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OBELICS – Optimization of e-drive concepts with scalable realtime models and functional testing based on real use-cases

Horst Pfluegl[a]*, Hellal Benzaoui[b], Benjamin Zillmann[c], Tomaž Katrašnik[d], David Delichristov[e], Raul Estrada Vazquez[f], Matthieu Ponchant[g], Nicola Tobia[h]

[a]*AVL List GmbH, Hans-List-Platz 1, 8020 Graz, Austria*
[b]*Volvo Group Trucks Technology, 1, avenue Henri Germain, 69806 Saint Priest Cedex, France*
[c]*Robert Bosch GmbH, Renningen, 70465 Stuttgart, Germany*
[d] *University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, 1000 Ljubljana, Slovenia*
[e] *Virtual Vehicle - Das virtuelle Fahrzeug Forschungsgesellschaft mbH, Inffeldgasse 21/A, 8010 Graz, Austria*
[f] *FH Joanneum Gesellschaft mbH, Werk-VI-Straße 46, 8605 Kapfenberg, Austria*
[g] *Siemens Industry Software, Le Diagonal, 150 Avenue de la Rêpublique, 92320 Châtillon, France*
[h] *Centro Ricerche Fiat Scpa, Strada Torino 50, 10043 Orbassano, Italy*

Abstract

Wide global deployment of EVs is necessary to reduce transport related emissions, since transport is responsible for around a quarter of EU CO_2 emissions and since more than two thirds of transport-related CO_2 emissions are from road transport. OBELICS addresses the urgent need for new tools for multi-domain modelling and testing of EVs and their components in order to design and implement new, more efficient vehicles faster, while at the same time enabling modularity for mass production to significantly improve affordability. The overall approach of OBELICS is to develop a systematic and comprehensive framework for the design, development and testing of advanced e-powertrains and EVs. The resulting overall objectives of OBELICS are reducing development efforts by 40% while improving e-drivetrain efficiency by 20% and increasing safety by a factor of 10. Achievement of these objectives crucially relies on OBELICS advanced heterogeneous model-based test methods and tools as well as on innovative, scalable and easy to parameterize real-time models.
To ensure that the new methods and models enable real improvements, 17 different use cases are selected and specified along the e-vehicle development process to demonstrate and evaluate the improvements.
This publication divides the use cases into 4 application fields and describes exactly which engineering tasks can be more efficiently supported by model-based methods developed within the project, while it, in addition, highlights strategies for increasing efficiency, reduction of efforts and improvement of safety.

Keywords: Model based development; Real-time models; E-vehicle development process; Safety and Reliability; Co-simulation;

Horst Pfluegl. Tel.: +43-316-787-1587;
E-mail address: horst.pfluegl@avl.com; *Webpage:* www.obelics.eu

1. Introduction

The underlying concept of OBELICS is to implement systematic modelling and testing (and corresponding corrections) of the system from the begin phase which is often also referred to as frontloading methodology. Instead of designing and building the entire system and making corrections based on the gathered knowledge at the end, shifting to model-based design and testing enables engineering teams to more readily understand impacts of design changes, communicate design intent and analyze a system design before it is built. The components can be tested and validated very early in the development process through simulation and refined with additional detail, thus reducing the overall efforts of the EV development process. OBELICS builds upon available results of previous and ongoing EU-projects, such as ASTERICS, IMPROVE, ACOSAR, FIVEVB, 3CCAR which deal or have dealt with e-component/vehicle models, EV-virtual integration, co-simulation of real time (RT) systems, development of battery technologies/models, vehicle control, etc.

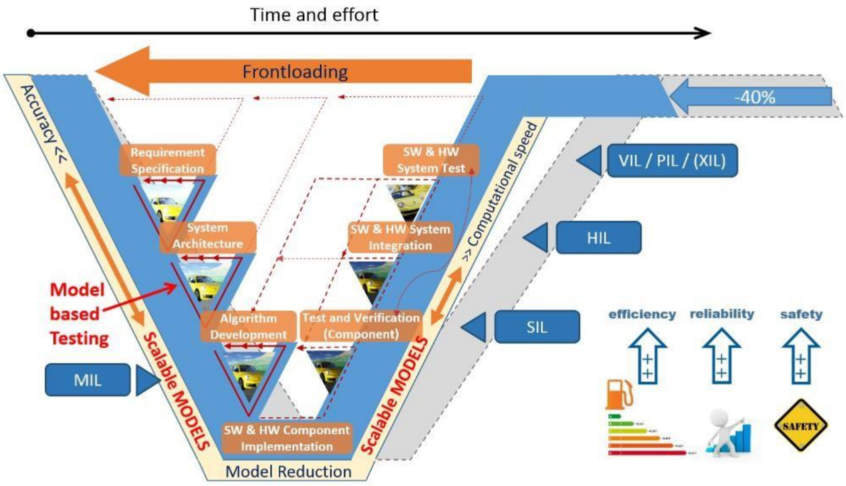


Fig. 1 OBELICS model-based development concept to reduce development and testing efforts, while increasing efficiency, reliability and safety

Besides developing new scalable (real-time capable) models and new testing and safety analysis methods, OBELICS has defined 17 real use cases, which will be used to prove the new models and methods with real world examples and demonstrate that the project goals can be reached. These use-cases have been clustered into 4 engineering areas - or so-called use-case clusters UCC - that represent typical and important engineering areas within the electric vehicle development process:

1. New e-drive concept & component sizing in earlier design phase with scalable models
2. E-vehicle system integration, optimization with real world verification and model-based testing
3. Battery design and testing for improved safety & reliability
4. E-motor, control and inverter design & testing

The different tasks and their reasoning for the 4 UCC’s, as well as the achieved highlights and importance of model-based approaches and methods are described in more details in the following chapters. E.g. What is the concrete engineering activity and the concrete goals? What is the advantage of using highly accurate multi-physical simulation models of electrical components of the vehicle or using model-based methods? And finally - what has already been achieved within OBELICS to support these engineering activities and how do these services contribute to achieving the project goals?

2. Engineering Clusters(domain) with specific use-cases

2.1. New e-drive concept & component sizing in earlier design phase with scalable models

Reasoning

Today's fast-changing electrified automotive landscape and new market opportunities stresses the carmaker to deliver more efficient vehicle designs in shorter time with less costs. Due to missing virtual tolls that would profoundly consider interaction between all relevant domains (electric, electrochemical, mechanical, thermal and control) in xEVs and corresponding testing methodologies, products might be non-optimized regarding vehicle energy efficiency and featuring higher production costs.

To develop cost effective and high-performance urban transport solutions, identification of the powertrain architectures, robust selection, sizing and virtual integration of the powertrain components for complete system performance optimization is crucial already in the early concept phase.

Design of battery electric vehicles, unlike their ICE counterparts, is quite flexible, which significantly enlarges potential design space. This is because of the absence of intricate mechanical arrangements that are required to run a conventional vehicle. Because of such flexibility, various powertrain topologies are emerging on the automotive market: EV powertrains can be front wheel drive, rear wheel drive, even all-wheel drive depending on vehicle application (passenger, commercial vehicles). Evaluation of these emerging electric powertrain concepts is usually done through simulations or calculations as a first step in the research and development process. Simulations are often done with models based on measurements of existing components and scaling existing component characteristics to meet new powertrain performance requirements. Rough control strategies (rule based) are typically considered by simulation engineers in early concept evaluation. By using sub-optimal control algorithms, the results of the concept selection can be biased towards the best-calibrated concept.

Challenges

By providing new methodologies and simulation tools supporting new fully integrated EV architectures and designs analysis, automakers and suppliers will be able to bring investigations of new generation of electric powertrain concepts on a higher level and deliver faster and more efficient vehicle designs in shorter time with less costs.

Within three industrial focused use cases from OEM's (RENAULT Trucks-VOLVO Group, FORD OTOSAN) and Tier 1 supplier (VALEO) in cluster 1 "New e-drive concepts and component sizing in earlier design phase", new, alternative electrical powertrain concepts for passenger car or multipurpose commercial truck application are explored to identify the most appropriate model-based design approaches. Through these use cases, OBELICS investigates advanced design methodologies to support exploration of new electrical powertrain architectures, system sizing and component design analysis and to address following design considerations:

- What are the most relevant electric powertrain architectures in relation to the target vehicle application and corresponding conditions of operations?
- How can we enable a fast and fair comparison sooner in the vehicle development process for robust concept selection?
- What is the right size of the component and the technology of the hardware to achieve higher efficiency on a vehicle level?
- How can we accelerate the execution of early phase design workflows to reduce development time?

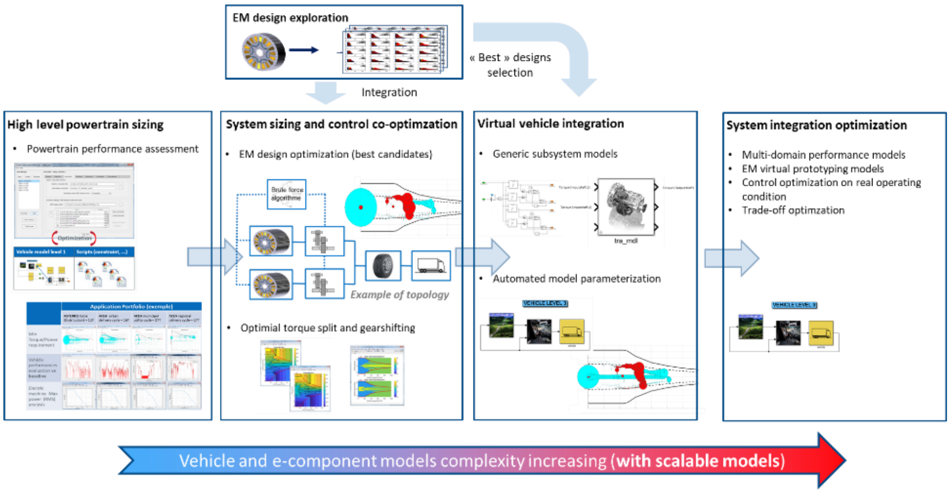
A common methodology, based on system engineering approach together with scalable models, sizing and virtual integration tools will be defined with a target to develop faster workflow execution shall be. Furthermore, a methodology for optimized powertrain sizing swill be developed, considering cost effective and more efficient EV design in the early phase of the vehicle development process as well as representative respectively real driving conditions.

Highlights

The automated workflow defined in the use case proposed by Renault Trucks (Volvo Group) and illustrated in Figure 2 aims to explore and evaluate new electric powertrain topologies for commercial vehicle development and to support exploration of scalable and modular powertrain concepts for a large product portfolio.

The key steps of this workflow and the corresponding methods and simulation tools development are:

- Powertrain performance assessment for high-level powertrain system sizing: to do that, optimization algorithms are coupled to the high-level powertrain model and the power and torque outputs at the wheels are optimized to match the performance of a reference truck. These results are used in the second step of the workflow presented in Figure 2.



- Fig. 2 Automated workflow and tool chain integration targeting optimized designs identification through evaluation of many different concepts and topologies as well as detailed understanding of the system interactions

- This second step comprises exploration of electric machine design and multi-domain performance assessment: the objective of optimizing the efficiency of the electric powertrain concept on complete vehicle level requires: a) defining components that fulfil basic powertrain performances requirements and b) elaborating the optimum combination of component characteristics to achieve the highest powertrain efficiency. This optimisation also comprises virtual selection of optimum electric machines. This selection requires exploration of a large component design space incorporating diverse machine characteristics and designs, which have to be evaluated on the vehicle level for best design identification. These tasks rely on innovative models of electric machines, which are capable of considering listed various without prior experimental inputs. Figure 3 illustrates a methodology and tools that enable virtual exploration of electric machine design comprising reference designs, performance assessment and automatic parameterization of the multi-domain performance model for system level simulation (including automatic electric machine thermal reduced order model generated from FEM).

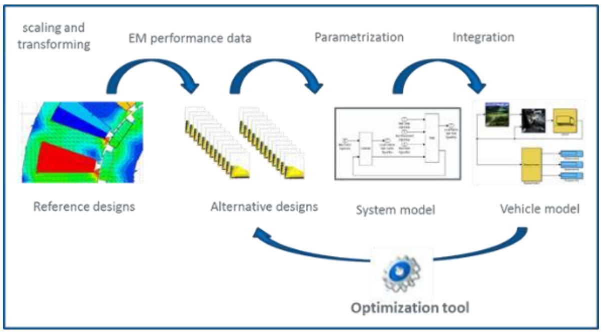


Fig. 3 Automatized workflow, methodology and tool for alternative electric machine design exploration and faster electric model parameterization for system level simulation

- Further steps in the proposed workflow comprise methodology for advanced powertrain control integration using optimal control techniques: control strategies play an important role throughout the vehicle development process to enable efficient operation of the electric vehicles at different stages of the development. Control strategies are especially important in early project phases to allow a fair comparison of different electric powertrain concepts for robust concept selection. Therefore, application of optimal control techniques is essential for the performance assessment of new powertrain concepts to ensure a fair comparison. In addition, development of generic control strategy models for vehicle system simulation is important for faster process execution in early phases. To support integration of control strategies generically and based on optimal control techniques, a methodology has been developed which consists of two steps: In the first step, brute force search method is applied in order to define the optimal motor torque and gear shifting controls to optimize vehicle energy consumption by selecting the best torque split and transmission ratios from a discretized set of possibilities. Brute-force search, also known as generate and test, is a very general problem-solving technique and algorithmic paradigm that consists of systematically enumerating all possible candidates for the solution and checking whether each candidate satisfies the problem's statement. In a second step, starting from this off-line numerical optimization, the optimal operation conditions are identified to build a map-based controller for integration in a vehicle model. This map-based control is an equivalent solution to the brute force method applied in the previous step.

Figure 4 shows some results related to an electric powertrain concept that considers two electric machines, one connected to a two-speed gearbox and one to a simple reduction gear. The main objective of this study is optimization of the electric machine design to enable operations of the electric powertrain at higher efficiency in relevant drive cycles. To do that, a large catalogue of electric machine characteristic have been generated from a reference design by varying electric machine diameter, length, number of turns, etc. Electric powertrain performance has been evaluated and compared for all alternative electric machine design characteristics. Analysis are done considering a drive cycle for medium heavy duty truck application (drive cycle developed by VOLVO in ASTERICS[1] EU project). The different plots show the drive cycle profile, the optimal torque split and gear-shifting for a particular powertrain configuration (depending on electric machine characteristics), the evaluation of all feasible electric machine designs and the identification of the best electric machine design.

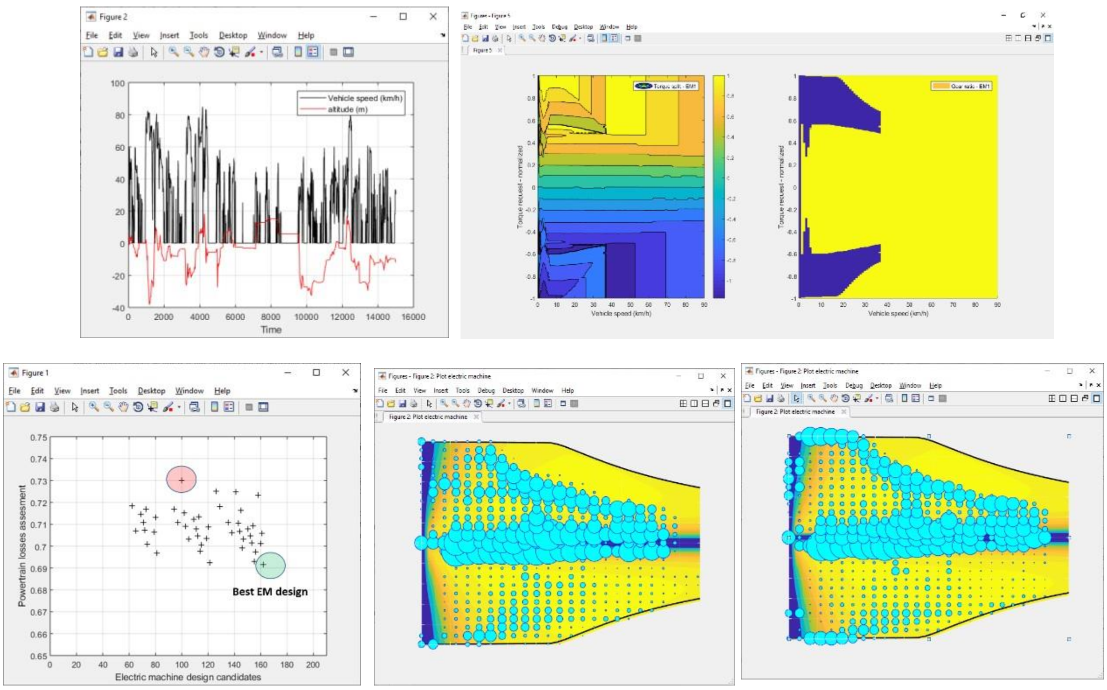


Fig. 4 Example of powertrain sizing analysis for best electric machine design selection from a large design space considering ASTERICS cycle and OBELICS optimization methods

Such approach and tools should enable faster execution of early phase sizing process including component design exploration for right sizing and a fair comparison of new electric powertrain concepts using optimal control technique for best concept selection.

[1] ASTERICS is the successor EU project of OBELICS. OBELICS builds on results of ASTERICS.

2.2. E-vehicle system integration, optimization with real world verification and model-based testing

Reasoning

E-vehicle system simulation, optimization & real-world verification with testing is one of the most timeconsuming tasks during the e-vehicle and e-powertrain development. The huge efforts do not only reside in creating and planning test-cases but also in setting up these test cases in different testing environments. Testing environments should also include different simulation models which substitute real system components. Especially, if certain tests must be repeated more often throughout the process, the needed efforts grow enormously, since every testing environment uses different tools and parameters. If, in additional, different variants of certain components or a system need to be analyzed – e.g. one inverter configuration could be used for different vehicle variants – the effort increases exponentially. The realization of one single test automation tool, which could be used for different test environments, would result in great simplifications and effort reductions. However, it is very important that results of different test environments are easily comparable with each other and provide the same results, which is ensured with back to back testing. To guarantee consistent results within development and testing procedures from office simulation to the first real vehicle prototype it is necessary to use the most reliable simulation models that are possible. There are many influencing factors that must be considered during the entire process and the earlier the requirements for the simulation models are defined, the more effective and consistent this process will be.

Challenges

The major challenge in this engineering domain is the integration of different models and their appropriate fidelity. For this purpose, it is very important to consider physical phenomena of the simulated system and to define consistent interfaces and characteristics of the modelled system. Another necessary feature is a powerful cosimulation approach when different simulation models from different software (SW) vendors are integrated in a common system level model. Efficient co-simulation approaches ensure high flexibility and time savings through re-use of models throughout the whole development process. In a co-simulation approach, a consistent interface design, SW & HW (hardware) constraints for the simulation environment, compatibility with the FMU/FMI standard for RT and non-RT target platforms and knowledge of communication constraints etc. are important. The simultaneous use of simulation models together with real components in one test environment is another request. This integration process is one of the biggest challenges. The models must be RT capable and, therefore, often include model-simplifications, which call for consistent scalability of the models. The methods to perform these simplifications must be fast and easy whilst preserving the real-time capability of the models. Further, models must be easily transferable from one testing environment to the next. To develop and demonstrate the benefits arising from model-based design, testing, integration and optimization in the e-vehicle development process, the use cases are taken from real world examples with real existing vehicles like FIAT 500e, sporty car KYBURZ eROD or truck VOLVO FL. Therefore, the appropriate accuracy and details of the models plays an important role and will be shown exemplarily for one use-case. The further technical topics include the parameterization of the models for the adaptation to a new virtual vehicle prototype, the integration methods and co-simulation capabilities of models of vehicle components and optimization techniques to reach the set of requirements for the envisaged vehicle.

Highlights

As exposed above, one of the main goals in the OBELICS project is the reduction of development and testing time efforts. Achievement of this target is demonstrated on a E-vehicle system integration cluster with a focus on testing and validation at virtual vehicle prototype level. The main objective is to enable and support significant and more intense is shifting of these time and resources consuming development, testing and validation activities from “real world” (real vehicle prototype) to the “virtual world” (virtual vehicle prototype). Realization of this strategy is demonstrated via the following approach:

1. Methodology design
    - Co-Simulation approach
    - Automated deployment process
    - Using intelligent optimization techniques (design techniques for vehicles; controller design workflow)
    - Components design with virtual models => feasibility assessment
    - Well defined set of testing and simulation scenarios during whole development cycle
2. Standardization/compatibility
    - Model scalability/interoperability
    - Interface consistency (150% interface definition)
    - Transferability/consistency of models throughout the development stages
    - Multi-domain and multi-physical model

3. Virtual testing
   - Components testing in virtual environment
   - Integrated whole system testing in virtual environment
4. XiL testing
   - Frontloading the test effort testing scenarios
   - Run faster RT models with FPGAs
   - Test reproducibility
   - Updating model parameters faster and use real measurements

Following example is result of the successfully used virtual vehicle prototype integration and further optimization of the e-powertrain efficiency. This use case has been developed in collaboration between Centro Ricerche Fiat and Siemens Industry Software.

The main aim is to simulate an electric vehicle, with its systems and subsystems, in different drive cycle scenarios and focusing on thermal management design. Vehicle FIAT 500e is taken as a reference case. This example demonstrates coupling between 1D and 3D models, developing a high-fidelity simulation on the thermal behavior of full vehicle, systems and components. The novelty of the proposed methodology arises from smart coupling strategy of several 3D models with a single 1D model used as a supplier of "variable boundary conditions" that reflect selected transient scenarios. The 1D model is used to simulate components and subsystems of the electric vehicle (battery, inverter, electric motor, cooling system, HVAC and others), replicating how they work, and which I/O are required or provided. They are mutually linked to simulate the behavior of a whole vehicle in real driving conditions. Focusing on the thermal management, such numerical simulations can provide information about the temperatures of each component and, therefore, the impact of the HVAC system characteristics and operational strategy on the vehicle range, through the electric consumption of the compressor. Simcenter Amesim V17 has been used for the 1D modelling. Even if a 1D model can connect all these subsystems of the vehicle, it cannot replicate with required fidelity some physical phenomena. This is the case for the air flow and all resulting phenomena, which in a vehicle inherently feature a 3D nature. Therefore, the only way to obtain a high-fidelity simulation is using 3D models with Computational Fluid Dynamics (CFD). For this methodology air flow is calculated in two different domains, which makes two 3D models, one for the vehicle (simulation of external flow around vehicle and under the hood) and another one for the cabin (simulation of internal flow for passenger comfort). For both simulations, solver used has been Simcenter Star-CCM+ 12.06.011. The coupling strategy applied in this project consists of running a 1D model and calculating the 3D model only when it is necessary.

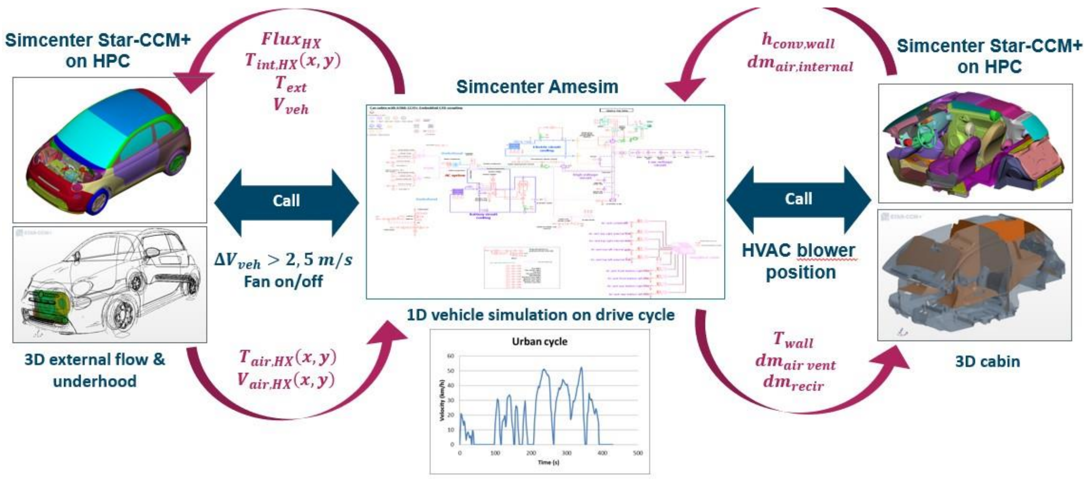


Fig. 5 Coupling strategy 1D & 3D models for EV thermal management design

With such a coupling approach, overall simulation, even for long transient scenarios like driving cycle, becomes affordable in terms of time and computational resources thanks to the use of HPC and smart coupling. 3D physical phenomena are still simulated with 3D model, but in a most efficient way with variable boundary conditions from the 1D model, allowing a very high-fidelity thermal system estimation for the electric vehicle and its components. Furthermore, this methodology will be used to optimize the thermal management and energy consumption in the electric vehicle, by testing and assessing new different strategies in less than one day each.

2.3. Battery design and testing for improved safety & reliability

Reasoning

Reliability of vehicle traction battery systems can be considered from different points of view. An important perspective is a reliable Battery Management System (BMS) that can monitor and control each cell of the battery system. The monitoring and control strategy form the basis to guarantee a high functionality and a long battery life, i.e. to avoid cell ageing as much as possible. The ageing behavior of the battery can be influenced by internal and external parameters. The internal parameters are specified by the battery manufacturer (e.g. material selection, material parameters, manufacturing quality, etc.). External parameters (e.g. cell balancing, charging method, max. operation temperature, etc.) are controlled by the battery management system (BMS). In order to optimize the external parameters, a large number of system parameters must be selected. For example, a high number of measurements at cell level is required to characterize the battery cell in the laboratory. Unfortunately, the parameters are not constant over the lifetime and therefore must be updated to avoid significant errors. Another limitation between laboratory battery tests and real applications is the sampling frequency, which nowadays is practically limited to 12 kHz due to the limitations of the battery test systems. Real frequencies caused by different effects of other drive train components are close to 20 kHz. The impact and effect of the high frequencies to the safety and reliability of the battery system are unclear. In addition to electrical reliability, mechanical reliability and safety are also very important aspects. Mechanical reliability is relevant for structural components, electrical tabs and various connections. A major challenge for the designer is always the assumptions of field relevant loads, which must be known for the design of reliable components. There are several standards for defining loads on a battery system, but some of them show inconsistencies between the different load assumptions. Consequently, reliability can be either very high (conservative strategy) or not so high (less conservative strategy). The first case leads to an overdesign of the battery and the second case to failures; both cases should be avoided.

Challenges

OBELICS investigates and implements advanced battery diagnosis methods to ensure safety and reliability of the battery system throughout its lifetime. This is achieved through accurate battery models and implementation of online cell impedance estimation to track and evaluate the safety status of the battery online. The aim of this work is to reduce the effort for characterization battery cells in the laboratory and to increase the battery safety by an order of magnitude. OBELICS first investigates new hardware and control structures for batterie test systems to achieve these higher frequencies for the test and thus the relationship between these high frequency signals and the reliability of the battery system. In order to cope with the complexity of the battery system in terms of design, load, function and damage mechanisms, a comprehensive technical understanding and suitable test facilities are required. The most difficult task is the correct determination of load profiles (mechanical and electrical) for testing to ensure high reliability and safety in practice, with OBELICS paying particular attention to the correct acceptance and evaluation of load profiles. All functional and safety aspects, whether electrical or mechanical, will be covered in this project by a new Failure Mode and Effect Analysis (FMEA), which considers probabilistic information of individual components to estimate the overall safety level of the system. This work opens a new way to increase the safety and reliability of a battery system through new measurement and analysis approaches that are not yet known. A demonstration will show that the new approaches are applicable in an industrial environment.

Highlights

The use case for load data evaluation for battery systems takes into account experimental load measurements on vehicle and test bench level. The experimental data covers the entire load transfer function from wheel suspension, vehicle frame, battery system to sub-components inside the battery system. The measurement chain gives the opportunity to capture the global (on vehicle mounting positions) and local (on module level) excitation of the battery system under real driving conditions. The battery test procedure is divided into two steps. The global battery excitation on the mounting points in the vehicle was derived from test drives performed on a rough road track with different speed levels. These data were used as input for a second test run with a stand-alone battery on a multiaxial test rig at Fraunhofer LBF Darmstadt, Germany. Here, acceleration sensors and strain gauges were applied inside the battery system to capture vibration response and local mechanical stresses of selected battery subsystems. The testing parameters of the test rig were optimized to achieve identical global excitations on the mounting positions compared to the vehicle test run. Finally, we were able to evaluate the given standards (e.g. ISO 12405) for battery validation testing with the rough road data and give recommendations to battery designer. The Fiat 500e vehicle and battery system were used for this evaluation. The battery system has a nominal voltage of 364 V and contains 97 battery cells arranged in five cell and six cell modules. In total 18 modules are installed in the system. It is a fully integrated "plug-and-play" battery pack system that includes connections for a high voltage main power inverter module, high voltage on-board charger, low voltage communications bus and coolant fittings. The total mass of the battery system is about 270 kg. The State of Charge (SOC) of the battery during the tests was about 80 %. A picture of the Fiat 500e battery on the test rig is shown in Figure 6.

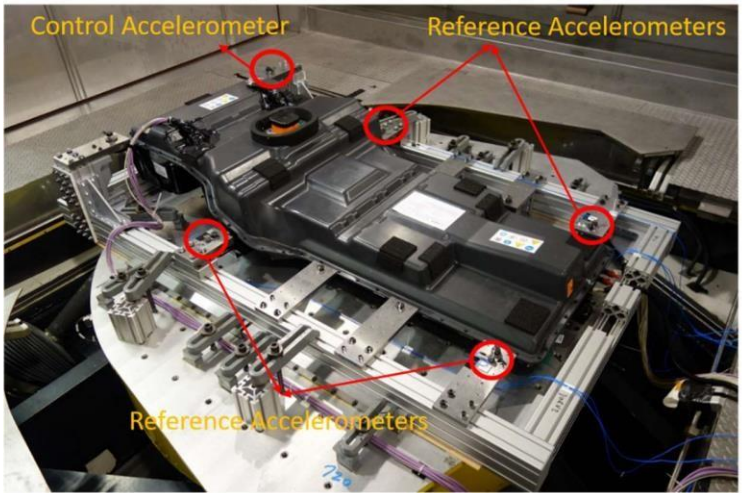


Fig. 6 Demonstration battery system on the multi-axial test rig incl. mounting fixture. The vehicle measurements on a rough road track were reproduced on the test rig by taking into account the global excitations on the mounting positions

Some selected results for a speed range from 20 km/h to 50 km/h are displayed in Figure 7. The Power-SpectralDensity (PSD) is shown for the global excitation and on module level inside the battery system. The PSD shows how the energy of a signal is distributed. As a reference, the standard IS0 12405 is displayed in the plots. The ISO standard shows a conservative approximation on the mounting points for speeds up to 30 km/h. Some frequencies slightly exceed the ISO standards for a speed level of 50 km/h. For the internal excitation there is a nonconservative approximation of the given ISO standard. The lowest speed level already shows higher energy frequency ranges which increase even more with higher speed level. Consequently, a reliability validation test on subsystem level by using the ISO standard as input would be non-conservative for the tested battery system. A subsystem requires different load conditions for validation, which can be approximated by using FE simulation approach. Unfortunately, the simulation parameter, especially damping behavior of contacts, are not always known which makes it challenging to predict the transfer function from the mounting to different subsystems. This study shows that the load within the battery system can be much higher compared to global excitation and a designer must take this behavior into account.

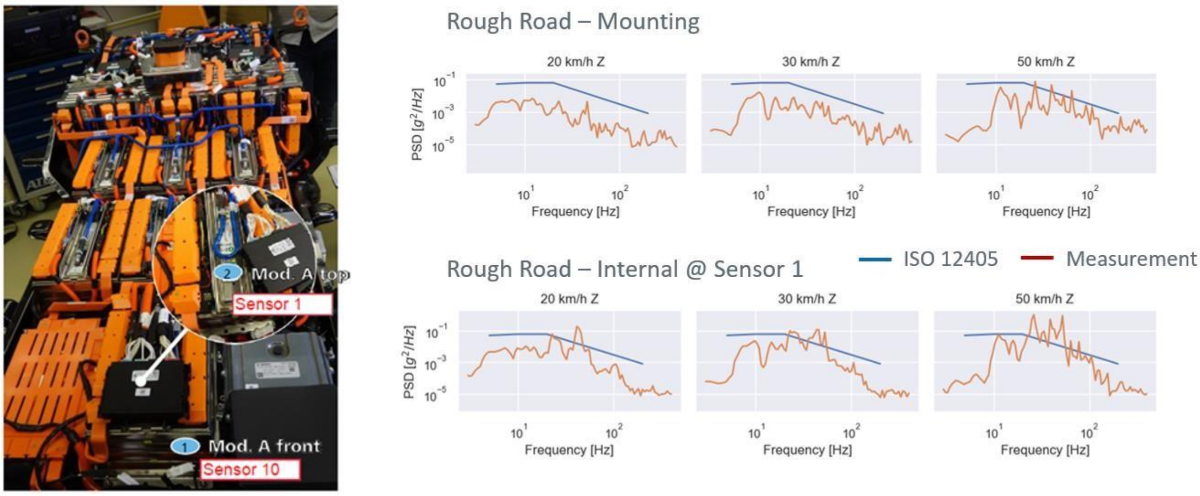


Fig. 7 Vibration response of the battery system on rough road conditions with different speed levels compared to the ISO 12405 standard. The vibration profile on mounting positions are in a good agreement with the ISO standard. The vibration response on subsystem level is underestimated by the ISO standard

2.4. E-motor, control and inverter design and testing

Reasoning

The high energetic efficiency and, therefore, the attractiveness of an electric powertrain lies mainly in the traction unit: e-motor and inverter. A well-designed electric powertrain can be twice as efficient as the powertrain with a conventional combustion engine. Moreover, a second relevant aspect is the flexibility in terms of volume that can be achieved with an e-traction unit. This is made possible above all by the use of new materials in the electric motor and inverter, as well as by higher frequencies and better integration of the components. These are two good reasons why electric vehicles are already showing strong growth rates, which is in the interest of all parties involved.

However, shortening the development time of electric motors, inverters and controls is an implicit market requirement that can be derived from the above. Therefore, when designing, implementing and testing these components, all necessary aspects have to be considered in order to achieve the best possible result in the first design: electrical, mechanical, thermal, magnetic and control engineering. However, all aspects are difficult to evaluate in one single test environment and, therefore, require research into new methods and test approaches that allow efficient optimization and verification in different phases of development within different test environments, if needed.

Challenges

Starting from the inverter, it is known that wide bandgap semiconductors such as silicon carbide (SiC) or gallium nitride (GaN) exhibit better thermal and switching behavior compared to pure silicon-based switches. The new semiconductor materials allow switching frequency to be increased to dozens of kilohertz while simultaneously reducing total energy losses. This allows the highest power densities to be achieved while simultaneously reaching very high efficiencies. Nonetheless, the latter also implies high-frequency effects such as electromagnetic interference (EMI) and the needs for faster sampling circuits and control loops.

Therefore, to ensure the necessary reliability of the HF inverter through model-based design, exact models from various technical domains as well as suitable test cases and test equipment are required. The validation of new test methods and models in different test environments is verified by three industrial use cases.

On the other hand, the efficient design of the electric motor, particularly its thermal aspects, is of great importance for a highly efficient overall system; since cooling capabilities define the motor performance. It is known that liquid cooling system in the housing of PMSM machine ('water jacket') offers a good trade-off between the price and performance. However, it is still a challenge to obtain an optimized design that considerers maximum load ability and over-loading ability of the main drive-train with real vehicle and road conditions. Hence, these design aspects are explored in two industrial use cases.

Highlights

In the area of E-motor, control and inverter design and testing, the achievements beyond the state of the art that the OBELICS project pursue, are summarized in the following seven points:

1. Frontloading methods and tools for complex, high fidelity models to reduce development and testing times
2. High frequency real-time capable models of inverters in FPGA
3. High fidelity real-time capable models of PMSM based on minimized input design parameters
4. Combination of high-fidelity multi-domain models in a single modeling/simulation environment
5. Trade-off analysis between different testing levels (HIL, P-HIL, test-beds) for e-motors and inverters
6. Test automation and optimization sequences for HF inverters
7. Optimization of PMSM design by hybrid testing techniques

All these points are dedicated to reducing the development and testing efforts of e-motor and inverters. In this sense, it is possible to take as an example from the list the real-time high-frequency models of FPGA inverters. Here the concept is to model both physical components and the control unit in the computer and then run the models on a real-time hardware platform. This concept can be defined as "frontloading", or Model Based Design process by using high fidelity models already in the early stages of development. However, increasing the fidelity of a model means that its real time capability is reduced in turn. Figure 8(a) illustrates the relationship between the complexity of the model and its real-time capability. A methodology to deal with these aspects has been improved in this project by FH JOANNEUM and is based on the milestones established in JPEC project[2].

[2] JPEC: JOANNEUM Power Electronics Center, Austrian research project, September 2014 - December 2018. Link: https://www.fh-joanneum.at/projekt/joanneum-power-electronics-center/

As already known, FPGA is an excellent candidate for allocating complex models able to run in extremely fast cycle times (<1us) without losing much precision in relation to the original computer models. However, the implementation of models in FPGA is not as straightforward as in soft-CPU's and therefore, methods and tools have been analyzed and developed in order to facilitate the implementation process. A graphical representation of this methodology is shown in Figure 8(b).

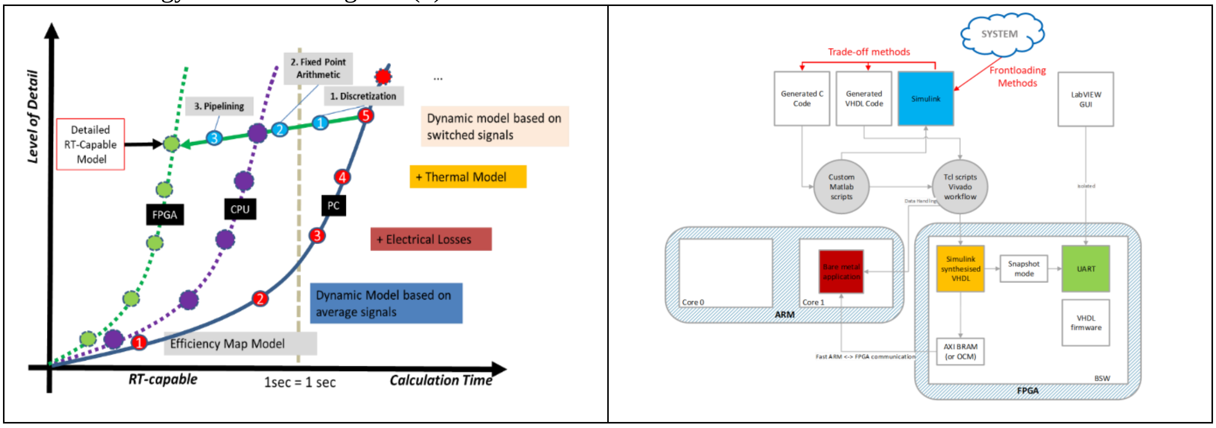


Fig. 8 (a) Model complexity versus (real-time) calculation time. (b) Development methodology for e-powertrains

As an outcome of this methodology, an Automatic Architecture Generator (AAG) has been developed. The AAG allows the Simulink developer to choose the architecture for which the model has to be developed (CPU or FPGA or both). The AAG is primarily dedicated to development and testing of HF inverters; however, it can be easily extended to other components.

Finally, the optimization of a PMSM e-motor design by hybrid testing techniques can be highlighted. In this approach, University of Ljubljana combines high fidelity models of Permanent Magnet Synchronous Machines running in a HIL system with a real cooling circuit that have been designed with 3D models and successfully converted to 0D models. The latter in order to optimize the design of e-motors in the early stages of development.

3. Conclusion

The partners in OBELICS have explored several use-cases with innovative model-based designs and testing methodologies and have worked on a new framework for further exploiting the results of the project in industrial environments and academic research. The models and simulation cases are extremely well designed and seamless scalability of more detailed models to real-time capable model enables very low additional efforts while traversing the V-development process. The interfaces have been designed with the aim to facilitate exchange of models between different partners and other industrial or academic users. The project partners will continue the collaboration on further use-cases until the end of the project and will have significant impact on future virtual design and testing of electric vehicles, thus leading to more efficient and safer electric vehicles, while keeping the development efforts as low as possible.

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