OBELICS

FACTS AND FIGURES

Full project name: Optimization of scalaBle rEaltime modeLs and functIonal testing for e-drive ConceptS
Acronym: OBELICS
Duration: 38 months
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EC Funding: € 9,077,497.50 million

PROJECT COLLABORATION

The OBELICS project has actively driven the collaboration with other GV 07 projects HiFi-Elements and DemoBase, for „Standardization" activities with regard to FMI/FMU and Battery safety standards. The aim was to create synergies and to reduce overlap in these activities.

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www.obelics.eu

Edited by Claudia Keinrath, AVL
Layout and Cover by Valentina Riedisser, AVL

PREFACE

This booklet summarises the key results of the research project OBELICS, a Horizon 2020, GV7 initiative for the optimization of scaleable models and functional testing for e-Drive concepts and vehicles.

20 partners from 9 European countries worked on methods and tools for the efficient design, development and testing of electric vehicles.

As electric vehicles are gaining more and more importance and sales figures and trends are also pointing significantly upwards, an efficient development process as well as energy-optimal design and operation of e-vehicles is of great importance. Also the safety of the vehicles, especially also of the battery during the whole operation, has to be controlled and improved accordingly.
The high-fidelity physical models, their easy integration and scalability and thus usage throughout the development process combined with state-of-the-art test methodology in different test environments are crucial ingredients for the success of this task.

Based on 17 different practical use cases, all methods and tools were reviewed, validated and their potential for improvement evaluated.

We are very proud that OBELICS contributes to a reduction of development efforts by 56%, an improvement of efficiency by 18% and an increase of safety by a factor of 17.

„Congratulations on the outstanding work," said Dr. Marina Kousoulidou, project officer at INEA, European Commission, at the final review of OBELICS. „You have achieved all the targets, and I am happy to say that in some cases more has been achieved than we expected."

A sincere thank you goes to all the authors and reviewers of this booklet. The work package leaders and the use-case leaders are listed here as representatives. The other authors are mentioned in the respective texts.

WORK PACKAGE LEADERS

Nicola Tobia (Centro Ricerche Fiat)
Tomaž Katrašnik (University Ljubljana)
Matthieu Ponchant (SIEMENS SAS)
Thorsten Fischer (AVL SFR)
Jürgen Nuffer (Fraunhofer LBF)
Mathieu Sarrazin (SIEMENS NV)
Mohamed El Baghdadi (Vrije Universiteit Brussel)

USE CASE CLUSTER LEADERS

Hellal Benzaoui (Volvo Group)
David Delichristov (VIRTUAL VEHICLE)
Benjamin Zillmann (BOSCH)
Raul Estrada Vazquez (FH JOANNEUM)

We would also like to thank our Project Officers Dr. Marina Kousoulidou and Dr. Monica Giannini (interim), who guided us very well through the project and the project management team of Uniresearch whose work made the project run smoothly from start to end.

Horst Pfluegl
Project Coordinator
horst.pfluegl@avl.com

Willem van Dorp
Project Manager
w.vandorp@uniresearch.com

OBELICS VISION

Over the past hundred years engineers and scientists have worked hard to perfect the way cars are designed, developed and produced; cars that have been powered nearly exclusively by internal combustion engines. Since around 2010 the automotive market has been undergoing drastic changes and shifted towards large-scale launches of electric vehicles (EVs). In Norway, new registrations of electric cars already exceeded those of conventional vehicles in June 2017. In 2020, according to CAM (center of automotive management) the total number of all e-cars sold in Norway was even higher than that of conventional cars.[1]

Developing an EV is radically different from developing a traditional car. All components are completely new, very different from combustion engine drivetrains and interlinked, which means they can strongly affect each other's performance. It is complex to find the global design optimum as there is not so much experience as for cars with combustion engines. Also, the technology itself is still under development, which requires a flexible development process, as there is not yet as much experience as with cars with combustion engines. How can these hurdles be overcome and affordable yet reliable EVs be brought to the market as quickly as possible?

OBELICS helped to solve these challenges by enabling what is known as frontloading: the use of virtual models to build and test new designs. Traditionally, vehicle design has been a (more or less) linear process: a design is created using preliminary data or expert knowledge, costly prototypes are built and tested and finally the design is corrected based on the test results. Instead, frontloading allows engineers to understand the impacts of design changes and analyze a system before it is built. Using advanced and easy to scale models and simulations, engineers can test and validate the components very early in the development process. Prototypes do not have to be built until an advanced (and computer-tested) design is available. Frontloading makes it cheaper and faster to develop new EVs.

To goal of the OBELICS project was to develop a framework for te design and testing of electrical powertrains and vehicles. The innovations will reduce the development effort by 40%, improve the drivetrain efficiency by 20% and increase the safety by a factor of 10. The models and simulations developed in OBELICS include new scalable (real-time capable) models and new testing and safety analysis methods.

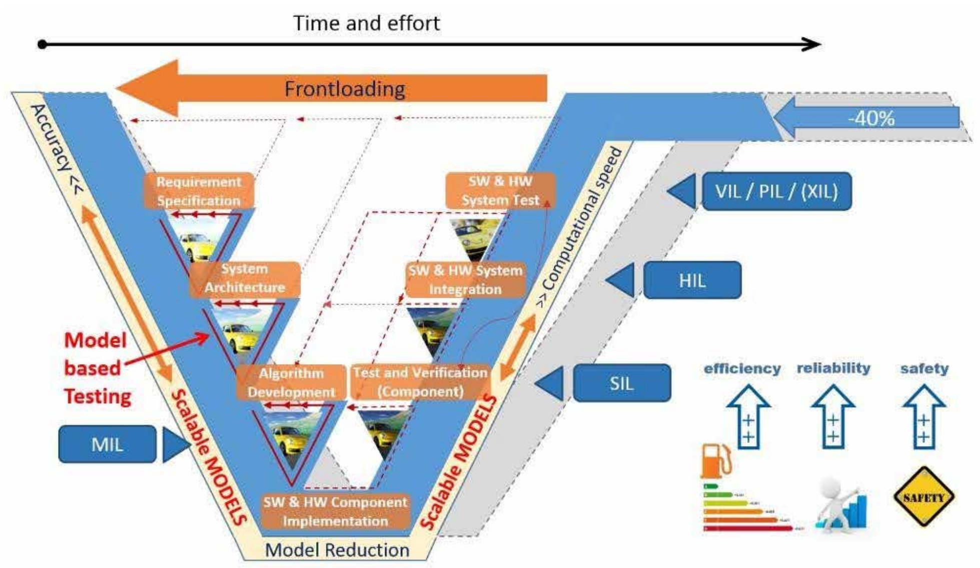

Fig. 1 provides the OBELICS model-based development concept to reduce development and testing efforts, while increasing efficiency, reliability and safety

[1] https://emobilitaet.online/news/wirtschaft/3901-norwegen-elektrofahrzeuge-%c3%bcberholen-erstmals-verbrenner-bei-neuzulassungen

A number of technical innovations were necessary to achieve the ambitious goal:

SCALABLE REAL-TIME MODELS & PARAMETER IDENTIFICATION
New models that can be used along the entire development & test cycle

MODEL INTEGRATION
The models need to be integrated and combined with (partial) physical tests, so-called "in-the-loop" setups

MODEL BASED TESTING & VALIDATION
Shortening the time between design and test by simplifying the handling of scalable real-time models for the purpose of testing and validation

SAFETY AND RELIABILITY
The safety and reliability of e-components and electric vehicle was addressed

SECOND LIFE BATTERY USAGE
Assessment of the reliability, energy content and viable commercial applications for battery systems considering environmental and economic cost

The project goal was demonstrated in seventeen use cases. These use-cases were grouped into four use-case clusters (UCCs), that overlap with important engineering areas in the typical electrical vehicle development:

UCC 1: NEW E-DRIVE CONCEPT & COMPONENT SIZING USING SCALABLE MODELS

UCC 2: SYSTEM INTEGRATION, MODEL-BASED TESTING AND VALIDATION

UCC 3: BATTERY DESIGN AND TESTING FOR IMPROVED SAFETY & RELIABILITY

UCC 4: DESIGN & TESTING OF E-MOTOR, CONTROL AND INVERTER

The use cases and how they contribute to the overall project goals are described in detail in the following chapters.

TABLE OF CONTENTS

TECHNICAL INNOVATIONS

SCALABLE REAL-TIME MODELS & PARAMETER IDENTIFICATION (BATTERY, E-MOTOR AND INVERTER)

TOMAŽ KATRAŠNIK

University of Ljubljana

One objective was to develop innovative, scalable and accurate (>90%) models for the development of drivetrain components (e-motor, batteries and inverters), validated with the XIL approach, that are based on first principles (mechanical, physical, electrochemical, electro-thermal, electromagnetic model basis) and allow for systematic scalability towards real-time models. Sub objectives were:

- development of models with high predictability and accuracy, enabling more accurate virtual prototyping and thus more efficient frontloading
- development of models and tools for batteries, e-motors and inverters in the areas of multi-physics multidomain performance models, model scalability approaches and parametrisation as well as configurator tools
- development of models that will additionally support seamless application of the models from MiL via SiL to HiL applications through innovative scalability approaches

Here are some of the results in modelling that were created in the course of the project.

NOVELTY BEYOND STATE-OF-THE-ART

Advanced electrochemical battery model
University Ljubljana, National Institute of Chemistry

The strong demand for a simultaneous increase in energy and power density as well as extended lifetime and increased safety of batteries at low battery cost poses major development challenges. A huge variation space of material selection and geometric properties inherently requires multiscale modeling and simulation support to create virtual prototypes with high accuracy, which must be suitable for the following requirements:

- more consistent representation of electrodes
- full interaction of the performance and the degradation models
- enablers for virtual battery safetyassessment

The advanced electrochemical battery model transfers the fundamental understanding of materials to the continuum cell level modelling through more consistent virtual representation of topological characteristics of the electrodes and coupling to lower scales via sequential linking. It supports coupled modelling of electrochemical, transport, and thermal phenomena, including side reactions of Solid Electrolyte Interphase (SEI) growth, decomposition and regeneration as well as Li-plating. Therefore, it features higher level of prediction capability and thus accuracy, when analyzing battery performance and degradation as well as safety relevant aspects.
Flexible model architecture enables seamless scalability of the level of detail and thus computation times through selection of dimensionality of the computational mesh of the sandwich, mesh density, number of particle sizes in the computational cells and virtual representation of agglomerates. Thereby, the same modeling framework is capable of supporting very detailed analyses as well as simulations, where computational times should be significantly faster than real-time.

Therefore, advanced electrochemical battery model represents a leap forward in more accurate virtual prototyping, since it enables more efficient frontloading and allows for approaching engineering limits with higher certainty. It, therefore, efficiently contributes to OBELICS objectives on reduced development efforts, improved efficiency of the e-drivetrain and increased safety.

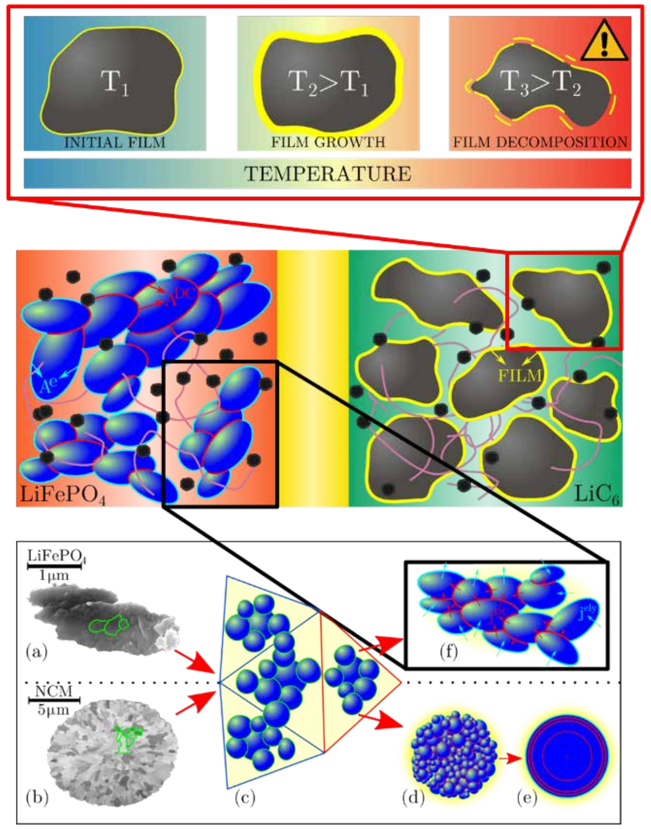

Fig. 2 depicts the development of the Li-ion battery modelling framework that is capable of modelling of coupled transport, electrochemical, heat generation and degradation phenomena

Advanced battery parameter identification
Vrije Universiteit Brussel

A very fast model identification test and process was developed. In order to develop an accurate electrical model for the battery, the model's parameters must be identified accurately. Therefore, the mathematical equations describing the model's behavior are considered as cost function of which system parameters need to be solved. For the optimization algorithm minimizing the error between model and physical system, specific measurements are needed.

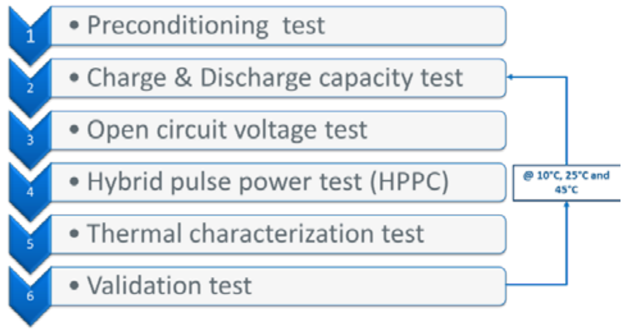

Fig. 3 shows the battery test methodology

An accurate method for data-driven model identification is the impulse response analysis. With this test, current pulses with specified pulse width and amplitude are applied to battery cells. As this system behaves nonlinearly in function of SoC, current and temperature, the excitation pulses are applied at various different conditions.

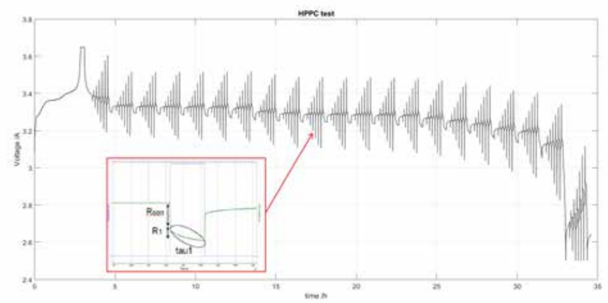

Fig. 4 provides system identification parameter estimation procedure for wide range of current and voltage levels during discharge

Permanent Magnet synchronous machine configurator
University Ljubljana

In order to support the development process of e-vehicles during the design phase with simulation models and later on, during testing and validation with appropriate real-time capable models, configurator tools that allow for fast and accurate creation of e-motor models out of given key performance parameters of the emotor were developed.
The model includes thermal, mechanical, electrical and magnetic effects on a high-fidelity level, which can be parameterized just by providing three relevant parameters for the e-motor.

The PMSM configurator as a tool provides a machine design suitable for pre-prototyping (preproduction) and gives corresponding performance characteristics based only on the inputs of the definition of three fundamental PMSM requirements only. The configurator is able to generate suitable parameters for the model to be used in the real-time system (vehicle) level, containing the real-time nonlinear PMSM machine model, which is connected to the frequency converter model on one side and to the vehicle model on the other side.

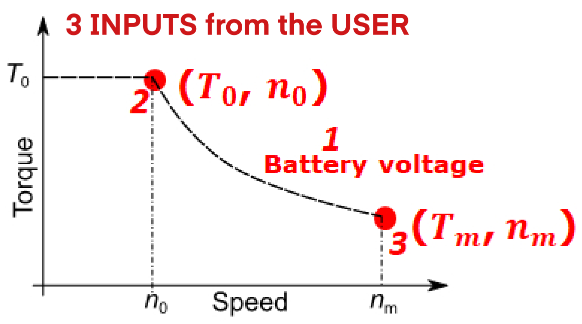

Fig. 5 shows the only 3 inputs for innovative e-machine configurator modelling tool

Accurate Multiphysics inverter models
Vrije Universiteit Brussel

The innovative OBELICS modeling approaches for power electronics converters cover the entire chain:

- innovative multiphysics models that include accurate loss and thermal models and also cover more detailed models at the switching frequency level
- model scalability approaches that enable consistent transfer from detailed inverter models to real-time inverter models
- innovative configurator tool that supports the determination of motor inverter design and corresponding performance characteristics based on basic system inputs
- parameterization tools that enable reduced development time

The innovative inverter models developed in OBELICS include a complete thermal model of the inverter architecture and take into account bidirectional operation of the inverter as well as accurate loss models, line and switching power losses, and have a modular structure that enables different topologies of the power electronic architecture.
From the hardware perspective, different technologies are supported, such as IGBT, MOSFET, Si, SiC or hybrid technologies. The model also includes control modules and can be integrated into the simulation of the entire system (powertrain) with quasi-standardized interfaces. In addition, configurator tools are available to adapt the model parameters to different semiconductor properties, currents, voltages, etc.

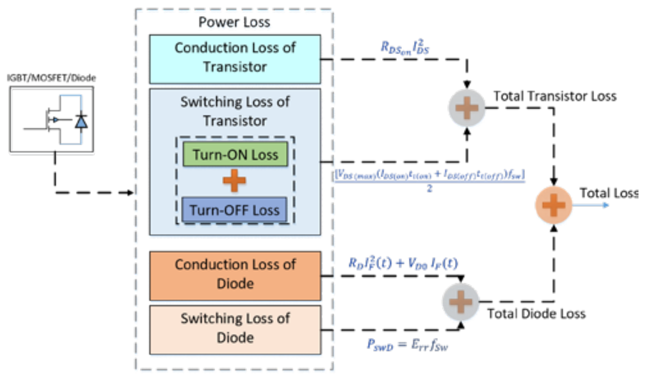

Fig. 6 shows the modeling architecture of inverter models

MODEL INTEGRATION

MATTHIEU PONCHANT
SIEMENS

In order to establish new processes adapted to electric vehicle design, the automotive industry needs to be supported by a new generation of industrial modeling and simulation tools that allow the study of innovative configurations in combination with all relevant systems that affect performance and comfort.
Of all the on-board systems, the powertrain and major auxiliaries have the greatest impact on the performance of an electric vehicle. To accelerate the design process, it is therefore crucial to consider and optimize these interactions very early in the design phase. Optimal sizing of the main powertrain components (battery, inverter, electric motor) is the best guarantee for optimal vehicle performance.
In order to correctly size the components, it is necessary to integrate the respective submodels into an overall model. In order to find the best possible solution quickly and stably, the vehicle performance including physical/functional aspects such as brake mixing strategies, transmission, chassis, thermal systems, cooling, air conditioning, etc. must be modeled appropriately and realistically.

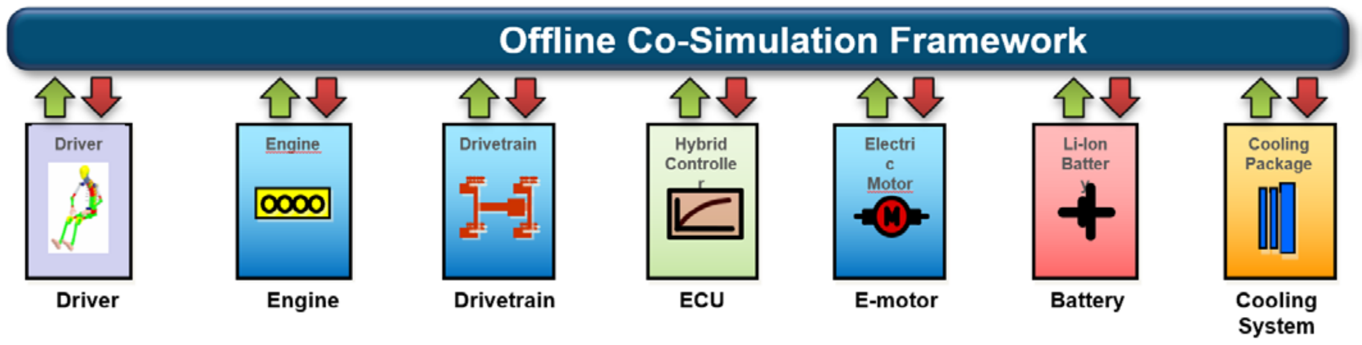

Fig. 7 shows that Model.CONNECT™ / Amesim was used to establish a Co-Simulation Framework for e-components and related vehicle and environmental models

NOVELTY BEYOND STATE-OF-THE-ART

The OBELICS simulation framework for the design and development of electric powertrains and vehicles includes the following components:

- various types of Real Driving Condition (RDE) cycles to account for a variety of environmental conditions and states (e.g., road gradient, temperatures, speed/load profiles)
- model libraries for all electric powertrain components that can be easily linked to each other and to other vehicle components, and ultimately to the environment and the respective environmental conditions, via standardized interfaces
- a complete simulation environment suitable for standardized models that can be easily used and shared for co-simulation and real-time simulation together with other models or real components
- a new method for optimizing e-drivetrain design

RESULTS

The new methods and tools developed in OBELICS lead to a realistic behavioral simulation of all systems and components involved in the EV powertrain and are characterized by the following features:

- standardization of model interfaces for all components, in collaboration with the HiFi-Elements project
- subsystem identity card, which was used to define all simulation-relevant properties for E-components and other vehicle components within OBELICS
- modeling coupling strategies for semi-synchronous co-simulation models
- model reduction strategies to enable model scalability from SIL to MIL to HIL
- integration of newly developed models of e-components of the project into entire vehicle simulation prototypes

Most of the demonstrators using these integration methods are described in UCC1 & 2 for various e-vehicle architecture prototypes and simulations (VALEO 48V car, Fiat 500e, Kyburz SimRod, Volvo eTrucks, Ford Otosan eTrucks).

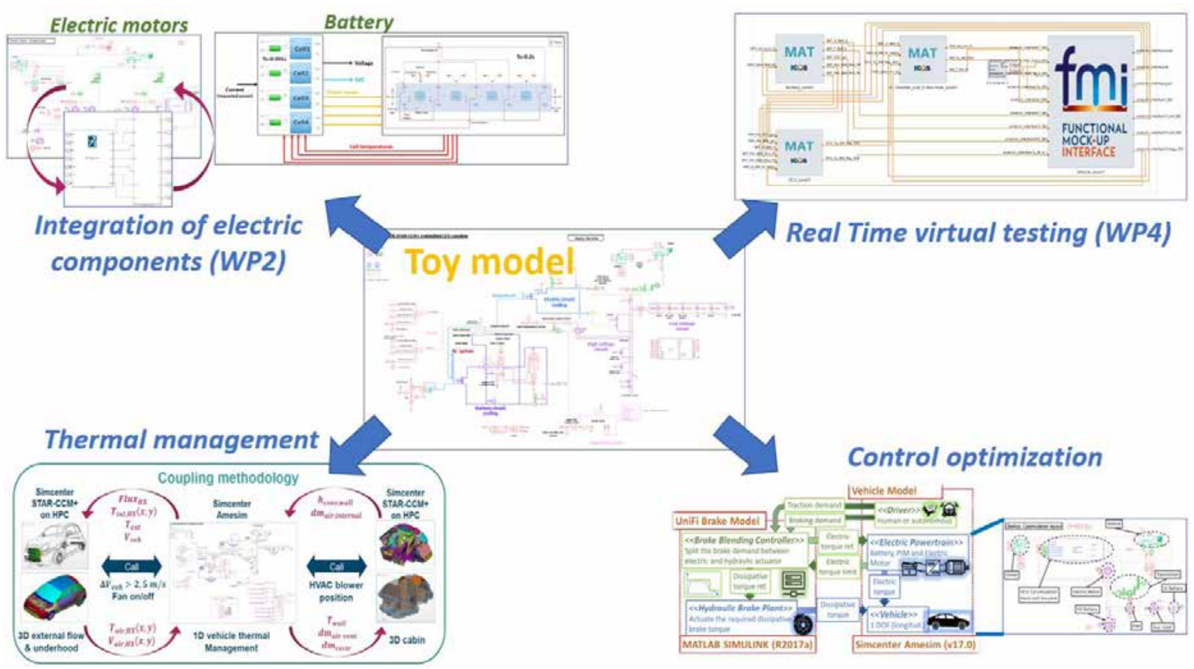

Fig. 8 shows the e-component models and vehicle model (toy model) can be applied in several applications of the development process

MODEL BASED TESTING & VALIDATION

THORSTEN FISCHER

AVL

Model-based test procedures enable testing of electrical components and vehicles at very early stages of the development process. In this process, virtual models of the components are tested alone or together with physical components. These procedures aim to shorten and reduce the time and resources required from design to final release and this is of high importance for all OEM's to remain competitive. In particular, simplifying the handling of scalable real-time models for the purpose of testing and validation is also very important so that the models can be used throughout the development process.
The efficient use of MIL, SIL, HIL and XIL test environments require appropriate test cases for RF inverters with e-motors and batteries, including their infrastructure and test equipment. Another important point in the development is a constant benchmarking of the solutions and back-to-back tests to show a comparison over the development process between different test environments.

NOVELTY BEYOND STATE-OF-THE-ART

OBELICS model-based testing methods include the following procedures and features among others:

- new scalable models for electric machines in order to test inverters
- high-frequency technologies to test highly dynamic behavior of e-components
- simplified modification of FPGA-based model parameters during system-level testing
- new advanced test and simulation techniques and tools based on FPGA-based real-time HIL bench simulator
- battery test methods that combine mechanical and electrical testing

RESULTS

Inverter Testing
In the OBELICS project, novel control algorithms on FPGA-based platforms have been developed and optimized for operation in power HiL devices in order to be able to represent much higher dynamics and thus to allow a much more realistic emulation of real behavior, leading to a significant acceleration of the component and system test process. By using SiC power electronics, the losses of inverters can be drastically reduced, which subsequently allows power densities of up to 10 kW/dm3 to be represented. With increased signal bandwidths of up to 100 kHz, inverters can be realistically tested. The necessary electric motor models have also been successfully developed.

Battery Testing
Within OBELICS, an advanced method for accelerated testing under realistic battery operating loads with combined and properly tuned electro-mechanical-thermal loading has been developed. The accelerated test approach considers only damage-related contributions from combined loading scenarios, thereby significantly reducing test time.
The testing approach was supported by a battery attribute assessment method and corresponding metrics that are based on a descriptive battery model. This provides insight into the relationships between the battery attributes (which are targets in the development), the battery hardware at the component level, and also the software used to implement the battery subsystem functions.
Furthermore, OBELICS has developed battery test equipment using SiC power semiconductors that realistically represent (up to 20kHz) the ripple loads in the electrical drive train caused by the power inverter feedback to the battery.

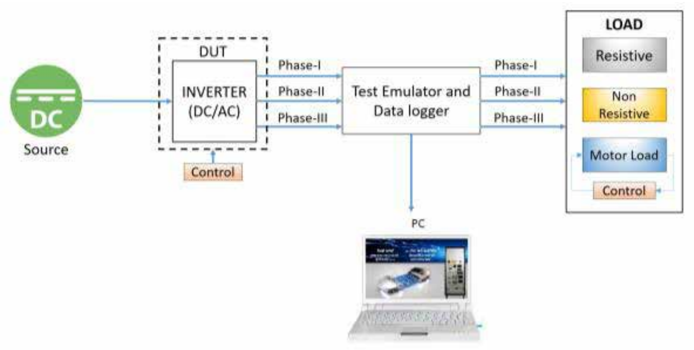

Fig. 9 provides the Power-HIL test setup for Inverter tests, with data logger

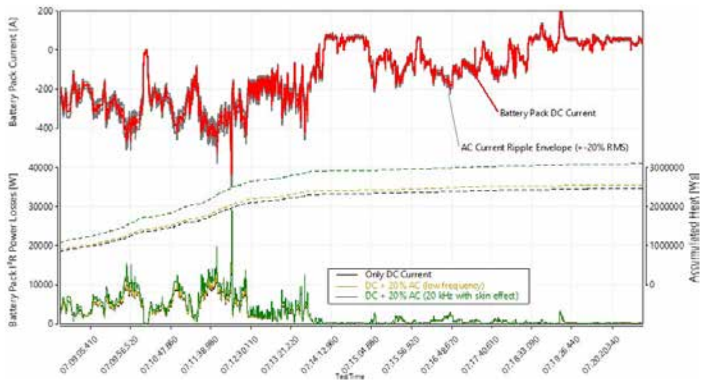

Fig. 10 depicts a realistic battery pack testing with 20kHz ripple, emulated according to realistic road measurement

SAFETY AND RELIABILITY

JÜRGEN NUFFER

By combined numerical and experimental means, a method for the evaluation of the functional safety and reliability of electrical powertrains was derived. These properties shall be evaluated already in the design phase with respect to the implementation. Furthermore, monitoring concepts for critical parameters that influence system safety, functional safety and reliability were derived. A further goal was the derivation of monitoring concepts for the most critical parameters that influence system safety, functional safety and reliability.

To reach these goals the following activities were executed:

- methodology for assessing safety, functional safety and reliability
- monitoring and diagnosis concepts for ensuring system safety, functional safety and reliability
- virtual and experimental assessment of unctional safety, reliability and safety of the OBELICS drive train
- recommendations (guidelines)

NOVELTY BEYOND STATE-OF-THE-ART

- Set up of a probabilistic Failure Modes and Effects Analysis (FMEA) which allows to quantitatively calculate resulting system failure probabilities from given (sub-)component failure probabilities (necessary to prove the safety improvement)
- Evaluation of the impact of SoC and temperature on mechanical safety and reliability of the battery
- Combination of experimental and virtual methods to evaluate the safety and reliability of power train components like, battery, inverter, e-machine, Battery Management System (BMS) Software, Braking system along several length scales
- New insights in failure mechanisms on lowest system levels (e.g. Battery cell and electrodes chemistry)
- Novel monitoring strategies for batteries based on innovative on-board impedance spectroscopy techniques were developed

RESULTS

New insights in failure mechanisms on lowest system levels (e.g. Battery cell and electrodes chemistry)

A new modelling framework was developed within the OBELICS project which enables fully coupled simulations ranging from the vehicle level, cooling system to the intercell phenomena. Developed modelling framework therefore:

- features unprecedented design capability by coupling between electrochemical, thermal and degradation
- models in temporally and spatially resolved manner
- allows for modelling deviations in the manufacturing processes
- enables development of reduced models with comparable accuracy
- enables support for Battery Management System (BMS), a key element in the EV, by simulating multitude of battery cell models in different current load scenarios and temperature conditions
- forms a basis for advanced observer models

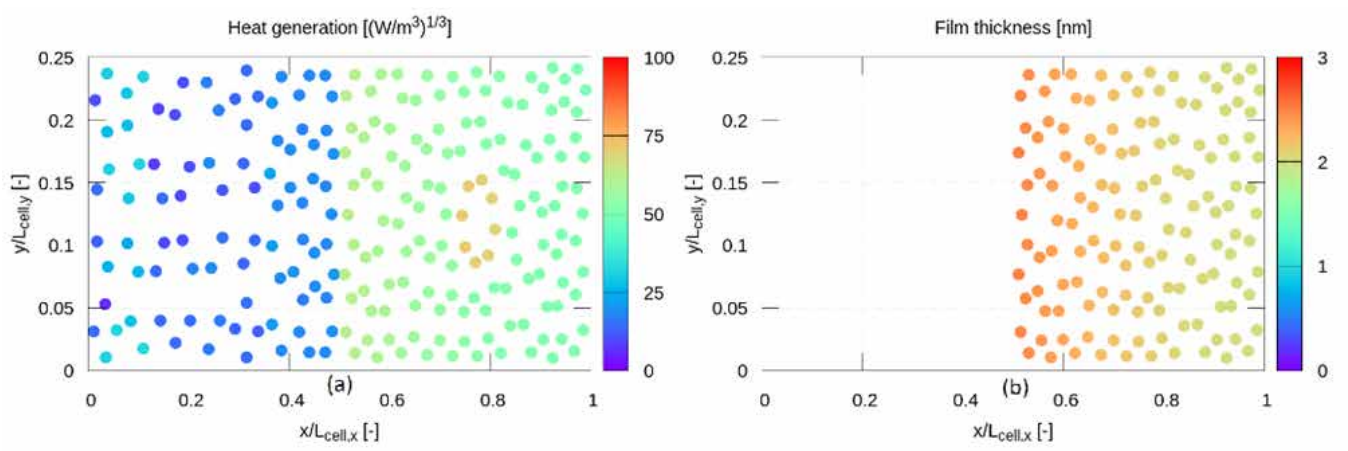

Fig. 11 provides a snapshot of the heat generation (left) and film thickness (right) on a 2D discretised domain with a decreased local porosity in the middle of the anode during battery cycling with a ±2C rate

Set up of a probabilistic Failure Modes and Effects Analysis (FMEA) allowing to quantitatively calculate resulting system failure probabilities from given (sub-)component failure probabilities (necessary to prove the safety improvement)

Based on the output results of the proposed modelling framework described in the previous section, a unique methodology was developed to transfer simulation as well as experimental results from deterministic domain to the probabilistic domain through the probFMEA.

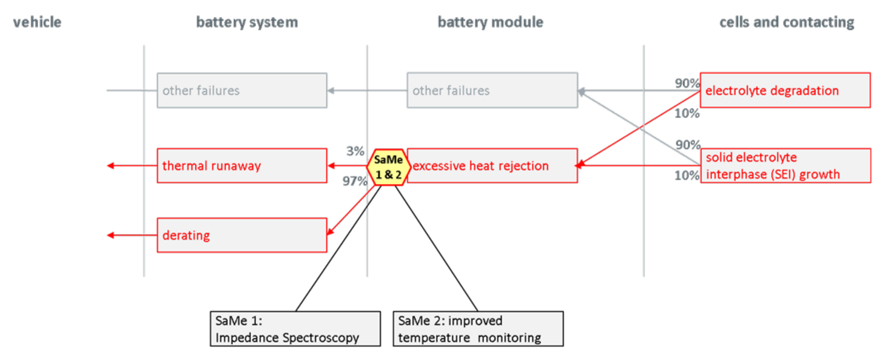

Fig. 12 shows a simplified causal relation as exemplary demonstration of the logics represented in the probFMEA Bayesian network

It was shown, that the probabilistic FMEA used throughout the development cycle for a safety/reliability – oriented development contains several benefits compared to a classical approach:

- due to the fact that the benefits from a classical FMEA and FTA (Fault Tree Analysis) are combined, the development process will be more efficient and time-saving
- since the probFMEA makes use of quantitative input values and processes quantitative output values, these metrics can be used directly for safety assessment according to standards (e.g. ISO 26262)
- the probFMEA is in general more precise than a FTA calculation
- the probFMEA is able to provide failure probabilities on anyhierarchical intermediate system level. In case of an electrified power train, for instance, the subsystems "battery", "inverter" and "e-machine" can be analyzed separately by determining failure probabilities for each component. Also, their combination to a holistic system failure probability is possible
- since in OBELICS a special technique for tranferring (virtual) simulation results into failure probabilities and implementing these into the probFMEA and the V-cycle, a holistic chain of data flux from simulation into direct use in the V-cycle was established

SECOND LIFE BATTERY USAGE

MOHAMED EL BAGHDADI

VUB VRIJE UNIVERSITEIT BRUSSEL

Repurposing automotive Li-ion batteries for a second life after their retirement as energy storage systems in electric vehicles is an important research domain that requires more standardization. Characterizing battery parameters by system identification, and developing testing and monitoring procedures for documented first and second life use for tracking of the battery's aging evolution and health status were identified as key focus points. Optimized advanced battery test procedures and methods in line with existing international standards and potentially inspiring future standards were developed. The goal was to assess the reliability, energy content and viable commercial applications for battery systems considering environmental and economic cost. The main objectives of this research were:

- evaluation of existing international standards for Li-ion batteries in electric vehicles
- optimization of test procedures and promotion as standard practice in further research and development
- offering a database and tool for an integrated approach of second life battery usage considering technical, economical, safety and environmental factors

Battery test procedures have been demonstrated in OBELICS use cases.

NOVELTY BEYOND STATE-OF-THE-ART

- Thorough evaluation of international battery standards for design, performance and safety on cell and pack level and identification of optimization potential for high-frequency electric vehicle systems considered in OBELICS.
- Reliable and automated methods and procedures for parameter identification of battery models to be used with online state estimation (state of charge and health, remaining lifetime).
- Development of a methodology to link the second life battery to appropriate applications (e.g. as stationary storage system with photovoltaic installations) and definition of optimization target as joint economic and environmental indicator.
- Multidisciplinary approach assessment tool with 2nd life battery performance model, from battery testing up to full system simulation with aging and performance parameters, LCA, system control and economic indicators.

RESULTS

The thorough analysis of standards for Li-ion batteries and the market of 2nd life batteries, led to an integrated approach and more insights on how to deal with these batteries before and during their primary use as electric vehicle power source and how to test, characterize and monitor the key parameters of these systems. After disposal from the vehicle, their usefulness and viability for second life applications has been illustrated for stationary power applications in telecom and railway industries for example. Along with economic cost, environmental cost was considered too in defining credit value of second life batteries.

- Established test procedure to assess batteries at their begin of life and end of life and with check-up intervals during use expressed in cycle or calendar time.
- Formulation of estimation and parameter identification techniques and online methods for battery state monitoring.
- Test and performance parameters of Li-ion batteries and their variability for second life use based on aged cell test results.
- Demonstration of second life battery case studies to show the economic and technical viability of Li-ion batteries in photovoltaic installations powering telecom stations or off-board energy storage for railway vehicles.
- A simulation tool linking the different LCA and LCC considerations with technical and physics system models, with which 2nd life battery performance is modeled and simulated in the new application comparing data with other suitable technologies (e.g. other type of batteries).
- With this analysis on optimized test procedures and 2nd life usage of Li-ion batteries, a contribution to standardization and reduced total cost of ownership of EVs is made, while allowing second life use in a safe, reliable and sustainable way.

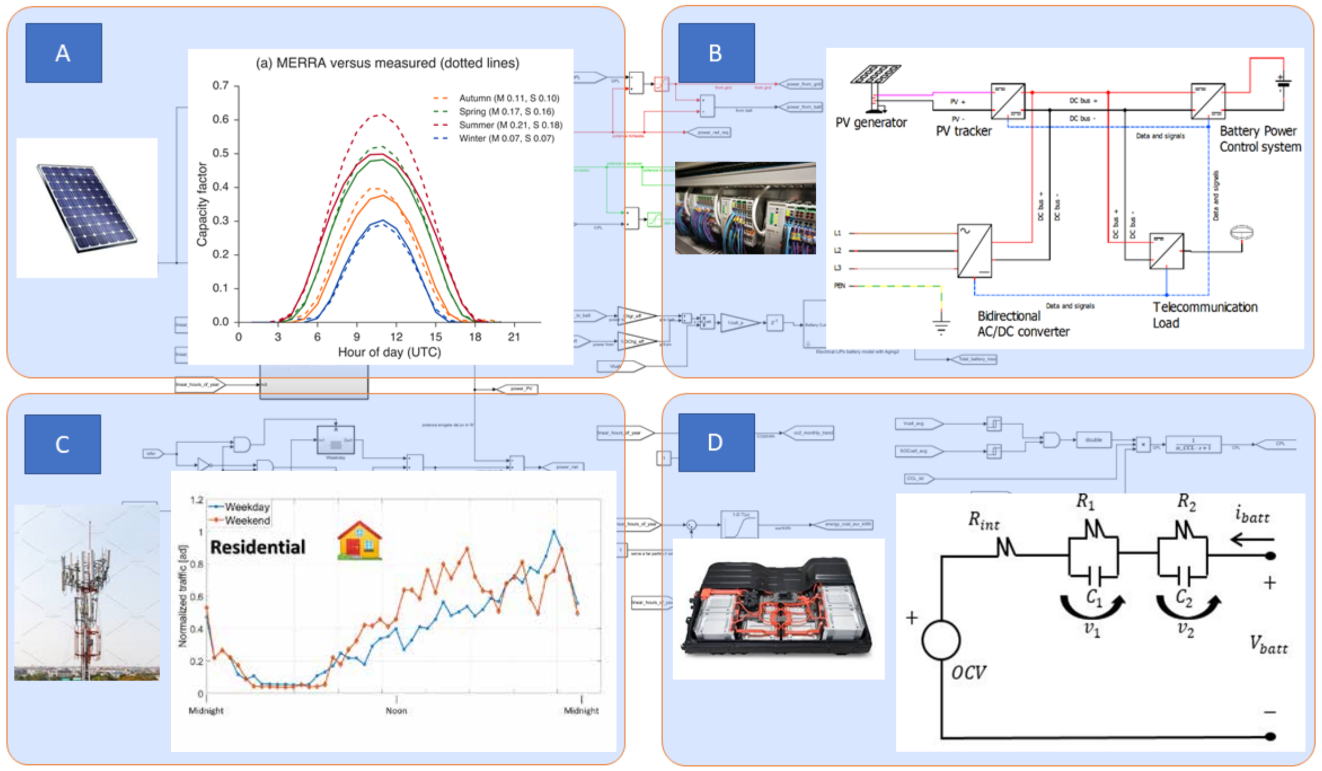

Fig. 13 shows a layout of integrated 2nd life usage model for telecom base station with PV-installation and stationary battery, incl.: A) PV generation unit; B) Energy management and conversion unit; C) Radio-base unit and energy consumption estimation; D) 2nd life automotive battery, including efficiency, SoC and SoH assessment

USE CASES

UCC 1

UCC 2

UCC 3

UCC 4

The project goals were demonstrated in seventeen use cases. These use cases have been grouped into four use case clusters (UCCs), overlapping with important engineering areas in the typical electrical vehicle development:

UCC1

New e-drive concept & component sizing using scalable models

UCC2

System integration, model-based testing and validation

UCC3

Battery design and testing for improved safety & reliability

UCC4

Design & testing of e-motor, control and inverter

UCC 1

NEW E-DRIVE CONCEPT & COMPONENT SIZING USING SCALABLE MODELS

HELLAL BENZAOUI

Today's lack of new investments and skills with regard to the fast-changing electrified automotive landscape and new market opportunities stresses the carmaker to deliver more efficient vehicle designs in shorter time with less costs, considering electric powertrain architectures from conventional vehicles with integration of available powertrain components (electric machine, battery, axle…). But on the other hand, this leads to non-optimized solutions regarding vehicle energy efficiency, at higher product cost.

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 in early concept phase.

Therefore, related activities at the beginning of the vehicle development process, where prototypes are not available are critical for efficient and cost-effective product development.

Additionally, the interaction between control and hardware makes it impossible to define a powertrain concept with both parts being optimal. In this context, alternative methodologies such as co-design need to be considered to target both hardware (topology, sizing) and control optimization in early concept stages.

With three industrial prospective 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 were explored to identify the right model-based design approach. Through these use cases, OBELICS investigated advanced design methodologies to support new electrical powertrain architecture exploration, system sizing and component design analysis and addressed the following design considerations:

- what are the most relevant electric powertrain architectures in relation to the target vehicle application and corresponding condition of operations?
- how can a quick and fair comparison be made for a robust concept selection earlier in the vehicle development process
- what is the right size of the component and the technology of the hardware to achieve higher efficiency on a vehicle level?
- how can a faster workflow and sizing process execution be reached in early phases to enable large design space explorations?

A common methodology was defined based on a systems engineering approach combined with scalable models, sizing, and virtual integration tool development aimed at faster workflow execution. Furthermore, a methodology for optimized powertrain sizing was developed, considering cost effective and more efficient EV design in the early phase of the vehicle development process as well as representative and real driving conditions, respectively.

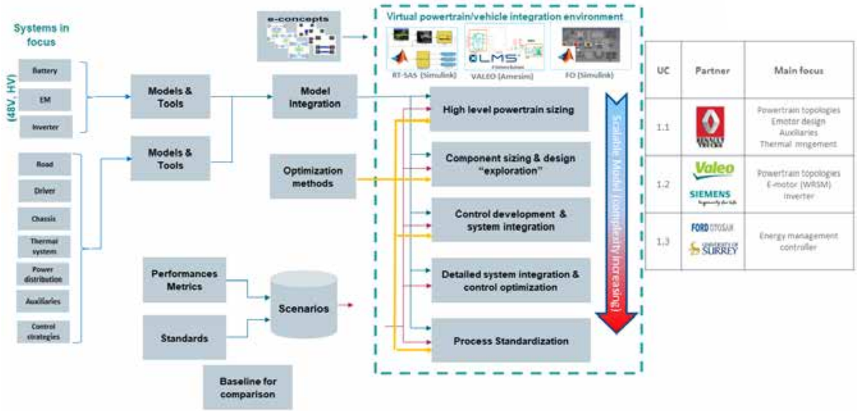

Fig. 14 provides an overview of UCC1 and the generic process and model integration workflow

OVERVIEW OF ALL USE CASES IN THE CLUSTER

UC 1.1 – RENAULT E-TRUCK MODEL-BASED DESIGN & SIMULATION

Evaluation of EV design concepts for next-generation electric powertrains of commercial vehicles in virtual environment with full vehicle simulation and detailed multiphysics models of E-components. Approaches such as defining the process for accelerated powertrain. Design execution including component design exploration and optimization. Generic and systematic methodology for evaluating the requirements of a complete powertrain. Exploration of electrical machine design and performance evaluation. Toolchain for complete powertrain system design optimization.

Partner: Renault Trucks SAS (RT-SAS)/Volvo Group, University Ljubljana (UL)

Targets: Efficiency improvement by 25%, and the reduction of development efforts by 35%.

UC 1.2 – VALEO IN-WHEEL 4-X E-POWERTRAIN CONCEPTS WITH 48V

Study of new electric vehicle architecture, with a 4-wheel drive concept (48V in-wheel e-motors) with superb energy consumption. Tests on bench evaluated the models (e-motor / inverter models / scalability). Impact factors and project objectives i.e. development time reduction and efficiency improvements were demonstrated on a few steps from optimization of the exiting 4WD AMESIM model (parametrization, fidelity) through co-simulation of the optimized 4WD AMESIM model with other models like brake blending controller, 4 e-machines model or EV thermal model. Each individual strategy brings from 10% up to 20% of energy consumption improvement. Time effort reduction was measured as CPU calculation time.

Partner: VALEO Equipements Electroniques Moteurs (VALEO), SIEMENS Industry Software SAS (SIE-SAS), University Florence (UNIFI)

Targets: Reduction of development efforts by 20% and design flexibility increase by 20%. Expected cost reduction by 15%.

UC 1.3 – FORD OTOSAN E-VEHICLE CONTROLLER DESIGN AND TESTING

Study of a rear-wheel and all-wheel-driven fully electric refuse truck models. The 18-tonne truck runs on the lithium polymer-based batteries and is designed for urban environments with short routes to cut down air pollution. The main aim is to increase the overall efficiency of the electrified truck and to establish reduction on development timeby systematic model-centric approach that harmonizes the proposed methods and tools for faster and flexible development of control software, and integration of the models of the vehicle sub-systems. To achieve this, a 7 step fast and robust conjoined design and control based powertrain optimisation strategy was developed. The method consists of: i) Drive Cycle Characterization, ii) Virtual Interface Model Generation, iii) Global Sensitivity Analysis, iv) Design Exploration, v) Intelligent Vehicle Component and Topology Assesment, vi) Hypercube based Powertrain Level Optimisation, and vii) Real-time Control Level Optimisation Tools.

Partner: FORD Otomotiv Sanayi Anonim sirketi (FO), University of SURREY (US)

Targets: Reduction of development and testing efforts by 15% and efficiency improvement up to 15.5%.

SOLUTIONS

Design Methodology

- Co-Simulation approach
- Automated deployment process
- Use of 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 at the start and during the development cycle (real electric driving cycles)

Standardization/compatibility

- Scalability / interoperability
- Multi-domain and multi-physical model, generic test platform and interface consistency as well as flexibility

XiL testing

- Reproducibility (transfer real test into test environments)
- Updating model parameters faster, using real measurements
- Efficient measurement of battery electrical parameters on battery cell level
- Frontloading the test effort testing scenarios

OBJECTIVES REACHED

Use-case Name	UC	Obj 1: Target 40% Reduction of dev. effort/time	Obj 2: Target 20% Efficiency Improvement	Obj 3: Target safety increase by Factor 10
Renault E-Truck model-based design & simulation	UC1.1	50,0%	9,0%	n/a
48V e-powertrain concepts for 4-wheel drive electric vehicle	UC1.2	64,4%	13,6%	n/a
Ford Otosan e-vehicle controller design and testing	UC1.3	62,2%	15,5%	n/a
Objectives per use-case cluster 1	**UCC1**	**58,9%**	**12,7%**	n/a

RENAULT E-TRUCK MODEL-BASED DESIGN & SIMULATION

HELLAL BENZAOUI, RAFAEL KLUPPEL SMIJTINK

Renault trucks (Volvo Group) contributes to UC1.1 with the development of tools and methods for evaluation and exploration of electric powertrain topologies for commercial vehicle development, focusing on scalable and modular powertrain concepts for a large product portfolio. Contribution of this UC to OBELICS objectives involves the reduction in development and testing time in the early phase of powertrain development, and increase of efficiency of the powertrain through better sizing and concept selection aligned with optimized controls.

IMPACT ON THE DEVELOPMENT PROCESS

In order to achieve objectives of the OBELICS project the following methodology and tools were developed:

The contribution to beyond the state-of-the-art can be summarized by the following items:

- scalable or generic models of powertrain components as well as high level virtual system integration tool enabling faster vehicle and powertrain modeling process execution for multiple powertrain layouts simulation and component variant integration studies
- integrated framework and flexible tool-chain for analyzing and solving a wide range of design optimization problems (powertrain topology, technology, component sizing and control)
- faster analysis and evaluation of alternative architectures for truck powertrain electrification and robust selection in early project phase according to vehicle mission (application)
- integrate multiple methodologies in a single sizing process, common interfaces between tools
- powertrain component based design parametrization and feasibility evaluation with multiple trade-off evaluation
- PMSM configurator tool enabling large design exploration by varying key design parameters (active length, diameter, ...); automatic generation of system models (including thermal model) for vehicle level performance simulations
- integration of control optimization in the sizing process and process automatization for multiple powertrain variants evaluation
- multi-domain performance models including thermal aspects
- systematic automatized framework for achieving an optimized design for a varied product portfolio

CONTRIBUTION TO OVERALL PROJECT TARGETS

The use case was evaluated with different vehicle architectures and models created in the project. This enabled a reduction of development time and increase of efficiency of the powertrain in all evaluated architectures.

CONTRIBUTION TO SPECIFIC OBJECTIVES

The specific objective in this use-case was the evaluation of different LD/HD applications by use of simulation methods. The vehicle and component models were integrated in a Volvo/Renault specific, Matlab-based simulation tool that was extended with models of OBELICS partners that support the standardized modelling interfaces. With this approach a very fast and accurate simulation of vehicle architectures in different test cycles was enabled and performed in the project.

RESULTS & EVALUATION

The complete powertrain sizing toolchain successfully reduced development time in early project phases. This reduction comes from the scalability of the models, modularity of tools with common interfaces and optimization techniques that are highly automated. Additionally, this methodology can be used over a wise product and application range.
For an EV powertrain to be efficient and robust, proper management and selection on the powertrain components are critical (electric machine, transmission systems …). With the automatized optimization tool, we are able to assess different component design variants and requirements and not only design better powertrains, but also reduce the development time.

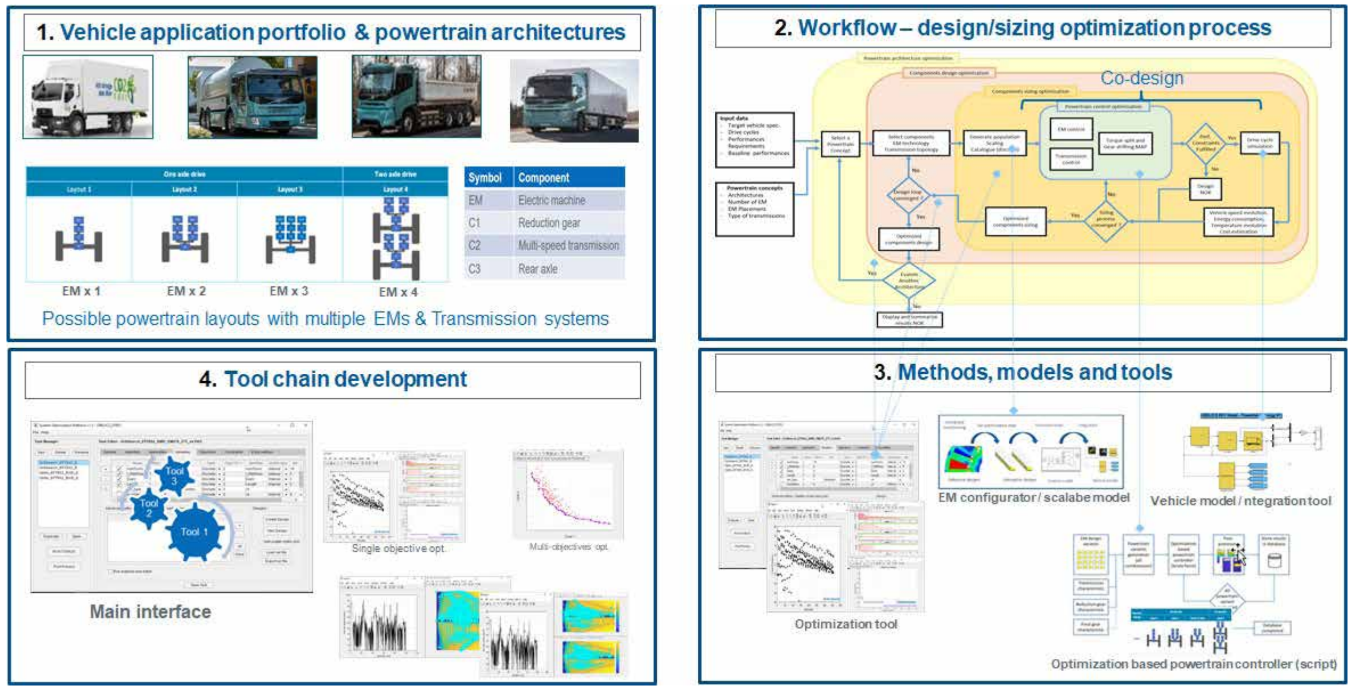

Fig. 15 shows the proposed design process and tool chain for new e-drive concepts analysis and sizing optimization in early phase

48V E-POWERTRAIN CONCEPTS FOR 4 WHEEL DRIVE ELECTRIC VEHICLE

KAZUSA YAMAMOTO, FRANCK SELLIER

Valeo SIEMENS

According to new mobility trends, a concept for a 4-wheel drive electric vehicle running on 48V was developed. The goal of UC1.2 was to design and test this vehicle in a completely virtual environment using a co-simulation of Simcenter Amesim and Matlab. The virtual design is based on data from a real e-machine and is used to determine how the vehicle will perform in an urban environment (i.e. city and highway driving).

IMPACT ON THE DEVELOPMENT PROCESS

Using the co-simulation, the following was developed:

- the optimal size of the key components is determined, based on the e-machine efficiency map and on common vehicle parameters, taking into account urban driving patterns
- the vehicle performance is improved (better acceleration time, battery autonomy) using an optimization tool like HEEDS. The vehicle parameters are updated (gear ratio, vehicle weight, battery pack) in an automated iteration considering several performance tests at the same time (Worldwide harmonized Light vehicles Test Procedure (WLTC), speed, gradeability)
- the thermal system is integrated and the vehicle was tested virtually in a real life scenario (road slope, driving behavior) to get close to real driving conditions
- an advanced control strategy was used to minimise the energy consumption on board: brake blending strategy, control of the e-machine (differentiate rear/front torque request) and auxiliaries (air conditioning, heater)

CONTRIBUTION TO OVERALL PROJECT TARGETS

The developments were a success. A first sizing was done using a baseline 48V Amesim VCU (Vehicle Control Unit) same torque request at each e-motor. According to vehicle strategy enhancement (such as brake blending or optimized e-machine control), the result shows that the EV efficiency improvement reached 17%, depending on the specific drive cycle (JC08 or WLTC). However, in a real road test (RDE) and considering thermal system thus extra consumptions (such as air conditioning system for driving comfort) the improvement is 4.5-8.8%.

The tests show that the simulation platform can perform fast tests regardless of the model complexity. Simulating a WLTC (that in real life takes 1800s) takes 0.6s in a basic test, and 369s in a co-simulation.

CONTRIBUTION TO SPECIFIC OBJECTIVES

The new approach allows for more design flexibility. A common set of Amesim submodels (e.g. driver, vehicle, transmission, e-motors and batteries) can be used to test different EV architectures (e.g. 2 axles drive versus 4 wheel drive). This allows the engineers to quickly test the designs in various driving conditions.

Cost reduction – 48V EV concept average energy consumptions on WLTC with auxiliaries system 12.86 kWh/100km.

RESULTS & EVALUATION

Main simulation results to assess vehicle performance are the evolution of the battery SoC, the average energy consumption and the effective vehicle speed, additional real behavior obtained are auxiliaries current consumptions or evolution of cabin temperature.

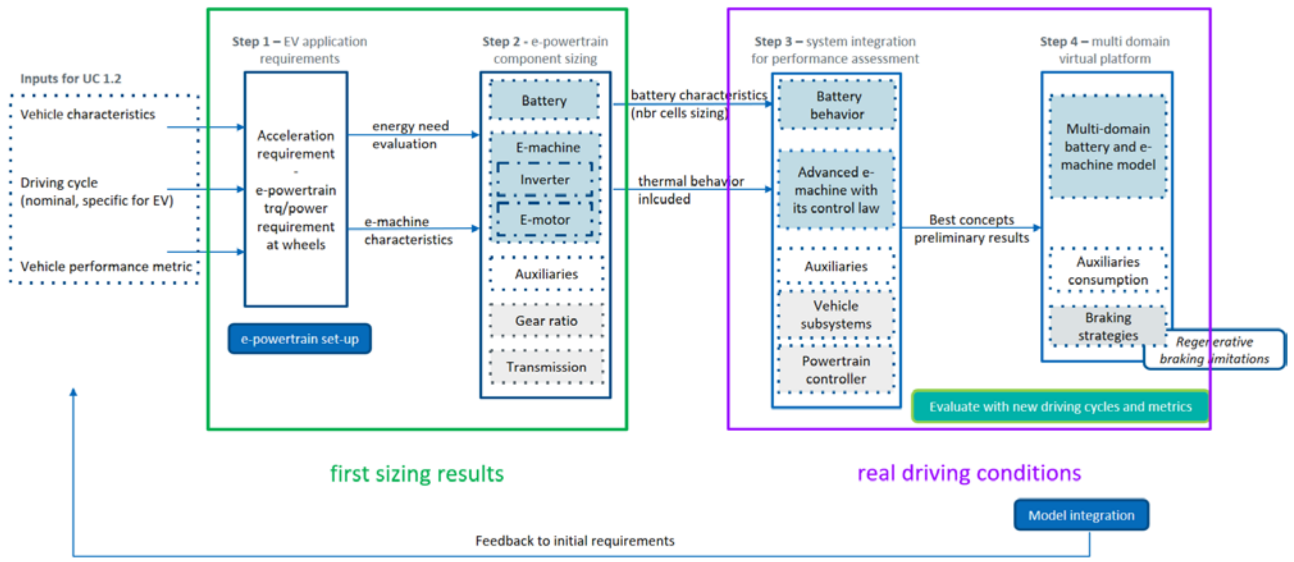

Fig. 16 shows the proposed methodology for 48V EV concept study

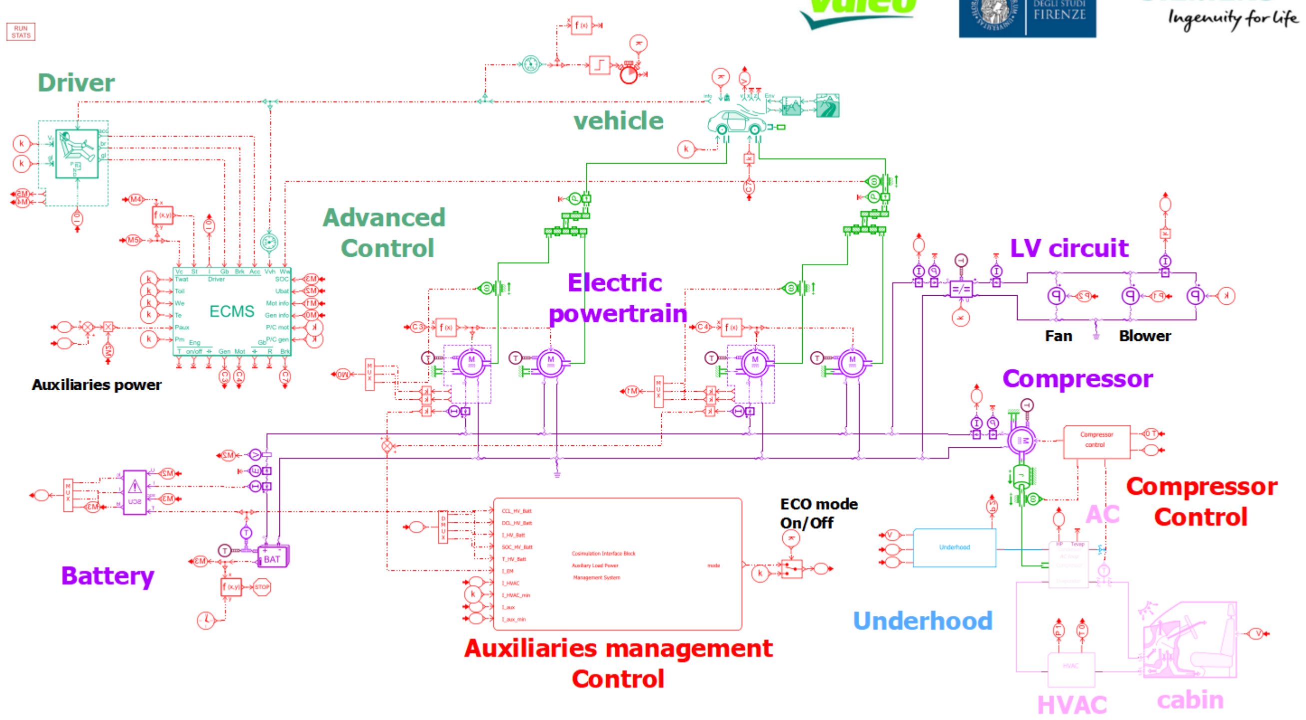

Fig.17 provides the 48V EV model optimized for real driving conditions

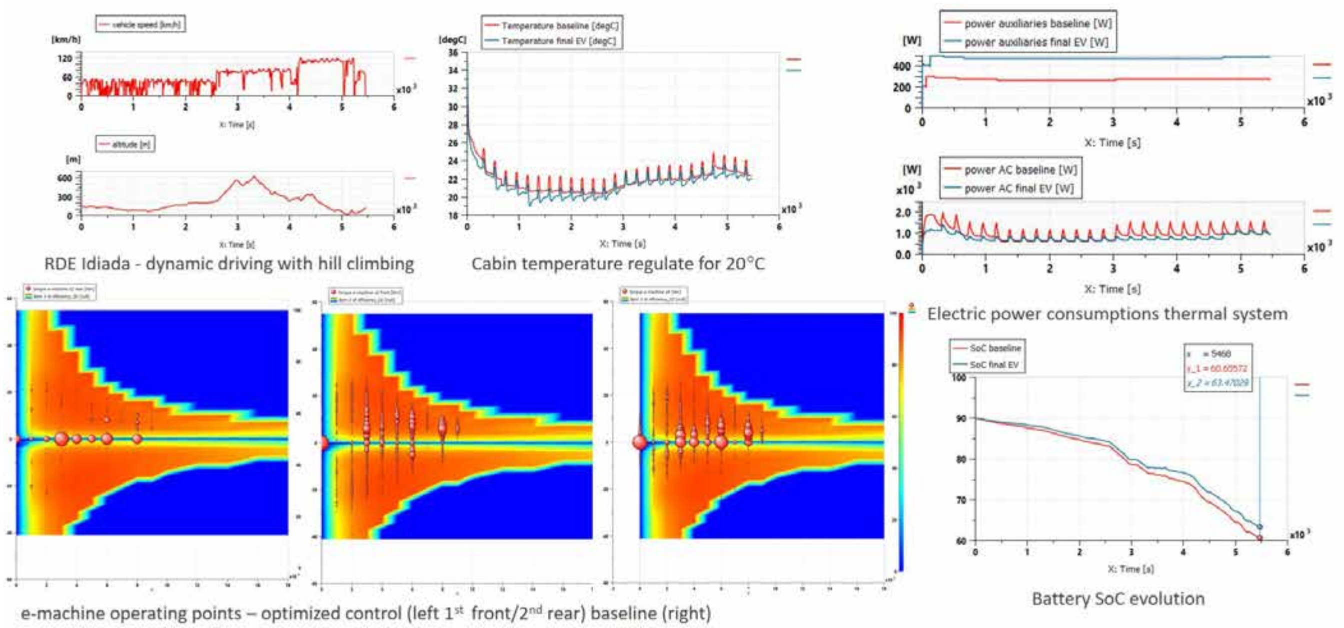

Fig. 18 shows the comparison of thermal baseline with final EV design - RDE Idiada @35°C

PERFORMANCE & EFFICIENCY OPTIMIZATION OF ELECTRIC VEHICLE BY OPTIMIZED VEHICLE CONTROLLER

CANER HARMAN, AHU ECE HARTAVI KARCI

FORD OTOSAN UNIVERSITY OF SURREY

Ford Otosan is developing a rear wheel and all wheel driven heavy duty electric truck. In this use case control models were developed to size powertrain components and make the design as efficient as possible. New tools were developed to build control software faster and in a more flexible way, and integrate sub-system models. In addition, one-pedal driving was investigated to assess how it affects the overall vehicle efficiency.

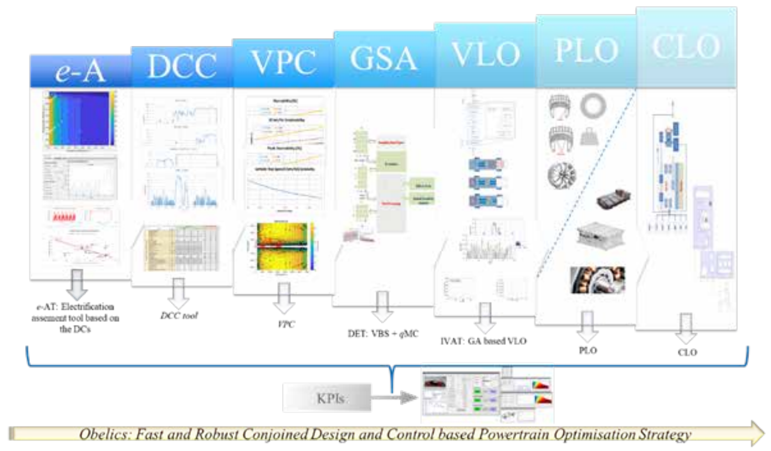

Fig. 19 shows the 7 step methodology developed for fast and robust conjoined design and control-based powertrain optimization strategy

IMPACT ON THE DEVELOPMENT PROCESS

In order to achieve OBELICS objectives following methods and tools were developed:

- a virtual tool for cycle characterization
- an automatic interface model generation tool to eliminate the time-consuming and error-prone steps of manual integration
- a virtual tool for torque and power requirement calculation and sensitivity analysis
- a tool that gives a quick estimation of the expected fuel economy based on the pre-defined constraints are developed
- required capabilities of all vehicle sub-system for embedded control software development phase were identified
- intelligent vehicle component and topology assessment tool was developed to reduce the development time while improving the overall efficiency at vehicle level
- optimum battery sizing using multi-objective hypercube optimisation
- real-time implementable adaptive optimum control algorithms were developed both for rear wheel and all-wheel drive vehicle
- an automatic code generation was also utilized to eliminate the time-consuming and error-prone process of real-time code implementation.

CONTRIBUTION TO OVERALL PROJECT TARGETS

The tools developed in the scope of the use case have contributed directly to two main targets of the OBELICS project which are: i) efficiency improvement up to 15.5% ii) reduction in development time by 15%. This is due to the fact that a fast and robust conjoined design and control based powertrain optimisation strategy was followed; which is built on 7 toolsets. Furthermore, with the use of automatic code generation feature error prone steps are eliminated.

CONTRIBUTION TO SPECIFIC OBJECTIVES

An analytical environment for model integration achieved and standard interfaces were defined for models for easier integration. The parametric tools were developed to support the product development process of the electric refuse truck by evaluating and iterating design options. Furthermore, with the developed real-time control algorithms, efficiency is improved. The parametric feature enables the toolset to be used for different vehicle architectures.

RESULTS & EVALUATION

Heavy duty electric truck powertrain sizing under real world operation was completed under the scope of UC1.3 based on the methodology proposed in the figure below.

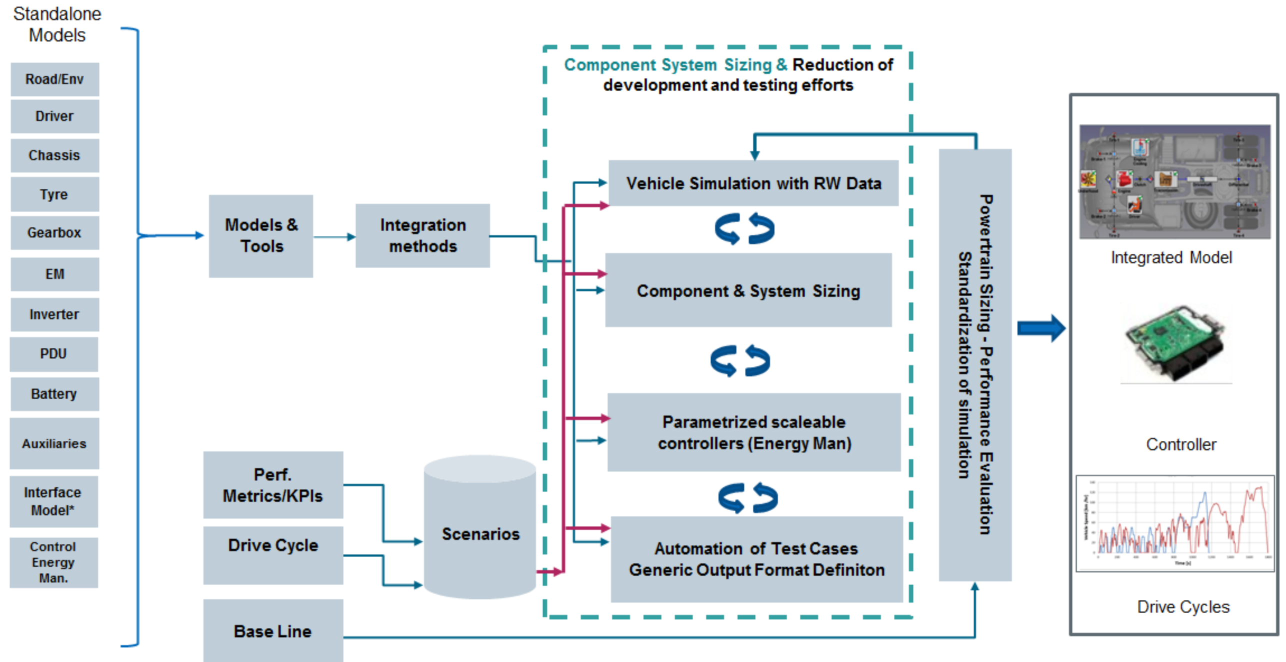

Fig. 20 shows the proposed methodology for analytical development

Real world data collection and characterization of cycle data was performed. 2nd order equivalent circuit based battery model was developed and correlated against tested data for accurate voltage and current therefore thermal behavior. Similar to the battery model electric motor and entire vehicle model was generated and these models were correlated against collected vehicle data for transient operation. Models were integrated with the help of a model integration tool.

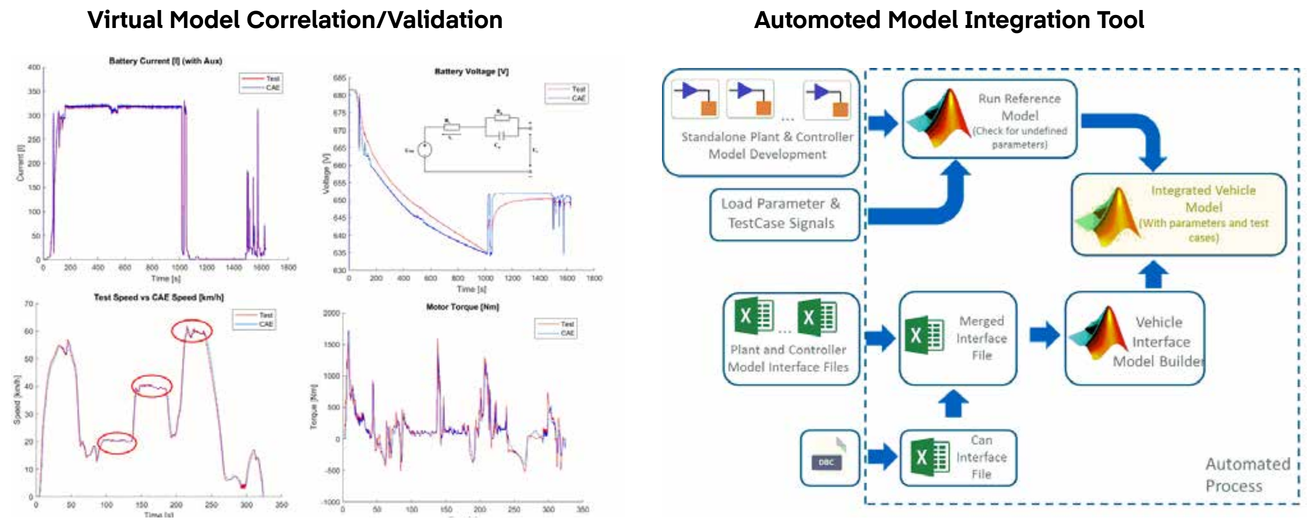

Fig. 21 shows the integrated model correlation status (left) and the automated model integration approach (right)

At last, various selected duty cycles, vehicle masses, e-motor, FDR, tyre, etc. were fed into the model to estimate the effect on real world performance. Apart from the analytical work, powertrain specification and evaluation of powertrains in future was also performed and reported.

The table below shows the calculated time reduction and efficiency improvement over baselines:

Tool/Method	Time Improvement			Efficiency Contribution		
	TC [s]	R [s]	C2TR [%]	EC [%]	R [%]	C2ECR [%]
Interface Model Generation	15 min	45 min	67%	NA	NA	NA
Control Strategy Improvement	NA	NA	NA	92.5%	100%	7.5%

TC: Time Consumed
EC: Energy Consumed
C2TR: Contribution to Time Reduction
C2ECR: Contribution to Energy Consumption Reduction
R: Reference

The contribution of the tools for performing optimization at different levels starting from vehicle level up to control level is summarized in the below table:

UC1.3 OBELICS TOOLS	Tool	Topology	DC	Time Improvement			Efficiency Contribution		
				TC [h:m]	R* [m/h/d/w]	C2TR [%]	EC [kWh]	R [kWh]	C2ECR [%]
	VLO	RWD	ESK	~6:00	~weeks	>70	108.08	110.1	1.83
		$AWD_{50:50}$	ESK	~6:00	~weeks	>70	94.84	97.04	3
		RWD	NREL	~2:00	~weeks	>70	11.68	11.74	4.88
		$AWD_{50:50}$	NREL	~2:00	~weeks	>70	16.71	17.1	2.28
	PLO	RWD	ESK	~4:30	~days	>50	78.04	80.11	2.65
		RWD	NREL	~2:30	~days	>50	19.09	20.46	4.34
	CLO – I	RWD	ESK	~2:30	~days	>50	51.87	53.72**	3.57
		RWD	NREL	~1.15	~days	>50	12.22	12.38**	1.3
	CLO – II	$AWD_{30:70}$	ESK	–	–	–	42.37	44.12***	3.99
			NREL	–	–	–	7.06	7.282***	3.11

*The time reduction is made wrt traditional techniques (experience/calculation based).
**Energy consumption reduction is made wrt fixed parameter controller.
***Energy consumption reduction comparison wrt single motor architecture.

SYSTEM INTEGRATION, MODEL-BASED TESTING AND VALIDATION

DAVID JORDAN DELICHRISTOV

virtual vehicle

For the development of future, optimal pure e-vehicles, it is very important to identify the right strategic, decisive factors, such as which platform and
which system architecture will be used, or which system voltage 400 [V] or 800 [V] is optimal for this kind of e-vehicle. These decisions are subsequently important for the expected development-, test- and production-times and costs. This means that the early concept phase of e-vehicle development, when prototypes are not yet available, is crucial for efficient and cost-effective product development.
The model-based simulation and development of the virtual prototype is nowadays mostly based on the integration of the scalable models of system components with different fidelities. A large part of the development time is required for the verification and validation of the multi-domain and multi-physics models with different fidelities. Modern techniques like co-simulation help to reduce effort and get a good simulation result.
Model based development and testing, and optimization including real world verification is a very important part, not only for component development. Activities such as creating and planning test cases, but also setting up these test cases in different test environments take a huge amount of time and money. To minimize or even avoid these aspects, different approaches and methodologies were used in the OBELICS project and verified in different use-cases as described below and applied with very good results.

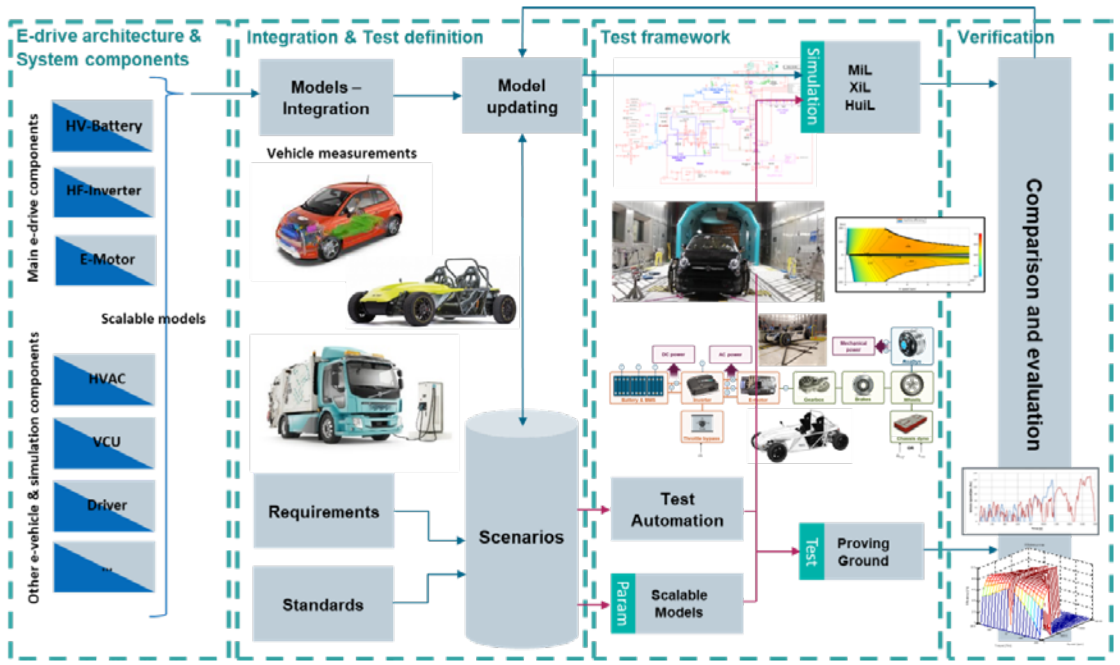

Fig. 22 shows the overall view of the model integration framework and process workflow which was adapted to specific use cases

OVERVIEW OF ALL USE CASES IN THE CLUSTER

UC2.1 – FIAT 500E REFERENCE MODEL PARAMETER IDENTIFICATION USING TEST DATA

Development of the testing procedures that allow the identification of e-powertrain models based on experimental data collected directly on the vehicle, due to the lack of electric component datasheet. Identifying parameters to feed the electric powertrain models to be used in the target setting development phase. Target vehicle was an existing FIAT 500e for proving ground measurements which generated data for parametrization of the main e-drive components. Postprocessing techniques were used to generate accurate measurement data as much as possible.

Partner: Centro Richerche Fiat SCpA (CRF), Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA)

Targets: Reduction of testing efforts by 40%.

UC2.2 – E-POWERTRAIN MODEL-BASED CALIBRATION AND VALIDATION

This use case focused on the advanced testing of E-powertrains in different validation environments. It investigated methods combining physical components and simulation models in a consistent framework to enable the front loading of system validation.. This results in optimal design of future EVs in shorter timeframes and at lower costs. The SimRod has been selected as the System-under-Test (SuT) for this use case, as it represents a good state-of-the art electrical vehicle. Several simulation models were created and validated using novel identification methods. Additionally, an E-powertrain-in-the-loop setup was designed from scratch and validated using on-road measurements.

Partner: SIEMENS Industry Software NV (SIE-NV), SIEMENS Industry Software SAS (SIE-SAS), University of Florence (UNIFI) and Vrije Universiteit Brussel (VUB)

Targets: Reduce testing effort by 40%.

UC2.3 – MODEL INTEGRATION METHODS AND PLATFORM

This Use Case includes the usage of co-simulation for efficient integration of multi-domain subsystems for the entire system simulation and variant management over the entire development process (MiL, SiL, HiL, XiL). The methodology on how to improve development and testing time effort was demonstrated on a FIAT 500e in cooperation with UC2.1 (reference model) and UC2.5 (virtual vehicle prototype). The presented output is model-based development from a generic model (low fidelity) to RT-capable validated model in very short time to reduce effort from days to hours. Solutions like interface transferability (150% interface definition), consistent co-simulation toolchain like ModelCONNECT and TestbedCONNECT or FMU/FMI standard.

Partner: VIRTUAL VEHICLE Research GmbH (ViF), SIEMENS Industry Software SAS (SIE-SAS), Centro Richerche Fiat SCpA (CRF), University Ljubljana (UL), FH JOANNEUM Gesellschaft M.B.H. (FHJ), University Florence (UNIFI)

Targets: The co-simulation approach will support the reduction of testing effort by 40%.

UC2.4 – E-TRUCK VEHICLE THERMAL MANAGEMENT SYSTEMS OPTIMIZATION & VERIFICATION

This use case deals with eTruck performance improvement (trade-off process) and development effort reduction for thermal management regarding design, control, calibration, and validation. Used methods enable optimization in terms of cost & weight (topology selection, component sizing...) and in terms of efficiency (control strategy for minimum energy consumption / maximum performances). Within this use case a more accurate and representative thermal model was developed in the GT Suite software. A MILP (Mixed Integer Linear Programming) approach, enabled the optimization of the time to assess cooling capacity needs which reduce effort from several months to approximately 10 days. Efficiency improvement in case of battery heating occurrence is measured up to 20%.

Partner: Renault Trucks SAS (RT-SAS)/Volvo Group

Targets: The envisaged e-drive efficiency improvement is 30% and the testing effort reduction is 25%.

UC2.5 – FIAT 500E MODEL-BASED SYSTEM OPTIMIZATION AND MODEL-BASED TESTING

This use case focused on the creation of a virtual vehicle model platform, which can evaluate and optimize the electric powertrain energetic behavior in standard driving cycles and in real condition. A virtual simulation reproduces the reference vehicle FIAT 500e in terms of mission, environment conditions and use of auxiliary systems. A vehicle model was created in Simcenter Amesim software and a particular focus was put on thermal management, which was modelled through a smart coupling between 1D & 3D models. A virtual vehicle prototype of FIAT 500e was optimized to improve efficiency. The vehicle improvements are: two gears ratio transmission insertion, regenerative braking improvement, ECO-Mode intervention with HVAC limitation, e-motor & inverter efficiency improvement, controls optimization and heat pump insertion.

Partner: Centro Richerche Fiat SCpA (CRF), SIEMENS Industry Software SAS (SIE-SAS), VIRTUAL VEHICLE Research GmbH (ViF)

Targets: Vehicle efficiency improvement of 20% and testing effort reduction of 25%.

SOLUTIONS

Design Methodology

- Co-Simulation approach
- Automated deployment process
- Usage of 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 at the start and during the development cycle (real electric driving cycles)

Standardization/compatibility

- Scalability / interoperability
- Interface consistency (150% interface definition), transferability/consistency of models throughout the development stages (based on model scalability)
- Multi-domain and multi-physical model, generic test platform and interface consistency and flexibility

Virtual testing

- Virtual sensor
- Components testing in virtual environment

XiL testing

- Run faster RT models with FPGAs
- Reproducibility (transfer real test into test environments)
- Updating model parameters faster and use real measurements
- Efficient measurement of battery electrical parameters on battery cell level
- Frontloading the test effort testing scenariosFrontloading the test effort testing scenarios

OBJECTIVES REACHED

Use-case Name	UC	Obj 1: Target 40% Reduction of dev. effort/time	Obj 2: Target 20% Efficiency Improvement	Obj 3: Target safety increase by Factor 10
Electric Powertrain Model parameter identification using test data coming from Fiat 500e	UC2.1	46,0%	n/a	n/a
SIE-NV and SIE-SAS e-powertrain model-based calibration and validation	UC2.2	76,5%	n/a	n/a
VIF model integration methods and platform	UC2.3	37,0%	n/a	n/a
Renault E-Truck model-based system optimization & verification	UC2.4	50,0%	n/a	n/a
CRF 500e model-based system optimization and model-based testing	UC2.5	27,5%	20,5%	n/a
Objectives per use-case cluster 2	**UCC2**	**47,4%**	**20,5%**	n/a

ELECTRIC POWERTRAIN MODEL PARAMETER IDENTIFICATION USING TEST DATA OF FIAT 500E

ALFREDO PRIMON

CRF

In the frame of this UC testing procedures and parametrization methods were developed that allow the identification of e-powertrain models on the basis of experimental data collected directly on the vehicle.
The main benefit for OEMs is the parametrization at early vehicle development stages (mules building, benchmark analysis, competitors reverse engineering, etc) of the electrical traction components models, that can be used for updating and optimizing the efficiency and thermal simulations overcoming the issue related to the unavailability of this data at the very first stages of the development. In this way the overall time and effort spent for these kind of simulations could be reduced, avoiding the usual iterations needed when the data are incomplete and not sufficiently accurate.

IMPACT ON THE DEVELOPMENT PROCESS

The use of an enhanced modelling approach in order to optimize the testing procedures and parametrization methods that allow the identification of e-powertrain models on the basis of experimental data collected directly on the vehicle was demonstrated. Data filtering and selection of the electrical, thermal and mechanical values related to the electric traction components (battery, inverter and electric machine) was done subsequently.

Based on the available data and the sampling frequency the definition of the suitable components base for the electro-thermal model has been done keeping into account the maximum models fidelity that this methodology can achieve.

CONTRIBUTION TO OVERALL PROJECT TARGETS

The UC has contributed to the following OBELICS objective:

- effort reduction by 40% related to the characterization process of model parameters

CONTRIBUTION TO SPECIFIC OBJECTIVES

- E-component models for Fiat 500E (like in UC2.3) with interface definitions and implementations according to the proposed interface specification of OBELICS
- A new post-processing algorithm based on data acquisition done during track and roll bench testing was developed

RESULTS & EVALUATION

Within the use case a complete system model of the electric vehicle was generated and combined with models that were generated from test data on the proving ground. If a vehicle is already available, the combination of numerical models with other physical based models is a very good way to save time and effort for the creation of an overall efficiency map. The time and cost savings achieved in the use case are very high. The use-case objective of reducing the development time of the characterization process by 40% was fully achieved. In the use-case, the results were achieved by using 2500 km of driving (~40h of test time), which is very little compared to a conventional full characterization of a traction system (can typically take up to a month of development time).

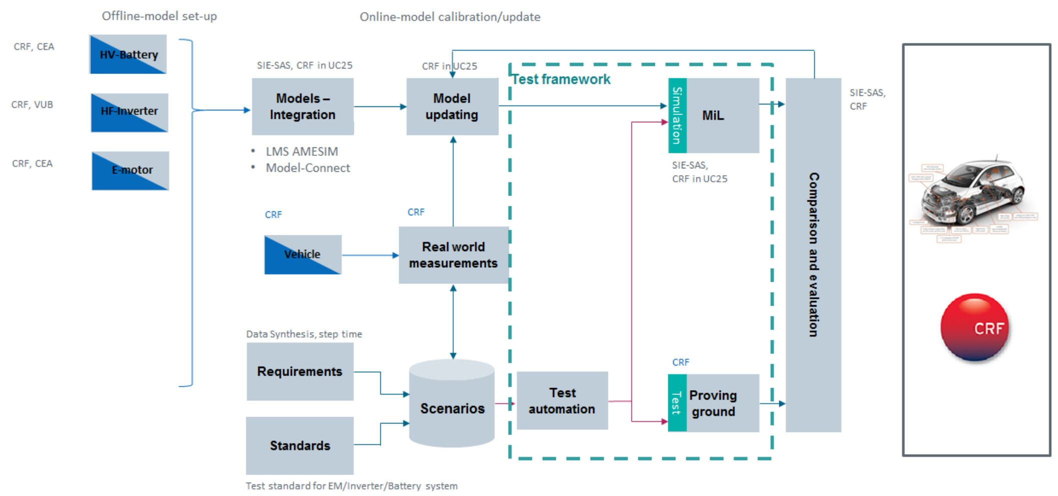

Fig. 23 shows the process of creating a full system model of the vehicle and combining it with real world data from proving ground tests

E-POWERTRAIN MODEL-BASED CALIBRATION AND VALIDATION

D'HONDT THOMAS, MOLLET YVES, FORRIER BART, SARRAZIN MATHIEU

SIEMENS

The ever-increasing complexity of e-powertrains, combined with stringent constraints on development time and cost, requires novel development and validation methods. A strong gain in system quality while saving validation effort can be achieved by frontloading the testing and validation to earlier steps in the design cycle. This is achieved through Model-Based System Testing (MBST), which combines both simulation models and physical components into a single and consistent validation framework.

IMPACT ON THE DEVELOPMENT PROCESS

In this use case, the MBST method was applied in two manners. Firstly, in-vehicle test data was used to identify and validate simulation models on a component and vehicle level. This enables engineers to always get access to accurate models to underpin design decisions. Secondly, real-time capable models were combined with a physical E-powertrain to form an X-in-the-Loop (XiL) setup. Hereby, a flexible validation environment is generated for frontloading testing. Both activities focus on increased fidelity and consistency, which is critical for making sound design decisions.

CONTRIBUTION TO OVERALL PROJECT TARGETS

The activities undertaken in the present use case have contributed directly to the OBELICS goals. Indeed, a reduction in development effort between 60% and 85% for specific identification and validation tasks was reached. This was mostly achieved by reducing the overall number of full-vehicle prototypes required for system validation. The automation and optimization of component testing also contributed to this goal. At the same time, an increase in overall vehicle efficiency by 0.85% was achieved through explorative testing on the XiL setup.

CONTRIBUTION TO SPECIFIC OBJECTIVES

Real-time scalable models are created and validated following new testing methods. They exploit vehicle-level data collected on the road or a chassis dynamometer to identify component-level variables. Subsequently, their integration with physical components, i.e. an E-powertrain, is achieved using real-time co-simulation. The resulting testing environment can be used to assess the energetic performance of an E-powertrain in a repeatable manner.

Fig. 24 shows the fully instrumented SimRod electric vehicle on a chassis dynamometer for component identification

RESULTS & EVALUATION

New models and the associated parameter identification methods are proposed. This includes a dynamic induction machine model, which accurately predicts the shaft output torque based on rotational speed and input voltages. Using the same chassis dynamometer dataset, a map-based inverter model and efficiency data on the powertrain can also be computed. Additionally, an accurate braking system model, including hydraulic, mechanical and thermal behavior is proposed. This multi-physical model can predict the dynamics of the braking plant during regenerative braking maneuvers. Finally, a battery model was created based on a fully automated identification toolchain.

Subsequently, those models were reused on the XiL E-powertrain test bench to supply accurate boundary conditions to the system-under-test. In combination with a real-time platform and proper actuators, the physical E-powertrain was interfaced with a virtual test vehicle. This enables the validation of the powertrain when the complete vehicle is not yet available. A reference driving cycle recorded in Leuven, for which full vehicle data is available, was used to validate the setup. Having checked the consistency of this test bench, the effect on system efficiency of new design improvements was successfully investigated.

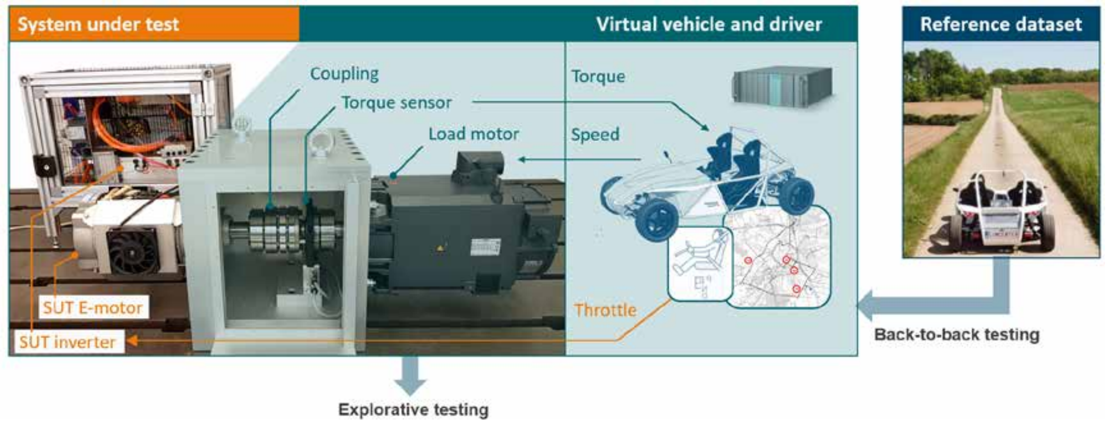

Fig. 25 shows that e-powertrain-in-the-loop test setup is quantitatively validated using on road data to enable explorative testing

VIF MODEL INTEGRATION METHODS AND PLATFORM

DAVID JORDAN DELICHRISTOV

virtual vehicle

One of the most discussed topics throughout the automotive industry, especially in the areas of engineering and development, is the time and associated costs involved. One of the main goals of the OBELICS project is to reduce the development and testing effort by 40%. As a specialist in the field of model-based co-simulation, Virtual Vehicle Research GmbH (ViF) supports OBELICS with unique technical solutions to reduce the test and development effort. The FIAT 500e as a conventional electric vehicle served as the base platform used to demonstrate the results and improvements. The main objective here was to create a FIAT 500e virtual vehicle platform using different scalable models, starting with the generic model (functional model) with parameterization based on the FIAT 500e reference model and ending with the RT-enabled optimized model with high fidelity, integrated new model approaches and optimized parameterization, in order to achieve another important OBELICS goal of increasing the efficiency of the e-drive train. The main partners were Centro Richerche Fiat SCpA (CRF) with the FIAT 500e base vehicle as reference model, SIEMENS Industrie Software SAS (SIE-SAS) with a vehicle model created in AMESIM and University of Ljubljana (UL) contributed with models of a HV battery and an E-machine. FH JOANNEUM Gesellschaft M.B.H. (FHJ) contributed their RF inverter with different fidelity and the University of Florence (UNIFI) contributed in the development of the energy management and the vehicle control unit.

IMPACT ON THE DEVELOPMENT PROCESS

The core of the use case methodology is the use of co-simulation for the efficient integration of the multi-domain capable and scalable subsystems of different software vendors like MATLAB-Simulink (The MathWorks, Inc.) or AMESim (Siemens PLM Software, Inc.) for the overall system simulation. The ViF used approaches and methods to achieve plausible and realistic simulation results in the development process in a very short time, from the very simple model (generic model) to the complex fidelity model with RT capability. We defined 150% of the interface were defined to be consistent and transferable throughout the development process. The co-simulation platform based on toolchain like Model.CONNECT™ and Testbed.CONNECT™ (AVL List GmbH) were used in our co-simulation. The Standard Functional Mock-up Interface (FMU/FMI) was used for an easy exchange of the components between different simulation platforms. The development environment fmi.LAB™ (AVL List GmbH) was used to create real-time applications and FMUs for various operating systems. ViF also defined a unique methodology for real-time capability analysis. This method uses a real-time factor to determine the optimal simulation time step for RT-capable subsystems and the optimal coupling time step for RT-capable co-simulation between them.

CONTRIBUTION TO OVERALL PROJECT TARGETS

- Development and testing effort reduction measured on platform FIAT 500e released November 2012 in USA
- E-powertrain efficiency improvement with use case 2.1 & 2.5 cooperation

CONTRIBUTION TO SPECIFIC OBJECTIVES

- Optimized model-based development process effort from generic model MiL to RT capable HiL simulation on the basis of the newly proposed methodology
- Co-simulation environment with focus on the main EV components like HV-Battery, HF-Inverter and E-Motor
- Proposed methodology enabled an easily virtually integrated proposed vehicle architecture for the new virtual vehicle prototype FIAT 500e
- Co-simulation enables easily and rapid prototyping verification and testing of the different system components as well as whole simulated system

RESULTS & EVALUATION

Defined methodology to help reduce the time effort for model-based development from generic model to RT-capable model.

- Creation of the system architecture for the prototype of the virtual vehicle FIAT 500e
- Definition of the 150% interface for the virtual vehicle prototype FIAT 500e. Ensure rapid prototype interoperability and compatibility during the development cycle
- Definition of the co-simulation platform Model.CONNECT™ and Testbed.CONNECT™, which guarantee the flexibility of component integration of different SW vendors during the entire development process
- Creation of the generic and reference model FIAT 500e as a basis for measuring the results achieved to increase efficiency. Cooperation with UC 2.1 & UC 2.5
- Creation of the new virtual vehicle prototype with high-fidelity RT-capable models such as E-machine and HF-inverter to improve the energy consumption of the vehicle for defined driving cycles
- Development of techniques such as brake blending controller, vehicle control unit, power management or coasting torque to improve vehicle efficiency
- Created a methodology using the RT factor to identify RT capable models and to optimize RT co-simulation settings such as simulation time step and coupling time step
- Development of a new interface between the simulation software AMESim and Testbed:CONNECT for RT applications using the fmi.LAB environment

Finally, the reduction in development and testing time effort achieved with the new approach is estimated to be around 25-30% and could be used for the FIAT 500e.

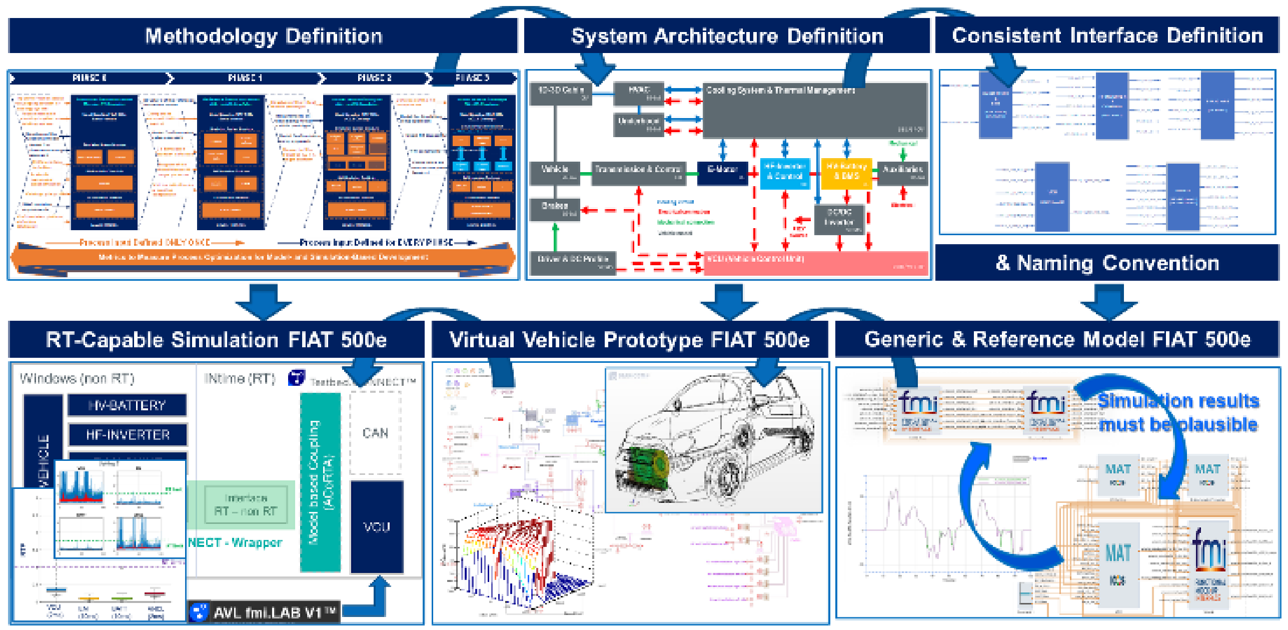

Fig. 26 provides an overview of the UC2.3 procedure

E-TRUCK VEHICLE THERMAL MANAGEMENT SYSTEMS OPTIMIZATION & VERIFICATION

RONAN MOTHIER

This use case is focused on methods and tools development to support Vehicle thermal management system development and optimization for battery electric vehicles. These methods and tools will be used in project early phase to support concept choice and component sizing as well as later during the development when it comes to control strategy definition. These methods bring new opportunities for system optimization in terms of cost & weight (topology selection, component sizing...) and in terms of efficiency (control strategy for minimum energy consumption / maximum performances...).

IMPACT ON THE DEVELOPMENT PROCESS

Complete vehicle use case consideration including detailed component thermal models brings a huge opportunity for new thermal system sizing, control and optimization. The result will be a downsized, more optimized (lighter, cheaper, and more efficient) system.
We developed more accurate and representative thermal models within this project, with a first focus on the most energy demanding components (Cab, Battery...). Some specific vehicle tests and measurement were performed within Obelics project to provide reliable data to these models. Thermal model were developed within GT Suite.
A MILP (Mixed Integer Linear Programming) problem was set and solved to find the most optimized cooling and heating capacity for meet performance and durability targets for each specific application. Results of this MILP problem is used to size the thermal management system.

CONTRIBUTION TO OVERALL PROJECT TARGETS

The results of this use case contribute to Obelics objectives by exploring and developing new technologies, which enable optimization activities. It is then now possible to find the needed cooling and heating capacity for vehicle thermal management system for each application or daily cycle.

- Effort Reduction: time to assess cooling capacity needs reduced from several months to approx. 10 days
- Efficiency Improvement: battery heating occurrence can be reduced up to 20%

RESULTS & EVALUATION

Models developed and tuned within Obelics thanks to specific test have gained a lot in accuracy, especially for the battery thermal model. For example, the gap between the model result and vehicle has been decrease to less than 0.5°C in any drive cycle circumstances, which is very good considering measurement accuracy.
Optimization model is featuring a battery degradation factor linked to temperature. This model can then balance performances, power consumption and battery lifetime expectancy depending on thermal management sizing.

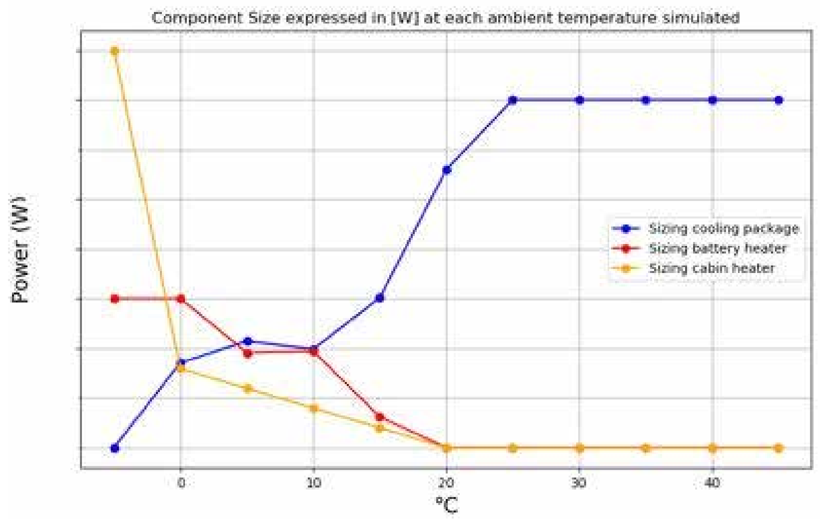

Fig. 27 shows the optimized cooling and heating capacity for a BEV for a target daily cycle, depending on ambient temperature

FIAT 500E MODEL-BASED SYSTEM OPTIMIZATION AND MODEL BASED TESTING

NICOLA TOBIA

The intention of UC2.5 was to demonstrate that the methodology developed within OBELICS, including an enhanced vehicle virtual model platform, can be applied to reproduce the vehicle behavior in a real driving condition in which all the vehicle systems and subsystems interact and contribute to the overall vehicle energy consumption.

From a modeling perspective, there is a need for further development of the current methodology, where accurate and realistic models with strong interaction between systems and boundary conditions are required.

IMPACT ON THE DEVELOPMENT PROCESS

First of all, main effort was taken to create a methodology that couples 1D software (Simcenter Amesim) and 3D software (Simcenter Star-CCM+), in order to obtain a very detailed model and very accurate results. This virtual simulation has been then validated on standard cycles (NEDC, WLTC) comparing with experimental testing on FCA climatic wind tunnel.

Finally, a vehicle optimization from energetic point of view was carried on, in order to find more efficient solutions.

CONTRIBUTION TO OVERALL PROJECT TARGETS

- A new virtual simulation methodology was implemented, that can integrate different tools together and therefore help vehicle development, reducing testing loops
- Efficiency of the Fiat 500e was improved by 20%. A real use of the vehicle has been considered, optimizing the electric powertrain and its interactions with the other vehicle systems

CONTRIBUTION TO SPECIFIC OBJECTIVES

The UC accomplished the following objectives:

- scalable Models for thermal systems (1D or 3D)
- environment for virtual integration: whole vehicle can be replicated in all its systems and subsystems detail

RESULTS & EVALUATION

This use case shows an innovative virtual methodology to couple 1D and 3D models, capable of simulating in detail several systems and subsystems of the vehicle with all their interactions.

Computation time of this simulation is still affordable with HPC and an impressive correlation with experimental results has been obtained.

Finally, it has been shown how this methodology can be used to optimize a vehicle from an energetic point of view, or to evaluate different solutions for several vehicle systems.

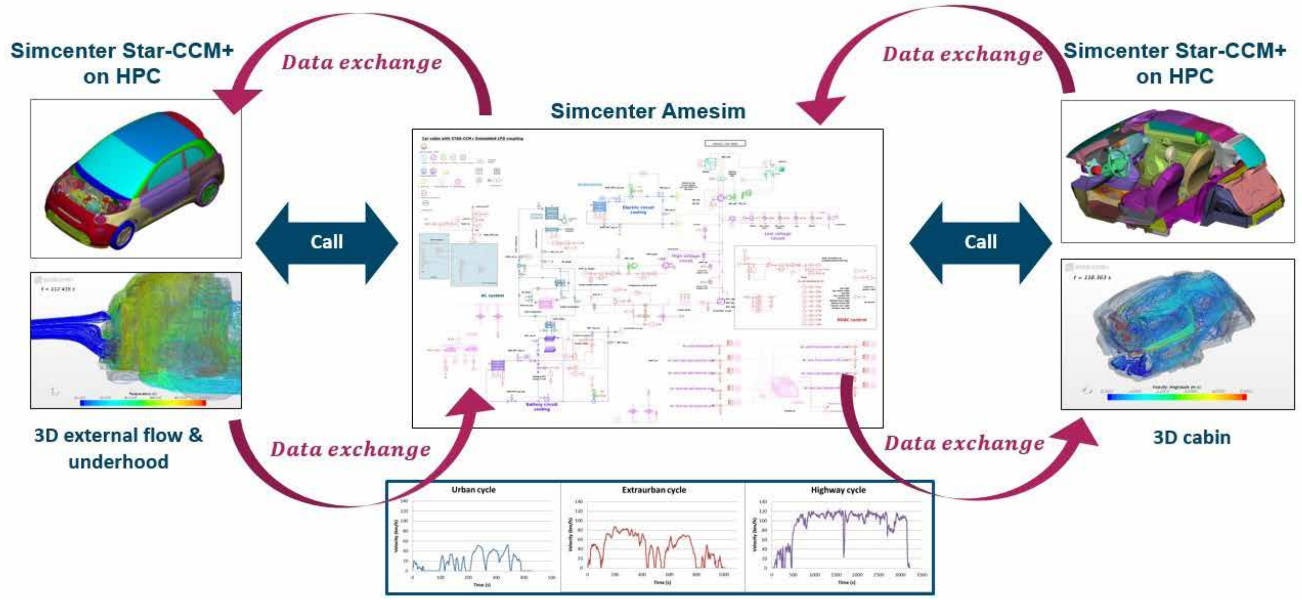

Fig. 28 depicts the proposed virtual simulation methodology

BATTERY DESIGN AND TESTING FOR IMPROVED SAFETY AND RELIABILITY

BENJAMIN ZILLMANN

BOSCH

UCC 3 considers the mechanical and electrical safety of HV battery systems. One major perspective is a reliable Battey Management Sytsem (BMS) which is able to monitor and control each cell of the battery system. The monitoring and controlling strategy is the baseline to guarantee a high functional ability and a long lifetime of the battery in terms of cell ageing. A high number of measurements on cell level are required to determine the BMS input parameter. Unfortunately, the parameters are not constant over the lifetime and therefore they need to be updated. Significant errors can occur if the parameters are not updated. The first UC was established by developing an online battery diagnosis method. Another limitation between lab battery testing and field applications is the sampling frequency which is currently limited to 12 kHz in the lab. Vehicle applications show frequencies up to 20 kHz caused by different effects of other drive train components. The effect of the high frequencies to the safety and reliability of the battery system is unclear and were therefore addressed in UC 3.2. UC 3.3 focused on the mechanical reliability of the battery system. The mechanical reliability is relevant for structural components, electrical tabs and various different joints. Comprehensive technical understanding and appropriate testing facilities are required to deal with the complexity of the battery system with respect to construction, load, functional and damage mechanisms. The most difficult requirement is the right assumption of loads (mechanical and electrical) for testing, to ensure a high reliability and safety in real world environment. In the framework of this UCC all functional and safety aspects, either electrical or mechanical was covered by a new Failure Mode and Effect Analysis (FMEA) which takes into account probabilistic information. UCC3 focused on the experimental work, consequently the model development is not a major topic.

OVERVIEW OF ALL USE CASES IN THE CLUSTER

UC3.1 – BATTERY SAFETY IMPROVEMENT AND TESTING

This use case investigated battery diagnosis methods to ensure safety and reliability of the battery system. This was achieved through accurate battery modelling and implementation of online cell impedance estimation and tracking in order to assess the battery safety status online.

Partner: CEA

Target: Decrease the effort dedicated to battery cell characterization in lab, and to increase the battery safety by an order of magnitude.

UC3.2 – 20KHZ BATTERY ASSESSMENT AND TESTING TECHNOLOGIES

UC 3.2. developed affordable high performance testing technologies for realistic battery testing with frequencies up to 20kHz.

Partner: AVL

Targets: The target was to achieve 40% reduction in battery testing effort.

UC3.3 – BATTERY MECHANICAL RELIABILITY TESTING

UC3.3 analyzed the impact of different operational modes to the mechanical reliability of the battery system

Partner: BOSCH

Targets: Reduction in development time and increase of safety.

UC3.4 – FORD OTOSAN COMMERCIAL VEHICLE DEMONSTRATOR

UC3.4 introduced a safer software development process with enhanced safety features

Partner: University of SURREY (US), FORD Otomotiv Sanayi Anonim sirketi (FO).

Targets: Improved safety by a factor of 10.

SOLUTIONS

- Generation of representative Nyquist of the impedance of a cell by using a reliable model calibrated on only a few points of characterization
- Integration of new FPGA board to the power stack
- Generation of higher switching frequency by using SiC MOSFETs
- Measurement of mechanical loads on battery system in the field
- Mechanical loading on battery system by using simplified vehicle model

OBJECTIVES REACHED

Use-case Name	UC	Obj 1: Target 40% Reduction of dev. effort/time	Obj 2: Target 20% Efficiency Improvement	Obj 3: Target safety increase by Factor 10
CEA Battery safety improvement and testing	UC3.1	n/a	n/a	Improvement factor: 20 Improvement: 95%
AVL 20kHz Battery assessment and testing technologies	UC3.2	44,8%	n/a	Improvement factor: 1.33 Improvement: 25%
Bosch Battery reliability testing (and safety improvement)	UC3.3	n/a	n/a	Improvement factor: 1.5 Improvement: 33%
Ford Otosan light commercial demonstrator	UC3.4	n/a	n/a	Improvement factor: 1.2 Improvement: 17,8%
Objectives per use-case cluster 3	**UCC3**	**44,8%**	n/a	**Improvement factor: 17** **Improvement: 94,1%**

BATTERY SAFETY IMPROVEMENT AND TESTING

MARCO RANIERI

The main objective of UC3.1 is to investigate the possibility of determining the state of a battery cell while it is used, in real time and with an embedded approach. This goes with the idea of opening the path to the integration of smart functions into a Li-ion cell, in the framework of the Smart Cell concept. The main purpose of this approach is to enhance the safety level of a battery cell, minimizing the impact on the battery pack complexity thanks to the development of an embedded microcontroller-based system.

IMPACT ON THE DEVELOPMENT PROCESS

The used technique is the Electrochemical Impedance Estimation, followed by the classification of the difference residuals obtained from an accurate cell model, developed for that specific cell.
In more simple words, a small electronic circuit, directly coupled with the Li-ion cell, was developed first. Its purpose is to activate the cell with a controlled current, below 400 mA and for a tenth of milliseconds, while acquiring the voltage level of the cell. Then the micro-controller calculates the impedance and sends the data out to the PC. At the same time, lab equipment does the same, in order to have a reference measurement. Bringing the cell to different States of Charge and Temperatures, made it possible to determine the accuracy of the electronic embedded system in various conditions. The result is satisfactory.
As a second step, a cell model (that means an equivalent circuit, with parameters) was developed. This is able to predict the impedance of the cell as output depending on the cell state parameters as input. The impedance result obtained from the model is accurate as long as the cell stays in a stable state.
Comparing the impedance result from the embedded system to the ones from the cell model can provide useful information about the safety level of the cell: if the results are similar, the cell is stable; otherwise, it means that some changes are happening and possibly dangerous states, as the thermal runaway, can appear. This comparison is performed by the classification of difference residuals from the two techniques.

CONTRIBUTION TO OVERALL PROJECT TARGETS

- Safety increase: the cell becomes safer, as thermal runaway can be predicted 95% of times of its possible occurrences
- Cell instrumentation: the embedded demonstrator and the enhanced cell model open the path to an integrated system performing real-time measurements and cell state estimation

CONTRIBUTION TO SPECIFIC OBJECTIVES

- Embedded electronic system for the cell EIS estimation, fully tested at different Temperature and State of Charge conditions on a Li-ion cell
- Enhanced Li-ion cell model development, which can provide a virtual impedance estimation compliant with the reality
- Procedure development to exploit the results obtained from the two techniques described here above

RESULTS & EVALUATION

From the embedded electronics, estimating the electrochemical impedance of the cell and exploiting it to deduce its temperature, the tested accuracy is of +/-2°C, whatever the State of Charge is.
Coupling the electronics and the model results, we estimate that the thermal runaway can be predicted 95% of times.

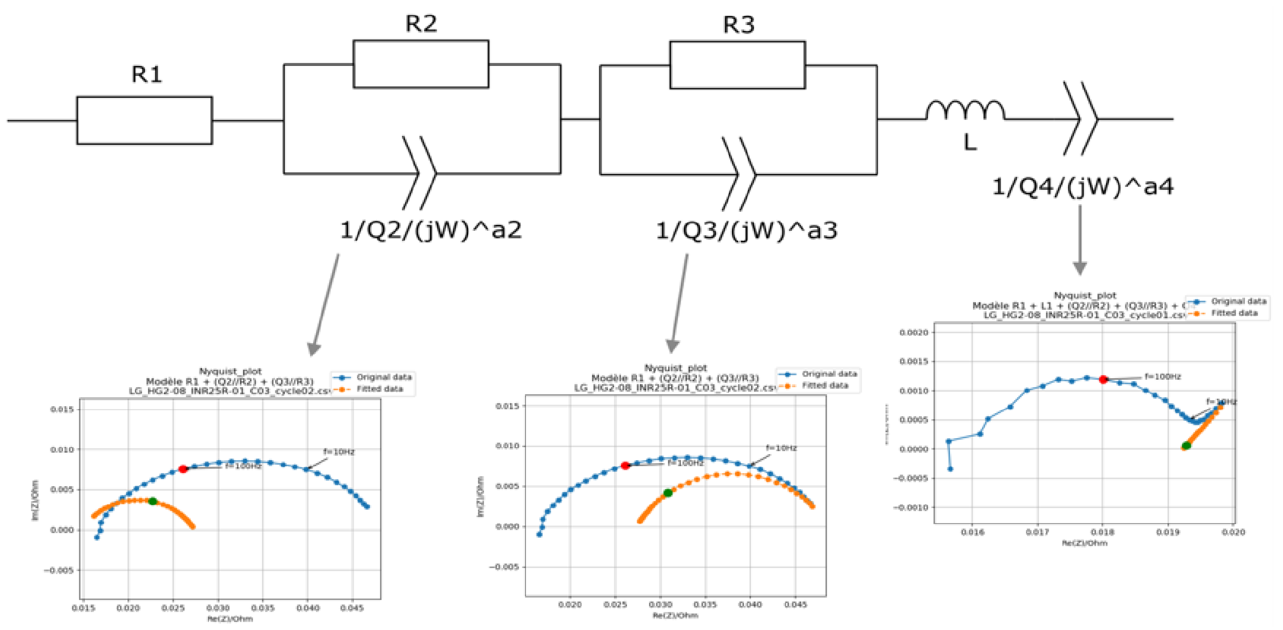

Fig. 29 provides a cell model, including: CPE capacitances (Constant Phase Element), three elements (except the series resistance R1), each one contributing to a specific range of the Nyquist diagram spectrum

20KHZ BATTERY ASSESSMENT AND TESTING TECHNOLOGIES

OLIVER KÖNIG

AVL

The battery pack is a central component in the powertrain as well as in the entire electric vehicle. In order to steeply increase the market share of electric vehicles, a two-fold improvement in battery testing is needed. Firstly, reducing the testing effort for the battery during the development process in order to reduce time to market. And secondly, increasing the fidelity of battery testing in order to improve quality and – more importantly – safety.

IMPACT ON THE DEVELOPMENT PROCESS

On the testbed, the battery pack is operated on within a controlled environment (temperature, humidity) and the electric charging and discharging power is injected by a battery pack tester. This battery tester receives the set-points from the testbed automation system and sends a controlled output current to the real battery. These setpoints are usually artificial and don't account for the effects given by the other components of the electric powertrain such as power electronic converters, motors, cables and electromagnetic interference (EMI) filters.

However, Inverters and E-motor as well as other converters (DC/DC, on-board chargers, ...) do not draw a smooth discharge current but also impose harmonics and current ripple onto the battery current. Therefore, test profiles for battery should account for such effects in order to have realistic testing conditions.

Within OBELICS, tools for simulating the components of an electric vehicle in real-time have been developed. The important aspect is, that not only each component on its own is simulated, but all core components of the powertrain as an interacting compound. This allows to test a battery pack on a testbed while the rest of the vehicle is simulated concurrently. Realistic test profiles don't need to be recorded on the road anymore but can be generated on the fly with a real-time model.

For this to work, suitable battery pack testers are needed. And also, the simulation of the battery's load must be executed at faster sampling rate in order to capture high frequency effects.

CONTRIBUTION TO OVERALL PROJECT TARGETS

Effort Reduction

- Reduced cabinet volume of the test system by more than 40% by utilizing SiC technology compared to a conventional Si-based test system

Safety Increase

- For an exemplary setup, the peak thermal losses inside the battery pack amount to 30 kW (e.g. during full acceleration) when testing only with a smooth DC discharge current. However, when testing with a high amount of current ripple at 20 kHz, the peak thermal losses can increase by 25% up to 37.5 kW. Covering this in an early phase on the testbed – and not only during road testing – reveals potential thermal design issues and hence increases overall quality and safety of the entire vehicle

CONTRIBUTION TO SPECIFIC OBJECTIVES

Less floor space is needed in the test facility and the reduced cabinet height reduces the effort during installation of the equipment. With an increased output current (from ±800 A to more than ±900 A) and increased power capability, more testing needs can be covered with one battery pack tester instead of operating two devices in parallel (which previously resulted in twice the cost and floor space).

With a faster control platform and new control algorithms, the coupling between the real battery and the virtually simulated rest of the powertrain can be improved. The results from the other use cases 2.3, 4.1, 4.2 and 4.4 are great tools for achieving this.

RESULTS & EVALUATION

Within this use case, a prototype of a battery pack tester for voltages up to 1200 V was designed, built and evaluated. Silicon carbide (SiC) power semiconductors were used to increase the power density and the overall material effort for the battery test system.

This prototype was successfully tested against the specifications for steady state power capability and for its ability to impose an AC current ripple onto the battery testing current. With an additional external ripple generator, it is possible to inject AC currents even up to a frequency of 20 kHz into the battery pack under test.

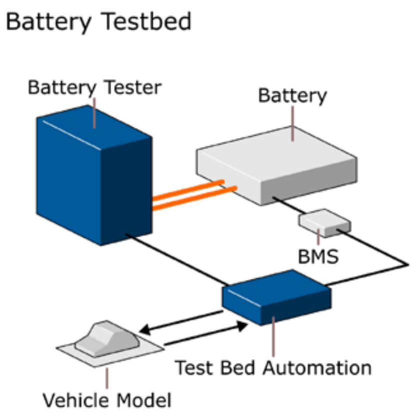

Fig. 30 depicts a Battery Pack Testbed

Fig. 31 shows the Prototype Testing and Validation

BATTERY MECHANICAL RELIABILITY TECHNOLOGIES

BENJAMIN ZILLMANN, KAI SANDMANN, JÜRGEN NUFFER, MATTHIAS RAUSCHENBACH, ASHWIN KARTHIKEYAN, RÜDIGER ZINKE

The battery itself and the entire system have raised high expectations in electric vehicles. The most important requirement on a battery system is the safety over the entire lifetime of a vehicle. There are two major classifications in terms of lifetime or reliability for a battery system: mechanical and electrical reliability. To describe the system reliability of the battery pack both classifications have to be combined. The electrical reliability is captured by the OBELICS UC 3.1 & 3.2. The mechanical reliability is covered by this UC and relevant for structural components, electrical tabs and all kind of joints. The focus was set to vibrational loads to the battery system which represents one of a main mechanical load scenarios during the lifetime. This study analyses the global and local excitations of the battery system incl. internal components to evaluate existing validation standards. Furthermore, this UC explored different numerical models to describe the vibration transfer path from the road to the battery system to propose an monitoring concept for predictive safety/maintenance of a battery system.

IMPACT ON THE DEVELOPMENT PROCESS

UC 3.3 proposed a measurement technique for vehicle batteries to validate existing safety standards. This fundamental understanding is very important to assess the given load assumptions in widely used standards. Furthermore, we could give a list of recommendations for future battery vibration testing to increase safety. Additional, a vehicle model was proposed to cover the transfer path from the road to the battery system to increase the understanding of the battery vibration response in wide range of load amplitudes. The virtual load data assessment can be used as generator for load collectives of different rough road tracks. Consequently, the safety aspect can be covered by considering a wide range of loads and additionally the testing time can be reduced.

CONTRIBUTION TO OVERALL PROJECT TARGETS

The activities undertaken in the present use case have contributed directly to the OBELICS goals. It was demonstrated that the entire UCC 3 shows a safety improvement by factor 17, by taking the mechanical and the electrical safety into account. This study achieved a safety improvement of factor 1.5 by just taking the mechanical part into account. Other than the mentioned safety improvement this study substantially contributed to a deeper understanding of the vibration response under field relevant loading conditions.

CONTRIBUTION TO SPECIFIC OBJECTIVES

A detailed measurement technique was shown to cover the vibration response of the battery system inside the vehicle and on a multi-axial test rig under a wide range of environmental influence factors. This combination allows to cover the global and local vibration response of the battery system. The results help to understand the complex behavior of a battery under vibration loading.

RESULTS & EVALUATION

Based on an extensive measurement campaign on the Fiat500e battery system we can conclude the following findings:

- testing temperature has only a minor impact on the damage values
- the external excitation has a major impact on the damage, which depends on a lot of factors, e.g. vehicle type, battery position in the vehicle, mounting situation, use case of the vehicle, etc.
- the SOC has a major impact on the vibration response of the battery module due to the swelling behavior of the battery cells
- the ISO 12405 vibration profile is in a good agreement on global basis
- the vibration response of internal components of the battery system shows a significant energy increase compared to the ISO 12405 profile

We proclaim a safety improvement of 1.5 by variate the SOC value during vibration testing. This procedure is also closer to the field loading and therefore relevant for all battery systems.

From the simulation results for vibration load data estimation of the battery system, we conclude the following lessons learned:

1. the vibration transfer models have to be calibrated for each vehicle. A vehicle specific parameter set cannot be transferred to a different vehicle. Therefore, vehicle measurements are required
2. the simulation results significantly improve by using all three spatial direction. The agreement between simulation and measurement is reduced by using only the main excitation axis z
3. using an artificial intelligence approach (Neural Networks) is very effective and seems to be promising for further applications

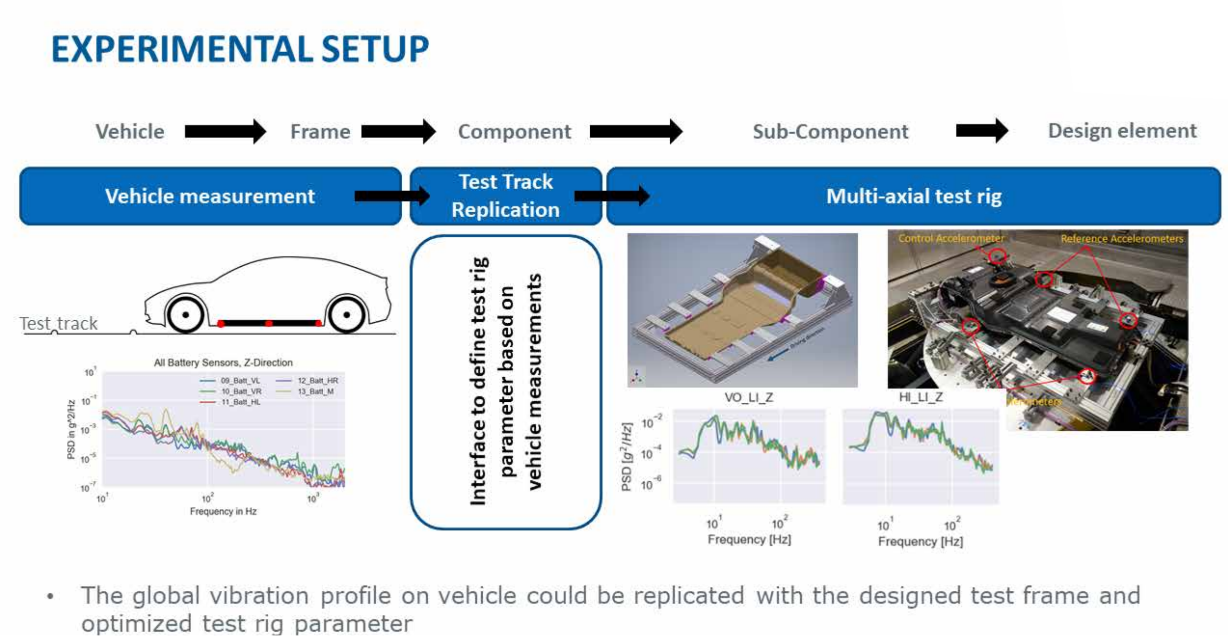

Fig. 32 provides the vibration measurement strategy to analyze the mechanical safety and reliability of vehicle battery systems

FORD OTOSAN COMMERCIAL VEHICLE DEMONSTRATOR

AHU ECE HARTAVI KARCI, CANER HARMAN

Race among the vehicle manufacturers to develop safer and more efficient electric vehicles with the shortest time to market, push the boundaries of powertrain components and related embedded software designs. In OBELICS, one of the main objective is to enhance the overall safety of the electrified road vehicles. In this context aim of Use Case 3.4 is to introduce a safer software development process, and algorithm to enhance the overall safety of electric vehicles. Having the expertise in the field of electric vehicle and advanced control software, University of Surrey (US) has proposed a solution to enhance the overall safety of the electrified refuse truck proposed by Ford Otosan through a systematic, analytical, and objective software development process along with Safe by Design (SbD) approach for the safety critical embedded software, while making conform process with ISO26262 easier.

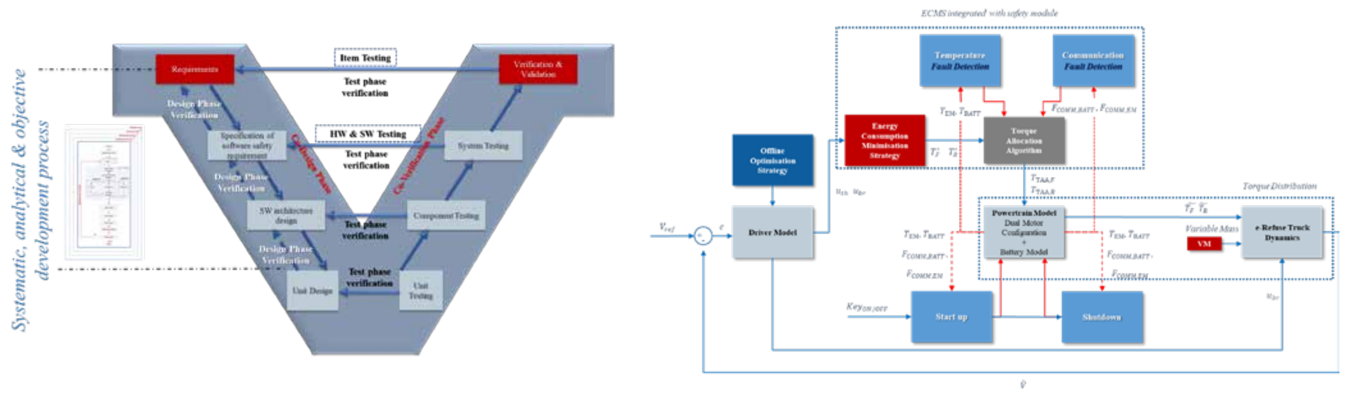

Fig. 33 shows a systematic, analytical, and objective software development process (left) and a safe by design approach for the safety critical embedded software (right)

IMPACT ON THE DEVELOPMENT PROCESS

The focus of the use case is on the improvement of the safety of the electrified powertrain through the use of more systematic and SbD approach for the soft ECU. To enhance the safety of the software both the development process and the code development phase are considered in the scope of UC3.4. Accordingly, firstly US came up with a systematic, analytical and objective software development approach to ensure that electrified road vehicle algorithm developments conform to ISO26262. Secondly, US and Ford Otosan developed together a flexible and safe start-up and shutdown sequence controller enabling the vehicle to reach a safe state when encountering random temperature faults and communication errors during the daily operation routine of the vehicle. Thirdly, a modular safety integrated energy management algorithm was developed that moderates the torque to mitigate unsafe consequences of the failure during the vehicle operation. Lastly, a modular fault tolerant algorithm is developed that allocates the torque between electrical machines (EMs) of an all-wheel drive electric refuse truck in case of an abrupt additive temperature fault based on the risk decision unit. As a result, by the proposed systematic, analytical and objective software development procedure and SbD approach not only the development time is reduced but also failures are identified and mitigated in the early design phase that enhances the reliability and the safety of the software.

CONTRIBUTION TO OVERALL PROJECT TARGETS

The UC has contributed to the OBELICS objectives:

- reliability Improvement: The proposed systematic, analytical and objective software development approach will improve the software reliability by a factor of 17.8 which will also enable algorithm to conform ISO26262
- safety Improvement: The developed modular SbD approach integrated with safe shutdown (SDSC) and start-up (SSC) sequence controller not only reduces the development time but also enhances the safety of the software by 16.7%

CONTRIBUTION TO SPECIFIC OBJECTIVES

The UC accomplished the following objectives:

- design of systematic, analytical and objective software development process based on ISO-26262 to eliminate SW error in all development stages
- development of failsafe modular torque moderation algorithm against the abrupt additive temperature faults for RWD configuration
- development of fault tolerant torque allocation algorithm against the temperature and communication faults for AWD configuration
- virtual assessment of functional safety of safety integrated energy management algorithm for electric refuse truck via software fault injection technique

RESULTS & EVALUATION

Systematic, analytical, and objective safety critical embedded software development process is proposed that has improved the overall functional safety of the soft ECU by:

- enabling identification and mitigation of software failures at early design phase
- integration of visibility tools and parametrization
- enhance objectivity via using quantitative software FMEA approaches

Development of modular fail-safe torque moderation algorithm integrated with safe start-up and shutdown sequence controller against EM temperature faults by prioritization of safety over performance.

- Bringing the vehicle into a safe state in case of a temperature fault
- Prioritization of the health of the critical powertrain components via reducing the loading during the temperature rise, by reducing the overloading index (OI) to zero
- Enhancing the EMs life-time by reducing the thermal stress during the operation

Test Case	Method	OI [%]	v_{rms} $[km/h]$
1A	*Failsafe*	0	2.56
	Traditional	3.1	0.54
1B	*Failsafe*	0	1.91
	Traditional	3.4	0.75
2	*Failsafe*	0	3.66
	Traditional	7.1	0.91

Development of modular fault-tolerant torque allocation algorithm (mTAA) against EM, battery temperature and communication faults through:

- hardware redundancy for improved functional safety and velocity tracking performance (no sudden loss of vehicle control)
- torque compensation mechanism compensating maximum possible torque from the healthy EM to the EM working in reduce performance region
- reducing loading on either/both EMs while encountering faulty condition via bringing the OI to zero
- reduction of the thermal stress on both EMs for improved EM lifetime

Test Case	Method	$\mathrm{OI}_{\mathrm{EM,R}}$ [%]	$\mathrm{OI}_{\mathrm{EM,F}}$ [%]	v_{rms} $[km/h]$
1	*Fault Tolerant*	0	0	0.84
	Traditional	2	0	0.51
2	*Fault Tolerant*	0	0	9.5
	Traditional	2.9	29	6.6

E-MOTOR, CONTROL AND INVERTER DESIGN AND TESTING

RAUL ESTRADA VAZQUEZ

FH JOANNEUM University of Applied Sciences

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 materials allow highest power densities while simultaneously reaching very high efficiencies. Nonetheless, the latter also implies high-frequency effects and the needs for faster sampling circuits and control loops.

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.

Fig. 34 shows the HF inverter Power HiL test setup

OVERVIEW OF ALL USE CASES IN THE CLUSTER

UC4.1 – E-MACHINE TESTING & INVESTIGATION USING HIL FPGA TECHNOLOGY

Modeling of high frequency interactions (<20kHz) between the e-motor and the battery + load (DC/DC) through the inverter. Inverter model is implemented on real-time FPGA bench and compared to the real inverter (+e-motor) on HiL test bench.

Partner: VALEO

Targets: Reduction of development time and effort.

UC4.2 – ADVANCED INVERTER ARCHITECTURE, DESIGN AND TESTING NAME

Demonstration of frontloading and trade-off methods and tools for real-time usage of the HF inverter model and its control unit. Both run separately in prototype emulator platforms, which combines CPUs and Field Programmable Gate Array (FPGA) in a Model-based Design approach.

Partner: FH JOANNEUM (FHJ)

Targets: Reduction of development time and effort, model accuracy and performance.

UC4.3 – HF INVERTER DESIGN AND TESTING (P-HIL)

Development of testing and calibration methods for inverters used for different vehicle variants in different testing environments (HIL, XIL). Efficient back-to-back testing are developed and used to compare the results from different testing environments.

Partner: AVL SFR

Targets: Reduction of development time and effort.

UC4.4 – E-MOTOR CONTROLLER LAYOUT AND VALIDATION WITH HIGH FIDELITY MODELS

Analysis of warm-up of inverter dependent on electric load as well as virtual testing of inverter control functions for the final calibration of controller parameters in MiL and SiL environment.

Partner: AVL (AST)

Targets: Reduction of work on high-power HiL.

UC4.5 – MULTIVARIATE HIGH FIDELITY MODELS FOR E-MOTOR (OPTIMIZATION OF COOLING SYSTEM)

Development of an e-motor model with degradation prediction under arbitrary real driving condition and vehicle parameters, and with a unique feature of virtually scaling power ranges of E-motors cooling housing and system in HiL environment with the help of a baseline E-motor that will be scaled to desired power ranges.

Partner: University of Ljubljana (UL)

Targets: Reduction of development and testing time, improvement of performance and efficiency.

SOLUTIONS

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

OBJECTIVES REACHED

Use-case Name	UC	Obj 1: Target 40% Reduction of dev. effort/time	Obj 2: Target 20% Efficiency Improvement	Obj 3: Target safety increase by Factor 10
VALEO 20kHz Inverter + Machine behavior testing and investigation (48V)	UC4.1	74,7%	n/a	n/a
FH-J Advanced Inverter Architecture, Design and Testing (FPGA in-the-Loop)	UC4.2	61,4%	n/a	n/a
AVL SFR HF inverter design and testing (P-HIL)	UC4.3	55,0%	n/a	n/a
AVL e-motor controller layout and validation with high fidelity models	UC4.4	80,0%	n/a	n/a
UL multivariate high-fidelity models for e-motor	UC4.5	93,0%	20%	n/a
Objectives per use-case cluster 4	**UCC4**	**72,8%**	**20%**	n/a

E-MACHINE TESTING & INVESTIGATION USING HiL FPGA TECHNOLOGY

EL-HASSAN OURAMI

Valeo

UC 4.1 activities focussed on reducing development and test time in the verification and validation process of e-machine software. In order to achieve this objective, real time HiL bench is developed, the bench is based on FPGA technology to ensure good accuracy of model, e-machine (Valeo e-motor with integrated inverter) and battery are modeled and implemented on FPGA.

IMPACT ON THE DEVELOPMENT PROCESS

Development of a real-time HiL bench based on FPGA technology to ensure good accuracy of models. The objective was to test systems in the simulated environment, but with the same embedded SW that the one used in final product (vehicle).
HiL platform is completely safe, allows testing beyond the range and increases quality testing by increasing the scope of testing and coverage rate.

CONTRIBUTION TO OVERALL PROJECT TARGETS

In order to reduce the development and test effort in this use-case, real test time on a testbench should be reduced by pre-validation in a cheaper environment. Therefore the HIL environment was chosen for pre-validation and the tests on a machine test bench could be minimized. This approach safes time and money. To use the HiL setup, real-time capable, accurate models for inverter and e-motor were developed and parameterized appropriately to fit the test candidates. They run on an FPGA environment to fulfill the real-time capabilities.

CONTRIBUTION TO SPECIFIC OBJECTIVES

- Reduction of testing effort by 73.8% : the majority of tests are performed on the HiL platform, number of test platforms is reduced, as the HiL platform can be easily adapted to several products, as such adaptation does not require any change of mechanical parts but only of the models
- Moreover, as the HiL platform is often available before the actual prototype, it is possible to start testing very early and at the same time reduce development costs by detecting anomalies very early
- Improvement of development effort by 14.93%: the number of tests has increased with the HiL platform and the time needed to perform them has also decreased

RESULTS & EVALUATION

- Development of a FPGA accurate model of VALEO e-machine
- Development of FPGA real-time HiL platform increasing accuracy of models, HiL platform was evaluated by convincingly cross-tests with real product bench
- In order to increase HiL testing phase, HiL platform is fully automatic, automated test procedure and post processing enables to launch the overall test plan and generate test report and specification validation through a predefined script

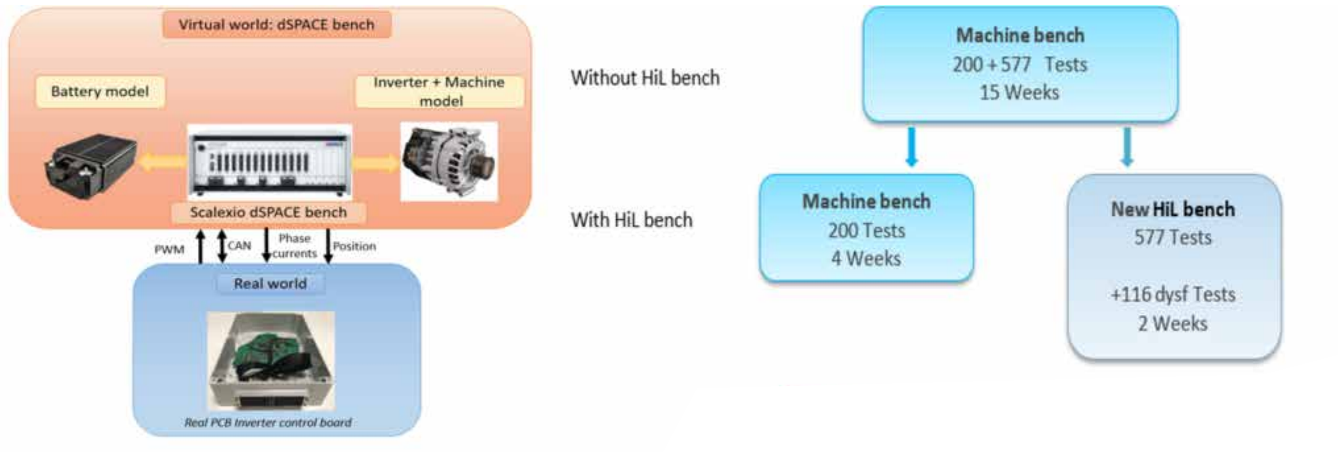

Fig. 35 shows the HiL-platform with the connection between virtual models and the real world inverter control board system (left). The right side shows the achieved reduction of development effort through the mixed use of machine bench and HiL-environment

ADVANCED INVERTER ARCHITECTURE, DESIGN AND TESTING

AIDA PREDA, ALFRED STEINHUBER , RAUL ESTRADA VAZQUEZ

FH JOANNEUM

The main objective of the Use Case 4.2 is to reduce the development time of high frequency (HF) inverters by front-loading the development and testing of its control unit based on high fidelity models. The physical components and the control unit are modeled in the computer and then run on distributed real-time hardware platforms. A crucial aspect for this UC, it is the execution time; which increases proportionally to the model level of detail. This leads to the possibility/necessity of accelerating the software by converting parts of the algorithm into hardware on the FPGA. The latter requires to develop guidelines for the proper conversion of the models to suit with the FPGA. Finally, it is desirable to support the end-user with automatic tools through the development process.

IMPACT ON THE DEVELOPMENT PROCESS

- Creation and test of HF inverter models which can be seamlessly used throughout different development stages
- Development of methods and tools for the partition of generated code from the simulation model between CPU and FPGA
- Derivation of frontloading requirements for the model's component that are allocated at the FPGA
- Enhancement of the software architecture and digital design for the internal and external communication of the RCP platform; which is based on the latest generation of Multi-Purpose System-on-Chip.
- Development of a software suite that guides the end-user during the development process and interacts in background with the base development

CONTRIBUTION TO OVERALL PROJECT TARGETS

- Effort Reduction: The process of developing and testing new HF inverter designs and control algorithm is shortened by avoiding hand-written HDL code and automating the deployment process for real-time hardware targets. The achieved reduction of 60% based on analyzed test cases
- Performance: Faster execution of models at the FPGA – ultra fast systems. Before >10us and during < 1us for simple models and maximum 2.5us for complex combined applications (CPU+FPGA)
- Model accuracy: RT deployment of detailed models that include several domains electrical and thermal layers and reconfigurable for different components and architectures. <90% for some operating points (Accuracy of ASTERICS Inverter averaged model) and >90% during OBELICS

CONTRIBUTION TO SPECIFIC OBJECTIVES

- Effort Reduction: Conducted test to measure time development in both a manual and automated mode showed the automated workflow to be 2.6 times faster
- Performance: SiC Power MOSFET model running standalone at 32ns
- Model accuracy: High frequency models can be emulated by implementing a complex FPGA model of the switching elements with good accuracy in relation to datasheet (>90% for the tested SiC MOSFET model)

RESULTS & EVALUATION

In order to evaluate the performance of the real-time platform a loopback test was implemented. The data of a continuously running simplified model was sent out from one UltraScale+ board and looped back over a second board. In this manner, the data has passed through two FPGAs, two ARM processors and the 1 Gbit/s communication line twice. The results show that the total roundtrip ranges from 15us to 21.1us for a CPU cycle time of 4us. The jitter of about 6us is expected because the CPUs of the two board are not running synchronously.

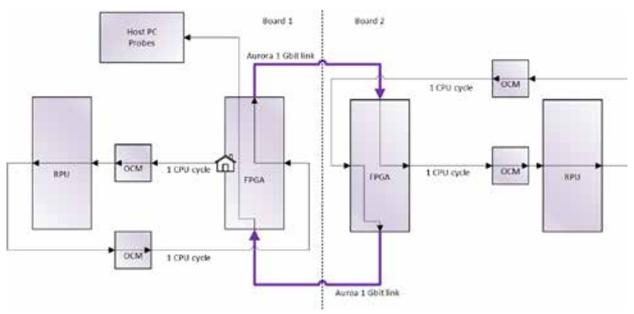

Fig. 36 shows the test setup for roundtrip time measurements

With more complex models running on the CPU, longer execution times are expected thus the roundtrip time will also increase. Nevertheless, these very short transmission times prove that also complex designs can be emulated or tested in real-time. This was demonstrated by executing the HF inverter and e-machine model in one board and the control unit in a second one. The execution time in this case was 2.5us.

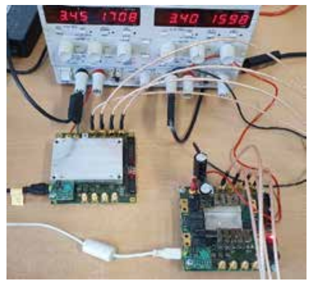

Fig. 37 shows the FHJ Hardware-in-the-Loop demonstrator. Two interconnected ZYNQ Ultrascale+ systems: One emulating at high frequency the e-machine and the inverter and the second one executing the control algorithm

Finally, the entire development process of combined applications (CPU+FPGA) is managed by an in-house developed Automation Tool, J-AAGUAR (JOANNEUM Automatic Architecture Generator for Ultra-fast Application in Real-time).

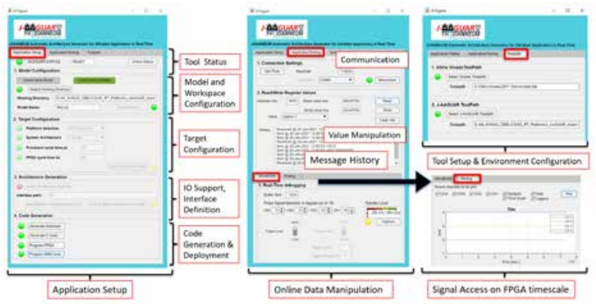

Fig. 38 shows the main features of J-AAGUAR (JOANNEUM Automatic Architecture Generator for Ultra-fast Application in Real-time)

UCC 4 | UC 4.3

HF INVERTER DESIGN AND TESTING

THORSTEN FISCHER

AVL

This use case will develop testing and calibration methods for inverters used for different vehicle variants in different testing environments. Efficient back-to-back testing will be developed and used to compare the results from different testing environments.

IMPACT ON THE DEVELOPMENT PROCESS

This use case presents the test methodology for testing and validation of the HF inverter under realistic high voltage load of an emulated e-machine (PowerHiL) as an alternative test concept to the previous dynameter utilization. The suggested approach requires the genreration of e-motor models that can run on the FPGA PowerHiL Platform and represent the e-mort in best way.

CONTRIBUTION TO OVERALL PROJECT TARGETS

- Effort Reduction (manually → fully automated test runs); front loading of the validation effort in the V-cycle process
- Efficiency Improvement; re-use of several test case scenarios and by usage of real time models based on FPGA
- Safety Increase; no rotating mechanical components, HV safety by reaching limits, destroying of the HV inverter by usage of automated Start-up- and Check-up test case

CONTRIBUTION TO SPECIFIC OBJECTIVES

A comparison of the measurements in between the test environment Hardware-in-the-loop / HIL (important in an early stage of the development especially for Hardware and Software related investigations) and the PowerHiL (immediately after the Signal HIL the subsequent test environment, but with realistic high voltage load) was made. Several important test categories were taken into account.

- Safety behavior
- Check-up investigations and Start-up behavior
- Calibrations
- Software Release tests
- Electrical tests according international standards
- Functional behavior, HF inverter specific

The frontloading approach is a very good means to save testing time and expensive iterations later in the project. Therefore the automatic test of inverters in PowerHiL environments have been proposed and executed.

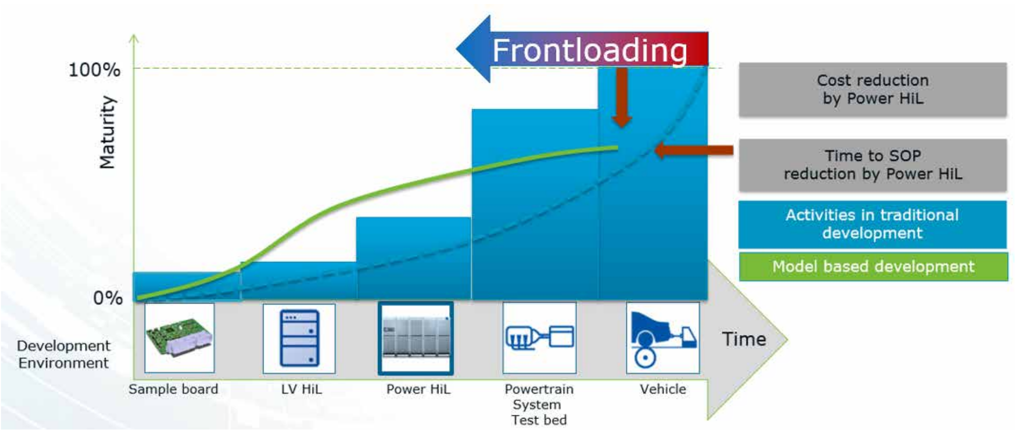

Fig. 39 shows the frontloading approach

RESULTS & EVALUATION

HF inverter efficiency shows no difference by usage of the origin E-machine in comparison to the emulated e-machine.

Based on fully automated execution of test categories, time savings of 60% average under consideration of test setup and configuration effort on PowerHiL was achieved.

It could be shown that the validation of power electronics can be fully met in a shorter time.

E-MOTOR CONTROLLER LAYOUT AND VALIDATION WITH HIGH FIDELITY MODELS

ALESSANDRO COLLA

AVL

Within this use case, it has been explored how a controller of an inverter for an electric motor can be tested virtually in an efficient way, using a multi-domain simulation based on high-fidelity models. Then a power loss map of the inverter was derived from such virtual tests for the evaluation of the vehicle energy demand with real-time capability and finally a coupled 3D thermal analysis of the inverter under load was carried out.

IMPACT ON THE DEVELOPMENT PROCESS

The virtual testing of the couple inverter-controller is must faster and wider in terms of range than an experiment, because different boundary conditions on different domains – thermal, electric and mechanical – can be considered. Consequently, the safety functionalities implemented in the controller can be already tested in early stage of the development, as the most stressful operating conditions can be easily realized. Moreover, the thermal analysis can be carried out at the same time, clarifying the performance of the inverter cooling in such limit conditions.

CONTRIBUTION TO OVERALL PROJECT TARGETS

The advantage of the simulation – high-fidelity and loss map generation – is overwhelming: 1 operating point is calculated in 4 minutes, which means circa 2.5 – 3 hours for a matrix of 6 speeds and 6 torques, while a typical measurement on testbed can take between 15 and 30 minutes and the preparation of the testbed itself at least 1 hour. Therefore, the usage of the simulations cuts down the typical testing time by the 80%, speeding up the integration process and enabling additional development tasks, such the optimization of the switching strategy.

CONTRIBUTION TO SPECIFIC OBJECTIVES

A high-fidelity physical model of an inverter in order to directly analyze the impact of the control units on the vehicle efficiency and performance was created and connected with a production-grade controller, in order to test their interaction virtually. The information gained in this phase are then transferred to vehicle and thermal analyses, filling the gap between the different multi-physical simulation.

RESULTS & EVALUATION

A complete workflow for in-depth analysis of a physical inverter model, suitable for different applications and scalable to different electronic devices was developed. It begins with the physical modeling of the inverter electric network, from which a power loss map is derived to be used into a real-time vehicle model. Therefore, the effect of the switching strategy or component choice at inverter side on the vehicle efficiency can be evaluated directly.

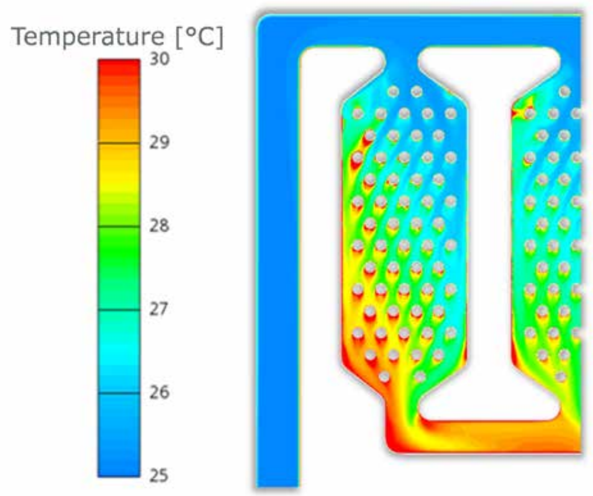

Fig. 40 depicts one of the output of the thermal analysis – the coolant temperature field below the IGBTs, where it trails of the warmed coolant after the cooling pins and the progressive coolant warming through the cooling plate are clearly visible. Most of the fins are place below the chip dies to maximize the heat removal; with the presented configuration, the coolant increases its temperature of 5 °C (the chip stabilizes at 200 °C)

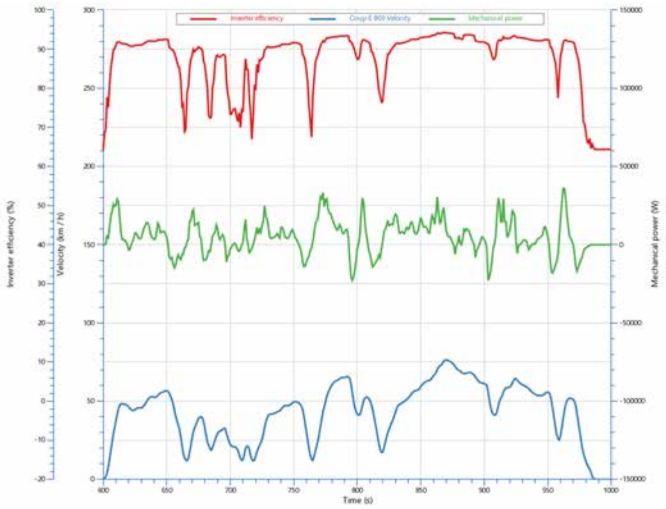

Fig. 41 shows the typical results of vehicle efficiency analysis during a driving cycle: from bottom to top, the velocity of the "medium" section of the WLTP in blue, then the mechanical power of the electric motor in green – positive during traction or negative during recuperation, and finally the efficiency of the inverter machine – interpolated by the map generated by the UC workflow

MULTIVARIATE HIGH FIDELITY MODELS FOR E-MOTOR (OPTIMIZATION OF COOLING SYSTEM)

URBAN RUPNIK, MARIO VUKOTIĆ, MARTIN MAVRIČ, DAMIJAN MILJAVEC

University of Ljubljana

This use case use an PMSM (Permanent Magnet Synchronous Machine) multi-physical machine model (including electric, magnetic, thermal, mechanic and ageing sub-models) with degradation prediction under arbitrary real driving condition and vehicle parameters, and with a unique feature of virtually scaling power ranges of PMSM machine cooling housing and heat exchanger system in HiL environment.

IMPACT ON THE DEVELOPMENT PROCESS

This Use Case demonstrates loadings and developed methods and tools for testing of the geometry based PMSM under real driving conditions. The proposed HIL emulates the main drive-train of vehicle with the road conditions and/or driving cycles. The cooling system and cooled housing in these real conditions give to PMSM real load-ability and over-load-ability. By adopting real cooling system, the performance curve of PMSM is analyzed and studied towards improvement. The results give the realistic in view of different cooling geometries (indirect liquid cooling) designs of PMSM housing and cooling system. The scalability of proposed system is available on e-machine model side, housing side and on heat exchanger side. Modelling of electro-magnetic and thermal effects of the PMSM machine analyzed in WP2 and WP3 as well as developed PMSM multi-physical model (electric, magnetic, thermal, mechanic and ageing) are demonstrated in this Use Case.

CONTRIBUTION TO OVERALL PROJECT TARGETS

The Use Case demonstrates the use of PMSM multi-physical models coupled with Scalable cooling (housing and heat exchanger) in Hardware-in-The-Loop testing facility. The developed HiL environment is allowing to reduce the development effort by more than 90%, giving the possibility to improve the vehicle system level efficiency, increase the load-ability as well as over-load-ability of studied e-machine and augment safety in terms of thermal e-machine degradation.

Developed scalable multi-physic e-machine (PMSM) models with innovative scalable E-machine (PMSM) configurator modelling tool allows system engineer to include the models into the vehicle-level scalability optimization process for a vehicle requirement, driving conditions as well as overall driving cycle e-machine efficiency improvement. On the other side, the new E-machine configurator tool provides: design, material and energy consumption optimization of E-machine (PMSM) as well as deliver the e-machine design suitable for prototyping (production).

Main contributions of UC 4.5 towards project targets are:

- combination of high fidelity multi-physical models in a single modeling/simulation environment
- reduction of PMSM machine development time for more than 90%
- reduction of thermal testing effort (> 60%)
- increased vehicle performance by giving the possibility to improve the vehicle system level efficiency through higher PMSM machine thermal load-ability and over-load-ability

CONTRIBUTION TO SPECIFIC OBJECTIVES

The design procedure developed within the OBELICS project gives the geometric, electric, magnetic, thermal and ageing models combined into real time system level multi-physical PMSM model. The example of connection between the vehicle system engineer input and e-machine geometry as output is shown on Figure 13. The design time is in the range of minutes. The software-in-the-loop (SIL) of the real time PMSM machine thermal HIL system is developed in the single software environment where all E-machine physical sub-models are implemented. The measured data coming from the real Hil system are used to drive the software E-machine sub-models; as well the data coming from the models are transferred to the real hardware. In this way, the realistic behavior of E-machine multi-physical model is achieved and tested.

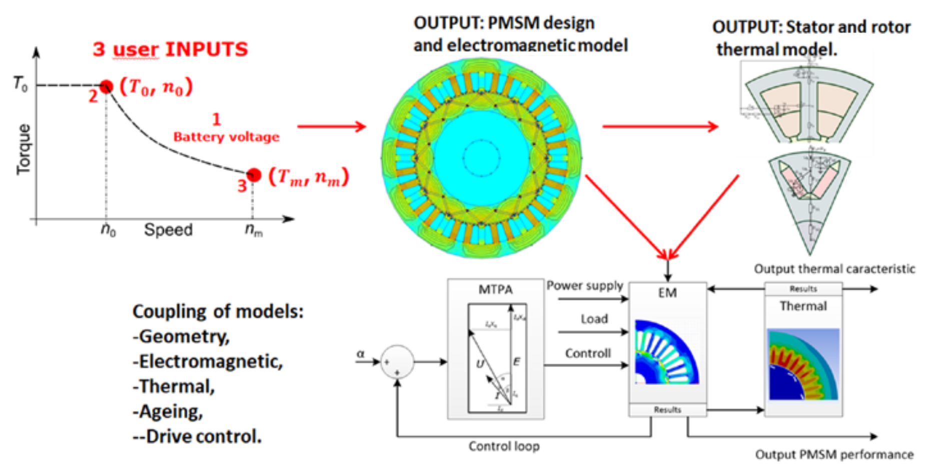

Fig. 42 depicts an innovative E-machine configurator modelling tool automatically forming scalable multi-physic e-machine models

RESULTS & EVALUATION

The integration and use of multi-physical PMSM model, developed within the project and used in UC 4.5, is forming the real time system level model platform. The system level multi-physical PMSM model is real time model with time increment between two calculations lower than 0.5 ms. This allows the model to be also used in vehicle level simulations. A simple vehicle model is added to the SIL stage for more realistic behavior to the real time thermal HIL system testing. In the proposed HIL system within UC 4.5 the real time PMSM multi-physical model was used as a SIL connected to HIL and supplying it with loss energy data flow. The real time system level PMSM model involves: geometry, temperature dependent electromagnetic properties, and temperature dependent losses, further on describing its thermal behavior. The proposed HiL is composed of integrated scalable electromagnetic model, thermal model and aging model coupled with real-world cooling system. The real time HIL system is developed towards testing the maximum load-ability and over-load-ability of the main drive-train with real vehicle and road conditions.

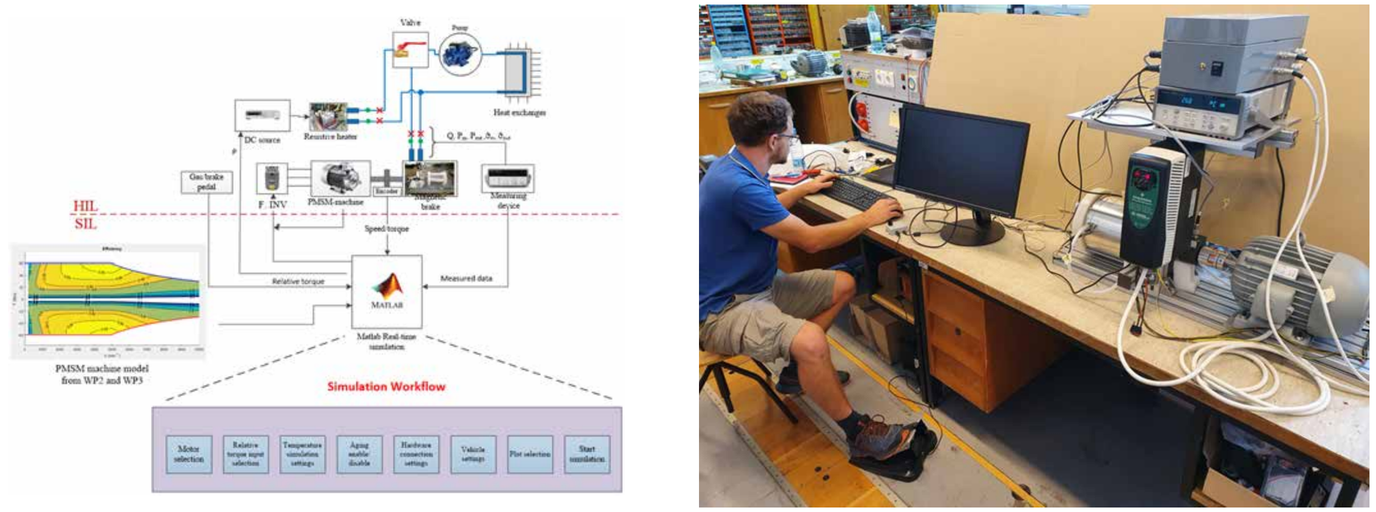

Fig. 43 shows the proposed real time HIL testing system

LIST OF FIGURES

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CONTACT DETAILS

Horst Pfluegl, Project Coordinator, horst.pfluegl@avl.com
Willem van Dorp, Project Manager, w.vandorp@uniresearch.com
www.obelics.eu