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Optimization of scalaBle rEaltime modeLs and functIonal testing for e-drive ConceptS

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Publishable Executive Summary

This document presents different tools developed either for early design phase or for virtual integration studies. Each tool is designed for a specific purpose from electric vehicle architecture design exploration to full complete electric vehicle integration analysis. These tools answer different requirements presented in the OBELICS grant agreement, allowing reduction of time and effort in development process as highlighted in the left part of the V-cycle (requirement/specification definition & System architecture selection) in one hand and right part in second hand (test and verification, verification software system integration) in Figure 0-1:

- Configuration and automation capabilities in the tools
- Standardized process implementation and user interface
- Process execution validation

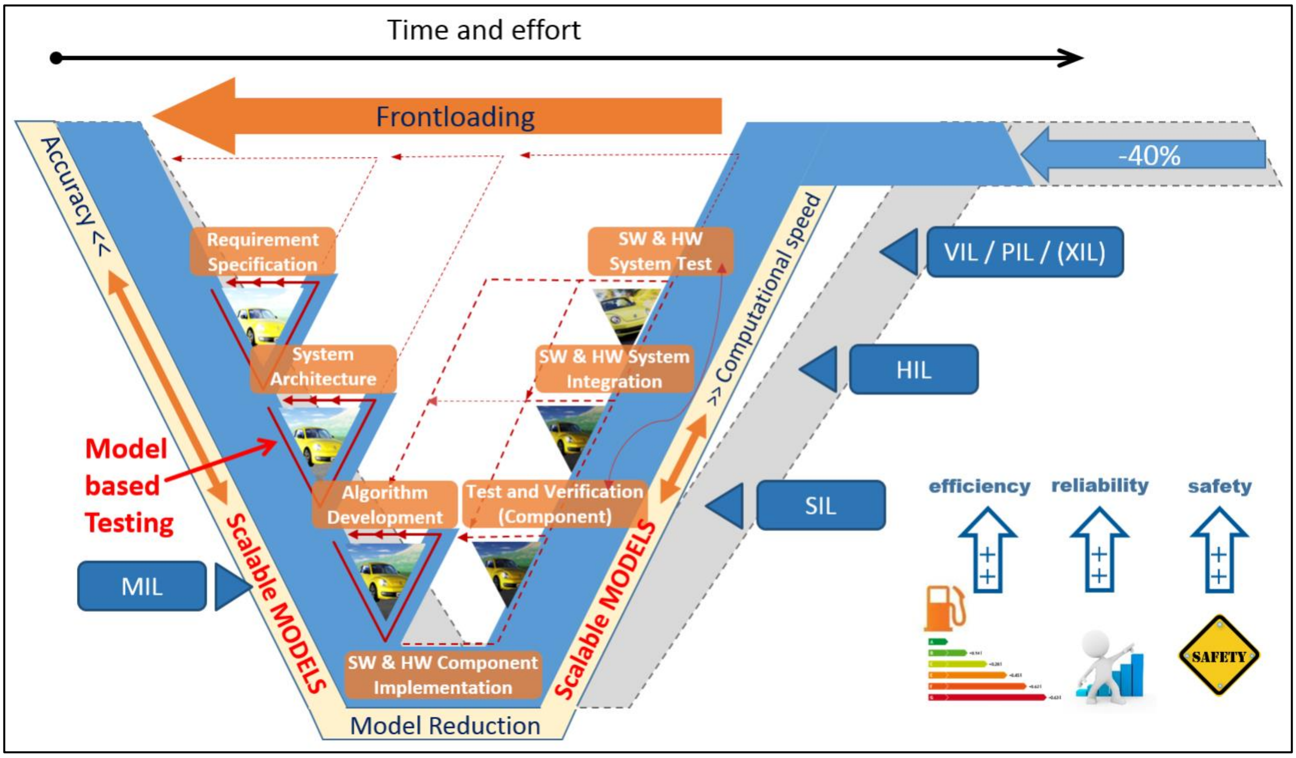


Figure 0-1: OBELICS model-based development concept to reduce development and testing efforts.

Some tools and methodology focus on the trade-off process optimization by considering different electric vehicle powertrain architectures and analysis the relevancies of each of them. Processes have been standardized to generate specification of all electric subsystem like the battery and the E-motor. Other presented tool is dedicated to generic braking model integration, but not only the plant model but also the control dedicated with a focus on energy saving and methodologies. Another methodology focuses on standardized virtual integration allowing 1D and 3D model co-simulation on desktop and HPC. This method is being standardized/automated through python script and allow deeper trade-off analysis with complete subsystem interaction impact.

Finally, these tools developed by simulation expert are accessible to non-expert thanks to standardized process and user interface leading to design phase time reduction which is key objective of this project.

1 Introduction

In the context of offering flexible vehicle line-up virtual integration by allowing execution of integrated sizing and calibration processes reducing costs and delay while ensuring optimal vehicle performance, tools supporting advanced EV trade-off process have been developed, especially in the task 3.3 dealing with these topics. Indeed outputs from others WP3's tasks have used to support the development of these tools, like toy models [1] from task 3.2 or control strategies [2] from task 3.4 or electric component models from WP2 [3], [4] & [5]. Furthermore, these tools have been used and validated through WP6 demonstrators, where results and analysis are detailed.

Two kind of tools have been developed in the task 3.3:

- Tools for early phase concept analysis
- Tools supporting virtual system integration

Both tools are complementary, because first ones deal with early design phase, where subsystem are not specified yet (purpose of these tools) and latter ones deal with integration phase, where all subsystems are designed and need to be validated at the full vehicle system level.

The objectives of early phase concept analysis are the reduction of the gap, that may occur between simulation expert (generally in one domain or subsystem) and vehicle architects. Indeed, by supplying high level of accessibility non expert people can evaluate multiple vehicle configuration for different realistic conditions while balancing vehicle attributes and generate specification and requirement to simulation expert in each domain. Such tools will be presented for either the full vehicle level or component levels.
The objectives of tool supporting virtual system integration is a combination of several functions ensuring consistent and relevant vehicle level model integration to realize simulation for different realistic condition while validating component/subsystem design with interaction of all other subsystems. These functions cover the following capabilities:

- to run simulation in different generation from desktop to HPC and to ensure stable co-simulation
- to offer standardized processes implementation through scripting like python script
- to optimize process execution especially with the management of models in co-simulation.

2 Tools for early phase concept analysis (RT-SAS, VALEO/SIE-SAS, UNIFI)

In this chapter, several methods for early concept phase will be described and have been illustrated in different use cases.
In this concept phase, generally few information are available and only main requirements are already set, like vehicle range target and vehicle weight target. Nevertheless, it is important to have as soon as possible good insight of the vehicle to properly generate specification of all subsystems, especially the electric powertrain. That is why auxiliaries and thermal management must be integrated even in this early phase as highlighted in Figure 0-1.
Furthermore, automatic configuration to explore as much as possible potential architecture is a key point to reach more and more constraint targets from regulation. Then standardized process and modeling tool is also important to reduce the design and development phase allowing the maximum user with common simulation tools.

2.1 RT-SAS (VOLVO) – UC1.1: Electric powertrain optimization tool

The optimization of an electric powertrain aims to provide a system design that can meet all performance and packaging requirements while minimizing the objectives e.g., the added cost and/or energy consumption (range) of the vehicle. Moreover, the optimization process itself must have the following characteristics:

- It must use components and system models with a sufficient level of detail to capture all relevant interactions between the different components,
- It must provide results that can serve as a starting point for a final design,
- It should require a short set-up time and be computationally efficient to execute in order to reduce development times and associated costs,
- It must be flexible, allowing the introduction of new technologies, components, topologies or system layouts as they emerge and finally,
- If cost minimization is a major objective of the optimization, then accurate cost models for the different components based on a similar set of assumptions needs to be implemented in order to ensure that the cost-tradeoffs between the components are being correctly captured.

The overall powertrain design and optimization process proposed in UC1.1 is semi-automated in order to enable a faster exploration of the design space (powertrain layout, component design and sizing) and optimization process execution. The user still needs to set up the analysis and configure the different tools. When a powertrain model is required for new topology performance analysis, it needs to be developed by the user. Nevertheless, with the availability of high-level virtual integration tools, this powertrain model can be developed faster either by sharing standardized model interfaces, increasing re-usability of models or by using parametrization scripts. Moreover, a general optimization framework is also considered enabling its deployment for solving a wide range of optimization problems through the development process.

2.1.1 Design optimization process

Design optimization of an electric powertrain system, as for hybrid electric powertrain, can be formulated as a multi-objective optimization problem that spreads over multiple levels (topology, technology, component sizing and control). The design optimization process implemented in UC1.1 is strongly inspired by the methodology and the optimization framework as described in for hybrid electric vehicle design optimization [6]. This complete design process together with its different (nested) design levels is depicted in Figure 2-1.

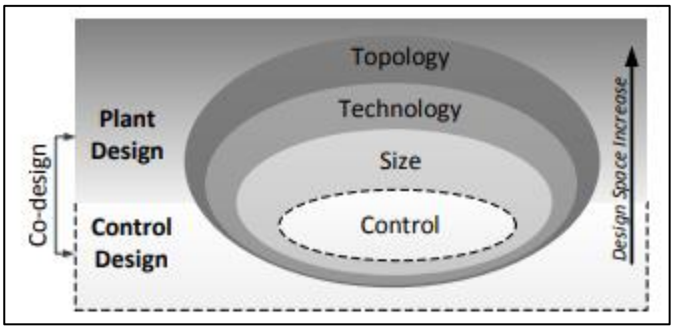


Figure 2-1: Multi-layers system design methodology

The topology, technology and sizing of components are layers related to the physical system. The control layer is dependent on the physical system, yet it will not change its physical parameters (e.g., the battery size, electric machine type or gear ratios). These physical system parameters will act as bounds with which the control algorithm must cope. In addition, the BEV topology will define the variables of the control algorithm (i.e., their number and type). This inter-dependence (coupling) between the plant design layers and the control algorithm supports the statement that the performance, which is obtained from optimal per-layer design, is influenced by the design of other layers.

Figure 2-2 describes the design optimization process considered in UC1.1. This process includes the following design layers: topology, component, sizing and control. This design methodology differs from other methods by its very general framework and by a systematic analysis of the powertrain system.

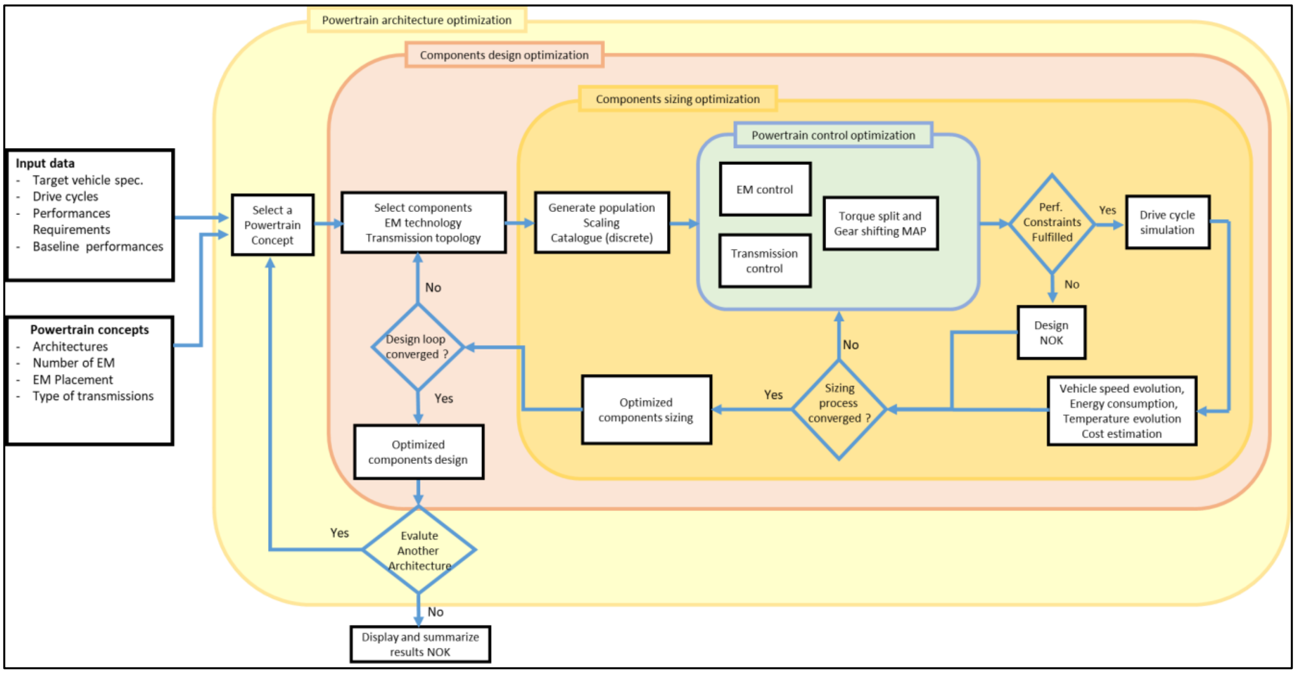


Figure 2-2: UC1.1 optimization design process

Two approaches are possible in the powertrain component sizing optimization layer. The first approach consists of a grid search; it creates and run a batch of parameter combinations (experiments). It can create full factorial batch (all combinations) or reduced parameter combinations. The second approach performs optimization tasks in order to minimize/maximize user cost function(s) under certain constraints. Moreover, both backward and forward approaches are considered for vehicle drive cycle simulation. Table 2-1 summarizes all the approaches developed for component sizing optimization problem.

Table 2-1 Possible approaches related to component sizing optimization

Optimization methods	Vehicle model for powertrain performance assessment	
Grid search	Backward model	Forward (and scalable) model
Optimization algorithm	Backward model	Forward (and scalable) model

2.1.2 Configuration and automation capabilities

2.1.2.1 Optimization tool

The application of VOLVO's in-house optimization platform caters in supporting the workflow and the optimization problems defined in UC1.1 due to its automation capabilities. The existence of both continuous and discrete design variables defined in UC1.1 requires the extension of its features to be able to handle mixed integer problems. This platform is generic and highly configurable, enabling its deployment for solving a wide range of optimization problems. In step 1, it is used to determine the torque and power requirements at the wheel, while in step 2 it is used to optimize powertrain component design and sizing towards energy efficiency, performances evaluation or powertrain cost. In the later steps, it is can be used to calibrate the controller parameters. For all these steps once the process is configured, the optimization is run without the provision of user input, in order to save time, the process can be split in multicore mode running parallel loops simultaneously. There is also a possibility to interrupt the optimization process in between in order to view the progressive result and can be continued from the stopped step.

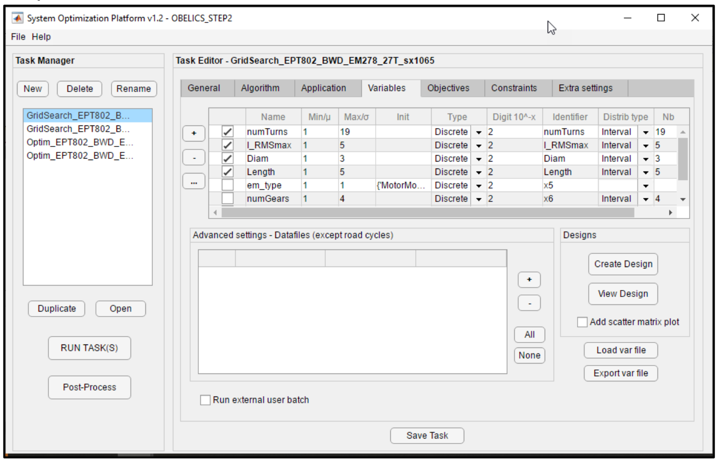


Figure 2-3: VOLVO's in-house optimization platform main user interface

2.1.2.2 PMSM configuration tool

An advanced model for PMSM multi-domain performance simulation has been developed in WP2 (details are reported in deliverable D2.2). This model is based on finite element modeling methods for accurate prediction of magnetic, electric and thermal behaviors. Scalability technics have been developed in order to reutilize data from this finite element multi-domain model (by far the most time consuming) to be able to evaluate the effect of changes in electric machine design parameters on the electric machine performances characteristics and therefore impacts on powertrain efficiency on drive cycle operations. Figure Figure 2-4 summarizes the different steps involved in this workflow where execution has been automatized with the help of dedicated parameterization scripts.

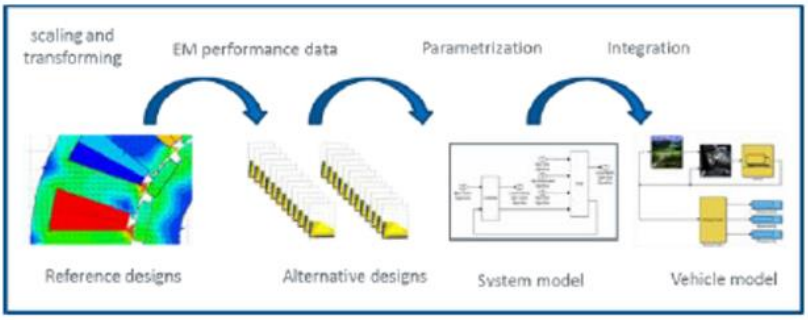


Figure 2-4: Automated process for alternative EM (PMSM) design exploration

Alternative electric machines design can be generated from a reference design by varying the design parameters such as active length, diameter, inverter maximum current or number of turns. For each alternative design; scalable electric machine performance models are automatically generated (map-based model, multi-domain performance model) for electric machine sizing optimization with vehicle level system simulation.

2.1.2.3 Powertrain high level integration tool

To support various powertrain topologies exploration and multiple powertrain configuration analysis in early project phases, new requirements have been considered for the development of a more flexible modeling environment leading towards a faster vehicle/powertrain system modeling process execution. This flexible vehicle and powertrain modeling framework is based on the existing in-house virtual integration environment (GSP) presented in deliverable D3.1, mainly dedicated today for detailed system integration analysis in the design, verification and validation phases. For the development of this flexible powertrain modeling framework, several requirements are considered from the existing in-house simulation tool GSP to keep a continuous simulation environment between early & design phase for vehicle modeling & data management, among which the most important are:

- Simulink as simulation integration platform
- Vehicle/powertrain model development according to VMA standard (Vehicle Modular Architecture)
- Generic architecture and interfaces for vehicle sub-system models, as illustrated in the figure, to enable plug-and-play operation of the simulation models.

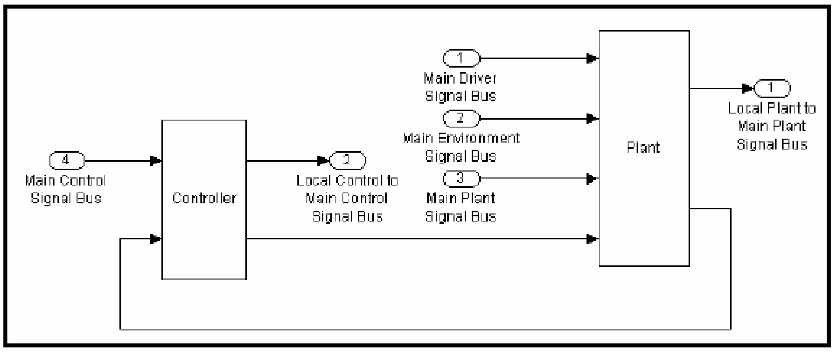


Figure 2-5: Generic architecture adapted for vehicle sub-system models implementation

To increase tool flexibility and enable faster vehicle modeling process, new requirements and guidelines are considered to support the development of generic vehicle subsystem model enabling multiple configurations of key powertrain component (electric machine and transmission systems). In addition to battery, electric machine or inverter systems, transmission systems are one of the key systems for new electric powertrain concepts development. While transmission design for conventional vehicles is rather fixed or rarely evolved, there is much more flexibility in transmission design when it comes to battery electric vehicles. Therefore, development of flexible transmission models is necessary to support the powertrain system sizing studies, in particular the transmission pre-design analysis with a possibility of large design space exploration.

2.1.2.4 Powertrain control process for multiple variant analysis

The development of the powertrain control strategies plays an important role throughout the vehicle development process to enable efficient operation of the electric vehicle in the different stages of the development. Control is especially important in early project phases to allow a fair comparison of different electric powertrain concepts for robust concept selection and tasks which is already difficult and has become even further complex with the development of innovative powertrain concepts combining multiple electric machines and multiple speed transmissions systems. Therefore, application of optimal control techniques is essential for the performance assessment of new powertrain concepts for a fair comparison. In addition, development of generic control strategy models for vehicle system simulation is important for faster execution of control development process in early phase. In order to support multiple powertrain concepts analysis with multiple e-component variants integration, application of optimization-based control design methodologies in the early stage of the powertrain control development process can help to cover many powertrain topologies and component configurations. With such approach, it is possible to automatize powertrain control process as illustrated in Figure 2-6 with a focus in this document on the powertrain layouts depicted in Table 2-2. The powertrain layouts can consist of multiple electric machines and transmission systems depending on the powertrain expected torque and power requirements at the wheels.

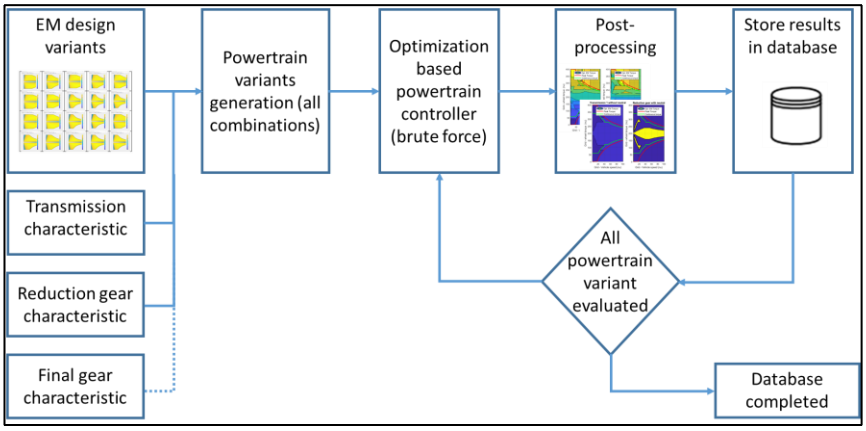
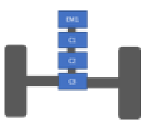
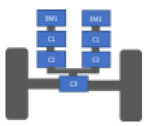
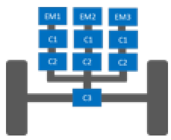
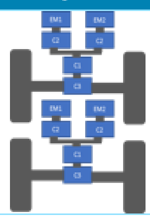


Figure 2-6: Powertrain control process description for multiple powertrain variants evaluation

Table 2-2 Example of powertrain layouts considered in UC1.1 for commercial electric vehicle application

Powertrain Topology	One axle drive			Two axle drive
	Layout 1	Layout 2	Layout 3	Layout 4
Layout				

The blocks C1, C2 and C3 can correspond to the following powertrain components:

- C1 can represent a simple reduction gear
- C2 can represent a single or multi speed transmission with or without neutral position (neutral position means that electric machine can be disconnected from the driveline)
- C3 can represent a simple reduction gear or a differential system.

For each component, an approximation of the losses can be formulated using an affine dependency relation between the component input and output power:

$$T_{out} \cdot w_{out} = \eta_{Ci} \cdot T_{in} . w_{in} - P_{idle,Ci}(w_{in}), \quad T_{in} . w_{in} > 0$$

Where P_{idle} is the power that the component Ci needs to idle at an input-shaft speed w_{in}. This equation is valid when the vehicle is in traction mode. If $T_{in} . w_{in} < 0$ a similar equation can be formulated to describe the losses for the component Ci that affects the regenerative torque

$$T_{in} \cdot w_{in} = \eta_{Ci} \cdot T_{out} . w_{out} - P_{idle,Ci}(w_{in}), \quad T_{in} . w_{in} < 0$$

Parameters related to C1, C2 and C3 components are listed in Table 2-3.

Table 2-3 Powertrain component loss model parameterization

Parameter	C1	C2	C3
Number of ratios	1	N	1
ratio	r_{c1}	$[r_{c2\_1}\ r_{c2\_2} \dots r_{c2\_n}]$	r_{c3}
Efficiency	η_{c1}	$[\eta_{c1\_1}\ \eta_{c2\_2} \dots \eta_{c2\_n}]$	η_1
Losses	α_{c1}	$[\alpha_{c1\_1}\ \alpha_{c2\_2} \dots \alpha_{c2\_n}\ \alpha_{neutral}]$	α_{c3}
	β_{c1}	$[\beta_{c2\_1}\ \beta_{c2\_2} \dots \beta_{c2\_n}\ \beta_{neutral}]$	β_{c3}
	D	D	D

A quasi-static model for the complete powertrain system can be established in the following form by combining these different component loss equations

$$\sum_{1}^{n} r_i \cdot \eta_i \cdot T_{EMi} = f(T_{wheel}, N_{wheel}, p_{c1}, p_{c2}, p_{c3})$$

This model makes it possible to link the powertrain control variables (T_{EM1}, T_{EM2},…,T_{EMn}: torque request related to electric machine 1, 2, …and n; transmission gear selection) to the powertrain torque demand T_{wheel}. Brute force search method is applied in order to define the optimal motor torque and gear shifting controls to optimize vehicle energy consumption by selecting the best torque split and transmission ratios from a discretized set of possibilities. Brute-force search, also known as generate and test, is a very general Problem-solving technique and algorithmic paradigm that consists of systematically enumerating all possible candidates for the solution and checking whether each candidate satisfies the problem's statement.

2.1.3 Trade-off process

The trade-off process can be performed considering different design objectives or vehicle attributes. In UC1.1, the following design objectives are considered:

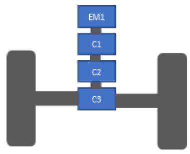
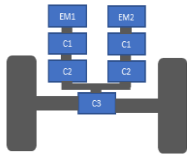
- Vehicle performances evaluated with real conditions of operations (drive cycles)
- Energy consumption (range)
- Component cost

Design optimization can be done considering a single objective (energy consumption) or multiple objectives for trade-off analysis. For component cost objective evaluation, only cost of the electric machine is considered here with a simple cost model (linear relation between cost and electric machine power rate). Considering the total cost of ownership (energy cost, all powertrain component cost, maintenance cost …) as objective in the trade-off process could deliver more relevant results. This was not considered in this study due to the complexity of the evaluation of such objective (uncertainties on input, lack of economical knowledge …).

2.1.4 Process execution on a case study

In this section, the proposed process and methodology are used in the design and optimization of an electric powertrain for multi-purpose commercial vehicle application (distribution, refuse …). Two powertrain layouts are in focus in session and shown in Table 2-4.

Table 2-4 Powertrain layout and configuration in focus

Current product	Corresponding layout	Powertrain configuration
		• EM1 • C1: Not considered • C2: 2 speed transmission • C3: rear axle
		• EM1 = EM2 • C1: Simple gear (left) • C2: 2 speed transmission (left) • C3: rear axle

The execution of the design process described in figure will mainly focus on the two following optimization layers:

- Component sizing optimization,
- Powertrain control optimization.

The main objectives involved is the optimization of the sizing of a PMSM electric machine by taking into consideration efficiency, cost and performance also considering new assumptions for the powertrain design optimization: targeted electric vehicle with new characteristics, vehicle operating on new drive cycles; ASTERICS cycle and some of ACEA cycles are discussed in this session. The main steps in these two nested layers are:

- powertrain component population (with a focus only on PMSM electric machine),
- Powertrain control optimization,
- Component sizing optimization.

2.1.4.1 EM design generation

EM design candidate are generated from for example two permanent magnet synchronous machine (PMSM) reference designs by varying the following electric machine design parameters: active length, diameter, inverter maximum current and number of turns. A “short” (respectively “large”) EM catalogue is obtained from PMSM reference design 1 and PMSM reference design 2; respectively with the following design parametric values:

Table 2-5 Design parameter considered for PMSM electric machine scaling

	PMSM Reference design 1	PMSM Reference design 2
Active length	5	9
Diameter	3	7
Inverter maximum current	5	5
Number of turns	19	18
Number of combinations	1425	5670
Number of feasible designs generated	**278**	**1836**

From the scaling done in Table 2-5, 278 alternative designs among all possible combinations (1425) have been generated (not all combinations are possible). Similarly, 1836 alternative electric machines among 5670 possible combinations are obtained considering PMSM reference design 2. Figure 2-7 illustrates the scaling considered for the PMSM reference design 2 and performance assessment for some of these generated designs.

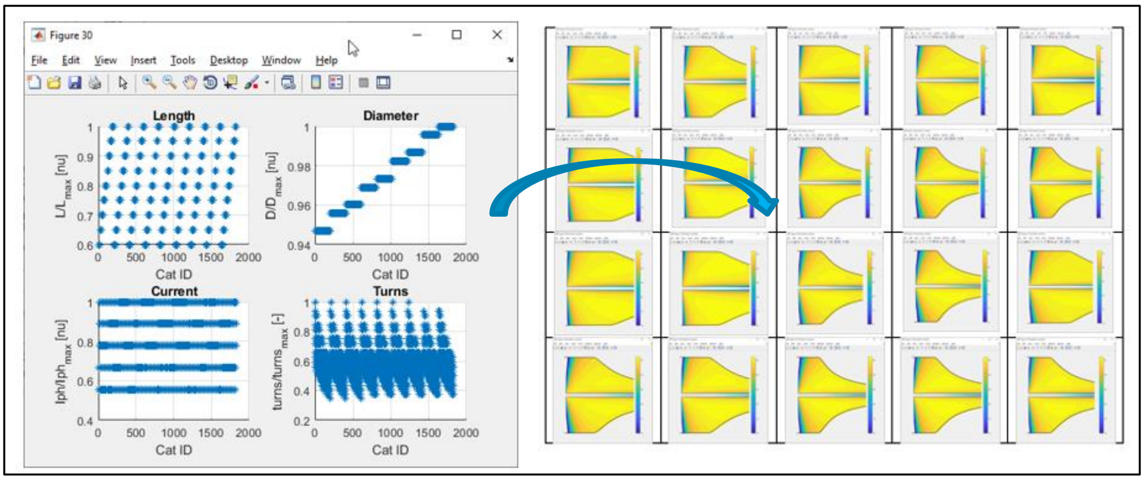


Figure 2-7: Example of EM scaling (diameter, length, number of turns …- Example of performances MAP for vehicle level simulation of electric machine designs from this design space

2.1.4.2 Powertrain control process evaluation

The powertrain control process is evaluated considering powertrain layouts 1 and 2. For powertrain layout 1, torque distribution and 2-speed gear-shifting maps are calculated considering all electric machine design variants defined in Table 2-5 (1836 EM variants); for powertrain layout 2, torque distribution and gear-shifting maps are calculated considering alternative design variants VOLVO FE and Tesla semi-trucks (clutchable electric machines).

- **Powertrain control with multiple EM design variants**

When in the early phase of designing an electrical platform, proper management on the powertrain like the correct Electric machine design selection and its involvement in the sizing of the powertrain is critical. With the list of multiple combination of design parametric EM design variants available, an efficient and fast powertrain control can be achieved with regarding component design variant selection as illustrated in Figure 2-8 for different electric machine design variants.

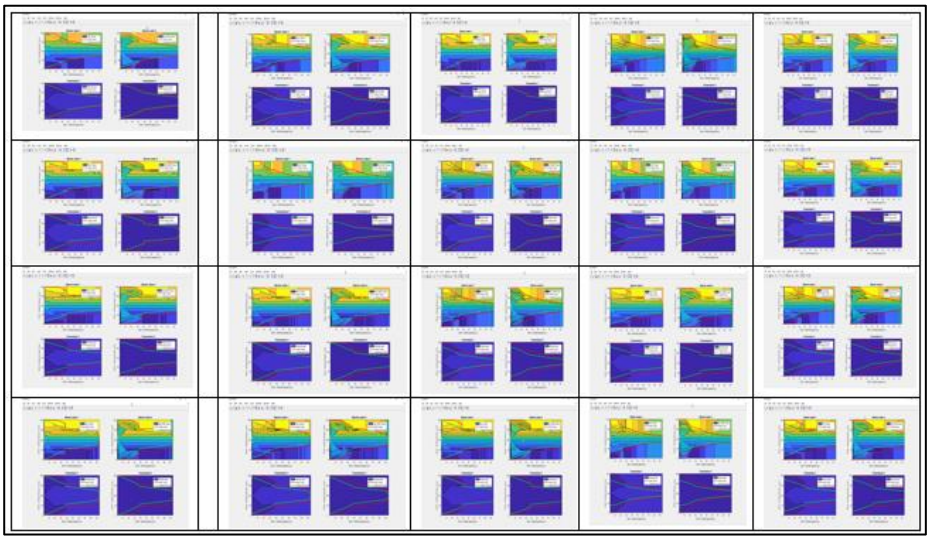


Figure 2-8: Optimal electric machine torque distribution (EMx2) and gear selection (2-speed transmission)

- **Powertrain control with multiple transmission design variants**

Table 2-6 and Table 2-7 illustrates the electric machine optimal torque and gear selection (gear 1, gear 2, ..., neutral) that can be implement for VOLVO FE and Tesla semi-truck vehicle performance and efficiency simulation for baseline design and design variants.

Table 2-6: VOLVO FE and TESLA Semi-truck electric machines optimal torque split for baseline and design variants

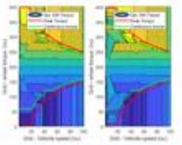
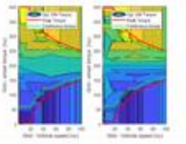
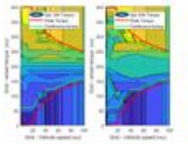
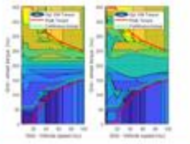
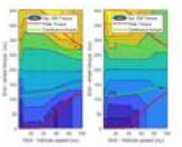
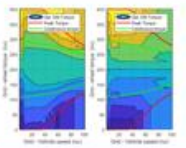
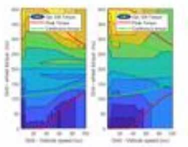
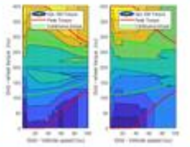
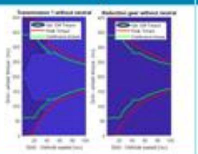
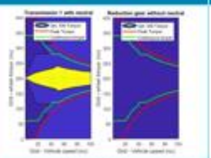
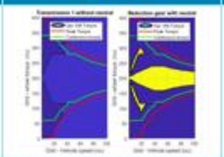
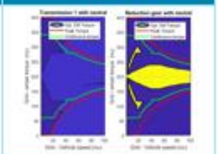
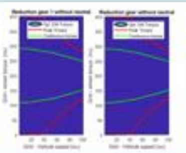
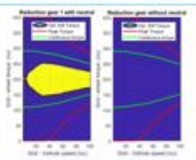
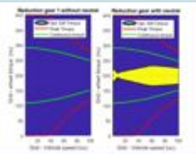
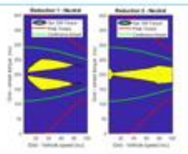
Topology	For baseline design	For design variants		
		Variant 1	Variant 2	Variant 3
VOLVO FE 				
TESLA Semi-truck 				

Table 2-7: Table VOLV FE and TESLA Semi-truck transmission optimal control for baseline and design variants

Topology	For baseline Design	For design variant		
		Variant 1	Variant 2	Variant 3
VOLVO FE 				
TESLA Semi-truck 				

2.1.4.3 Component sizing optimization

Consider the effect of component sizes on the optimization of BEV design, a baseline is selected for the electric machine. The sizes of corresponding component are varied during the early design process using the varied scaling factors and baseline parameters. Defining components that fulfil basic powertrain performances requirements and elaborating the optimum combination of component characteristics to achieve the highest powertrain efficiency. In this case, study the objective is to assess the area of evaluating the different variants of machine types from a fixed catalogue of pre-calculated list, and optimizing the selected parameterization and a multi-domain performance assessment in order to achieve the target of optimizing the efficiency of the electric powertrain concept on complete vehicle level requirements. The problem of design optimization of this E-Machine component can be tackled in two different approach, by using the backward approach and the forward approach.

- **Based on backward vehicle simulation**

With integrating the in-house optimization tool, we can initiate the initial backward approach, which includes the grid-search algorithm, and the optimization-based algorithm where a differential algorithm is used to undergo a design optimization for the appropriate component selection method. This backward approach utilizes the brute force calculation script in order to assess the optimum feasibility of EM design with respect the different Vehicle application and the drive cycle. This will give in some key feedback input to the forward approach with the control map files generated.

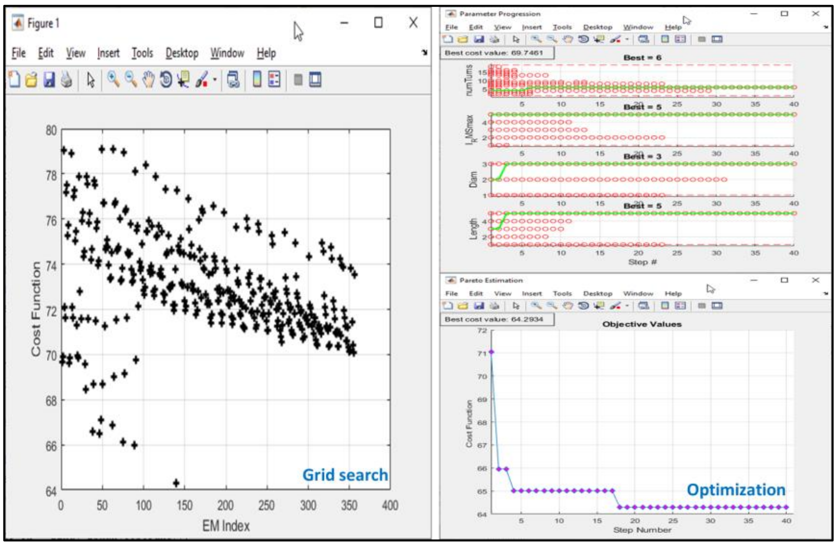


Figure 2-9: Component sizing optimization with backward vehicle simulation with a) grid search and using b) optimization algorithm

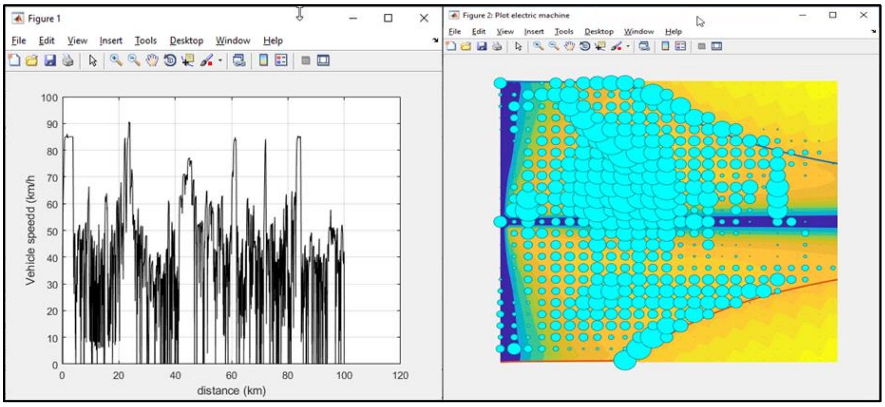


Figure 2-10: Vehicle speed considered for backward calculation ((ACEA Urban delivery cycle - 16T vehicle application), EM best candidate and EM operating points with powertrain layout 1

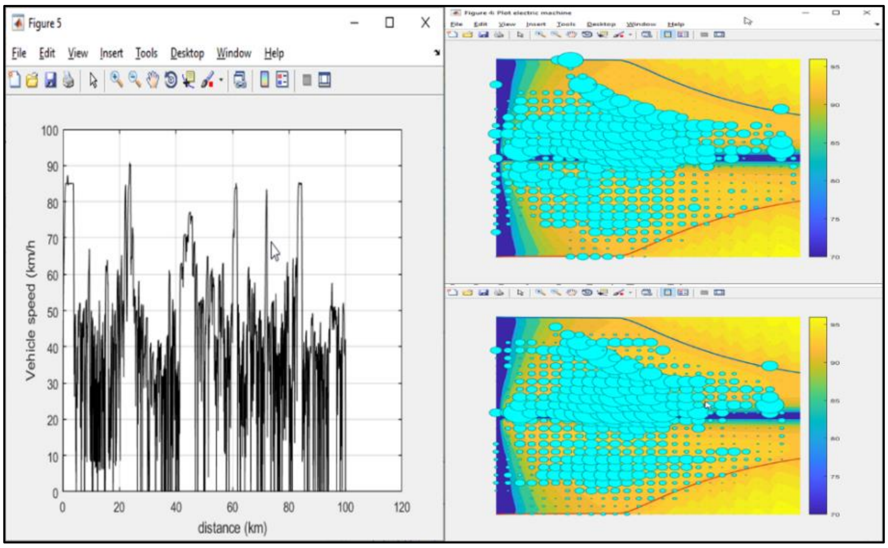
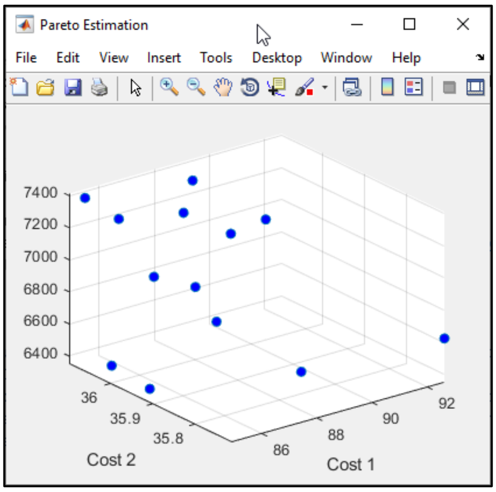


Figure 2-11: Vehicle speed considered for backward calculation ((ACEA Urban delivery cycle – 27 T vehicle application); EM best candidate, EM1 and EM2 operating points with powertrain layout 2

- **Based on forward vehicle simulation**

With the forward approach, based on the iterated control map files generated using the backward optimization, and the data settings of the improved target vehicle spec and model, we find the performance analysis of this vehicle powertrain system with the multiple EM catalogue and obtain the optimized result for various road applications. The main benefit of this approach is the use of a more realistic vehicle that includes keys powertrain component limit among which impact of torque interruption during gear shifting or electric machine thermal limitation. The forward optimization will also suggest us the study of the performance constraint where in, we will be able to assess the gradeability, startability and acceleration evaluation of the target truck with the feasible EM candidate. This will help us narrow down on the more feasible passed designs.



1	2	3	4	5	6	7	8	9	10	11	12	13	
'Result filename'	'numTurns'	'I_RMSmax'	'Diam'	'Length'	'Avg_obj'	'Cost 1'	'Cost 2'	'Cost 3'	'perfoConst...	'perfoConst...	'perfoConst...	'designCon...	'des
'Vehicle_Matrix_STEP14_10_1.mat'	7	3	4	8	1.9511e+03	86.6748	-36.1033	5.8028e+03	-21.6000	-1.3530	-2	-1	-566
'Vehicle_Matrix_STEP2_15_1.mat'	8	4	6	8	1.9832e+03	86.3438	-36.1643	5.8994e+03	-22.8000	-0.4470	-3.8000	-1	-433
'Vehicle_Matrix_STEP2_15_1.mat'	8	4	6	8	1.9832e+03	86.3438	-36.1643	5.8994e+03	-22.8000	-0.4470	-3.8000	-1	-433
'Vehicle_Matrix_STEP18_12_1.mat'	6	4	5	8	2.1343e+03	86.2162	-36.0892	6.3528e+03	-24.3000	-3.2790	-7.7000	-1	-499
'Vehicle_Matrix_STEP10_2_1.mat'	6	5	5	8	2.2236e+03	86.1812	-36.1055	6.6209e+03	-25.3000	-3.3380	-3.7000	-1	-499
'Vehicle_Matrix_STEP7_7_1.mat'	6	5	6	8	2.2334e+03	86.0772	-36.1081	6.6502e+03	-25.3000	-3.7140	-7.7000	-1	-433
'Vehicle_Matrix_STEP10_2_1.mat'	6	5	5	8	2.2236e+03	86.1812	-36.1055	6.6209e+03	-25.3000	-3.3380	-3.7000	-1	-499
'Vehicle_Matrix_STEP15_5_1.mat'	6	5	1	8	2.1839e+03	86.3303	-36.1160	6.5014e+03	-25.1000	-1.8610	-3.5000	-1	-772
'Vehicle_Matrix_STEP14_4_1.mat'	6	5	7	9	2.2422e+03	86.1563	-36.1123	6.6765e+03	-25.4000	-3.7780	-7.7000	-1	-368
'Vehicle_Matrix_STEP17_8_1.mat'	8	5	6	8	2.0667e+03	86.2873	-36.0972	6.1501e+03	-23.2000	-0.4440	-7.7000	-1	-433
'Vehicle_Matrix_STEP10_2_1.mat'	6	5	5	8	2.2236e+03	86.1812	-36.1055	6.6209e+03	-25.3000	-3.3380	-3.7000	-1	-499
'Vehicle_Matrix_STEP12_7_1.mat'	6	5	4	8	2.2136e+03	86.3059	-36.1200	6.5908e+03	-25.3000	-2.9650	-3.7000	-1	-566
'Vehicle_Matrix_STEP10_2_1.mat'	6	5	5	8	2.2236e+03	86.1812	-36.1055	6.6209e+03	-25.3000	-3.3380	-3.7000	-1	-499
'Vehicle_Matrix_STEP15_5_1.mat'	6	5	1	8	2.1839e+03	86.3303	-36.1160	6.5014e+03	-25.1000	-1.8610	-3.5000	-1	-772
'Vehicle_Matrix_STEP10_2_1.mat'	6	5	5	8	2.2236e+03	86.1812	-36.1055	6.6209e+03	-25.3000	-3.3380	-3.7000	-1	-499
'Vehicle_Matrix_STEP12_7_1.mat'	6	5	4	8	2.2136e+03	86.3059	-36.1200	6.5908e+03	-25.3000	-2.9650	-3.7000	-1	-566
'Vehicle_Matrix_STEP18_12_1.mat'	6	4	5	8	2.1343e+03	86.2162	-36.0892	6.3528e+03	-24.3000	-3.2790	-7.7000	-1	-499
'Vehicle_Matrix_STEP12_4_1.mat'	8	5	5	8	2.0575e+03	86.2287	-36.0968	6.1224e+03	-23	-0.1040	-4	-1	-499
'Vehicle_Matrix_STEP10_2_1.mat'	6	5	5	8	2.2236e+03	86.1812	-36.1055	6.6209e+03	-25.3000	-3.3380	-3.7000	-1	-499

Figure 2-12: Multi-objectives for EM component sizing optimization and detailed results

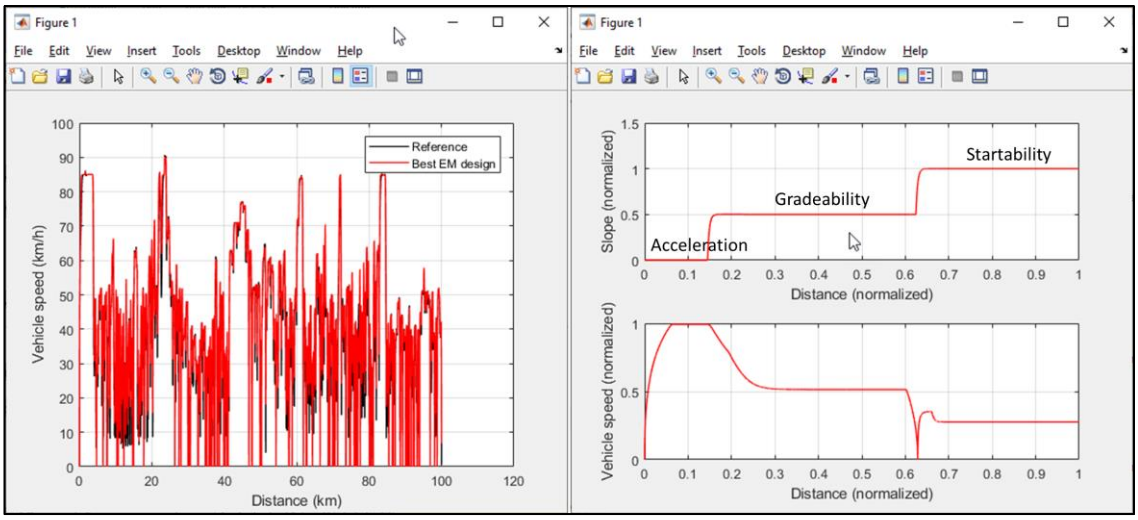


Figure 2-13: Vehicle speed comparison (ACEA Urban delivery cycle) and performance constraints verification (acceleration, gradability and startability) for best EM design

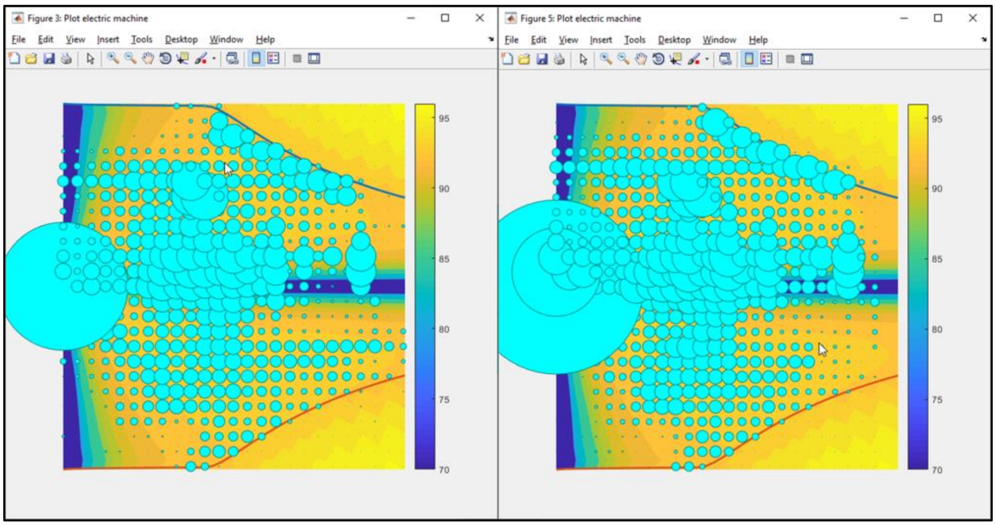


Figure 2-14: EM sizing optimization - Backward approach with single objective optimization (energy consumption) versus Forward approach with multi-objective optimization (vehicle performance, energy consumption and component cost)

2.2 VALEO/SIE-SAS – UC1.2: 48V electric vehicle configurator

2.2.1 Configuration and automation capabilities

UC1.2 focuses on 48V electric vehicle simulations. Two vehicle concepts have been evaluated, a 2 axles drive and a 4-wheels drive, leading to the development of two vehicle simulators using Simcenter Amesim. Standard components have been used to model complete vehicles.

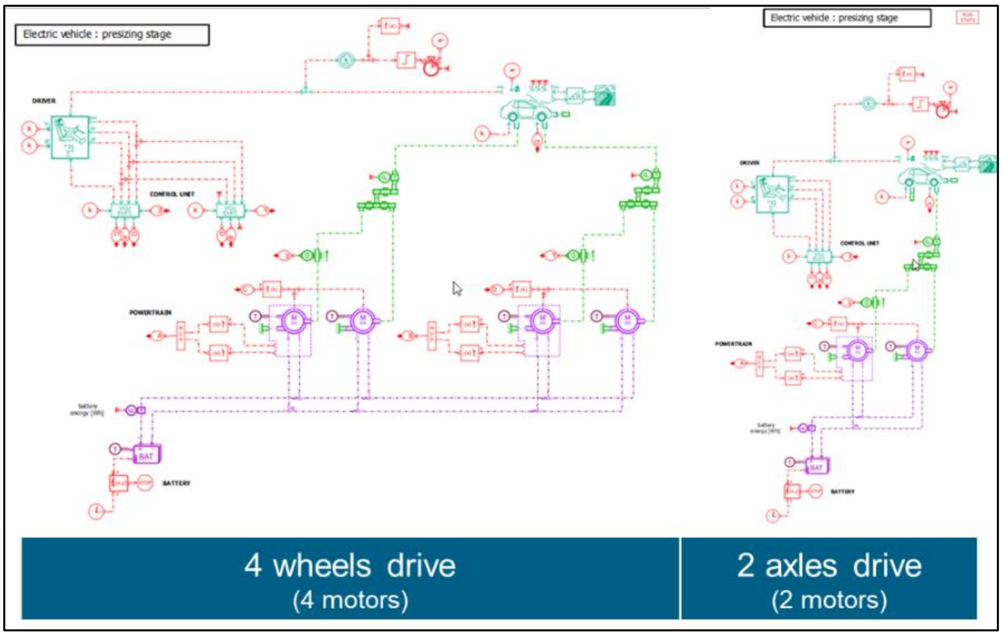


Figure 2-15: 48V EV architecture variants

Parameter optimization can be done using Amesim built-in parameter batches capabilities, using scripting (Python, Matlab) or by using external optimization tool. In this use case the baseline models have been parameterized using the Simcenter Heeds [7] tool.

2.2.2 Standardization

The two vehicle configurations share a similar structure and use the same sub-models for vehicles, driver, transmission, e-motors and batteries. E-Motors used in the two simulators are strictly identical. Battery packs are using the same pre-calibrated cell models, and only differs the packs configurations (numbers of parallel modules).

The standardized interfaces developed in WP3 and described in [8] have been used. This enables to adjust the modeling level of each subsystem depending on the simulation focus (scalability), as well as to easily add additional subsystems to the baseline models. For instance, map-based quasi-static e-motor models are used for energy consumption on driving cycle evaluations but are replaced by electromagnetic thermal model in Simulink using co-simulation to check the influence of dynamics effect on energy consumption.

2.2.3 Trade-off process

The trade-off process is performed in three steps:

- 1st step: optimization of the transmissions and battery pack sizing
- 2nd step: optimization of e-motor control strategies
- 3rd step: optimization of auxiliary power management

1st Step description: Multi-objective optimization using Heeds

The Heeds-Simcenter Amesim portal allows to modify parameter values (including initial values of state variables) and extract variable values of the Amesim model. The portal launches Amesim with customized python code to update and/or extract details of the model. The main vehicle parameters optimized in this process are the transmission parameters (front and wheel gear ratio, wheels dimensions) and the battery pack configuration.

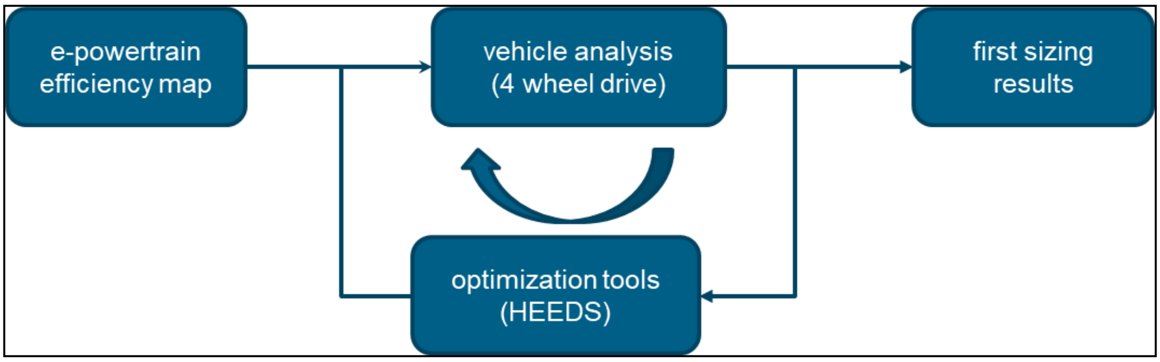


Figure 2-16: HEEDS optimization process

The optimization objectives are the following, using three variants of the Amesim simulator:

- to maximize the powertrain efficiency on a WLTP driving cycle,
- to maximize acceleration while ensuring gradability test.

Multiple instances of the Amesim models can run simultaneously on the same computer. Indeed, the number of instances to run concurrently is limited by the number of cores of the machine, allowing HEEDS to complete design explorations significantly faster than running sequentially. Nevertheless, some calculation on HPC for bigger design of exploration is also possible.

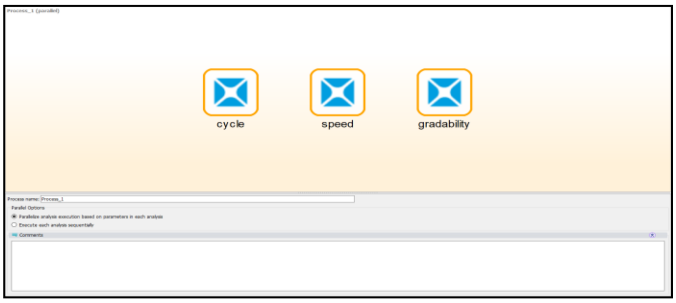


Figure 2-17: Simcenter Amesim simulator variants in HEEDS

The Hybrid Adaptive Method SHERPA has been chosen for the optimizer and the analysis has been launched on 500 iterations. Heeds post-processing capabilities enables to analyze the different design performed and to identify relationships between variables and/or responses using correlation plots. From the feasible designs, the best compromise has been selected and is use as input to the optimization of the e-motor control strategy.

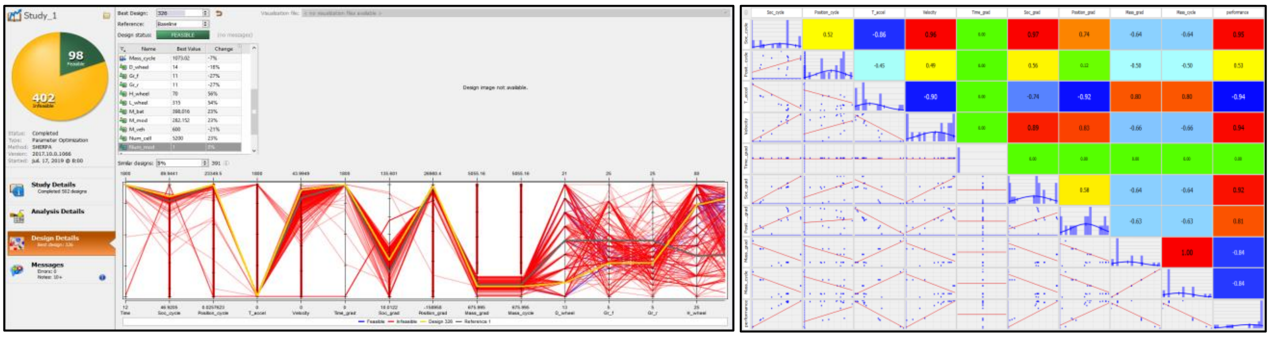


Figure 2-18: HEEDS study results

2nd Step description: optimization of e-motor control strategies

An optimal control of the electric machines has been generated using the Simcenter Amesim Hybrid Optimization Tool (HOT). HOT is based on optimal control and specifically on the method known as Pontryagin's Minimum Principle (PMP). With this control, the torque distribution between the machine is optimized, and the electric machines are operating on a larger range and for operating points with higher efficiencies. The regenerative braking is optimized as well.

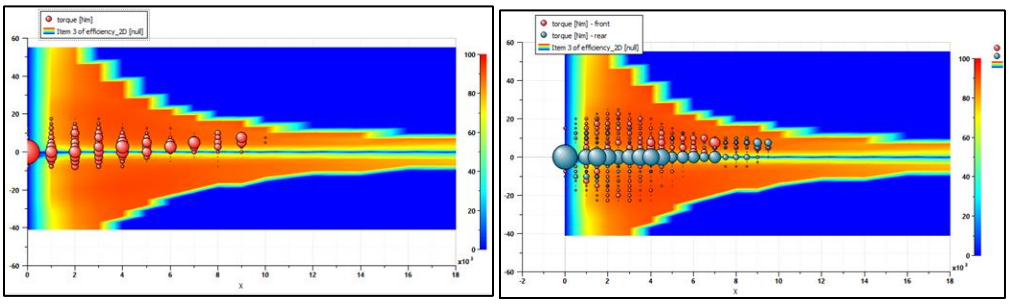


Figure 2-19: Electric machines operating point: baseline and optimized control

The potential gains of this control have been evaluated on 3 different cycles (WLTC class3, JC08 and specific city cycle), and import efficiency improvements can be achieved especially in urban conditions.

3rd Step: auxiliary power management

An auxiliary power management system has been introduced to optimize the trade-off between the average consumption and the driver thermal comfort. The auxiliary power management system has been developed by UNIFI in Simulink and is working in cosimulation with the Amesim multi-domain vehicle model. According to battery conditions (SoC) and cabin temperature, a strategy (Eco mode) is activated to reduce some none prioritized auxiliary consumptions (e.g. fan, blower, compressor).

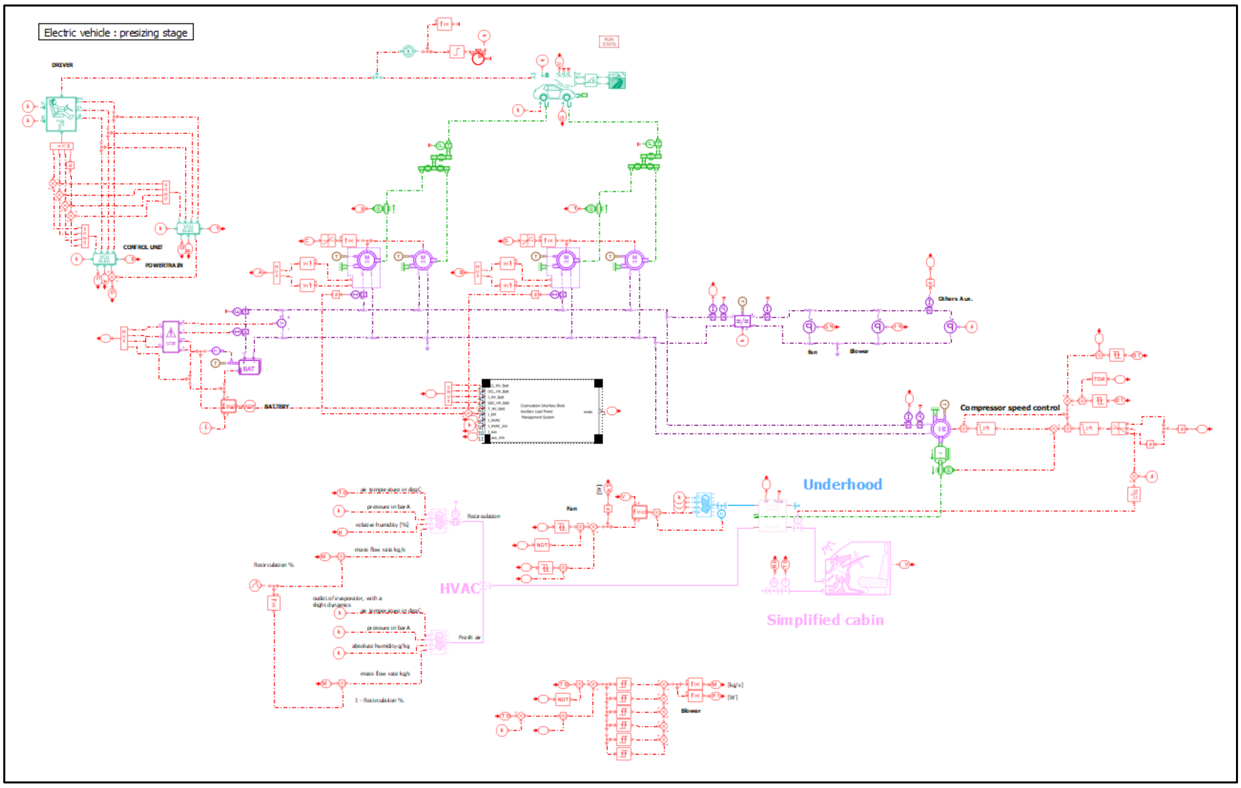


Figure 2-20: model including Air conditioning and auxiliary power management

With this three-steps optimization methodology significant improvement of the performances and efficiency of the vehicle has been obtained with respect to the initial baseline design. All results will be detailed in deliverable D6.1 (Design of new e-drive concepts, optimal system sizing based on high Level virtual system integration tools and simulation report on assessment of virtual simulation methods).

2.3 UNIFI/SIE-NV – UC2.2: Braking system model integration methodology

This work presents an investigation of braking system characteristics, brake system performance and component design parameters that influence brake pedal force and displacement characteristics. It includes detailed studies of individual brake system component design parameters, operation, and the linear and non-linear characteristics of internal components through experimental study and simulation modelling. Each brake system component was modelled individually before combining them into the whole brake system in order to identify the parameters and the characteristics of the internal components that influence prediction capabilities and allows real-time simulations. Within this study, two type models were created and compared. Moreover, an assessment is carried, in order to enable further implementation in a repeatable way.
The proposed approach aims at the definition of a standardized methodology allowing to define precise and reliable model of EV (so-called Toy model) by accounting in a more accurate and simplified way braking actuator non-linear model, to be easily adopted in the early design stage of several plant layouts. Calibration of the models is based on a systematic testing procedure, allowing flexible transition from MiL to HiL.
This supporting tool, useful for components sizing and investigation, has been applied to a reference UC, as described in the following pages. Conclusion on the effectiveness of the proposed methodology is done.

2.3.1 Configuration and automation capabilities

2.3.1.1 Challenges and Aims of the activities

OBELICS set the goal of applying the developed models to various case studies. In our work, we will focus on the UC2.2, i.e. Siemens SimRod Figure 2-21. The SimRod brake scheme is also represented. The plant is made by two TT pipelines, one for each master cylinder.

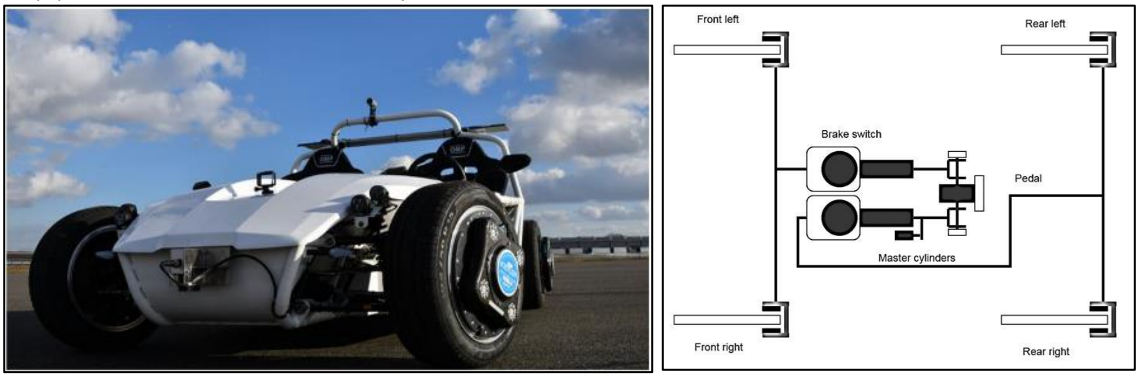


Figure 2-21: Siemens SimRod fully instrumented (left); SimRod braking system scheme (right)

The main goal for these activities is to develop a general brake model, real-time capable and able to assess the synergy within newly electric braking strategy. The test procedures carried out in previous work [1] [9] [2]. In the first part of this work a general description of the performed experimental activities, based on the previous model developed in Simulink environment [10] [11], is carried out and then a review of the entire model is made with a general assessment on the test procedures.
The resulting model consist of a hydraulic, thermal and wear behavior [11]. An in-depth analysis related to hysteresis is assessed. Previously proposed model was implemented in Simulink. The goal was the development of a standalone model able to receive braking demand and predict the braking torques, allowing to Model In the Loop e Hardware In the Loop simulations (MIL & HIL). Since a scalable model is needed to fit most case studies, the hydraulic plant was developed according to a functional decomposition method.

2.3.2 Standardization

2.3.2.1 Experimental Validation of Brake models: Hydraulic, Thermal and Wear

2.3.2.1.1 Hydraulic Model

Test procedure related to the hydraulic model is split up into two main parts:

- Calibration test: during this phase, the vehicle should be in standstill condition.

- *Validation test*: we proceed with a validation run to evaluate vehicle behavior in real operation.

Data used comes from a setup carried out in previous works [1] [9] [2] [10] [11]. Understanding how measurements and experimental test were carried out will be helpful to assess if calibration test procedures are adequate to determine braking system characteristics. The signals needed for model calibration are:

- *Pressure of hydraulic plant*: measured using 2 piezometric transducers, one for each axle. Since UC2.2 has a TT scheme, is correct to assume the same pressure for the right and the left calipers.
- *Pedal displacement or piston rod displacement*: since the UC2.2 doesn't have enough space to install a larger variety of displacement sensors, 2 wire displacement sensors have been applied.
- *Piston rod strain*: to measure the applied force on the pedal, 2 single-grid strain gauges were installed. This particular configuration allows us to compensate for the bending moves during load application.

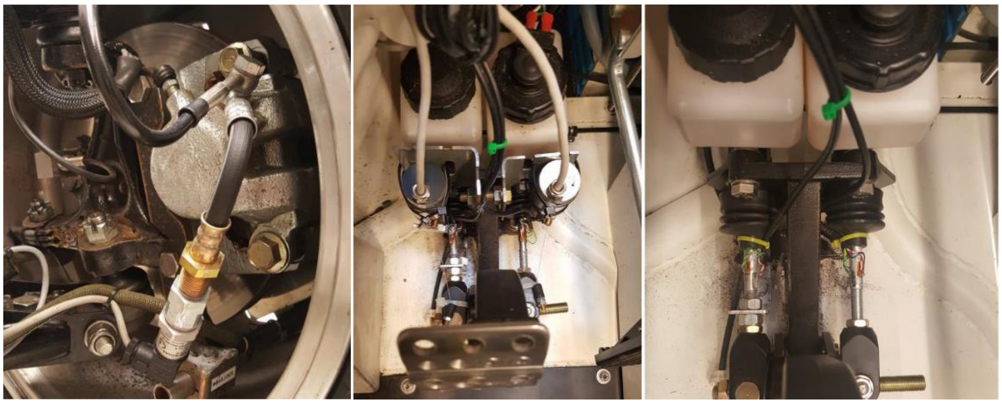


Figure 2-22: Pressure sensor (left), Pedal wire potentiometers (middle) and piston rod with strain gauges

2.3.2.1.2 Thermal and Wear Models

In order to better represent the phenomenology of our brake plant two important factors must be considered

- Thermal behavior
- Wear behavior

The first one will lead to a drop in the friction factor and a reduction in braking force while the other will cause severe environmental burdens related to PM emissions. Let's check some of the possible causes and which components are affected by these phenomena [11].

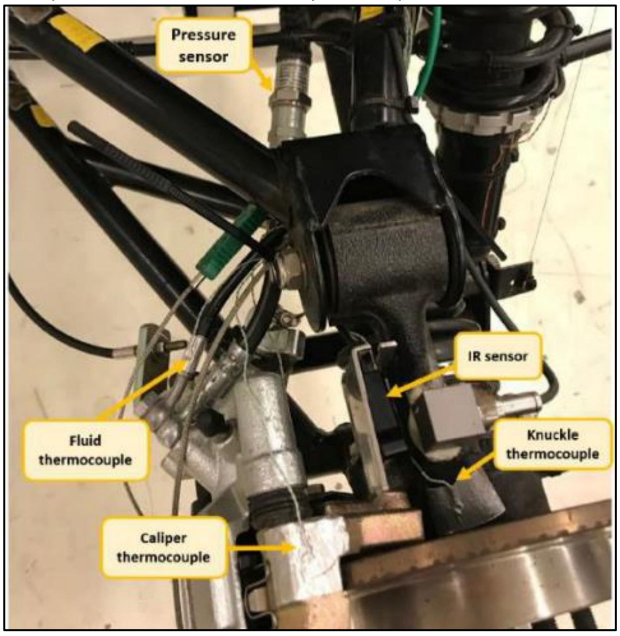


Figure 2-23: Sensors set up for the UC2.2

Let’s take an overview of the experimental activities conducted for the thermal and the wear model. Installed sensors are: Rubbing thermocouples, Pad thermocouples, IR sensors, Standard thermocouples, Pressure sensors and Torque sensors (Figure 2-23).

2.3.2.2 Model-based approach: The Braking System

In this work, brake models in Amesim environment were proposed and then validated by experimental results.
In modern vehicles, electronic control unit and mechanics automated actuations are constantly increasing. This means that testing entire systems in real vehicle start to be time-consuming lead the development process into time-to-market delay. In this scenario of uncertainty, related to EVs switch, ADAS offer growth and customer habits all the O&M, car manufacturers need to optimize the testing process switching from a real-world evaluation into accurate laboratory test campaign. Therefore Hardware-In-the-Loop simulations take the field both for the electronics and for the mechanical components [12].
Models can be validated early on through simulation and verified continuously as the component models are refined with additional implementation detail.
Force Imposed Model: The first part of the study is related to carry out a force-imposed model for the UC2.2 within the OBELICS project. In the previous work, a simplified hydraulic model was done, and reduced parameters needed to describe the system were estimated. The new aim for the activity is to improve the model adding new features and allowing better parameter estimation, maintaining the real-time capabilities (Figure 2-24).

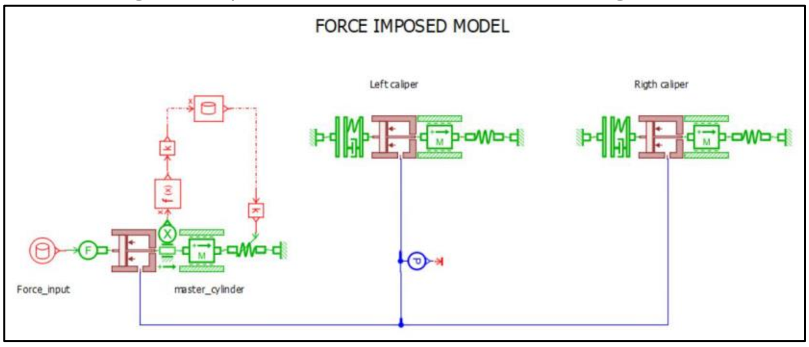


Figure 2-24: Force imposed model overview

Displacement Imposed Model: In this section, we will carry out a simple displacement-imposed brake model in order to predict the pressure giving master cylinder travel as an input. This will help in the implementation of the model in the Virtual Reality environment. Indeed, measuring the displacement is easier than install on the system any device capable to estimate the force with acceptable accuracy.
The model carried out share most of the part with the previous force-imposed model since one of the main purposes within the OBELICS project was to develop a model-based brake system able to switch easily between different configurations. This results in our case in a force-imposed model with a feedforward on displacement.

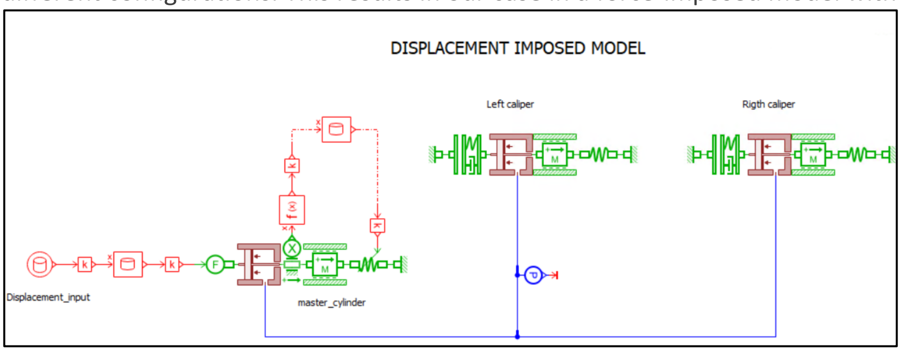


Figure 2-25: Displacement imposed model overview

2.3.2.3 Hysteresis behavior in brake plant

Hysteresis is a nonlinear phenomenon exhibited in various science and engineering field. Hysteretic systems often present a quasi-static response where input and output lead to a cycle and not a line as in the linear model assumption. This behavior is firstly due to the physics of the problem and for instance, is not that easy to properly understand all the physical law for every engineering application. This is an arduous task and most of the resulting models are too complex to be used. In this scenario, several mathematical models have been proposed in order to describe the hysteresis phenomena. One of the most used is the so-called Bouc-Wen model. Mechanical hysteresis in brake plant is a well-known effect. It will lead to delay in system reactions reducing both the pedal feedback and the control accuracy in safety systems like ABS and ESC.

Any investigation related to this application it's a complex task because conventional hydraulic brake system presents many hysteresis elements, e.g. vacuum booster, pipelines, brake cylinders, seals and friction pads [13].

In this chapter, an in-depth study for the hysteretic behavior is carried out and suggestion for new test procedures are assessed.

For the experimental validation, we exclude a priori the thermal effects since the tests are static and carried out at a constant temperature. We exclude also the elasticity of the pipeline since the hydraulic system for the UC2.2 it's equipped with stiff tube reducing the lung effect below zero.

The next step consists in removing the loops from the cycles, so we implement a sort of conditional sampling which avoids choosing points within the loops and then interpolate the sample vector with given equations. Then, estimate a 95% confidence interval or rather the interval where our hysteresis cycle will be with a 95% probability. What we can clearly see in Figure 2-26 is that the confidence interval plotted for the downhill curve seems to be thinner respect to the other two. This means that most of the backward travels come out with lower variability respect to the forward travel and it's attributable only to how the procedure was carried out. Related to these observations it's important to point out that tests were made with no speed control, leaving the experimenter free to impose the pedal velocity according to his capabilities. During forwarding travel tester is not capable to maintain a constant velocity while during the backward travel helped by the spring the experimenter is able to maintain the pedal rate within a lower spread. This also means that hysteresis cycles are affected by a different pedal rate that we are not able to characterize since in a single run more than one velocity can be detected.

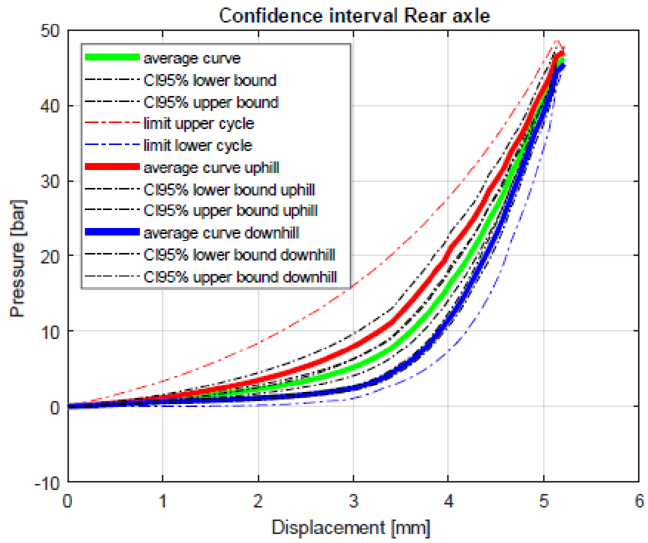


Figure 2-26: Confidence interval rear axle

2.3.3 Trade-off process

2.3.3.1 Force-imposed and Displacement-imposed Models Comparison

A global comparison between force-imposed model and displacement-imposed model is done, considering the results for at least one maneuver for each test set.

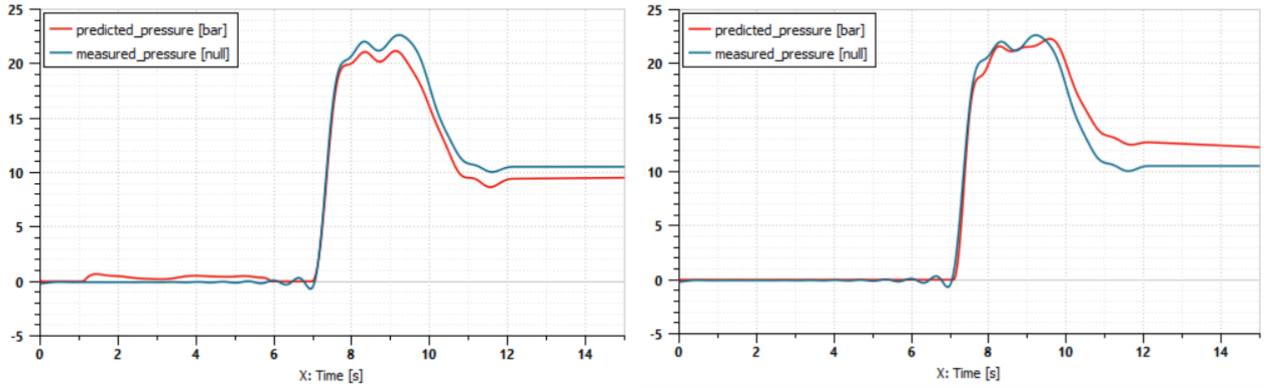


Figure 2-27: Force-imposed (left) and the Displacement -imposed (right) models comparison for the 30_kph_high test

In Figure 2-27 we can see a comparison between the displacement-imposed model and the force-imposed model. Regarding the near-zero pressure phase in the force-imposed model, we can see an error in the prediction. This is probably due to the fact that the strain measured during moving test is not that accurate like in the static calibration and this result in lower quality force and, therefore, in error in pressure prediction. Results of the displacement-imposed model for the same test is shown, as we can see there's a difference in the curve shape since the predicted one is scaled starting from the displacement one.

A possible explanation for this uncertainty in the pressure prediction consist of two overlapping phenomena:

- When the piston stop within near-zero velocity static friction is established and this results in a friction force. However, in a brake system, the friction coefficient is not the only things that cause a change in friction force. Indeed, the normal load applied to the gasket depends a lot from the pressure magnitude. This behavior's amenable to the seal shape that causes an increasing normal load on the seal introducing nonlinearity within the friction force estimation. When the master cylinder piston is moving, pressure and force showed a good correlation. Once displacement becomes stationary and the static friction is established, the relationship between force and pressure starts to diverge and is not recovered until the difference reaches a certain value that causes the piston to move.
- Another phenomenon is the delay between the displacement force and pressure. Firstly, the force at master cylinder start to rise and, once the force wins the preload value, the piston at the master cylinder start to move, however, it's only when pads come into contact with the disc that pressure will increase. This means that between pressure and displacement there will be always a delay.

This means that displacement-imposed model will be able to well approximate the pressure shape during the transient phase even with a little delay due to the aforementioned phenomenon. However, these contributions are reasonable for most of the performed tests.

In the following list, main observations are resumed

- Looking at the global assessment for the RMSE, it is clear that both models are good enough to allow pressure prediction within the UC2.2 braking system.
- To improve displacement-imposed model an approximate measurement for the pad disc clearance can be measured in further campaign test.
- A good pressure prediction is possible even neglecting the Coulomb friction within various components.
- Related to the test procedure, calibration could be revisited in order to assess leakage entity within various conditions. Single-step test results more suitable for our purpose and carrying out with one step maneuver at different displacement will be better to evaluate leakage parameter.
- Regarding the instrumentation, at least one more pressure sensor needs to be installed in order to carry out a proper validation for the master cylinder and asses pipelines elasticity.
- Strain measurement can be affected by chassis motion within various driving conditions.

2.3.4 Discussions and Conclusions

In this work, two complete brake plant models were carried out, a force-imposed model and a displacement-imposed model with feedforward displacement. In the overall model, all the contributions were considered, hydraulic, thermal and wear. Model validation for the hydraulic part has been carried out within different manoeuvres and within various moving, tests ensuring a statistical overview of the model accuracy. Moreover, a comparison between the two models is made in order to assess the pros and cons of both.

Above all, the most important thing that comes out from this study is a generalizable approach that allows the experimenter to move from raw dataset to a model coherent with the experimental results in a reduced number of steps. Within this purpose, a critical analysis of the test procedures and the measuring instruments is done considering all the limitations that these two aspects introduce.

Lastly, we focused on the hysterical behaviour in the hydraulic circuit of which a detailed study is reported. Further improvements related to this aspect are closely related to the calibration test procedures, that needs to be reorganized in order to accomplish the goal.

Trying to draw out overall conclusions

- Force imposed model and displacement-imposed model shown satisfying results within various moving tests procedures even with some limits due to nonlinearity that are not considered within this thesis.
- New methods able to characterize hysteresis behaviour have been carried out. This part has not been yet completed, however interesting conclusion on how the actual experimental data should be used and improved using other datasets from new activities, has been made.

Further improvements for this work will be carry out new calibration test procedures, to see if a proper hysteresis characterization is possible, perform an in-depth study on real-time capabilities and optimizing within this purpose and use a hardware platform able to translate input from user to input to software in order to enable the model to virtual reality environment. Finally, this methodology allows standardized process as well as process execution validation in early stage of the EV design development concept phase.

3 Tools supporting virtual system integration studies (SIE-SAS, CRF)

In this chapter, several methods for integration will be described and have been illustrated in different use cases. In system integration stage (complete vehicle modeling), subsystems generally come from different department. As example, electric powertrain and thermal comfort could be developed in parallel, as already described in previous deliverable [1]. Nevertheless, final validation by combining these subsystems and studying their interaction is mandatory to tends towards a closer behavior in terms of energy consumption.
Another challenge in integration process is the reliability in terms of connection. Indeed, the definition of inputs and outputs must be addressed early in design phase [8] to ensure consistent subsystem model development. So dedicated tool and method should be applied to ensure numerical stability and correct connection to reach consistent system integration studies as highlighted in Figure 0-1.

3.1 CRF/SIE-SAS – UC2.5: Integrated tool for virtual integration

3.1.1 Configuration and automation capabilities

Until now, with conventional powertrain, most part of components that have an impact from the energetic point of view have been modelled separately. In fact, from energy management point of view, cabin comfort auxiliary systems are not considered because the normative does not require their activation, and the cooling systems neither because the cycles are performed in a temperature condition (20-23°C) in which they do not affect significantly the powertrain performances.
Therefore, all subsystems are studied separately with minor integration between them (only some boundary conditions), as illustrated in Figure 3-1. This previous approach led to estimation of consumption, without considering realistic behavior or by combining consumption and thermal comfort.
Nowadays, an assessment of the vehicle energetic behavior in a more realistic condition than the one required for the CO2 homologation is becoming very important in order to avoid a too large gap between the vehicle consumption declared and the one observed by the customers. This item is of course important for vehicle with conventional powertrain, but it is even more to be monitored for electric vehicles in which the autonomy can have an important variation depending on the environment conditions in which the car works, the auxiliary's systems activation and the driving style.

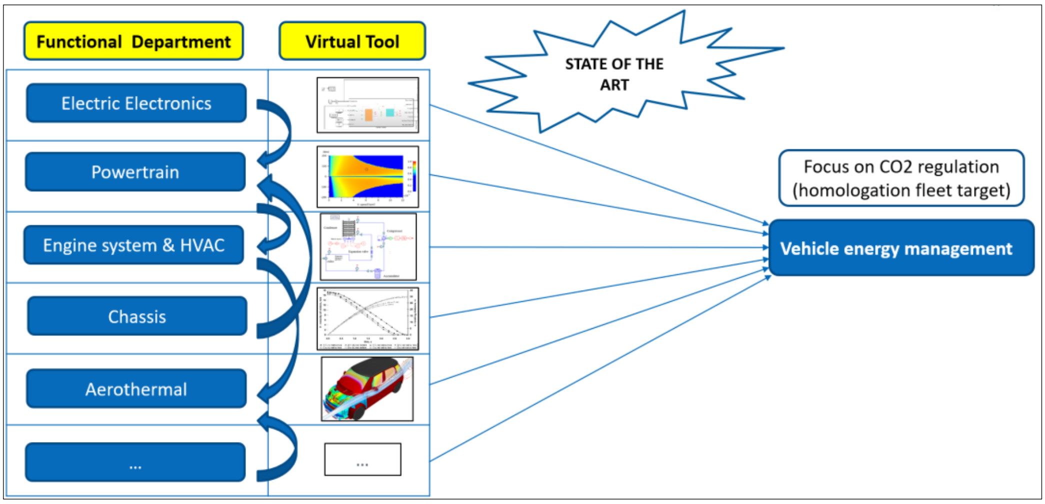


Figure 3-1: State of the art of virtual integration in CRF

A more realistic mission of the car means new complex requirements for the simulation tools that should be more accurate in several different conditions with a higher fidelity of the models.
Therefore, during this project, an enhanced modelling approach has been developed (described in D3.4), with complete integration of subsystem in order to integrate all subsystems in only one simulation tool. In this way, all

subsystems interact with others by sharing variable boundary conditions along more realistic driving cycle, especially for the thermal comfort, as illustrated in Figure 3-2.
Basically, 1D model, corresponding to the complete vehicle modelling from electric powertrain to all thermal subsystem, has been connected with 3D phenomenon like external flow, flow under the hood and internal flow in cabin, calculated using CFD on HPC.

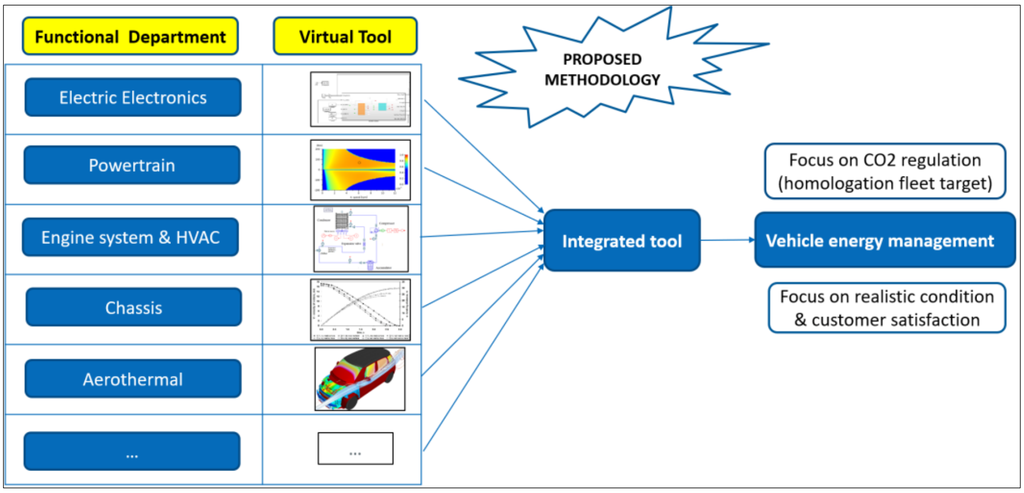


Figure 3-2: Integrated tool for virtual integration in CRF

3.1.2 Standardized processes implementation and user interfaces

By using standardized interface, integration can be easily performed, avoiding lot of wasting time in integration process. This approach is also applied for al level of modeling during the design cycle from functional model to mapped-based or detailed one. With this approach, the connection between system is identical and only physics inside subsystem model is changed.
Furthermore, the reduction of simulation tool by focusing on multi-physics tool like Simcenter Amesim™ [14] allows easier and faster integration for most of subsystem in a vehicle, as illustrated in Figure 3-3. Another important advantage is the numerical stability, because some information is generally lost in cosimulation environment due to the communication interval, which could lead to an energy misbalance.

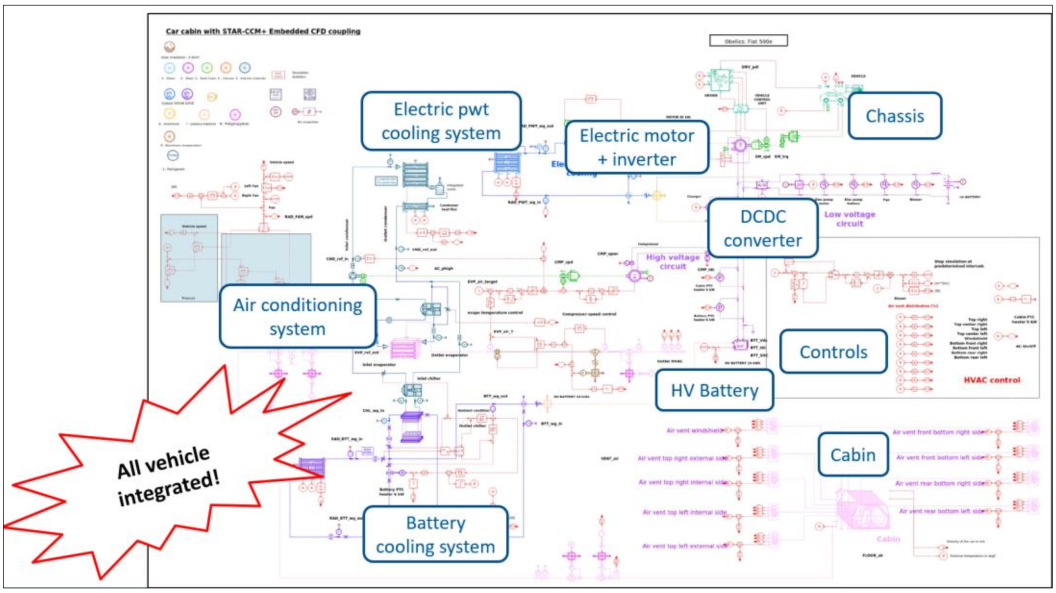


Figure 3-3: Vehicle subsystem integration in Simcenter Amesim

Nevertheless, some physical phenomenon could not be caught by 1D simulation, like 3D flow or 3D magnetics field calculation. In this case, some numerical "bridges" have been developed to connect these different levels of modeling, especially between Simcenter Amesim™ 1D system modeling and Simcenter STAR-CCM+™ 3D flow modeling, as illustrated in Figure 3-4.

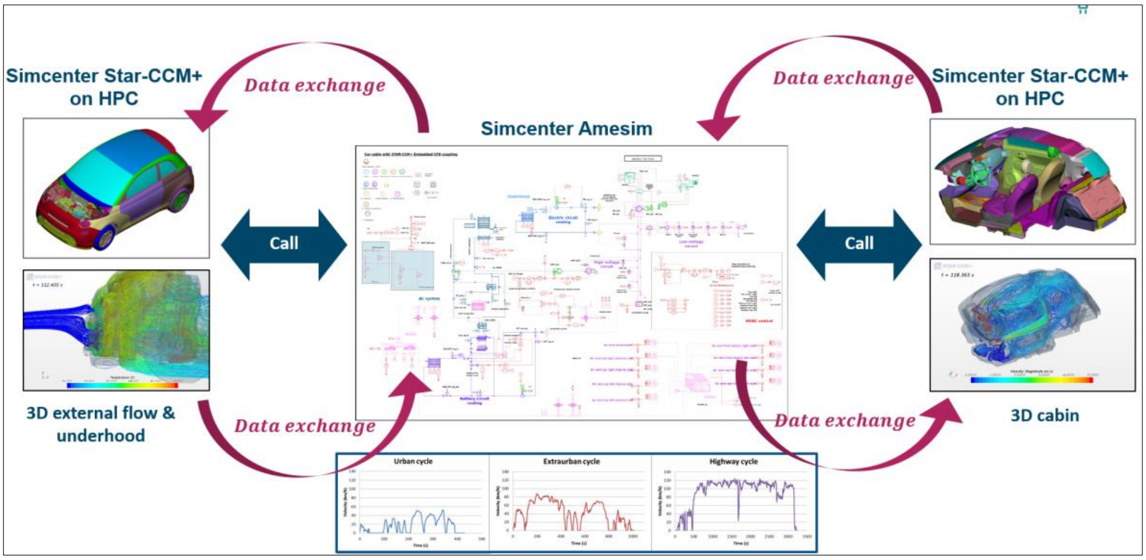


Figure 3-4: 1D/3D coupling interface integration

All models are easily piloted thanks to a python script that allows to launch 1D model locally and send 3D model on HPC before retrieving results.

3.1.3 Process execution validation on case studies

A dedicated coupling strategy has been developed in this use case to exchange data in a smarter way, by triggering the call of the 3D simulation and by storing previous results, as illustrated in Figure 3-5.
Some control signals have been defined, and their variation produces a CFD call (blue points in Figure 3-5). When an already run CFD calculation is needed, stored data are recovered and therefore a new CFD call is avoided (red points in Figure 3-5), with a consequent reduction in computational time.

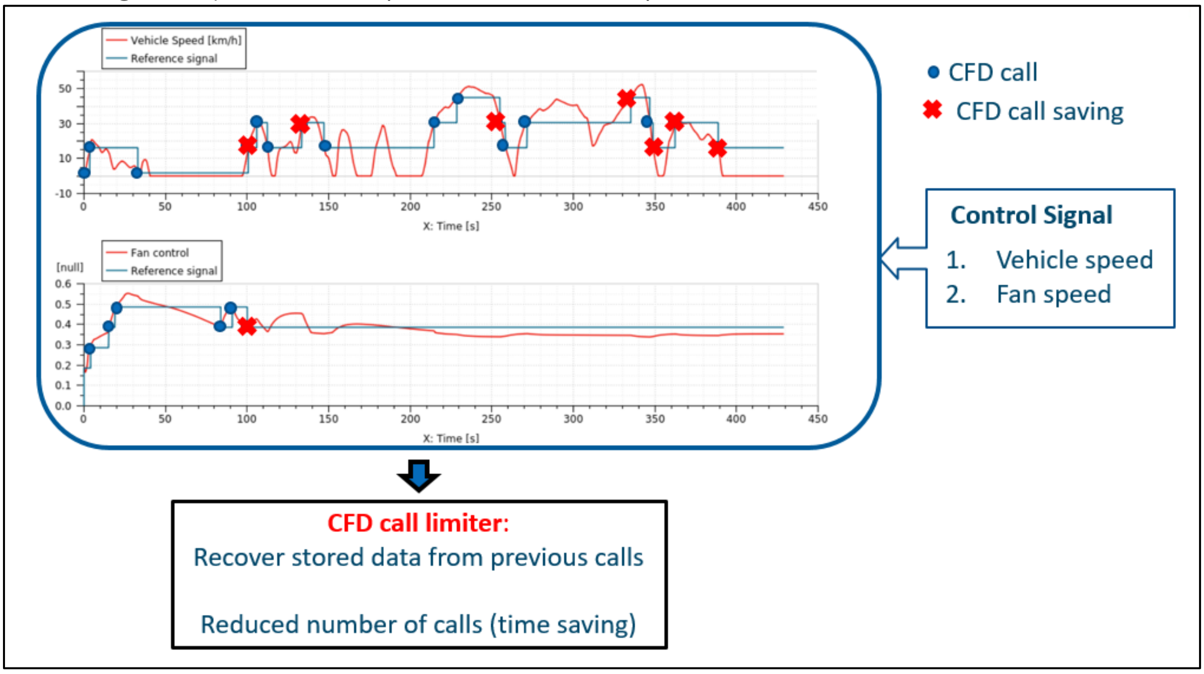


Figure 3-5: Coupling strategy between 1D and 3D models

This methodology allows interaction of all subsystems for a better understanding and study capability, but also allows running 3D simulation in driving cycle context in a limited time, as highlighted in Figure 3-6. We can observe that, thanks to this smart coupling, computational time becomes lower than one day for each analyzed scenario.

CFD time:
External CFD @ 280 CPU (HPC): 9 min
Cabin CFD @ 280 CPU (HPC): 3 min

Cycle	T ext	AC system	Computational Time
NEDC	35°C	ON	8 h
	23°C	OFF	2 h
	-10°C	ON	4 h
WLTP	35°C	ON	12 h
	-10°C	ON	6 h
Urban real driving cycle (429s)	35°C	ON	4.5 h
	-10°C	ON	2.5 h

Figure 3-6: Simulation time for different scenarios

All results will be detailed in deliverable D6.1 (Design of new e-drive concepts, optimal system sizing based on high Level virtual system integration tools and simulation report on assessment of virtual simulation methods). Additional results are also available in different publications [15], [16] & [17].

4 Conclusions

This document presents different tools developed by different partners (RT-SAS, VALEO, SIE-SAS, UNIFI, SIE-NV & CRF) either for early design phase or for virtual integration studies. All these tools are fully in line with OBELICS objectives to reduce time and effort in EV concept development. All detailed results and conclusion obtained thanks to these tools are described in deliverable D6.1.
Each tool is designed for a specific purpose from electric vehicle architecture design exploration to full complete electric vehicle integration analysis. These tools answer different requirements presented in the OBELICS grant agreement:

- Configuration and automation capabilities in the tools developed by RT-SAS and methods proposed by SIE-SAS
- Standardized process implementation and user interface in the tools developed by RT-SAS and UNIFI and CRF
- Process execution validation in the tools developed by RT-SAS and CRF

Tools developed by RT-SAS and methodology developed by SIE-SAS & VALEO focus on the trade-off process optimization by considering different electric vehicle powertrain architectures and analysis the relevancies of each of them. Processes have standardized to generate specification of all electric subsystem like the battery and the E-motor. UNIFI's tool is dedicated to generic braking model integration, but not only the plant model but also the control dedicated with a focus on energy saving and methodologies. SIE-SAS and CRF focus on standardized methodology for virtual integration allowing 1D and 3D model co-simulation on desktop and HPC. This method is being standardized through python script and allow deeper trade-off analysis with complete subsystem interaction impact.

Finally, these tools developed by simulation expert are accessible to non-expert thanks to standardized process and user interface leading to design phase time reduction which is key objective of this project.

5 Abbreviations and definition

ABS	AntiBlockierSystem
AC	Alternative current
ACEA	European Automobile Manufacturers' Association
BBC	Brake Blending Controller
BMS	Battery Management System
CA	Control Allocation
CAD	Computer Assisted Design
CCL	Charge Current Limit
CFD	Computational Fluid Dynamics
DC	Direct Current
DCL	Discharge Current Limit
EBD	Electronic Brakeforce Distribution
ECU	Engine Control Unit
EM	Electric Motor
ESC	Electronic Stability Control
ESP	Electronic Stability Program
EV	Electric Vehicle
FMI	Functional Mock-up Interface
FMU	Functional Mock-up Unit
GSP	Global Simulation Platform
GSPDB	Global Simulation Platform DataBase
HiL	Hardware In the Loop
HMI	Human-Machine Interface
HPC	High Performance Computing
HV	High Voltage
HVAC	Heating, Ventilation & Air Conditioning
ICE	Internal Combustion Engine
IWM	In-Wheel Motor
IM	Induction machine
ITEA	Information Technology for European Advancement
LV	Low Voltage
MCU	Motor Control Unit
MiL	Model In the Loop
NN	Neural Network
PI	Proportional Integral
PMSM	Permanent Magnet Synchronous Machines
RSM	Response Surface Methodology
RT-SA	Renault Trucks SA
SiL	Software In the Loop
UIC	Union International of Chemins de Fer
VMA	Vehicle Modular Architecture
VCU	Vehicle Control Unit
WRSM	Wound Rotor Synchronous Motor

6 Risk Register

6.1 Risk register

Mention here the risks that are linked to this deliverable. See the list of risks on the OBELICS sharepoint: https://projects.avl.com/16/0142/Documents/02_Deliverables/OBELICS_Deliverables%20list-TIMELINE_27092017.xlsx?Web=1

If a new risk occurred, please introduce in the table below, and mention;

"With reference to the critical risks and mitigation actions this deliverable is not linked to any open risk. See the monitoring file of the WPLB https://projects.avl.com/16/0142/Documents/02_Deliverables/OBELICS_Deliverables%20list-TIMELINE_27092017.xlsx?Web=1

New identified risks that occurred are listed in the table below.

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[2]	Solutions to overcome the risk
WPx.x	Describe here the risks!! And please refer to the section of the text in the document dealing with this.	Indicate the level	Indicate the level	Give a description how to overcome the risk / give here possible solution(s)

[1] Probability risk will occur: 1 = high, 2 = medium, 3 = Low

[2] Effect when risk occurs: 1 = high, 2 = medium, 3 = Low

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Project partners:

Partner no.	Partner organisation name	Short Name
1	AVL List GmbH	AVL
2	Centro Richerche Fiat SCpA	CRF
3	FORD Otomotiv Sanayi Anonim sirketi	FO
4	Renault Trucks SAS	RT-SAS
5	AVL Software and Functions GmbH	AVL-SFR
6	Robert Bosch GmbH	Bosch
7	SIEMENS INDUSTRY SOFTWARE NV	SIE-NV
8	SIEMENS Industry Software SAS	SIE-SAS
9	Uniresearch BV	UNR
10	Valeo Equipements Electroniques Moteurs	Valeo
11	Commissariat à l’Energie Atomique et aux Energies Alternatives	CEA
12	LBF Fraunhofer	FhG-LBF
13	FH Joanneum Gesellschaft M.B.H.	FHJ
14	National Institute of Chemistry	NIC
15	University Ljubljana	UL
16	University Florence	UNIFI
17	University of Surrey	US
18	Das Virtuelle Fahrzeug Forschungsgesellschaft mbH	VIF
19	Vrije Universiteit Brussel	VUB

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