMG. Hence, the proposal for the EMG and the EMG inverter should be the same. The detailed ECOCHAMPS proposal regarding lifetime for EMG and EMG inverter is summarized in the EMG section 2.3.3. The approach is based on common building blocks that can be used to design OEM specific cycles that are still comparable to a large extent.

Conclusion
The minimum drive cycle shall be common for EMGs and EMG inverters. The approach for both components is described in section 2.3.3 and is based on common building blocks. Even though, these building blocks can be used to design OEM specific cycles they are still comparable to a large extent. This comparability has a great potential to reduce lifetime testing efforts that are currently very high.

2.4.5 Definition of the term "continuous current"

Definition of requirement scope
The scope is the definition of the term "continuous current" which is currently defined differently by the OEMs. Most important is the time span which is linked to the required value.

Standardization proposal
The continuous current is a key design parameter not only for the design of EMG inverters but also for the two other main drivetrain components namely the traction battery and the EMG itself. This current is proposed to be a single value with an agreed time span. Especially for hybrid applications ECOCHAMPS proposes to define "continuous current" as follows:

- Current that a component can operate with for at least 60 minutes without degradation.

Conclusion
ECOCHAMPS proposes a definition of the term “continuous current” which is directly linked to a fixed duration. The proposed duration of 60 minutes is agreed among the project partners. Within this time the temperature of all drivetrain components is expected to reach a steady state.

2.4.6 High-Voltage DC residual ripple

Definition of requirement scope
The intention is to define a common requirement set for high-voltage DC residual ripple that the EMG inverter has to fulfil on the DC link.

Standardization proposal
Currently the ISO working group ISO/AWI PAS 19295: *Electrically propelled road vehicles -- Specification of voltage sub-classes for voltage class B* is developing voltage class specifications for electrically propelled road vehicles. This includes high-voltage DC residual ripple definitions as well.

Conclusion
ECOCHAMPS decided to support the actions in ISO/AWI PAS 19295. A parallel suggestion for high-voltage residual ripple will not be developed.

2.5 DC/DC-Converter

Scope of component
The scope is the DC/DC-Converter from high voltage, according to the defined voltage levels of 2.1.1, to 12 V or 24 V board net supply.

2.5.1 Operating time / lifetime

Definition of requirement scope
Definition of expected lifetime of a DC/DC-Converter mounted in CV application. The lifetime is split in active / driving and active / charging without further details. Those details might be specified in future standardization processes.

Standardization proposal
The idea is to take passenger car components and change operating conditions to achieve a longer lifetime by e.g. stricter temperature requirements. According to the know-how of the involved experts, 10 degree average temperature drop approximately doubles lifetime. Based on this assumption, the four standardization proposals are summarized in Table 2-23.

Table 2-23 Options for standardization proposal for lifetime for the DC/DC-Converter.

Option nr.	Option description	Comment
1	• Active / driving 8,000 h, • Active / charging 30,000 h (with max. output power of 600 W and cooling water active)	Complete carry-over from passenger cars
2	• Active / driving 15,000 h, • Active / charging 23,000 h (with max. output power of 600 W and cooling water active)	Application of passenger car component to CV; same design as option 1; shift between operating hours of the two modes (driving, charing); no additional costs expected compared to passenger car;
3	• Active / driving 15,000 h, • Active / charging 30,000 h (with max. output	Application of passenger car component to CV; technical limit of

		power of 600 W and cooling water active)	option 1 and 2 design; almost no additional costs expected
4	• •	Active / driving 30,000 h, Active / charging 50,000 h (with max. output power of 600 W and cooling water active)	new design, passenger car component not usable → expensive due to low quantities

While option two is based on a shift of operating times from active / charging to active / driving mode, option 3 extends the operating times by decreasing the average temperature load. With the cooling water distributions shown in Table 2-24 for active / driving and Table 2-25 for active / charging the operation times could be increased to 15,000 h and 30,000 h respectively.
Option 4 is a dedicated new design according to usual lifetime requirements of long haulage trucks. This would result in a complete new component with comparably low scaling effects.

Table 2-24 Cooling water distribution for active / driving 15,000 h.

Cooling water temperature	%	hours
-40 °C … -20 °C	4.0	600
-20 °C … 25°C	15.0	2 250
25 °C … 55 °C	30.0	4 500
55 °C … 60 °C	50.0	7 500
60 °C … 65 °C	1.0	150

Table 2-25 Cooling water distribution for active / charging 30,000 h.

Cooling water temperature	%	hours
-40 °C … -20 °C	4.0	1 200
-20 °C … 25°C	70.0	21 000
25 °C … 55 °C	25.0	7 500
55 °C … 60 °C	1.0	300
60 °C … 65 °C	0	0

Conclusion
ECOCHAMPS proposes to use option 1 and option 3. For low operation time applications use option 1 and carry over the part of passenger cars without changes. For high operation time applications use option 3. This would still require higher testing efforts compared to option 1, but is probably no new design, depending e. g. on the temperature distribution. For very high lifetime requirements an individual design or maybe a schedule change of the component will be required.
For standardization of this requirement a temperature distribution is absolutely necessary to be attached to the lifetime figures. Option 3 can be considered as an example on how to probably achieve reasonable lifetimes based on passenger car components.

2.5.2 Continuous power step down

Definition of requirement scope
Continuous maximum power for energy transfer from HV (typically 400V) to LV (typically 12V or 24V).

Standardization proposal
In order to meet the requirements of the different vehicle classes it was decided to propose a modular approach. Therefore, different power classes for the DC/DC-Converter will be defined. If higher power is requested, several modules are combined.

Table 2-26 Options for standardization proposal for continuous power step down of the DC/DC-Converter.

Option nr.	Option description	Comment

1	3.6 kW passenger car component	"magical figure" for passenger cars is motivated by one-phase (16A/230VAC) normal chargers
2	2.0 kW @ 24 V	2.0 kW are sufficient for CV
3	1.0 kW @ 12 V	Use 2 in series to get 2.0 kW
4	4.5 kW @ 24 V	Requested for bus applications

Mirror Group Comment:
If the DC/DC-Converters are connected in series (comment in option 3), then both must operate at the same time. This might cause a decreased reliability. If one fails, then the DC/DC-System cannot operate anymore.

Conclusion
The experts for medium-duty and heavy-duty trucks have confirmed options 2 and 3. However, for bus applications 2.0 kW modules are not sufficient. A combination of several modules is not suitable, because the power needed would require too many of the proposed modules (six in total) and thus would result in too much effort. Therefore, another power class of 4.5 kW (Option 4) was added to the proposal for further discussion.

2.5.3 Cooling system and temperature

Definition of requirement scope
Scope of this requirement are temperature range and operating conditions for the cooling of the DC/DC-Converter.

Standardization proposal
For DC/DC-Converters water cooling is set as a standard. Option 1 is defined for the modules regarding the 1.0 kW and 2.0 kW modules proposed in section 2.5.2. Option 2 is requested for the 4.5 kW DC/DC-Converter that is intended for bus applications.

Table 2-27 Options for standardization proposal for cooling system and temperature of the DC/DC-Converter.

Option nr.	Option description	Comment
1	Passenger car standard • Component should allow vacuum filling of cooling circuit • Pressure drop @ flow rate @ temp. for a given media should be defined, proposal is: 200 mbar @ 5 l/min @ 25°C with G40 H2O mix 50:50	
2	Cooling system specification requested for 4.5 kW modules • Pressure drop @ flow rate @ temp.: 10 mbar @ 1.2 l/min @ 55°C for 50:50 water-glycol-mixture	

Option 1

- Temperature range is -40°C to 65°C for full power operation with possible decrease at temperatures above 65°C (decrease at 85°C to 50 % load).
- Allowed ambient temperatures (at the housing of the DC/DC-Converter) are -40°C to 120°C for full operation and cooling active.
- Typical cooling fluid flow is 5 l/min.
- Max. allowed pressure drop is 600 mbar.
- Max. pressure in cooling circuit is 3.5 bar.

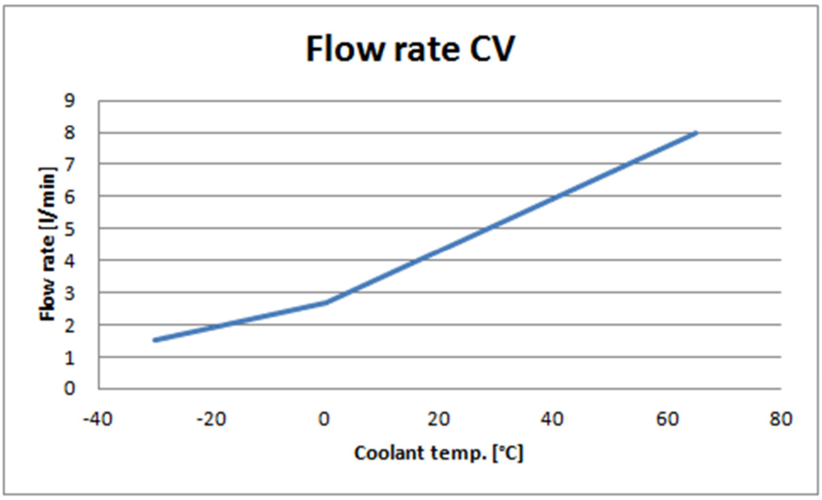


Figure 2-2 Typical dependence of flow rate vs. temperature.

Option 2

Proposed cooling parameters for the 4.5 kW module are:

- Temperature range is -40°C to 80°C for full power operation with possible decrease at temperatures above 80°C up to 150°C (continuously to 0 % → the DC/DC-Converter is shut down)
- Minimum flow is 1.2 l/min
- Maximum coolant temperature is 55°C
- Specification for continuous power of 4.5 kW:
  2.5 l/min @ 55°C coolant temperature and max. 70°C ambient temp @ 1 m/s air movement
- Figure 2-3 shows the relation of pressure drop and volume flow for 50:50 water-glycol-mixture @ 50°C

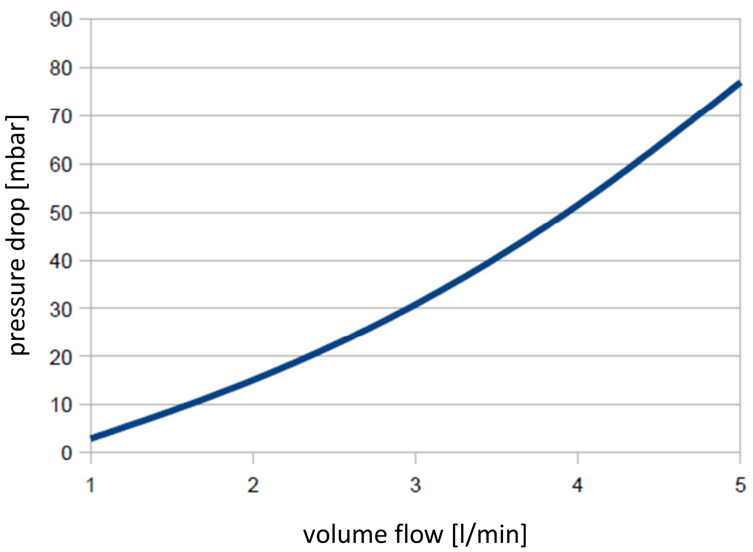


Figure 2-3 4.5 kW Component: Pressure drop dependent on volume flow for water-glycol mixture @ 50 °C fluid temperature.

Conclusion

Option 1 has been confirmed for medium-duty and heavy-duty truck applications. Option 2 has been added for bus applications requiring 4.5 kW at 24 V.

2.5.4 Mounting position, humidity and temperature load spectrum

Definition of requirement scope

Define a mounting position for the DC/DC-Converter and try to find existing norms for humidity and temperature load spectrum that could be applied.

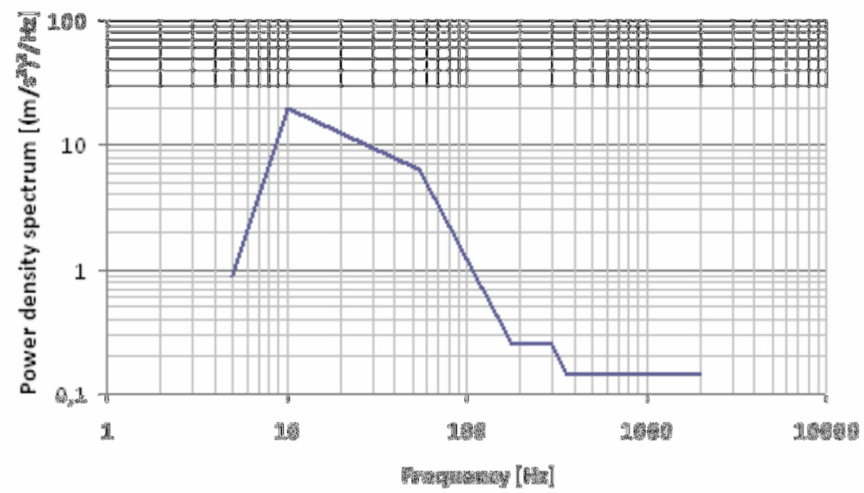
Standardization proposal

The mounting position of the DC/DC-Converter is difficult to standardize, because different mounting positions lead to different component designs. Therefore, it was decided to propose worst-case mounting positions or exclude position (e.g. wheel box and underfloor) as basis for standardization. The different suggestions are summarized in Table 2-28.

Table 2-28 Options on defining a worst-case mounting position.

OEM	Worst-case mounting position	Temperature range
1	Engine compartment (in the front of the vehicle)	-30°C…120°C
2	Defining a worst-case solution is difficult and always more expensive. It would be better to have more positions to select from. Suggestion: classify a product regarding ISO 16750, e.g. • Vibrations: ISO 16750-3 test VI, VII or VIII • Temperature ranges: ISO 16750-4 code D, H, J or N • Pollution: IP class, resistance to automotive fluids, etc.	
3	In order to save costs, the proposal is to decide for a frame mounted position. In this case temperature ranges and possibly the vibration requirements can be reduced. Depending on the mass of the DC/DC-Converter (> 5 kg) the vibration requirements should be acc. ISO 19453 (under development by ISO). The IP class remains unaffected and shall be IP67 & IP6K9K.	-40°C…80°C
4	• No definition of a worst-case position • Excluded positions: wheel case, underfloor, engine compartment with inverter / powertrain-attachment.	

Shaking profile acc. to LV124 vibration profile D (body-mounted parts)



Ambient temperature distribution for driving

Ambient temperature	%	hours
-40 °C … -10 °C	6.0	900
-10 °C … 25 °C	20.0	3 000
25 °C … 40 °C	33.0	4 950
40 °C … 50 °C	23.0	3 450
50 °C … 60°C	9.0	1 350
60 °C … 65 °C	2.6	390
65 °C … 70 °C	1.9	285
70 °C … 75 °C	1.8	270

75 °C … 80 °C	1.7	255
80 °C … 85 °C	1.0	150

Ambient temperature distribution for idleness

Ambient temperature	%	hours
-40 °C … -10 °C	10.0	3 000
-10 °C … 25 °C	15.0	4 500
25 °C … 40 °C	45.0	13 500
40 °C … 50 °C	20.0	6 000
50 °C … 60°C	9.0	2 700
60 °C … 65 °C	1.0	300
65 °C … 70 °C	0.0	0
70 °C … 75 °C	0.0	0
75 °C … 80 °C	0.0	0
80 °C … 85 °C	0.0	0

5

- Mounting position is chassis
- Vibrations, temperature ranges and pollution are defined by chassis mounting position according to ISO 16750 / ISO 19453
- The IP class remains unaffected and shall be IP67 & IP6K9K.

Conclusion

After evaluation of the proposed options, option 5 has been confirmed by the experts, e.g. the DC/DC-Converter will be mounted at the chassis and ISO 16750 / ISO 19453 will be applied. The IP class of the component is IP67 & IP6K9K.

It is expected, that the chassis mounting position need to be specified more precisely. For bus applications, chassis shall include e.g. roof and the back of the vehicle.

Remark: The ‘chassis’ as mounting position (see option 5) is not specific enough. E.g. in hybrid bus applications DC/DC-Converters are mounted on the roof or at the back of the vehicle, which needs to be covered. A more precise statement would be appreciated.

<u>Mirror Group Comment:</u>

For the mounting position of the DC/DC-Converter, the experts have suggested a frame mounting. Considering position on a bus frame structure – as outlined this could be also the roof of a bus – the term “chassis” could be too limiting. A more precise description is probably necessary (as suggested in the document).

2.5.5 Mechanical interface & installation space

Standardizing mechanical interface and installation space would be very helpful, but seems not feasible due to different application scenarios.

The following design guidelines are suggested by the MSF:

- Put high voltage and low voltage connections on different/opposite faces.
- Maximal two faces of the component should be used for electric connectors.
- The high voltage connector shall be a 2 pin connector.
- An important and probably expensive “detail” regards the B-connection/isolation to the DC/DC-housing. On the one hand B-connected is cheap. On the other hand B-isolated is expensive but still the preferred solution for CV due to the ground concept of trucks and the option to connect DC/DC-Converters in series.

With this conclusion housing design is still application specific but it has a potential of saving a remarkable portion of the development costs. This requirement will not be discussed further within the ECOCHAMPS project.

2.5.6 Control interface and signals

Definition of requirement scope
Defining a control interface for a DC/DC-Converter with 12 V or 24 V output.

Standardization proposal
For the DC/DC-Converter a CAN-interface shall be standardized. Possible specifications for CAN-signals are ISO 11898 or SAE J1939 with hybrid extension (currently under development).

Table 2-29 Options for standardization proposal for control interface and signals of the DC/DC-Converter.

Option nr.	Option description	Comment
1	Minimal interface with pins • CAN H • CAN L • Interlock IN • Interlock OUT Control interface is completely based on CAN. HV interlock is passive and is actuated by the HV connector: no action within DC/DC-Converter.	

2	Standard signal interface with 10 pins
	• CAN H (in)
	• CAN L (in)
	• KL15 (or KL75)
	• KL30
	• Interlock IN (passive)
	• Interlock OUT (passive)
	• KL31
	• 3xReserve e.g.
	  ○ CAN H out,
	  ○ CAN L out,
	  ○ Future applications
	Control interface is completely based on CAN.
	HV interlock is passive meaning that the interlock is broken by disconnecting either the HV and/or the signal connector.	

3	Standard signal interface with 13 pins Pin assignment option 1 • KL15 • KL30 • KL31 • **RUN** (wake up) • **BOOT** (initializing) • CAN-H (in) • CAN-L (in) • CAN-H (out) • CAN-L (out) • 120 Ohm • 3xReserved (e. g. RS232) Pin assignment option 2 • KL15 • KL30 • KL31 • Interlock in	

• Interlock out • CAN-H (in) • CAN-L (in) • CAN-H (out) • CAN-L (out) • 120 Ohm • 3xReserved (e. g. RUN (wake up), BOOT (initializing))

For all options:

- Standardized CAN signals are
  - IN: desired state (off, standby, buck-mode)
  - IN: emergency shutdown
  - IN: desired LV output voltage
  - IN: max. LV output current
  - IN: max. HV input current
  - OUT: actual state (off, standby, buck-mode, limited power, error)
  - OUT: error code (if in error state)
  - OUT: actual LV voltage
  - OUT: actual temperature of power electronic
  - OUT: actual LV current
- CAN properties are
  - Extended frame: CAN 2.0B interface
  - Highspeed CAN (250kb and 500kb selectable by parameter)
  - CAN FD (tolerant) with maximum data rate of 2Mbps
  - SAE J1939-71 messages (where possible)
  - Daisy chain of CAN connections on ECU
  - PCB prepared for termination resistor
  - Wake up shut down over CAN

Conclusion

Option 2 has been confirmed during the initial workshops. Afterwards, option 3 has been proposed additionally. Both solutions need to be discussed by a future standardization groups with a wider circle of stakeholders.

2.6 Electric Air Compressor

Scope of component

The scope of this component is a:

- fully integrated
- stand-alone
- electrically driven

rotary vane air compressor. Thus, the component contains air compressor, e-motor, inverter and ECU.

2.6.1 Rotational speed and air flow

As the rotary vane is a fixed displacement compressor, airflow is directly linked to rotational speed at the various pressure requirements. OEMs are not interested in the rotational speed but rather the airflow.
Special requests from OEMs investigate flows from 50 l/min to 550 l/min free air delivered (F.A.D.). However, the normal requirements are between 150 to 400 l/min. There is legislation that governs the maximum "pump-up time" to fill the air system. As the system volumes vary so much by OEM, the flow requirement also varies.
Standardizing this requirement would give no additional benefit, because the same components run on different speeds to adapt to the airflow. Therefore, this requirement has been skipped. Please refer to existing standards, e. g. ECE R13.

2.6.2 Non-electrical interfaces

Definition of requirement scope

This requirement specifies the pneumatic and cooling connection as well as the mechanical mounting interface of the air compressor. Since the air compressor is a standalone component and therefore a self-contained system, no hydraulic interface will be defined.

Standardization proposal

Mounting interface

The mounting of an electric air compressor is dependent of the available installation space and position in the vehicle. It is very diverse, but to satisfy both OEM and supplier needs concerning common basis, hole pattern guidelines according to VDA should be considered.

Pneumatic interface

Table 2-30 defines the pneumatic interface.

Table 2-30 Proposal for pneumatic connections for the pneumatic interface of the Electric Air Compressor.

Option nr.	Option description	Comment
1	compressor suction connection: M30x1.5 min. 17mm deep	
2	compressor pressure connection: M26x1.5 min. 12mm deep	

Cooling interface

Table 2-31 defines the connection for the cooling interface, if the compressor is liquid-cooled.

Table 2-31 Proposal for cooling connections for the cooling interface of the Electric Air Compressor.

Option nr.	Option description	Comment
1	Cooling connection: M16x1.5 min. 11mm deep	If the compressor is liquid cooled

Conclusion

The proposed interfaces have been confirmed by the experts. Air cooling is not specified, due to the complexity of the system, however pneumatic interfaces would remain consistent for both cooling methods. VDA guidelines for the mounting interface exist for passenger car components. It should be investigated if they can be applied to commercial vehicle components.

2.6.3 Oil intrusion into piping / system

Definition of requirement scope

The scope for this requirement will be an actual value range for the level of oil intrusion permissible into the OEMs air system.

Standardization proposal

The proposal for this requirement is that the permissible level of oil intrusion should be dictated by the OEMs need for clean air in their system balanced against the increase of the compressor volume and weight by adding secondary separators. As an industry standard, oil intrusion is measured in parts per million [ppm] or milligrams of oil per cubic meter of air [mg/m3].

Through knowledge of the application, the proposal is that up to 3 ppm [3.6 mg/ m^3] should be the standard permissible level of oil intrusion. A better separation than 3 ppm would add weight and volume to the compressor, which would not be justifiable by the small reduction in ppm. If the separation is worse than 3ppm, the compressor operation would be compromised by the increase in oil depletion.

Table 2-32 Options for standardization proposal for oil intrusion into piping and system of the Electric Air Compressor.

Option nr.	Option description	Comment

1	0 ≤ 3 ppm [0 ≤ 3.6 mg/m^3] weight of oil

Conclusion
The value of 3 ppm [3.6 mg/ m^3] has been confirmed by the experts.
During the process the question arose if oil intrusion increases with component age. But there will be no aging effect on the oil intrusion within the service life of the filter and separator if they are changed at the agreed service intervals. That means the suggested level of oil intrusion can be maintained over the component lifetime.

2.6.4 Service intervals and operating intervals between services

Definition of requirement scope
The scope for this requirement will be an actual value range for the continuous operating hours of the compressor between services, and proposals for overall service intervals. For this requirement service means changing the oil of the compressor.

Standardization proposal
The proposal for this requirement is that the service intervals of the compressor should be dictated by the hours of total contiguous operation of the compressor, to a point that sees no detrimental effect to the performance of the compressor. Through knowledge of the application, plus expected consumption and degradation of the compressor oil, the proposal is that 4 000 hours of total contiguous operation should be the standard operating interval between services.

However, it is recognized that, to save on time, the servicing of any ancillary component should be in line with the service intervals of the OEMs vehicle. It is assumed that there will be an annual service required for the OEMs vehicle and that the compressor, if it has not already reached 4 000 hours of total continuous operation, should also be serviced at this point.

Table 2-33 Options for standardization proposal for service and operating intervals of the Electric Air Compressor.

Option nr.	Option description	Comment
1	4 000 h of total continuous operation between services	Whichever comes first
2	Annual service in line with the vehicle	Whichever comes first

Conclusion
This proposal mainly reflects the supplier view. Since the component will not be engine mounted anymore and thus be driven independently from vehicle engine intervals, OEMs needed to check their requirements regarding continuous operating hours of the air compressor. As a result of this consideration, the OEMs confirmed the proposed 4 000 hours.

2.6.5 Maximum air pressure

Definition of requirement scope
The scope for this requirement will be an actual value for the maximum air pressure the compressor must achieve to meet the demand of the OEMs air system.

Standardization proposal
The proposal for this requirement is that the maximum air pressure should be dictated by the OEMs need for air balanced against the compressor’s capability and the legislative pump up requirement times as outlined in ECE R13. As an industry standard, pressure is measured in bar.

Through knowledge of the application, the proposal is that 12.5 bar should be the standard maximum air pressure required by the OEMs to fill and maintain their air systems within the legislative time frames taking into account ancillary air systems as well as the braking system.

As the compressor has a fixed compression ratio, to achieve better pressures than 12.5 bar would add extra stress to the parts and excessive heat load to the OEMs cooling system plus a reduction to the compressor efficiency due to increased air losses.

However, requests from the OEMs are a maximum pressure of 13.5 would be required to comfortably support their system pressures. For this reason three options from 12.5 to 13.5 bar will be proposed for further discussion.

Table 2-34 Options for standardization proposal for maximum air pressure of the Electric Air Compressor.

Option nr.	Option description	Comment
1	12.5 bar	This is the preferred supplier option
2	13 bar	
3	13.5 bar	This is the preferred OEM option

Conclusion
ECOCHAMPS initially proposes 13.5 bar as maximum air pressure for the electric air compressor. Nevertheless, further discussion with standardization organization and a greater set of stakeholders are needed to conclude on the maximum required air pressure.

2.6.6 Electrical interface

Definition of requirement scope
Define form and pin connections of electric connections.

Standardization proposal
Since the electric air compressor will be a fully integrated component, the electrical interface will define the high voltage connection and the communication interface only. For communication CAN will be used.

Table 2-35 Options for standardization proposal for the electrical interface of the Electric Air Compressor.

Option nr.	Option description	Comment
1	• HV-DC and CAN connectors • Plug connection	HV-Plug should fulfil IP 6K9K and IP 67
2	• HV-DC and CAN connectors • Cable connection	Preferred option

Conclusion
The proposed options have been confirmed, it is agreed that a cable connection is preferred. Thus, each OEM can either use a cable lug or apply an individual plug.

2.6.7 Maximum air flow

Definition of requirement scope
The scope for this requirement will be an actual value for the maximum air flow the compressor must achieve to meet the pump up time of the OEMs air system.

Standardization proposal
The proposal for this requirement is that the maximum air flow should be result from the OEMs need for air balanced against the compressor’s capability and the legislative pump up requirement times as outlined in ECE R13. As an industry standard, flow is measured in liters per min [l/min].

Through knowledge of the application, the proposal is that 400 l/min (F.A.D.) should be the standard maximum air flow required by the OEMs to fill and maintain their air systems well within the legislative time frames taking into account ancillary air systems as well as the braking system. As the compressor has a fixed displacement, to achieve better flows than 400 l/min (F.A.D.) would add excessive power load to the motor and would cause the compressor to put too much load on the batteries.

Table 2-36 Options for standardization proposal for maximum air flow of the Electric Air Compressor.

Option nr.	Option description	Comment
1	400 l/min (F.A.D.) continuously @ 13.5 bar	This is the preferred option

Conclusion

During workshop discussions the question arose, if it is possible for the OEMs to go for a lower value than the proposed 400 l/min. Even though it is possible to set a lower value, regarding future applications, a higher air flow leads to lower duty cycles and thus gives a higher potential for energy optimized operation. That's why it is recommended to use 400 l/min continuously F.A.D. @ 13.5 bar.

2.6.8 Reference cycle

Definition of requirement scope

Find a suitable method for defining a reference cycle. Since the reference cycle has major influence on the component development costs, finding a standardization for it would be highly beneficial.

Standardization proposal

For standardization of the reference cycle, the different vehicle classes should be considered. Standardization could define a method for creating a reference cycle or several fixed cycles. (Note: For the compressor it is better to keep it running for a certain time instead of turning it on and off frequently.)

Table 2-37 Options for standardization proposal for a reference cycle for the Electric Air Compressor.

Option nr.	Option description	Comment
1	Configurable synthetic test cycle for single component; e.g. composition of full-load operation, off-load operation and on-load operation, with possible parameters • duty cycle • on-load level • time spans	e. g. Figure 2-4
2	Defining one realistic cycle based on option 1	
3	Definition of a (configurable) drive cycles	Not realizable

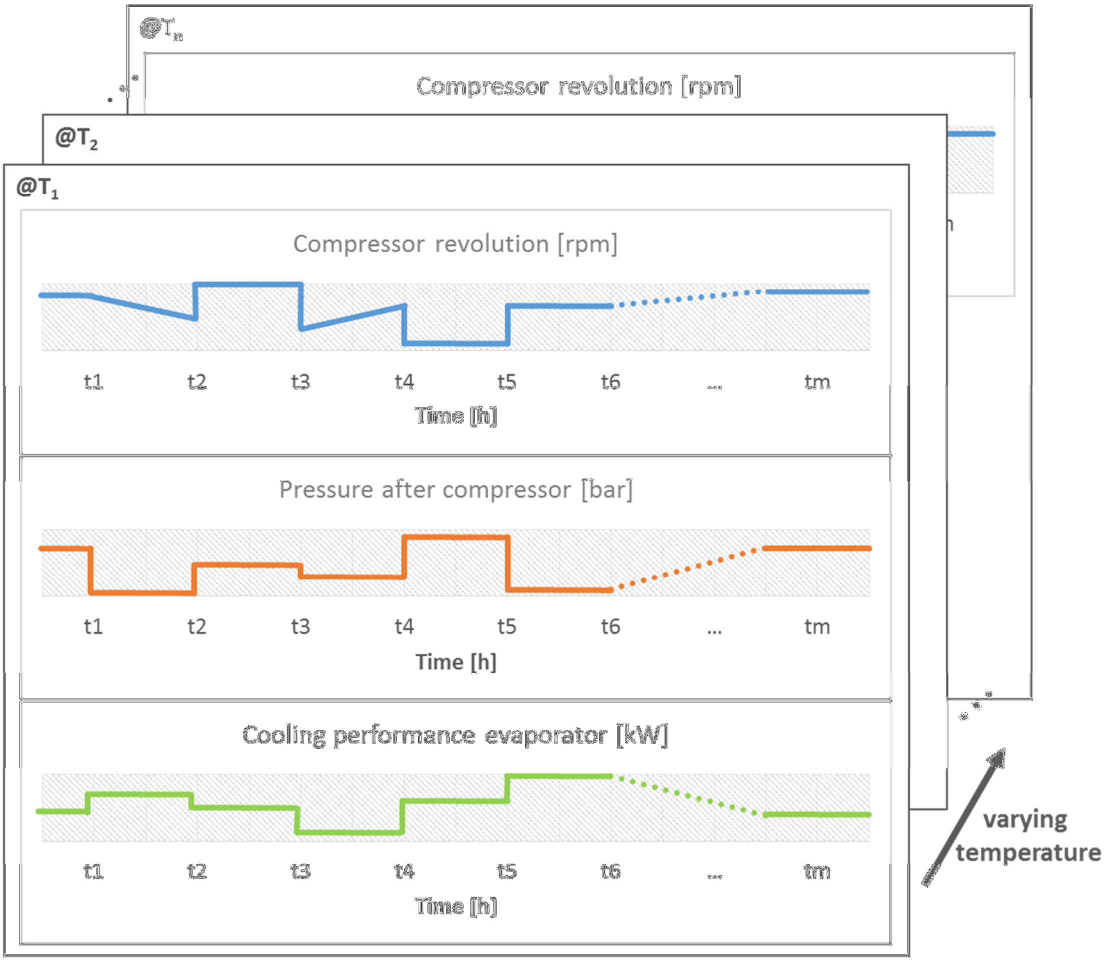


Figure 2-4 From HVAC: Example: Configurable test cycle.

Conclusion

Defining a fixed reference cycle for all or for each vehicle class would be most beneficial, but is on the other hand difficult to agree due to different OEM demands. A first step in this process could be the definition of at least a method, e.g. the definition of a configurable test cycle or single test cycle modules that can be configured and combined respectively.

The definition of a drive cycle for the vehicle instead of a reference cycle (laboratory test on component level) seems not to be suitable, since the supplier cannot prove their component performance integrated in a vehicle.

For further steps it is proposed that the OEMs provide their reference cycles to a neutral partner e.g. standardization bodies. Those try to combine these cycles on an anonymous basis and develop a standard proposal if possible.

2.6.9 Mechanical shock and maximum acceleration forces

Definition of requirement scope

Find suitable methods or existing norms for shock tests and define maximum g-acceleration for all directions.

Standardization proposal

Table 2-38 Options for standardization proposal for mechanical shock and maximum acceleration forces of the Electric Air Compressor.

Option nr.	Option description	Comment
1	Try to find suitable norm, possible norms are • ISO 16750-3 Road Vehicles – Mechanical Loads	Preferred option

	• DIN 72300-3 Kfz-Elektrik Teil 3: Mechanische Beanspruchung • EN 60068-2-27 (1995-03) - Umweltprüfungen – Teil 2: Prüfungen; Prüfung und Leitfaden: Schocken	EN 60068-2-27 is already used as a basis by OEM
2	Define shock test • sinusoidal half-wave, saw tooth, trapezoidal • shock response • spectrum • max. acceleration 300g • shock duration 1..50ms	

<u>Mirror Group Comment:</u>
DIN 72300 series is withdrawn. The current reference standard is ISO 16750 series.

Conclusion
During the group discussions about environmental conditions it was decided to refer to ISO 16750 for low weight component (≤ 5 kg) and to ISO 19453 for heavier components (> 5 kg). This is also in line with section 2.1.3 Environmental conditions. This holds for mechanical shock and maximum acceleration forces as well.

2.6.10 Sloping mounting position

Definition of requirement scope
The scope for this requirement will be an actual value range for the permissible deviation from a horizontal mounting position required for optimal compressor performance.

Standardization proposal
The proposal for this requirement is that the permissible deviation from a horizontal mounting position should result from the compressor's operational constraints for optimal performance, taking into account sloped road conditions.

Through knowledge of the application, the proposal is that there should be a maximum deviation from the horizontal of 25° for the mounting position of the compressor inclusive of the angle of the road.

Deviations of more than 25° from the horizontal inclusive of the angle of the road, will cause restrictions and may prevent suitable lubrication to the appropriate areas of the compressor, leading to seizures and over-heating failures.

Table 2-39 Options for standardization proposal for the sloping mounting position of the Electric Air Compressor.

Option nr.	Option description	Comment
1	≤ 25° from horizontal (including road incline)	This is the preferred option.

Conclusion
New findings state that, since this requirement holds for longitudinal and transvers direction, 25° are not sufficient (e. g. for truck applications). The updated request is 30°, which, from supplier side, can be achieved, as long as the road angle is included.

2.7 Electrohydraulic Power Steering

Scope of component
The scope of this component is a

- fully integrated
- stand-alone

- electrically driven (low voltage)

electrohydraulic power steering. Thus, the component contains steering pump, e-motor, inverter and an electronic control unit (ECU).

2.7.1 Operating time (Mileage)

Definition of requirement scope

Since mileage cannot be tested the scope of this requirement will be the definition of operating times. Mileage is rather an information, not a requirement.

Standardization proposal

For standardization option 1 is to define operating hours for each vehicle class. Option 2 is to define one operating time for all vehicle classes.

Table 2-40 Options for standardization proposal for operating time of the Electric Air Compressor.

Option nr.	Option description	Comment
1	City bus • 15 years, 50 000 h (800 000 km) Heavy duty vehicles • 15 years, 30 000 h (1 500 000 km)	
2	40 000 h (1 200 000 km)	

Conclusion

Operating times should be defined for each vehicle class, according to the idea of option 1. Since the electrohydraulic steering pump is not engine mounted, operating times should be calculated according to the real operation intervals of the pump (demand-based operation). Nevertheless, these operating times might come very close to vehicle operation times due to the fact that if the CV is operational (KL30), the steering pump needs to secure a minimum system volume flow to be able to react to unforeseen steering situations. This affects all operation modes (DNR). This might be just idle-mode but it adds up to the operation time with a certain percentage as well.

In order to achieve a useful specification Table 2-41 defines operating times regarding continuous operating time per day and operation days per year for the different vehicle classes.

Table 2-41 Options for standardization proposal for operating times of stand-alone pumps.

Criterion	Heavy-duty CV	Bus
Continuous operating time of system per day	10 h	18 h
Operation days of system per year	250 d	300 d

2.7.2 Minimum volume flow at given pressures

Definition of requirement scope

The steering pump shall provide at least the following hydraulic volume flow at specified working pressure for maximal 10 seconds starting at a thermally stable state at Continuous Load Point ("Pressure-Volume Flow" working points).

Standardization proposal

Table 2-42 Options for standardization proposal for a minimum volume flow at a given pressure for the Electrohydraulic Power Steering.

Option nr.	Option description	Comment
1	Standardize interface specification without concrete values – only describing parameters are defined	
2	Standardize a single curve for minimum volume flow at given pressures	see Figure 2-5
3	Define lower and upper limit for volume flow	
4	Define continuous load point and maximum volume flow at specified pressure	

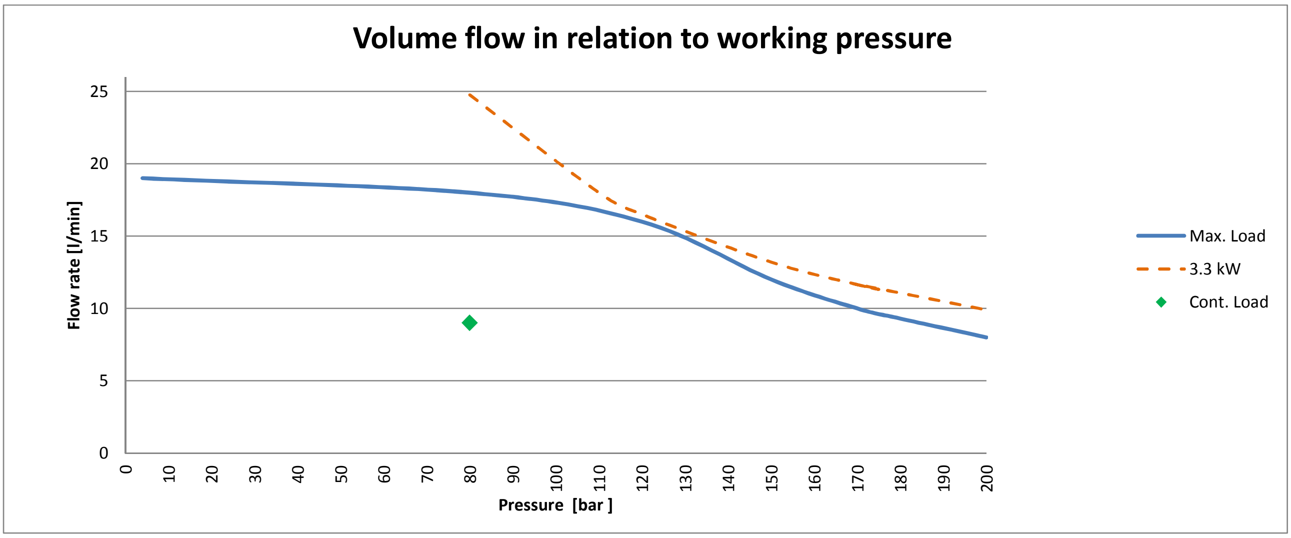


Figure 2-5 Dependency of hydraulic volume flow on pressure.

Conclusion

In order to design the steering pump the continuous load point and the maximum flow at a specified pressure need to be defined, as stated in option 4. The objective of this requirement will be the definition of these two parameters for each vehicle class. Table 2-43 shows initial proposals that need to be discussed with a greater set of stakeholders e.g. in standardization organizations. According to the given resulting power values, there might be the option to harmonize the requirements for heavy-duty CV and bus applications.

Table 2-43 Continuous load point and maximum flow at given pressure for a single steerable axle

Criterion	LD-CV	MD-CV	Heavy-duty CV	Bus
Continuous load point		12 l/min @ 100 bar	9 l/min @ 80 bar (1.2 kW)	10 l/min @ 63 bar (1.1 kW)
Max. flow @ pressure			11l/min @ 180bar (=3.3 kW) and 16l/min @ 110bar (≈3.0kW)	11l/min @ 180bar (=3.3 kW) and 16l/min @ 110bar (≈3.0kW)

2.7.3 Input/output-signals

Definition of requirement scope

The steering pump is designed to provide a demand-based steering assistance. It shall vary the hydraulic oil volume flow dependent on the actual driving situation. This requirement defines the input/output-signals, which allow a volume flow variation.

Standardization proposal

The steering pump control will be done by CAN.

Table 2-44 Options for standardization proposal for input and output signals for stand-alone pumps.

Option nr.	Option description	Comment
1	Rotational speed control	
2	OEM specific input/output set • e. g. vehicle speed, steering wheel rate (optional: door open signal, etc.)	operation strategy necessary (steering map)
3	Input signals • Rpm request • Vehicle speed • Steering wheel angle and rate • Torque request Output signals • Actual power • Actual flow (rpm-leakage) • Actual rpm value • Oil temperature (optional) • Error status • Operating status	

Conclusion

ECOCHAMPS proposed the definition of a standard set of input- and output-signals that the steering pump should provide, see option 3.

The torque related signal in option 3 are still in question. In principle, a torque request is feasible from technical point of view. Nevertheless, it may not make sense because of the following reasons:

- A complete control of an EHPS based on torque request would end in a not predictable functional behavior of the EHPS itself. The functional behavior (pump speed) would be significantly influenced by the hydraulic pressure in the steering system.
- In case of a torque request which is significantly below the required torque which is necessary to overcome the pressure in the steering system, the pump will stop working.
- In case of a torque request which is significantly above the required torque which is necessary to overcome the pressure in the steering system, the pump speed will be increased up to the maximal pump speed.
- There is only a small torque range, which allows a “real” control of the pump (not only full-speed/zero-speed operation)
- Due to the reason, that the torque is only estimated (not measured) the range for a torque controlled operation will be additionally decreased due to the tolerance chain calculation.
- In the field weakening area of the electric motor, the torque based control would get more complex.
- Due to the given high pressure dynamic in the steering system, we doubt that a CAN based communication is fast enough for a torque based control.
- Due to the reasons mentioned above, a torque based control would require a lot of pump- and electric motor know how at customer side in order to avoid full-speed/zero-speed operation.
- Additionally the complete control of the pump would be realized at different levels (vehicle-level, EHPS-level), which would be counterproductive in terms of reliability, robustness, maintainability and exchangeability.

For these reasons it is suggested to provide a torque limit request as an option for protection against too high current consumption. Nevertheless, this would lead to the risk of an unintended pump stop in case of a requested torque limit, which is significantly below the required torque.

An alternative is to replace the control parameter with "Current limit request". This would allow different approaches to realize a current limitation.

2.7.4 Basic functional requirements

Definition of requirement scope
This requirement shall define the basic functions to ensure safe operation in all operation modes and to protect the steering pump against overheating and environmental influences.

Standardization proposal
Table 2-45 describes the minimum set of functions every steering pump should have, but, of course, is not restricted to.

Table 2-45 Options for standardization proposal for basic functional requirements of electrohydraulic power steering

Option nr.	Option description	Comment
1	Demand-based steering support	Mandatory
2	Diagnosis	
3	De-rating at high temperatures (not a hard switch-off)	Oil temperatures > 70 °C , high PCB temperature, high EM coil temperatures …
4	De-rating at low voltages (not a hard switch-off)	Voltages < 24 V are critical to ensure full performance
5	Self-protection against over voltage, over current, over temperature	Error Message, pump shut down
6	Leakage Detection (e.g. broken hoses, less oil)	A leakage or mechanical fault shall be detected.
7	Voltage Level Compensation	Variations of the supply voltage shall not lead to variations in steering support (except de-ration at low voltages).
8	Optional: Cold activation (comfort function, low priority)	In order to ensure an accelerated heating of the hydraulic oil, the steering pump shall operate with and increased volume flow at deep temperatures.

Conclusion
It was agreed that the electrohydraulic power steering should provide the functionalities 1 to 8 described in Table 2-45.

2.7.5 Load spectrum mechanical operation and mechanical shock

Definition of requirement scope
This requirement defines the mechanical load spectrum and the mechanical shock.

Standardization proposal

Table 2-46 Options for standardization proposal for load spectrum mechanical operation and shock for electrohydraulic power steering

Option nr.	Option description	Comment
1	Mechanical Load: according ISO 16750 Code Letter L	ISO 16750-3 chapter 4.1.2.7 Test VII
2	Mechanical Shock: according ISO 16750 Code Letter L	ISO 16750-3 chapter 4.2.2

Conclusion

The result of the discussions about environmental conditions was to refer to ISO 16750 for low weight components (≤ 5 kg) and to ISO 19453 for heavier components (> 5 kg). This holds for mechanical shock and maximum acceleration forces as well.

2.7.6 Low voltage power net specification

Definition of requirement scope

This requirement specifies the main parameter related to the low voltage power net.

Standardization proposal

The suggestion standardization is a minimal requirement set for the low voltage power net.

Table 2-47 Options for standardization proposal for low voltage power net specification of electrohydraulic power steering

Option nr.	Option description	Comment
1	Supply voltage according ISO 16750 Code Letter F	16 – 32 V
2	Input current < 250 A	
3	Input current rise < 250 A/s	
4	EMC according to standards ISO 7637, ISO 11452, ISO 10605, CISPR 25	
5	Electrical loads according to ISO 16750-2 Code Letter F	

Conclusion

The low voltage power net should fulfill the following minimal set of requirements:

- Supply voltage according to ISO 16750 Code Letter F
- Input current < 250 A
- Input current rise < 250 A/s

Using ISO 16750 is also agreed for the low voltage power net of the A/C-compressor (see section 2.8.4), and for environmental conditions for low weight components, (see section 2.1.3).

2.7.7 Reference cycle

Definition of requirement scope

The scope is to find a suitable method for defining a reference cycle. Since the reference cycle has major influence on the component development costs, finding standardization for it would be highly beneficial.

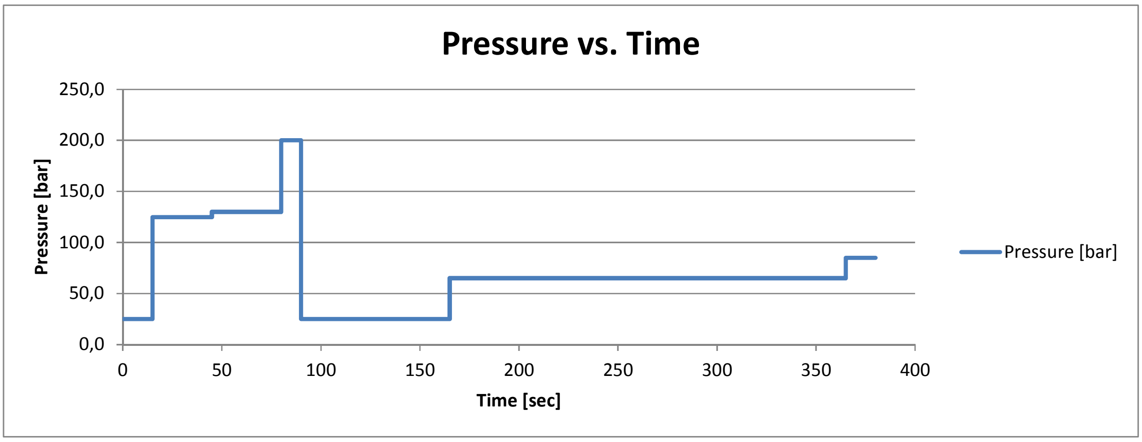
Standardization proposal

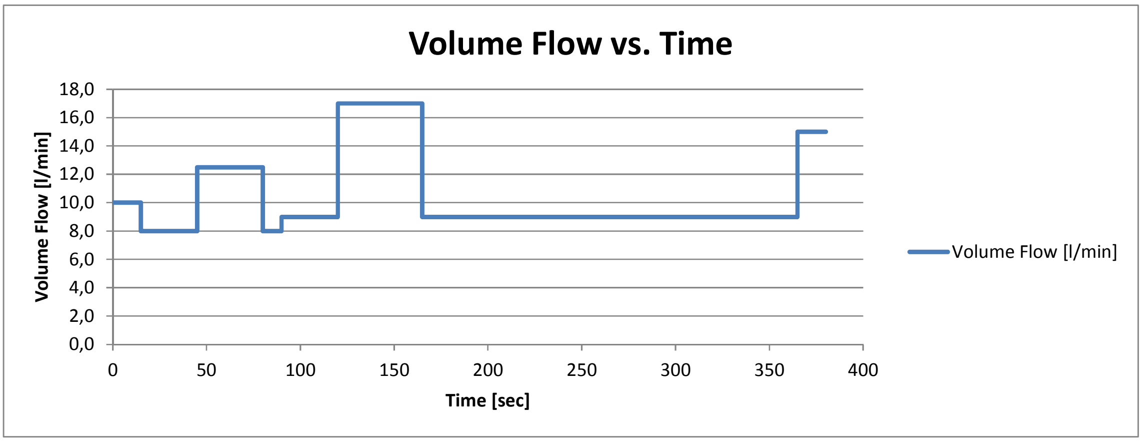
For a standardization of the reference cycle the different vehicle classes should be considered. Standardization could define a method for the reference cycle or one or more fixed cycle(s).

Table 2-48 Options for standardization proposal for reference cycle of electrohydraulic power steering

Option nr.	Option description	Comment
1	Configurable synthetic test cycle for single component; e.g. Composition of full-load operation, off-load operation and on-load operation, with possible parameters: • duty cycle • on-load level • time spans	
2	Defining one realistic cycle based on option 1 Examples: • e. g. Figure 2-6	
3	Definition of a (configurable) drive cycle Examples:	Not realizable

- configuration of example as in Figure 2-6
- specifications of
  - pressure vs. time
  - hydraulic power vs. time/pressure
  - volume flow vs. pressure





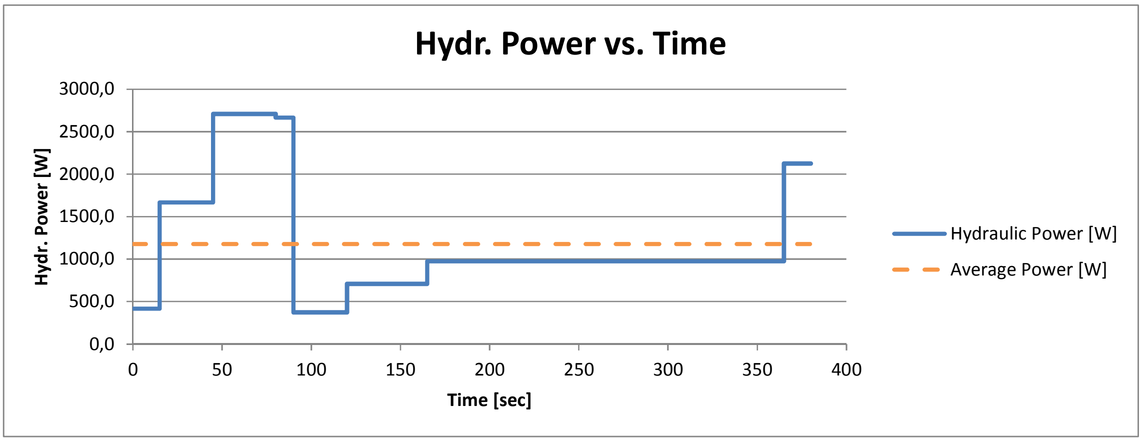


Figure 2-6 Example test cycle.

Conclusion

Defining a fixed reference cycle for all or for each vehicle class would be most beneficial, but is on the other hand difficult to achieve due to different OEM demands. A first step in this process could be the definition of at least a method, e.g. the definition of a configurable test cycle or single test cycle modules that can be configured and combined respectively. The definition of a drive cycle for the vehicle instead of a reference cycle (laboratory

test on component level) seems not to be suitable, since the supplier cannot prove their component performance integrated in a vehicle.
Another possibility would be that the OEMs provide their reference cycles (pressure vs. time and flow vs. time) to a neutral partner, who combines these cycles on an anonymous basis and develops a standardization proposal.

2.7.8 Hydraulic interfaces

Definition of requirement scope
This requirement specifies the hydraulic interface of the steering pump.

Standardization proposal
Table 2-49 describes standards for the hydraulic connections of the steering pump.

Table 2-49 Options for standardization proposal for hydraulic interfaces of electrohydraulic power steering

Option nr.	Option description	Comment
1	Pump suction connection: M26x1.5 min. 17 mm deep	
2	Pump pressure connection: M18x1.5 min. 14 mm deep	

Conclusion
ECOCHAMPS agreed on the proposals of Table 2-49.

2.7.9 Electric interfaces

Definition of requirement scope
This requirement specifies the electric interfaces of the steering pump.

Standardization proposal
Table 2-50 describes standards for the electric connections of the steering pump.

Table 2-50 Options for standardization proposal for electric interfaces of electrohydraulic power steering

Option nr.	Option description	Comment
1	Power interface connections (Plus, Minus): Stud bolts min. M8 for cable lug connection. The power connection is reverse polarity protected by Poka Yoke principle.	Poka Yoke e.g. realized by different stud bolt diameters (plus pole = M8, minus pole = M10).
2	Signal interface connection: 8-pole plug	

Conclusion
It has been agreed that the power supply should be connected via cable lug, refer to option 1 of Table 2-50.

2.7.10 Mechanical interfaces

Due to the novelty of electro-hydraulic power steering it was impossible to define a common denominator for the mechanical interface within ECOCHAMPS – especially where and how to mount the pump. Hence, there is no final conclusion for this requirement. Existing VDA-norms for engine driven power steering pumps may provide a guideline for a new standard.

2.8 A/C-Compressor

Scope of component
The different A/C-systems to perform passenger compartment cooling and hybrid battery cooling have been considered. There are three different types of A/C-circuits:

- Standalone passenger compartment/cabin cooling with electrical A/C-compressor (with separate HV-battery cooling),

- Standalone HV-battery cooling with electrical A/C-compressor, and
- Combined cooling of passenger compartment/cabin and HV-battery with electrical A/C-compressor.

Core component of all three variants is the electrical A/C-compressor. Therefore the expert consortium considers the specification of the A/C-compressor as most important beside the HVAC-system design.

A modularization of the HVAC can be achieved through standardization of the following components:

- Chiller for HV-battery cooling,
- Refrigerant shut-off valves,
- Refrigerant expansion devices, and
- HVAC control strategy.

The heating system is not in the scope of the ECOCHAMPS project.

With respect to EU 2006/40/EG we consider R134a as refrigerant for all HVAC-components for commercial vehicles, since EU 2006/40/EG forbids R134a solely for passenger cars and car like commercial vehicles.

The A/C-compressor discussed in this project is a high voltage electric refrigerant compressor including an e-motor, an inverter (optional), and a CAN-interface.

2.8.1 Performance classes

Definition of requirement scope

The scope of this requirement is the definition of several performance classes in order to provide HVAC-systems suitable for all vehicle classes. Vehicle classes are light, medium and heavy duty commercial vehicles as well as busses.

Standardization proposal

Table 2-51 defines three different performance classes for the A/C-compressor of the HVAC-system. The high performance class should be designed using common bus standards. Middle and low performance components should be designed according to common automotive standards.

Table 2-51 Options for standardization proposal for performance classes of A/C-Compressor

Option nr.	Option description	Comment
1	Performance classes in terms of cooling power: • **High performance** 20 - 30 kW (HV) HVAC-System cooling capacity for bus passenger compartment, incl. battery cooling, according to bus standards (low annual production volume) • **Middle performance** 8 - 12 kW (HV) HVAC-System cooling capacity MD/HD-Truck cabins and busses, incl. battery cooling, according to automotive standards (medium-high production volume) • **Low performance** 0.5 - 4 kW HVAC-System cooling capacity, solely battery cooling (LV & HV possible), according to automotive standards	Refer to standards: ○ SAE J 639 (Safety Standards for Motor Vehicle Refrigerant Vapor Compressions Systems) ○ All standards related to refrigerant R134a

Conclusion

Three different power classes were defined and confirmed in order to meet the requirements of all vehicle classes. High and middle performance classes consider cooling of vehicle interiors and battery. The low performance class is defined for battery cooling only.

2.8.2 Mechanical interface

ECOCHAMPS proposes to refer to existing and established VDA norms.

2.8.3 Electrical interface

Definition of requirement scope
Define form and pin connections of electric connections.

Standardization proposal
Table 2-52 describes the electrical interface using either a plug connection or a cable connection. Communication will be based on CAN.

Table 2-52 Options for standardization proposal for electrical interfaces of A/C-Compressor

Option nr.	Option description	Comment

1	Electrical connections realized using:
	• HV-AC/DC and CAN connectors
	• Plug connection
	• HV-Plug should fulfill
	  ○ IP 6K9K and
	  ○ IP 67	

2	Electrical connections realized using: • HV-AC/DC and CAN connectors • Cable connection	This is the preferred option

Conclusion
ECOCHAMPS agreed on option 1. The cable connection is the preferred solution. Thus, each OEM can either use a cable lug or apply a special plug. In the latter case, the plug should fulfill IP 6K9K and IP 67.

2.8.4 Low voltage power net specification

Definition of requirement scope
This requirement specifies the main parameter related to the low voltage (LV) power net.

Standardization proposal
Table 2-53 shows the low voltage power net standardization for the A/C-compressor.

Table 2-53 Options for standardization proposal for low voltage power net specification of A/C-Compressor

Option nr.	Option description	Comment
1	The LV power net should be designed in accordance with ISO 16750 Code Letter F (especially 16 – 32 V voltage level)	

Conclusion
As for the electrohydraulic power steering, it has been agreed to refer to ISO 16750 (see option 1) for the low voltage power net of the A/C-compressor.

2.8.5 I/O-signals and diagnostic outputs

Definition of requirement scope
Defining a minimum set of input and output signals including diagnostic outputs the component should receive and send.

Standardization proposal

A minimal set of input and output signals for the A/C-compressor is defined for standardization. Communication is based on CAN. Furthermore, norms that should be referred for CAN implementations are given.

Table 2-54 Options for standardization proposal for I/O-signals and diagnostic outputs of A/C-Compressor

Option nr.	Option description	Comment

1	Minimum set of CAN I/O-signals
	• Input
	  ○ Requested rotational speed (control)
	• Output
	  ○ Power consumption
	  ○ Actual rotational speed
	  ○ Pressure (optional)
	  ○ Discharge temperature (optional)
	Minimum set of CAN-signals for diagnosis
	• Electrical failures
		CAN-signals should be designed according to
		• ISO 15765 (Road vehicles - Diagnostics on controller area network (CAN))
		• ISO 14229 (Road vehicles - Unified Diagnostics Services)
		• Possible specifications for CAN implementations are ISO 11898 and SAE J1939

Conclusion

ECOCHAMPS proposes a minimum set of input and output signals as well as diagnostic outputs. Of course, component signals are not restricted to the ones defined here. Possible specifications for CAN implementations are ISO 11898 and SAE J1939. Diagnostic outputs should refer to ISO 15765 and ISO 14229.

2.8.6 Lifetime (EU-wide)

Definition of requirement scope

The scope of this requirement is to define one lifetime (for the EU-market) for all performance classes or, at least one lifetime for each performance class.

Standardization proposal

Table 2-55 proposes one component lifetime for all performance classes. This lifetime is based on vehicle lifetime.

Table 2-55 Options for standardization proposal lifetime of A/C-Compressor

Option nr.	Option description	Comment
1	The A/C-compressor should have a lifetime of 30 000 h (1 500 000 km) for all performance classes.	

Conclusion

This standardization proposal is based on the vehicle lifetime.

For the electric air compressor and the electrohydraulic power steering lifetimes are based on the real operating hours of the component, since they are not engine mounted. It should be discussed further, if lifetime could be defined for actual operating hours for A/C-compressors, because they are not engine mounted, too.

A lifetime of 30,000 h is specified for the ventilation fans. Since these components operate in all three use cases (cooling, heating *and* fresh air supply), they are the determinant of operating time. The A/C-compressors lifetime will be 30,000 h if the A/C-compressor is always in cooling/heating mode or below that. Therefore, this is a reasonable maximum operating time for A/C-compressors.

2.8.7 DV-testing

DV-testing is skipped as a requirement on component level and will be discussed on a cross component basis (refer to 2.1.4.)

2.8.8 Reference cycle

Definition of requirement scope

Find a suitable method for defining a reference cycle. Since the reference cycle has major influence on the component development costs, finding standardization for it would be highly beneficial.

Standardization proposal

For a standardization of the reference cycle the different vehicle classes should be considered. Standardization should define a method for the reference cycle or one or more fixed cycle(s).

Table 2-56 Options for standardization proposal for reference cycle of A/C-Compressor

Option nr.	Option description	Comment
1	Configurable synthetic test cycle for single component; e.g. composition of full-load operation, off-load operation and on-load operation, with possible parameters: • duty cycle • on-load level • time spans	e. g. Figure 2-7
2	Defining one realistic cycle for each performance class based on option 1	Preferred
3	Definition of a (configurable) drive cycle	Not realizable

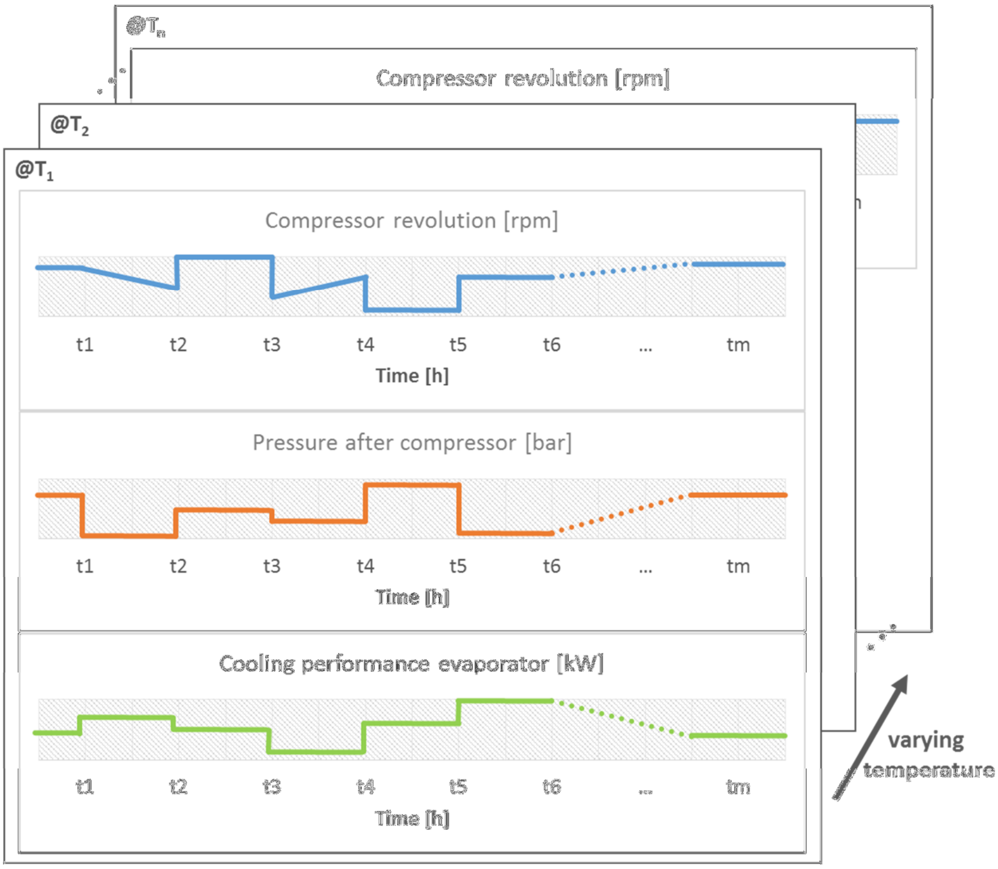


Figure 2-7 Example: Configurable test cycle.

Conclusion

Defining a fixed reference cycle for each vehicle class would be most beneficial, but is on the other hand difficult to achieve due to different OEM demands. A first step in this direction could be the definition of at least a method, e.g. the definition of a configurable test cycle or single test cycle modules that can be configured and combined respectively. The definition of a drive cycle for the vehicle instead of a reference cycle (laboratory test on component level) seems not to be suitable, since the supplier cannot prove their component performance integrated in a vehicle.

The attempt to develop a common basis included the following steps:

- OEMs sent their reference cycles to a neutral partner.
- The neutral partner tried to combine the cycles to one proposal.

Due to great differences in the cycles, it was not possible to make a proposal on this basis without making OEM specific details public. Hence, a standard can be achieved, if OEMs and suppliers are able to enter an open discussion.

3 Discussion and Conclusions

The Modular System and Standardization Framework (MSF) intends to provide pre-standard recommendations for electric drivetrain components and auxiliaries. The MSF combines standards on component and system level considering existing standards to an extent possible.

One major challenge was to find a common understanding of standardization over the different vehicle classes. In numerous discussions and workshops, OEMs and suppliers debated about component modularization and standardization over the vehicle classes. Even for a single vehicle class it is very challenging to agree on specific standardization proposals.

Nevertheless, within the MSF development phase the experts agreed on several component specific requirements that should be investigated for standardization. Many of those proposals could be confirmed within the project. For some of them it was not possible or reasonable to define a standard. Those requirements need further discussions with a greater set of stakeholders (e.g. national or European standardization organizations).
Some requirements could not be finished, due to their complexity or because proprietary information of OEMs was needed that could not be delivered or aligned.

Due to the successful confirmation of most of the standard proposals, the MSF draft was available for the component development within ECOCHAMPS. Approximately 80 % of the proposed MSF requirements were implemented into the developed components. Hence, the standardized application in different vehicle classes (MD, HD and city bus) is possible to a certain degree in future. For details regarding the component development, the implemented MSF requirements and an initial benefit analysis refer to deliverable D2.3.

During the development phase, the MSF was provided to a mirror group for feedback. This feedback has been added to this final MSF revision. If directly applicable the feedback was integrated in the standardization proposals itself. Further general comments are added as received in order to provide additional, unfiltered information for the reader. ECOCHAMPS deliverable D2.2 summarizes the details of the mirror group approach applied during the development of the MSF.

After finalizing the component and MSF development an in-depth impact analysis was performed. Component and vehicle experts from both OEMs and suppliers have performed an assessment on a per component per requirement basis. The intention was to evaluate the cost saving potential of each standardization proposal of the MSF to provide a guideline for future standardization activities. Based on the findings the standardization stakeholders can prioritize their topics. ECOCHAMPS deliverable D2.5 describes the results in detail.

All in all, the main objectives were achieved with the MSF. Nevertheless, the real benefit of the MSF development can be achieved only if the results will be transferred to the relevant norming and standardization groups after the project.

4 Recommendations

This document is the final revision of the Modular System and Standardization Framework that represents the result of the ECOCHAMPS standardization activities. A great number of experts from OEM and supplier side joined the workshops and discussions to find and negotiate standardization proposal that have a significant impact on hybrid driveline component costs as well as reducing time to market.

The initial MSF draft was continuously refined during the term of the ECOCHAMPS project. Hence, new findings from component and demonstrator vehicle development as well as the feedback from the mirror group were introduced.

It is recommended that the MSF will be published to a greater audience in order to use the results in future standardization processes. Due to the different viewpoints of OEMs and suppliers included in the MSF e.g. national and international standardization bodies get a holistic view on standardization options for many component specific requirements.

The provided proposals may be used as a starting point for further discussions. Together with the detailed impact analysis on a per requirement basis (see ECOCHAMPS deliverable D2.5) the MSF serves as a guideline for prioritizing future standardization activities.

5 Acknowledgement

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

Project partners:

#	Type	Partner	Partner Full Name
1	HD	DAF	DAF Trucks NV
2	LD	CRF	CRF S.C.p.A.
3	HD	DAIMLER	DAIMLER AG
4	HD	FPT	FPT Industrial S.p.A.
5	HD	IVECO	IVECO S.p.A.
6	HD	MAN	MAN Truck & Bus AG
7	LD	RENAULT	Renault SAS
8	HD	BOSCH	Robert Bosch GmbH
9	HD	ECS	Engineering Center Steyr GmbH & Co KG (Magna Powertrain)
10	LD	GKN	GKN Driveline International GmbH
12	LD	JMBS	Johnson Matthey Battery Systems Ltd
13	HD	SDIBS	Samsung SDI Battery Systems GmbH
15	LD	ETL	European Thermodynamics Ltd
16	HD	AVL	AVL List GmbH
17	HD	FEV	FEV GmbH
18	LD	RIC	Ricardo UK Ltd
19	LD	TEC	Fundacion TECNALIA Research and Innovation
20	HD	UNR	Uniresearch BV
21	HD	FHG	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V. - IVI
22	LD	IKA	Rheinisch-Westfälische Technische Hochschule Aachen
23	HD	JRC	Joint Research Centre
24	HD	VIF	Kompetenzzentrum – Das Virtuelle Fahrzeug Forschungsgesellschaft mbH
25	LD	QMUL	Queen Mary University of London
26	HD	TUE	Technische Universiteit Eindhoven
27	HD	HYDRO	Gardner Denver Ltd

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Appendix A – Abbreviations / Nomenclature

Symbol / Shortname	
AC	Alternating Current
A/C	Air Conditioning
AM/FM	Amplitude Modulation/ Frequency Modulation
ASIL	Automotive Safety Integrity Level
BMS	Battery Management System
BoL	Begin of Life
CAN	Controller Area Network
CV	Commercial Vehicle
DC	Direct Current
DIN	Deutsches Institut für Normung
DV	Design Verification
ECE	Economic Commission for Europe
ECU	Electronic Control Unit
EMC	Electromagnetic Compatibility
EoL	End of Life
EUCAR	European Council of Automotive R&D
F.A.D.	Free Air Delivered
HARA	Hazard Analysis and Risk Assessment
HD	Heavy Duty
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
HVIL	High-Voltage Interlock Loop
IEC	International Electrotechnical Commission
IP	International Protection
ISO	International Organization for Standardization
LD	Light Duty
LV	Low Voltage
MD	Medium Duty
MSF	Modular System and Standardization Framework
ODO	Odometer
OEM	Original Equipment Manufacturer
PC	Passenger Car
PCB	Printed Circuit Board
QM	Quality Management
RESS	Rechargeable Energy Storage System
R&D	Research and development
SAE	Society of Automotive Engineers
SoC	State of Charge
SoP	State of Power
TRL	Technology Readiness Level
VDA	Verband der Automobilindustrie e. V.

VDV	Verband Deutscher Verkehrsunternehmen
xEV	Types of (Hybrid) Electric Vehicles e.g. PHEV, HEV, EV

Appendix B – Benefit vs. Chances of realization Matrices

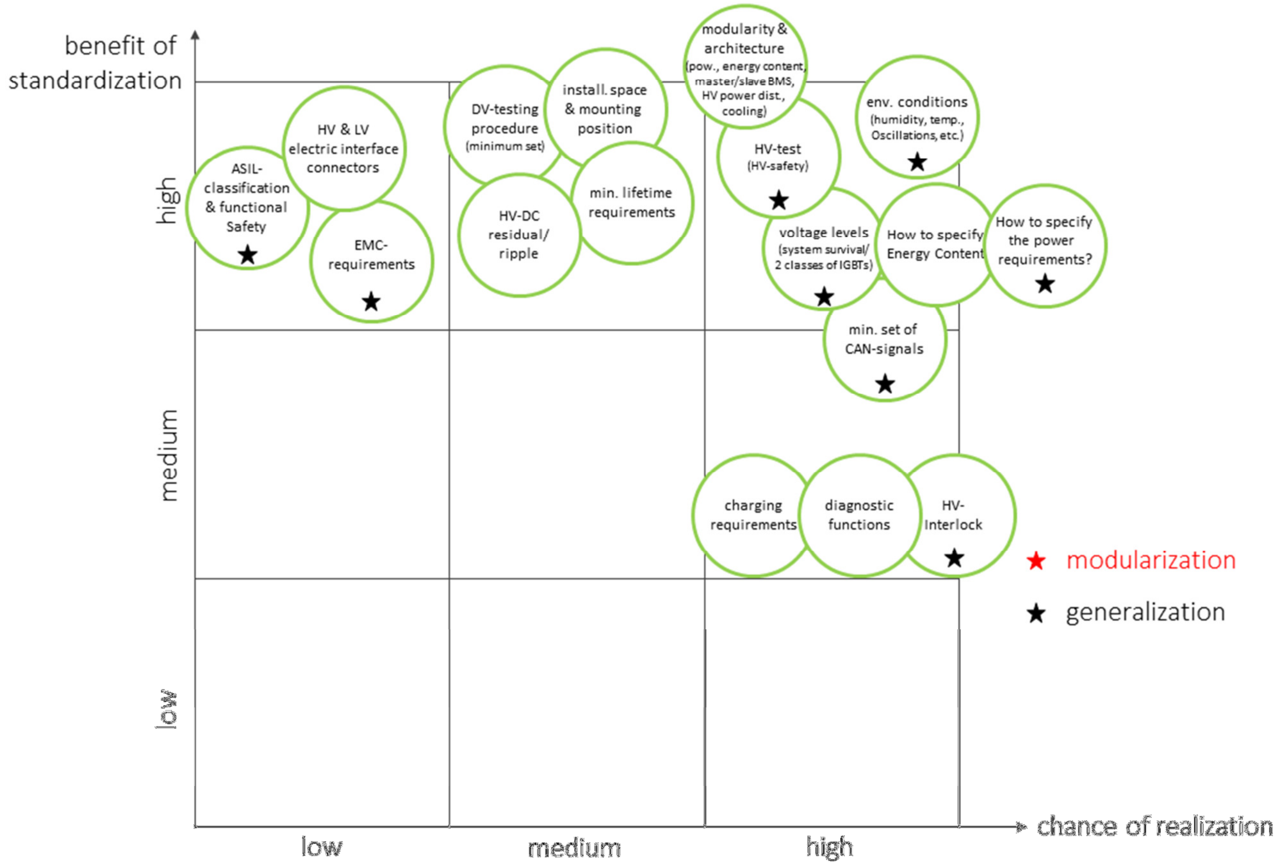

Figure 5-1 Benefit vs. chance of realization for the High-Voltage Battery System.

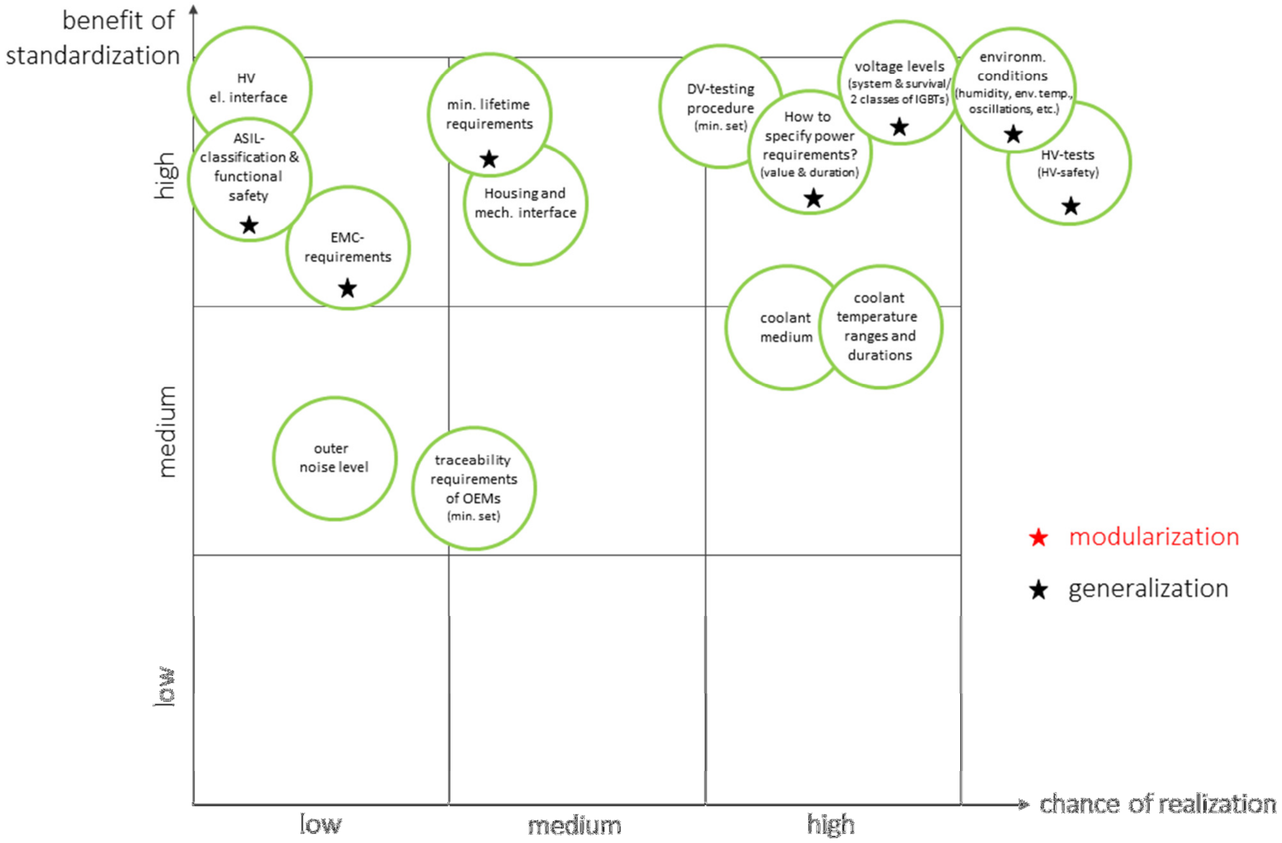

Figure 5-2 Benefit vs. chance of realization for the EMG.

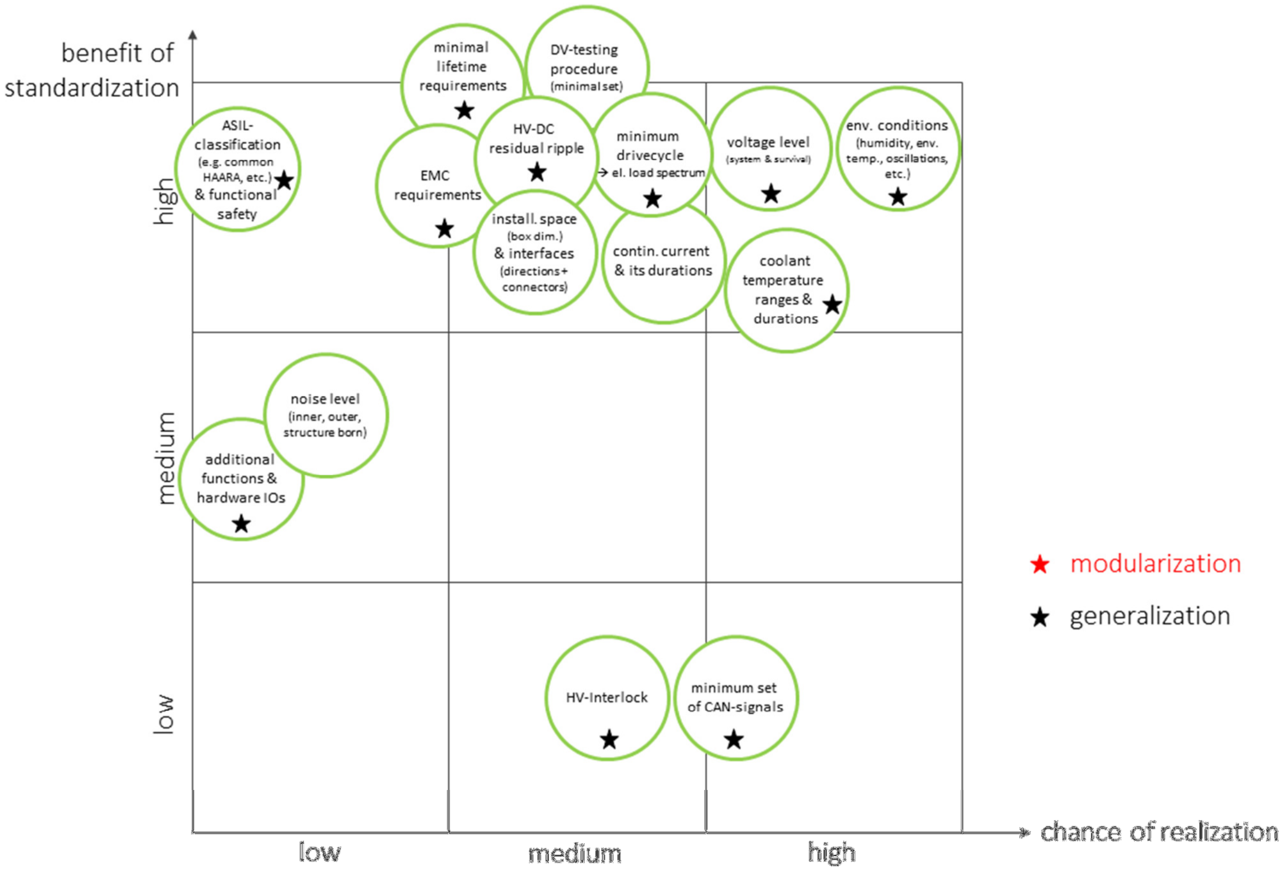

Figure 5-3 Benefit vs. chance of realization for the Inverter EMG.

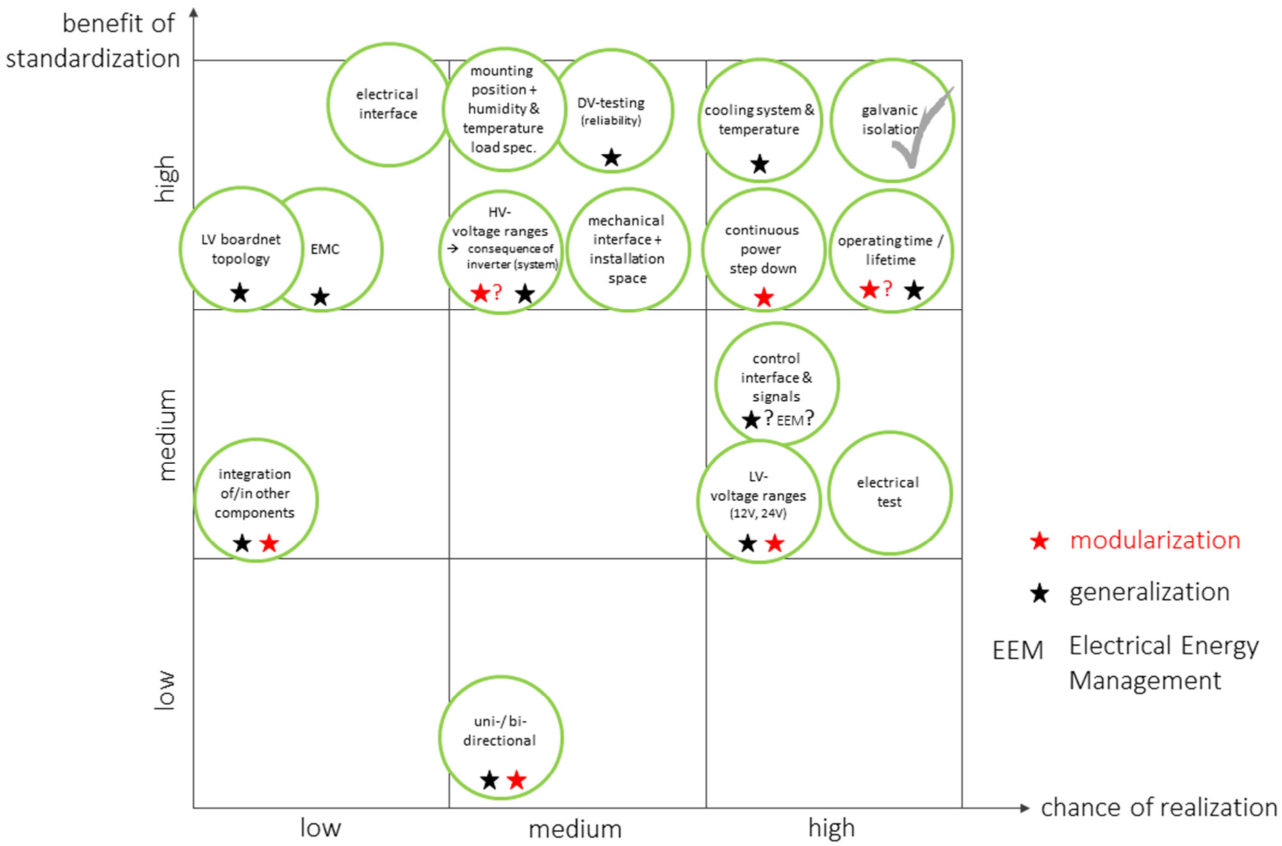

Figure 5-4 Benefit vs. chance of realization for the DC/DC-Converter.

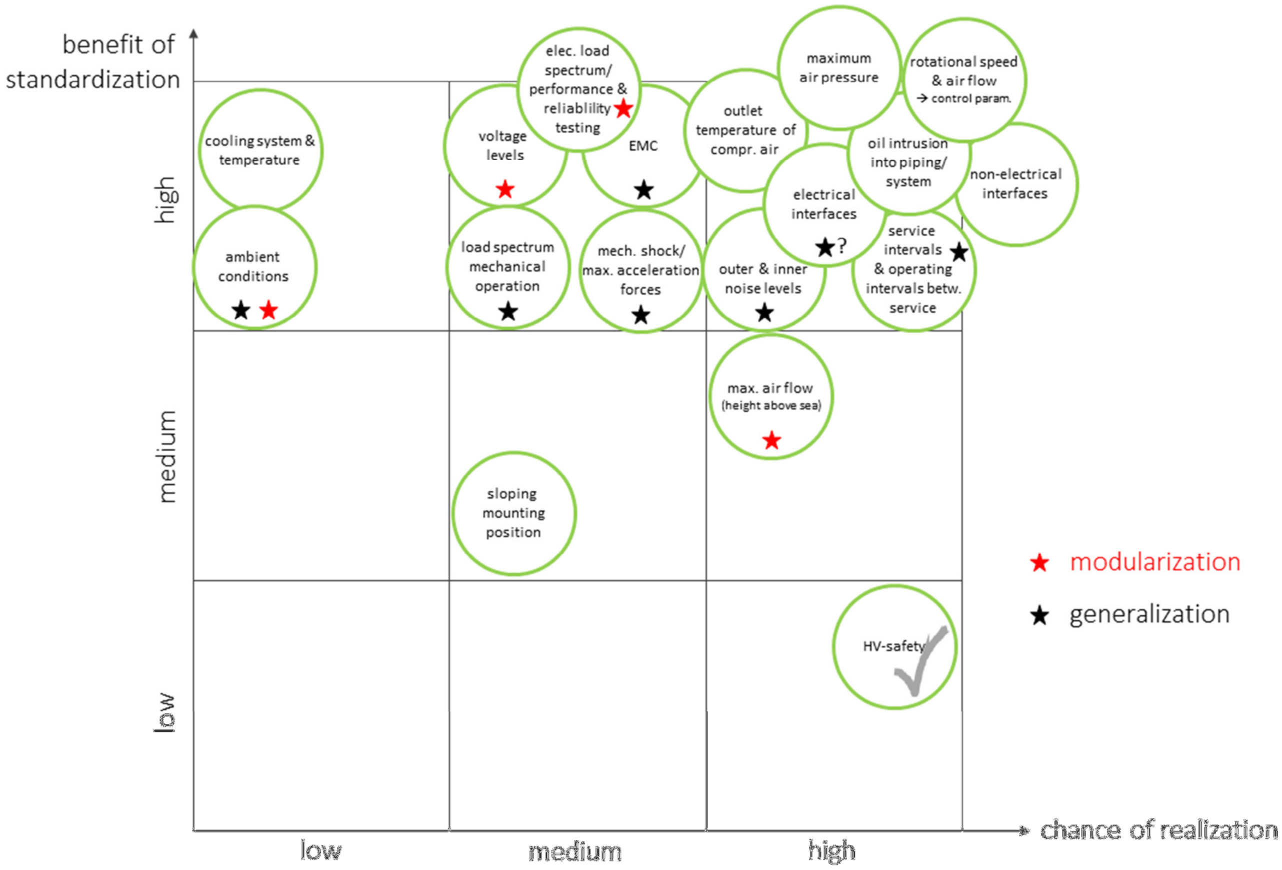

Figure 5-5 Benefit vs. chance of realization for the Electric Air Compressor.

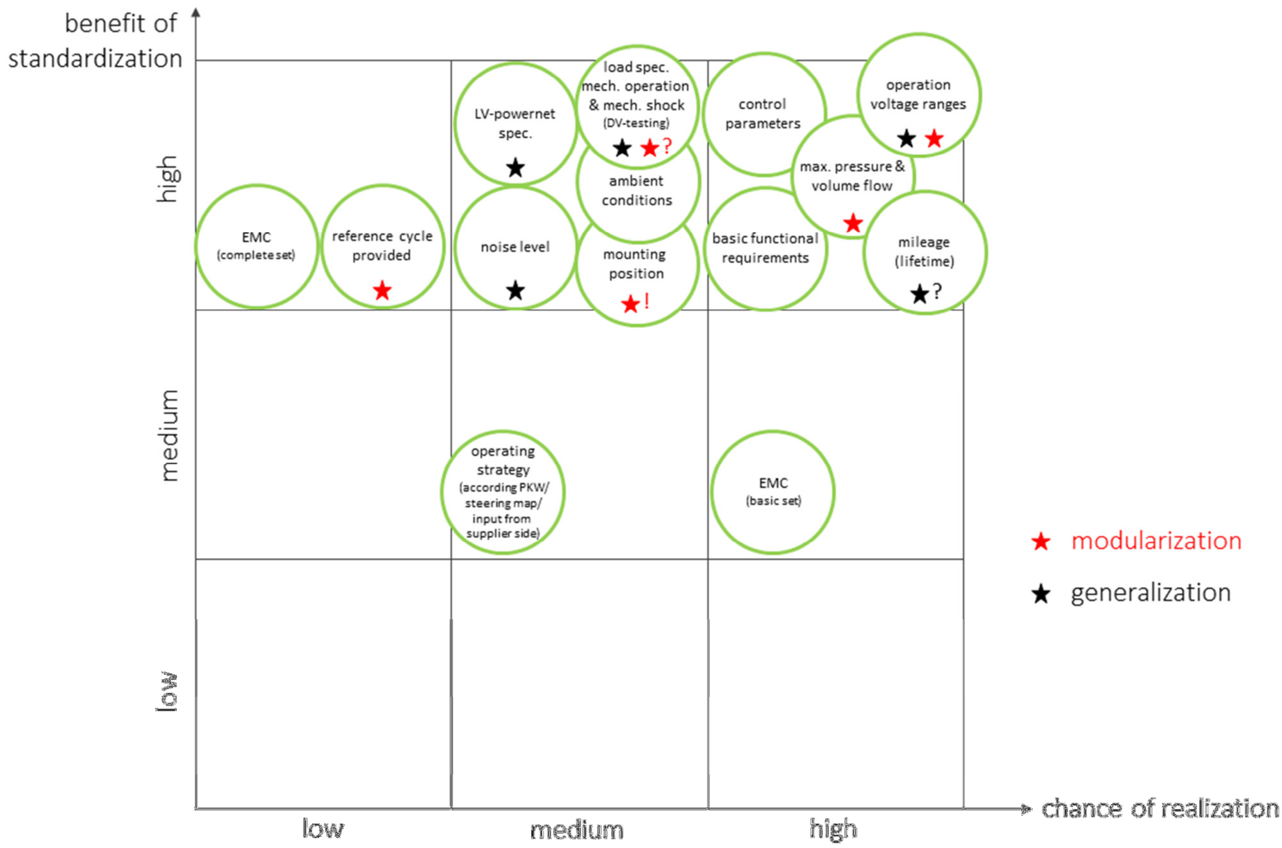

Figure 5-6 Benefit vs. chance of realization for the Electrohydraulic Power Steering.

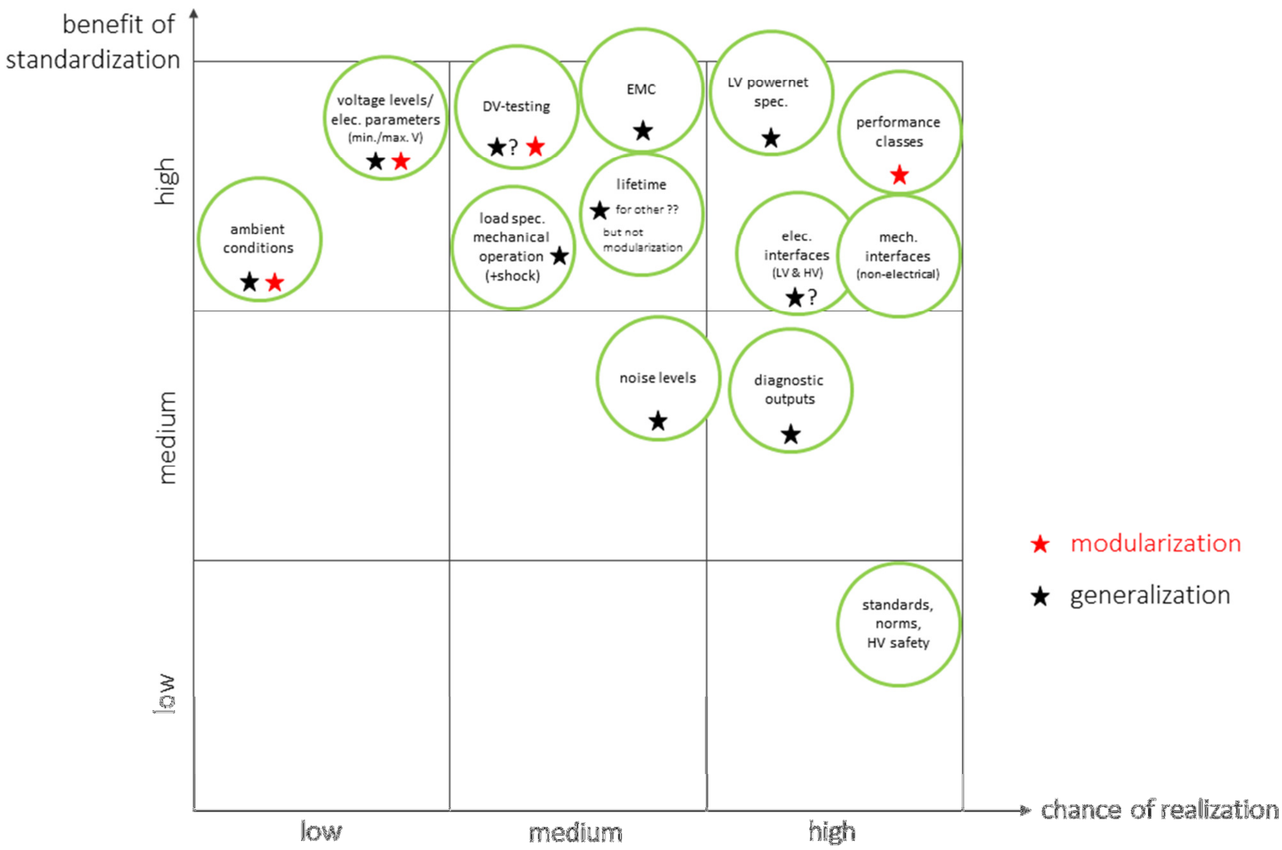

Figure 5-7 Benefit vs. chance of realization for the A/C-compressor.

Appendix C – Identification of cross component requirements

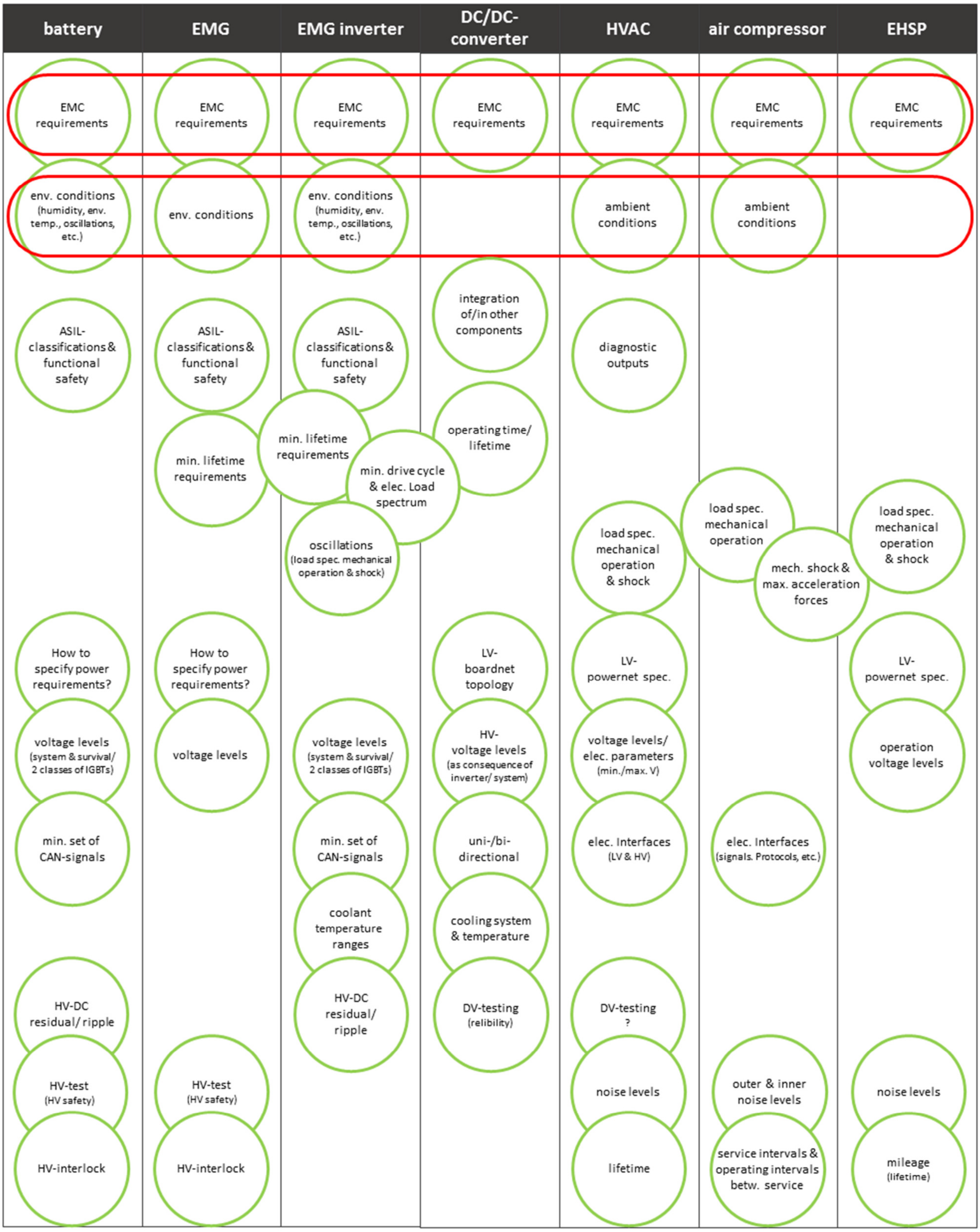

Figure 5-8 Cross component requirements.