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

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Publishable Executive Summary

This deliverable (D3.2) gives the description of new models, tools and methods supporting vehicle-level electric powertrain integration studies in a flexible and fast process.

These development tools will support new powertrain concepts, multiple configurations of physical and/or functional models and vehicle-level processing scalability to cover detailed to real-time compliant simulation, by using "toy models" as close as possible of the final demonstrators to early validate results maturity and ensure support for WP6 use cases defined in the OBELICS project.

These "Toy models" are composed of several mechanical, thermal and control subsystem models in combination of electrical components (Battery, motor & inverter) developed in WP2, as illustrated in Figure 0-1.

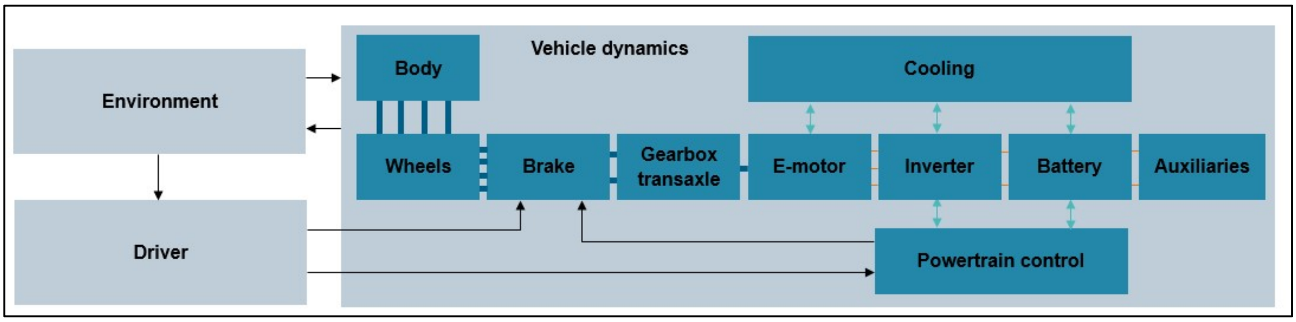

Figure 0-1 Toy model description

After reviewing all subsystems, examples of integrated toy model are also described and some preliminary results have been presented in order to highlight capability to such model in supporting new powertrain concepts.

1 Introduction

Electric Vehicle (EV) powertrain design are driven by vehicle power and range goals satisfying regulatory and real operations, while limiting components costs and insuring competitive production. It investigates key powertrain component sizing for a dedicated vehicle configuration (usually single motor FWD or dual motor AWD) but addresses chassis integration and auxiliaries in a later stage. These operations are supported by processes legacy of 100 years of engine-driven automotive design, leading to significant performances and acceptances issues when applied to electric vehicles.

First, it faces limitation in addressing, at industrial level, innovative powertrain designs involving more sizing dimensions and operation degrees of freedoms, for a full line-up of different vehicles configurations. Until now the vehicle powertrain design has focused on internal combustion engine (ICE), which was the only source of mechanical power. Torque was supplied to wheel through complex transmission (manual, automatic, continuous variable, dual clutch…) to optimize the fuel consumption. In the last decades, hybrid powertrains with additional electric vehicle have appeared, but still centralized around the ICE. Now with electric vehicle, motors become the main power source, without need of complex transmission, opening to complete breakthrough in term of powertrain architecture (one centralized motor to four in wheel).

Secondly, late consideration of strongly coupled systems leads to lower vehicle performance and comfort. Best examples are: a HVAC (impacting vehicle range over 50%) and chassis integration (brake blending, damping). Until now cooling were mainly passively managed with thermostat from more than 100 years. Air conditioning were mechanically connected to ICE through compressor without real control (compressor cycling...). Now compressor power is directly connected to high voltage circuit with high impact on vehicle range. A refined control has to be integrated to optimize this electric consumption and limit its impact on vehicle range. Furthermore, battery and motors has to work in optimal range of temperature to optimize their performance, meaning active cooling control becomes mandatory, with advanced electric pump and even heat pump (refrigerant loop not only used for thermal comfort but also for cooling purpose). In addition power flow only went from ICE to wheel with conventional vehicle, but now since HEV arise, power flows have to be considered in both direction (also from wheel to motor). The consequence on vehicle strategy has to be completely rethought.

Existing EV vehicle have been design based on conventional architecture, because new architecture are difficult to assess with existing tool. Control is mainly based on existing one, without exploring new integration between different subsystems. To set up new processes adapted to EV design, the automotive industry needs to be supported by a new generation of industrial modelling and simulation tools allowing the studies of innovative configuration combined with all the relevant systems impacting performances and comfort.

Providing new industrial tools and methods enabling the support at industrial level of new fully integrated EV architectures (electric, electronic, thermal, chassis) and designs, OEMs and tier 1 suppliers will be able to push beyond investigation of another generation of even efficient and affordable electric vehicles. This will enable new co-engineered optimizations of multiple combined components and controls to achieve higher overall vehicle performance, for conventional and automated operations. In this document, the first part is dedicated to new subsystem allowing more advanced and innovative powertrain architecture and deepened integration study, especially with control (braking & cooling). The second part highlight these complex integration issue, with different thermal subsystem and example of advanced control. Such toy models could be used to refine specification of electric component, validate the complete EV powertrain, but also to connect with virtual testing, reducing as a consequence the number and the duration of physical tests.

2 Toy model Subsystem description

Electric vehicles are not only composed of electric components. Indeed externally environment has to be considered and internally the chassis, the thermal system and control. All these subsystems are interacting altogether, making more complex the design of the electric powertrain. First of all a review of these components is presented to highlight the integration challenge between them.

2.1 Integration environments models

Several integration environments are being defined, covering simulation and co-simulation targets, standardized vehicle architectures, maneuvers, cycles (WLTC, real operations…), road topology, ambient conditions, and driver models.

2.1.1 Siemens environment model

2.1.1.1 Objectives

Objective of this subsystem is to supply external information from the vehicle, like ambient condition or driver behavior, as illustrated in Figure 2-1. Such subsystem is able to supply predefined condition like existing driving cycle, but also new kind of cycle like real driving scenarios. For the latter, new inputs are necessary like altitude or steering.

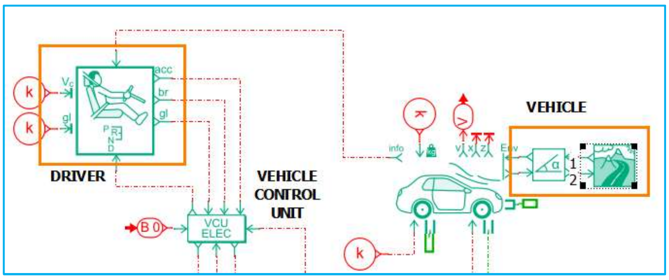

Figure 2-1 Siemens environment model overview

2.1.1.2 Driver model

Driver model dedicated to electric vehicle are already available. Indeed for such vehicle, gear shifting is not taken into account, only drive/neutral/reverse mode are considered. Acceleration and braking requests are both calculated with PI controllers. Furthermore anticipative control could be added but it is not necessary for such control.

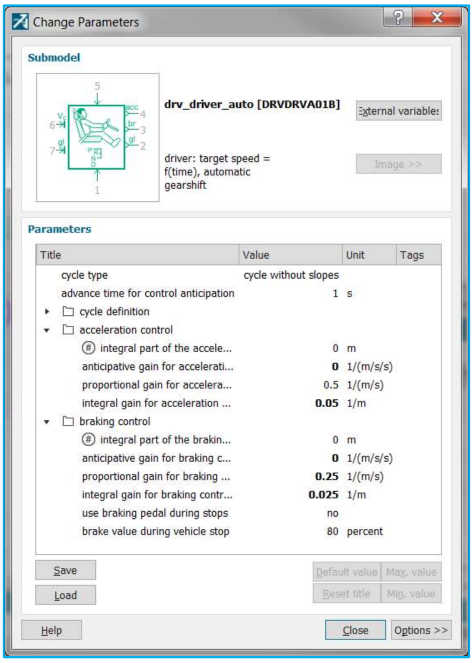

Figure 2-2 Siemens driver model

We can notice percentage of maximum brake torque is supplied when vehicle is stopped. In this case the value is set at 80%. The braking system is deeply detailed in section 2.6

2.1.1.3 Cycle model

Cycle models are now integrated in driver model to limit the number of component on the sketch. This model already contain a lot of predefined driving cycle from NEDC[1] to US/japan/European new standard, as illustrated in Figure 2-3

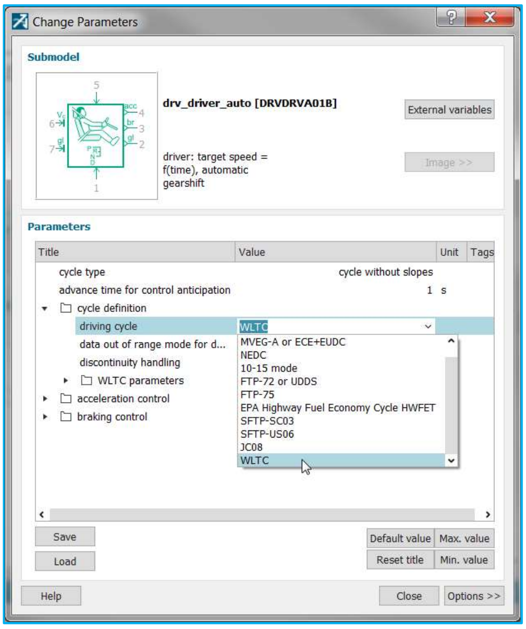

Figure 2-3 Siemens cycle model

[1] No more used for certification, but still useful for validation calibration process

Furthermore models allow user to add user defined scenario like real driving scenario. In this case 2 main files has to be filled; vehicle speed function of time or displacement and eventually gearbox ratio if necessary (only for manual transmission).

Road topology could be assessed by adding the slope, which is convenient for real driving scenario, as illustrated in Figure 2-4.

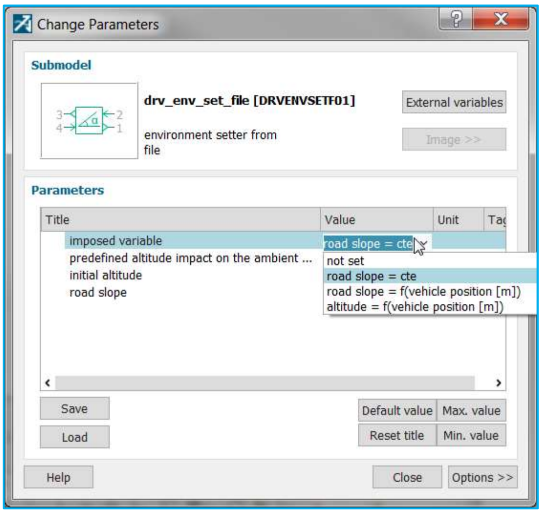

Figure 2-4 Siemens road slope model

2.1.1.4 Ambient model

Ambient condition could be set with only 2 inputs between the following 3: temperature, pressure and density. Generally temperature and pressure are considered, because they are measurable. So density is calculated by using perfect gas law.

Equation 1

$$\boldsymbol{\rho} = \frac{\boldsymbol{P} \cdot \boldsymbol{M_{air}}}{\boldsymbol{T} \cdot \boldsymbol{R_{air}}}$$

With M_{air} and R_{air} are respectively the molar mass of air and the gas constant, as illustrated in Figure 2-5

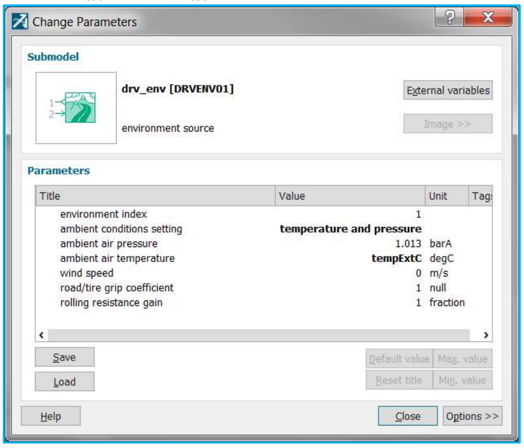

Figure 2-5 Siemens ambient model

We can notice the road/tire grip coefficient could be changed like between dry/wet weather conditions.

2.1.2 RT-SAS (VOLVO) environment model

2.1.2.1 Objectives

The environment model considered in VOLVO in-house simulation tools provides similar information than Siemens environment model and it consists of two models. The first model provides information on the driving conditions (road cycle characteristics and ambient conditions) whereas the second model reflects the behavior of the driver and computes therefore the following information: acceleration and brake torque demands.

2.1.2.2 Road and environment model

This model integrates the main attributes of the road cycle, namely the vehicle speed target, the road altitude and the stop location and duration. From these characteristics, the model determines a distance based or a time based signal for the vehicle speed target and road slope. Figure 2-6 illustrates for road attribute for the ASTERICS cycle developed for Medium Heavy Duty distribution truck with real operating conditions in the surroundings of Lyon (Berzi, et al., 2014).

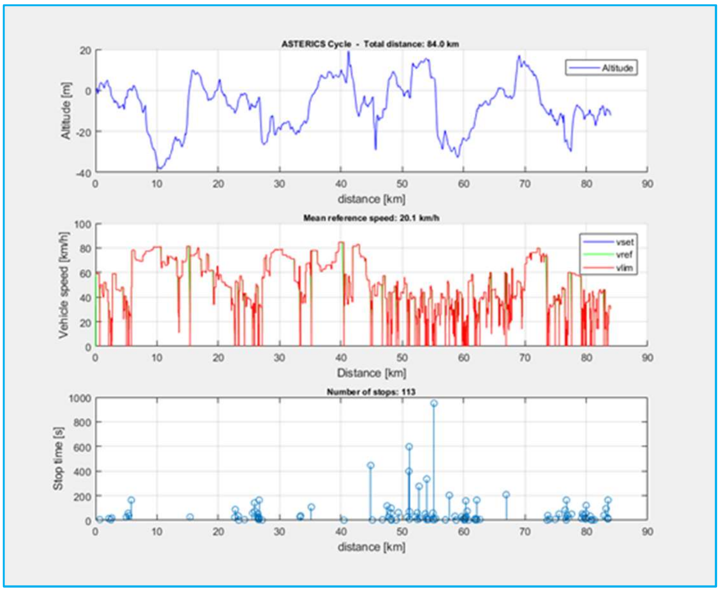

Figure 2-6: Data for ASTERICS cycle.

Other cycles will be considered among those some standards ACEA driving cycles for conventional heavy duty vehicles certifications, in particular regarding regional, urban and municipal utility (refuse) application. Internal cycles will also be considered by VOLVO for vehicle-level virtual electric powertrain integration studies but both characteristics of these cycles and corresponding simulation results will not be shared with all partners.

2.1.2.3 Driver model

This model is fairly standard and it consists in computing the torque demand as a function of the driving conditions (torque request for acceleration or braking of the vehicle). The driver model simply consists of a closed loop controller (PI), where, on the other hand, the parameters are automatically defined according to the vehicle configuration for faster and transparent model calibration.

2.2 Thermal systems integration model

New flexible physic-functional thermal systems models (0D, 1D, 3D) are being developed in the integration environments to simulate and optimize the thermal management architecture and consider its impact on component design (especially the battery) based on the applied drive cycle. These thermal models will cover thermal management (including battery) and comfort functions with standard and heath pumps technologies.

2.2.1 Siemens thermal models

2.2.1.1 Objectives

Objective of these subsystems is to give relevant information of temperature for the main electric components. Nevertheless balance with comfort should also have to be considered. Up to now, this double objective was difficult to handle for some different reasons:

- Computer performance
- Communication between different model, especially between 1D & 3D model

The proposed model is now able to connect not only conventional cooling circuit with under-hood but also with cabin model in order to assess the interaction between all thermal subsystems.
In Figure 2-7, 2 conventional cooling circuits are working for electric components, completed by an AC system with an additional chiller, meaning refrigerant loop is used both for comfort and battery cooling.

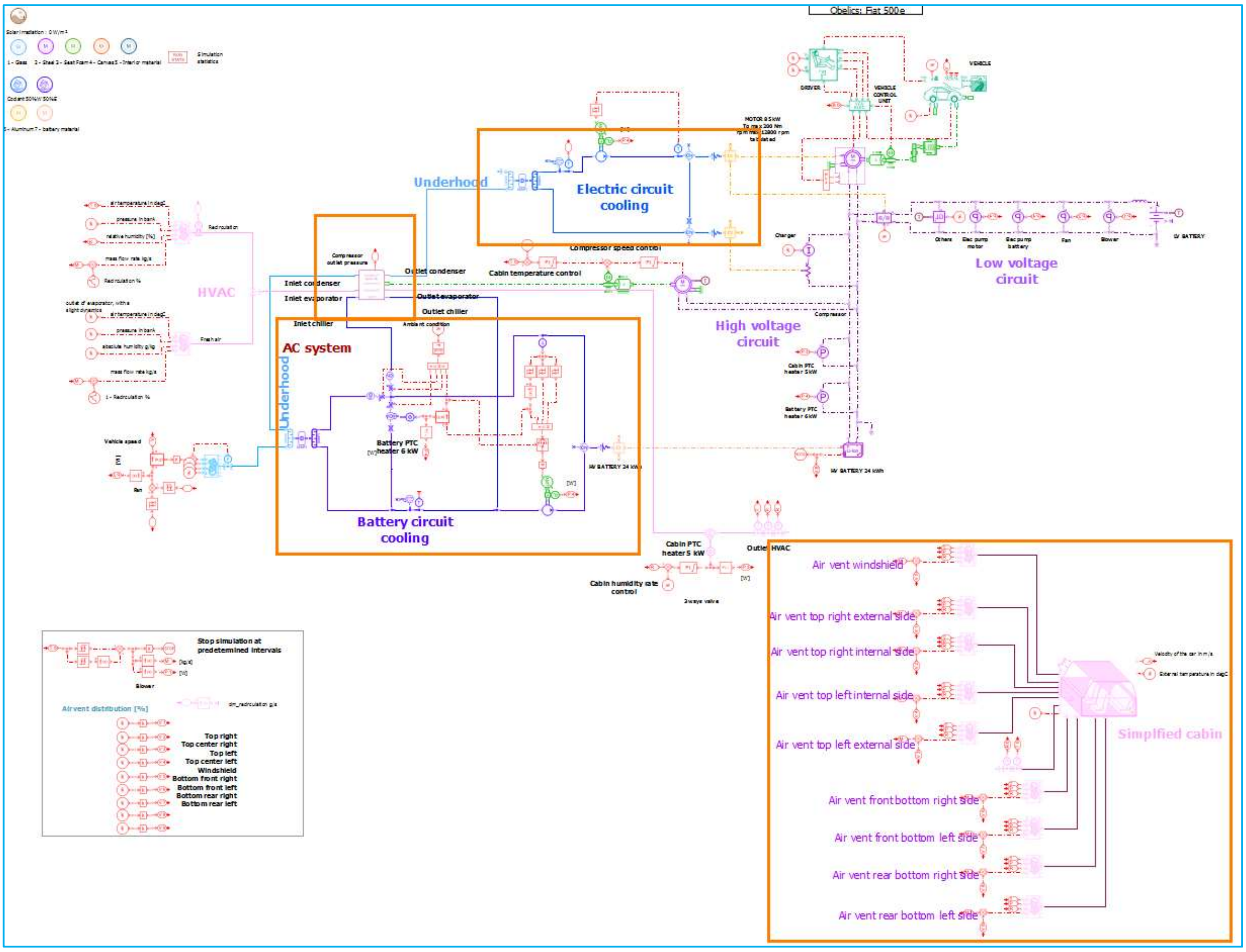

Figure 2-7 Siemens thermal models overview

2.2.1.2 Electric circuit cooling circuit

The electric cooling circuit is used to control temperature of different electric component such as the motor, the inverter and the charger in this case. Electric losses are transferred to thermal masses, which are cooled down with coolant.

The particularity of such cooling circuit is the flow rate is generated by an electric pump (connected to the LV circuit). So the latter could be easily controlled in order to supply coolant flow only when is necessary and as a consequence, limit the electric consumption.

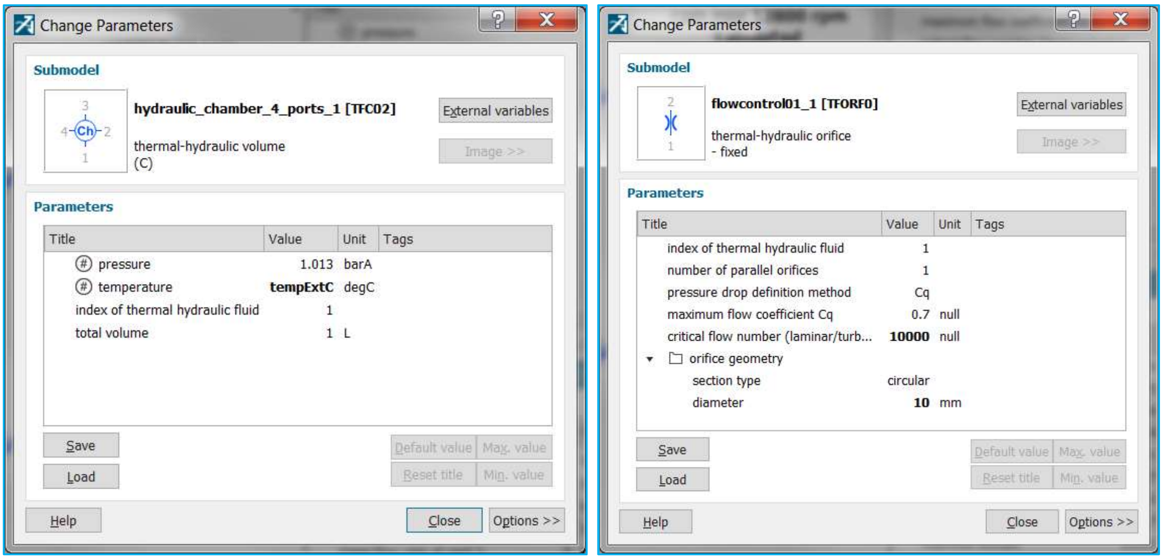

Figure 2-8 electric circuit internal flow passage modeling

Internal flow passages are modeled with a coolant volume and an equivalent singular pressure loss, as illustrated in Figure 2-8. Based on real geometry pressure loss could be estimated from CFD or from measurement.

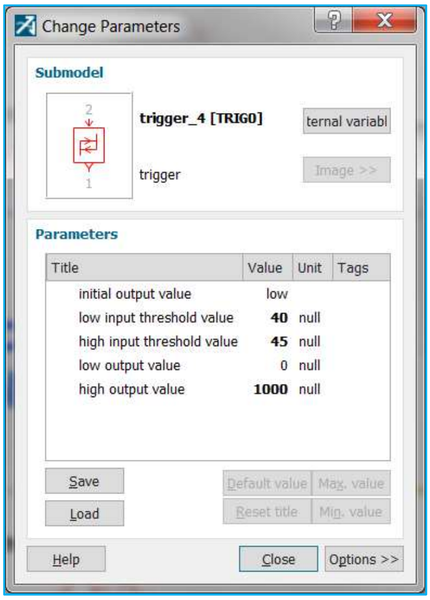

Figure 2-9 electric circuit control law

In this case, pump is switch on through a hysteresis control law and generates a 20 L/min flow rate with a speed of 1000 rpm, as illustrated in Figure 2-9.

Equation 2
$$\textbf{pump on } \boldsymbol{if\ T_{cool} > 45\ deg}\ \&\ \textbf{pump off } \boldsymbol{if\ T_{cool} < 40\ degC}$$

The coolant is cooled down thanks to radiator located downstream the AC condenser[2] and pressure is set with an expansion tank, as illustrated in Figure 2-10.

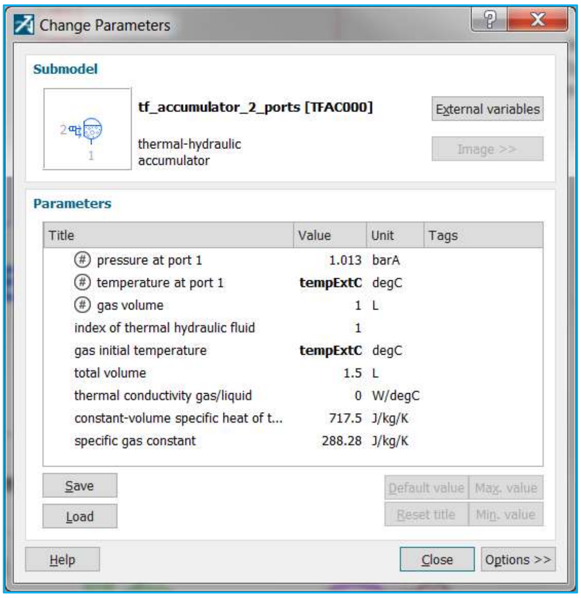

Figure 2-10 electric circuit expansion tank

In this subsystem, motor (and inverter) are combined within one equivalent thermal mass, as illustrated in Figure 2-11. Components are cooled thanks to coolant and internal convection heat exchange.

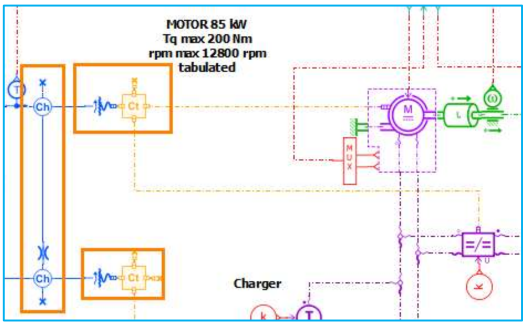

Figure 2-11 simple motor thermal model

During project motor and inverter thermal models will be refined to enhance the thermal control of these electronic components, based on model developed in WP2. Indeed based on level of modeling of some model, thermal masses could be split in several part:

- Motor: casing, rotor, stator…
- Inverter: casing, diode, transistor, heat sink… , as illustrated in Figure 2-12

[2] See under paragraph 2.2.1.4

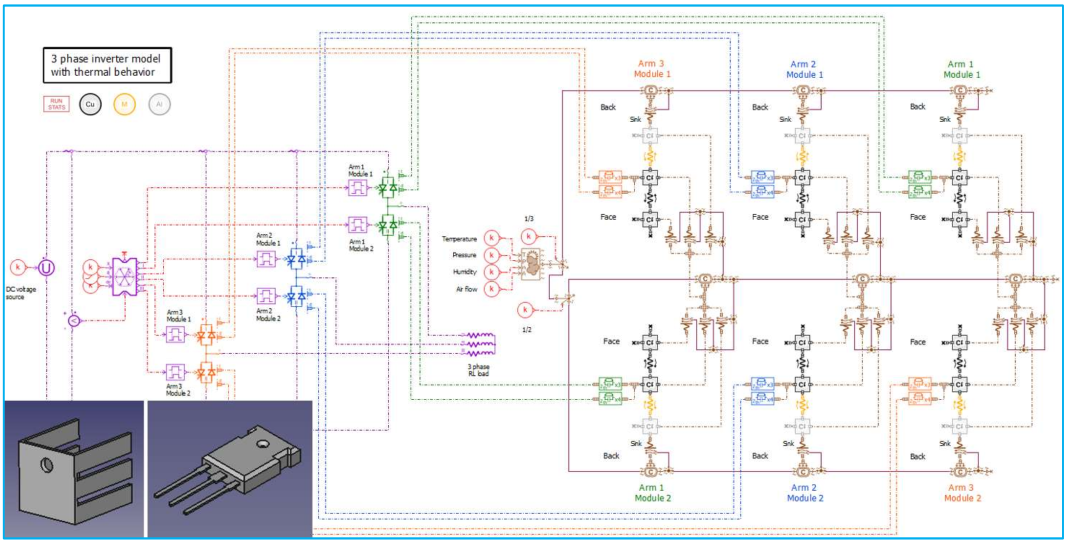

Figure 2-12 thermal model of 3 phase inverter

2.2.1.3 Battery cooling circuit

The battery cooling circuit is similar to the electric cooling circuit in the modeling approach. Nevertheless circuit is more complex, because battery internal flow passage[3] could be connected to 3 different branches, as illustrated in Figure 2-13:

- Radiator branch, similar to electric cooling circuit for normal condition (see 2.2.1.2)
- PTC heater branch, to warm battery if ambient is too cold
- Chiller branch (see 2.2.1.5) to enhance battery cooling if ambient is too hot.

Equation 3 $$\textbf{radiatior branch } \boldsymbol{if}\ \boldsymbol{T_{amb}}\ \boldsymbol{in\ range}\ [\mathbf{10}\ \boldsymbol{degC}; \mathbf{30}\ \boldsymbol{degC}]$$

Equation 4 $$\textbf{PTC heater branch } \boldsymbol{if}\ \boldsymbol{T_{amb}} < \mathbf{10}\ \boldsymbol{degC}$$

Equation 5 $$\textbf{chiller branch } \boldsymbol{if}\ \boldsymbol{T_{amb}} > \mathbf{30}\ \boldsymbol{degC}$$

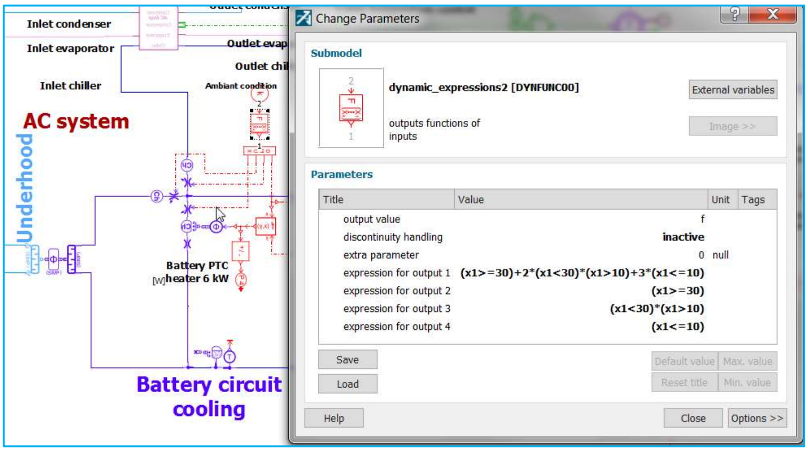

Figure 2-13 battery cooling circuit branch selection

[3] See similar description in paragraph 2.2.1.2

The PTC heater is an electric resistance in contact with coolant to warm it thanks to Joule effect. So the heating power (~6 kW) is also transferred to HV circuit, as illustrated in Figure 2-14.

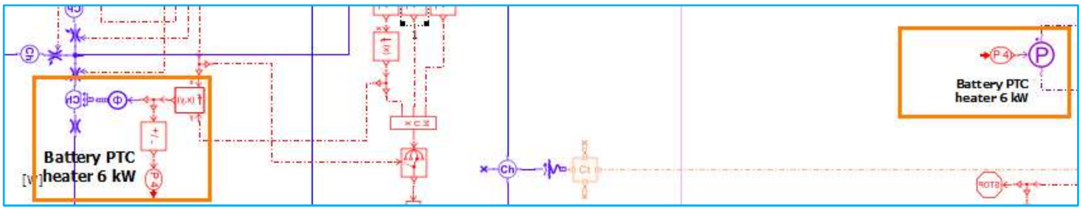

Figure 2-14 battery PTC heater model

In this model, battery thermal model is modeled with an equivalent thermal mass. This one is cooled thanks to coolant and internal convection heat exchange.

Figure 2-15 simple battery thermal model

During project battery thermal model will be refined to enhance its thermal control, based on model developed in WP2. Indeed based on level of modeling, thermal masses for each module (or cell) could be considered to study thermal behavior within pack, as illustrated in Figure 2-16.

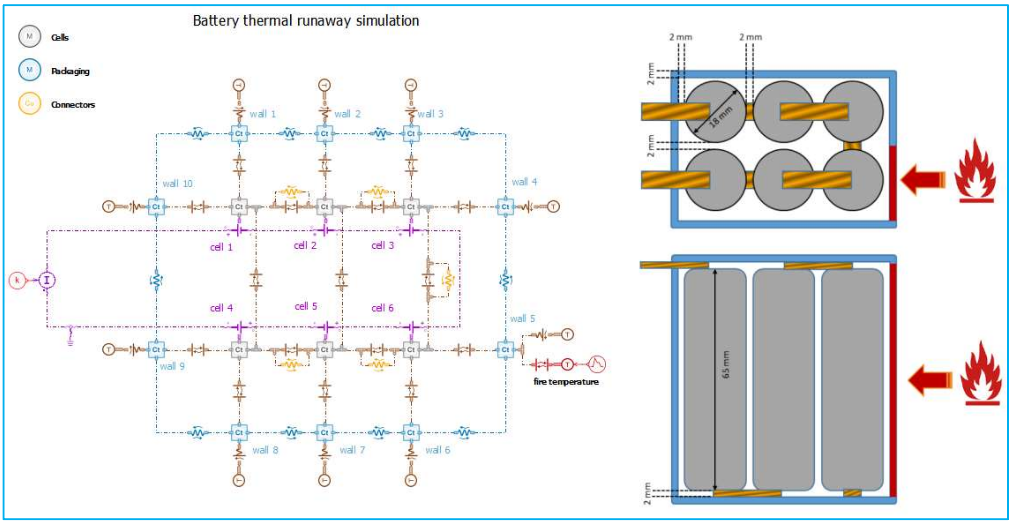

Figure 2-16 thermal model of battery used for thermal runaway detection

2.2.1.4 Under-hood

The under-hood flow is basically a 3D flow. In this project, we propose 3 levels of modeling from 1D to real 3D:

- 1D real-time compatible model
- Simplified 3D model based on few macro geometrical data
- Real 3D model based on car cabin CAD

The 1D real-time compatible model allows user to connect several stacked heat exchanger, by considering thermal interaction between them. Air flow under the hood is approximated by considering:

- Either a constant between vehicle speed and heat exchanger velocity

Equation 6
$$Q_{underhood,veh} = \rho_{air} \cdot S_{HX} \cdot \alpha \cdot V_{vehicle}$$

Where $\alpha \in [0,1]$ (Ap, 1999)

- A constant flow generated when fan is activated.

Equation 7 $$Q_{underhood,fan} = \rho_{air} \cdot S_{HX} \cdot K_{fan}$$

Where $k_{fan} \sim 2\ m/s$

These values will be updated for each UC based on experiment al test or refined CFD calculation based on 3D CAD; such approach is convenient because we can run model in fixed step with real-time capability after applying reduction methodology.

The final flow is the maximum between both expression described just above, as illustrated in Figure 2-17.

Equation 8 $$Q_{underhood} = max(Q_{underhood,veh}, Q_{underhood,fan})$$

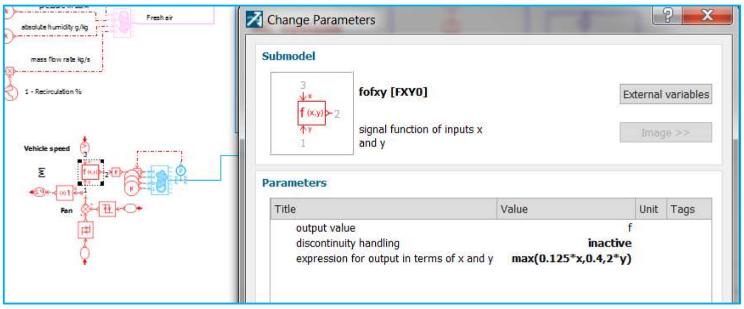

Figure 2-17 1D under-hood model

Now we have developed a simplified 3D model to considered 3D flow approach without complex CAD. 1D heat exchanger have been replaced by pseudo 3D model (3D for under-hood side and 1D internally). The interest of such approach is to consider inhomogeneous under-hood air flow due to obstacles. Indeed bumper, grille, fan shroud could generate non uniform flow. The Consequence is a non-uniform temperature distribution between heat exchanger, as illustrated in Figure 2-18.

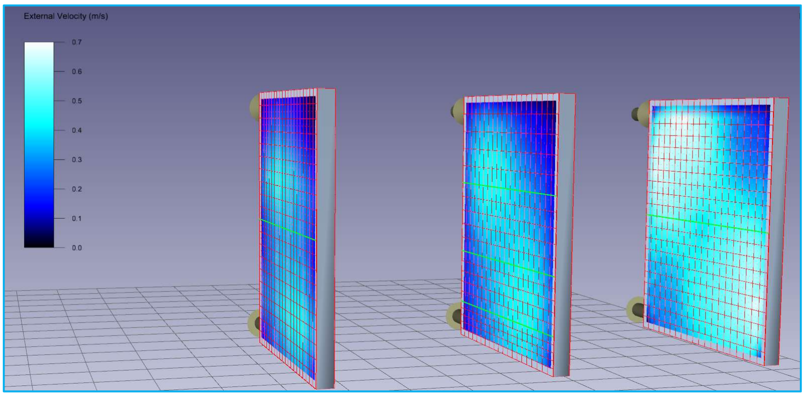

Figure 2-18 non uniform flow used for under-hood air flow calculation

A simplified 3D under-hood has been generated and used to create such air velocity map, as illustrated in Figure 2-19.

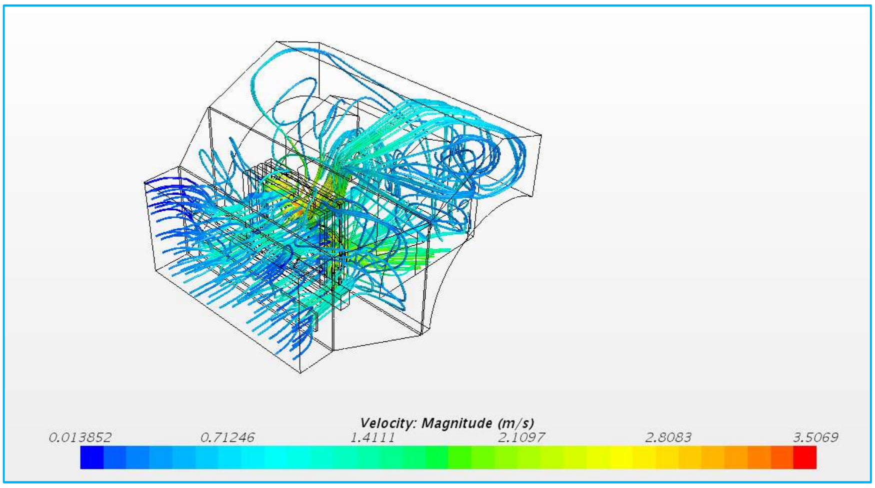

Figure 2-19 simplified 3D under-hood model

Data exchange occurs between Simcenter Amesim model and CFD model (STAR-CCM+):

- 1D model supplies heat exchange in 3D model
- 3D model supplies air velocity and temperature maps

This process is automatized thanks to a dedicated utility called embedded CFD, as illustrated in Figure 2-20.

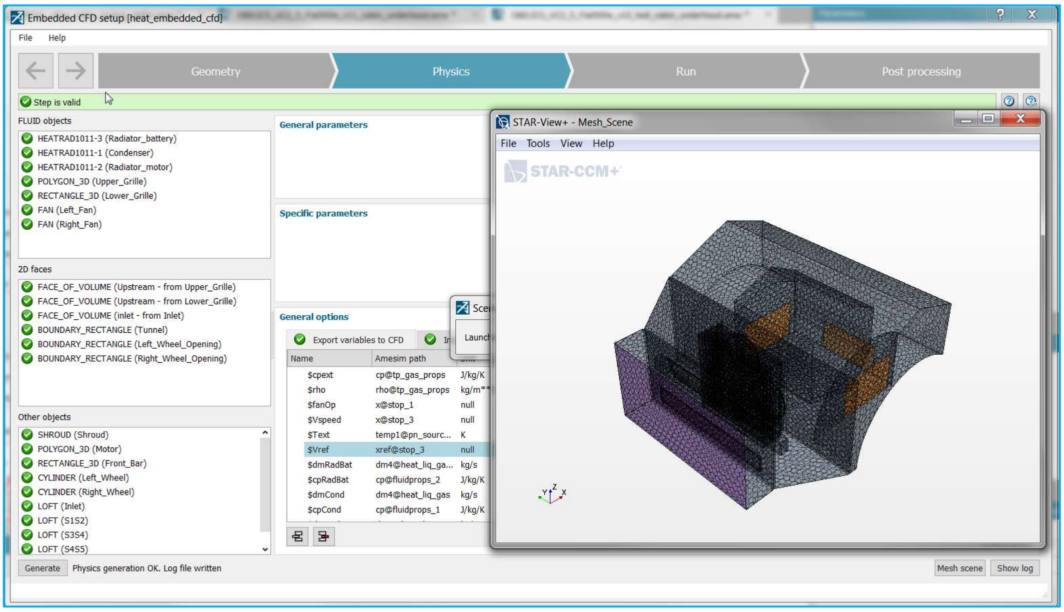

Figure 2-20 Siemens embedded CFD utility for under-hood

2.2.1.5 HVAC system

The HVAC system is composed of main 2 subsystems, as illustrated in Figure 2-21:

- The AC system coupling cabin cooling and battery cooling trough a chiller
- The air flow passage from ambient to cabin

The AC system model is a functional one up to now due to lack of information. Nevertheless such approach is enough:

- to estimate influence on the AC system on the battery trough an electrical compressor
- to supply fresh air to cabin
- to supply cooler coolant for battery

All heat exchanger are modeled by considering a global efficiency ϵ_{HX} (constant). The heat dissipation is the calculated by considering the following expression:

Equation 9 $$\phi_{HX} = \epsilon_{HX} \cdot min(\mathrm{dm_{ref}} \cdot \Delta H_{ref,max}, \mathrm{dm_{fluid}} \cdot \Delta H_{fluid,max})$$

Both $\Delta H_{fluid,max}$ & $\Delta H_{ref,max}$ correspond to the enthalpy difference calculated with heat exchanger inlet temperature.

Volume of refrigerant is also considered and thermal expansion valve is calibrated to insure a superheat of 5 degC at the evaporator outlet.

The compressor is modeled by considering constant efficiency and a displacement used to calculate refrigerant mass flow rate and also compressor torque.

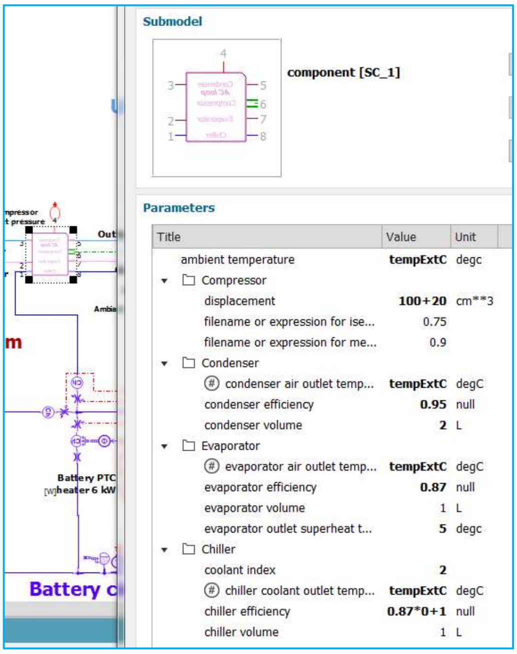

Figure 2-21 Siemens functional model of AC system

The HVAC air flow is composed of main 4 parts, as illustrated in Figure 2-22:

- the mix of fresh/recirculated air
- the evaporator (see just above)
- the cabin PTC
- the air vent distribution

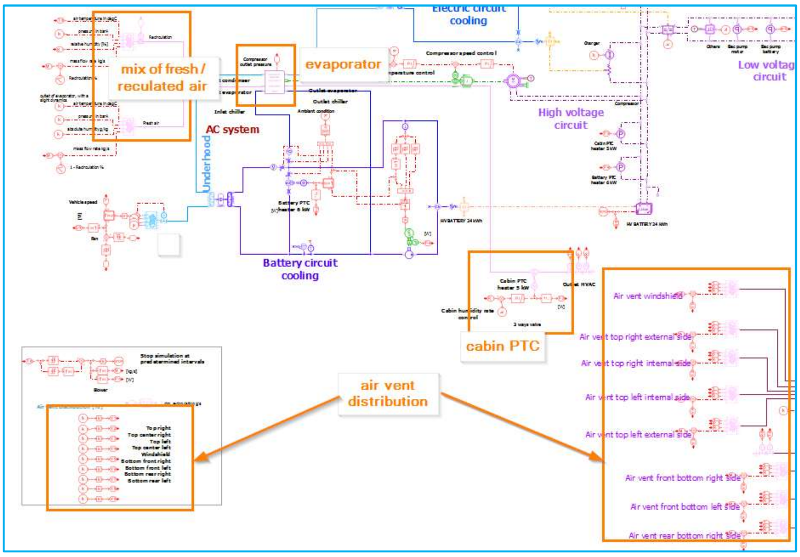

Figure 2-22 Siemens HVAC system

A mix of recirculated and fresh air can be considered. Indeed recirculated air is generally cooler than ambient, meaning gain of compressor consumption is expected. Nevertheless ambient air must be used, otherwise CO2 from passenger breathing could lead to asphyxia during long travel. The ratio (constant in this example) could be also controlled.

The cabin PTC is used because in winter condition, there is no more heat sources (unlike ICE heat losses in conventional vehicle). A PTC is connected to HV circuit so it has a direct impact on battery range. Another utility of PTC is the control of the relative humidity rate. Indeed cooled air from evaporator has a humidity rate close to 100%, which is constraint in term of passenger comfort. So PTC warm the air to reduce this humidity rate as described in Figure 2-23 (part C-D).

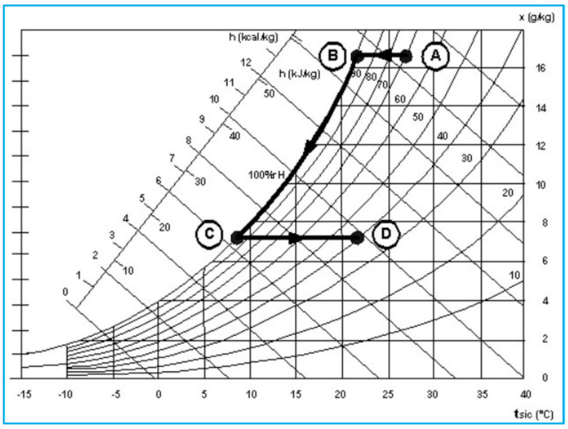

Figure 2-23 air cooling with humidification

Air vent distribution in cabin is generally controlled manually by passenger themselves, especially distribution between driver/front passenger, head/foot. In this model this distribution is controlled manually with constant, as illustrated in Figure 2-24.

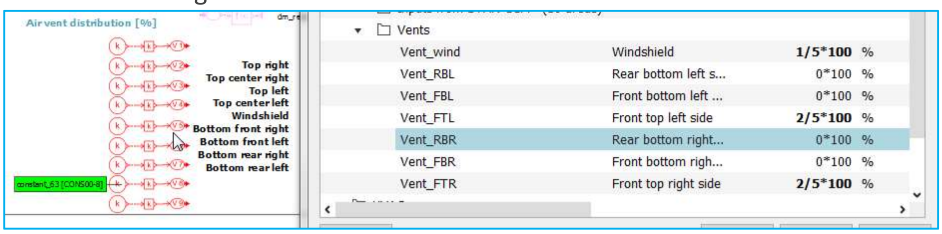

Figure 2-24 air vent distribution

2.2.1.6 Cabin model

Cabin model is generally composed of one equivalent volume to estimate cabin temperature. Unfortunately internal air flow occurs, especially internal recirculation. Such internal phenomena has an impact on recirculated air temperature. So average cabin temperature could be slightly different from cabin temperature on the foot, where recirculation flow is extracted.

1D cabin model is already available, but now simplified 3D cabin model has been developed using the same approach than the under-hood with smart interaction between 1D model and 3D model.

The 1D model is composed of 10 volumes with detailed heat exchange with different walls (glass, roof, floor, seat…), as illustrated in Figure 2-25.

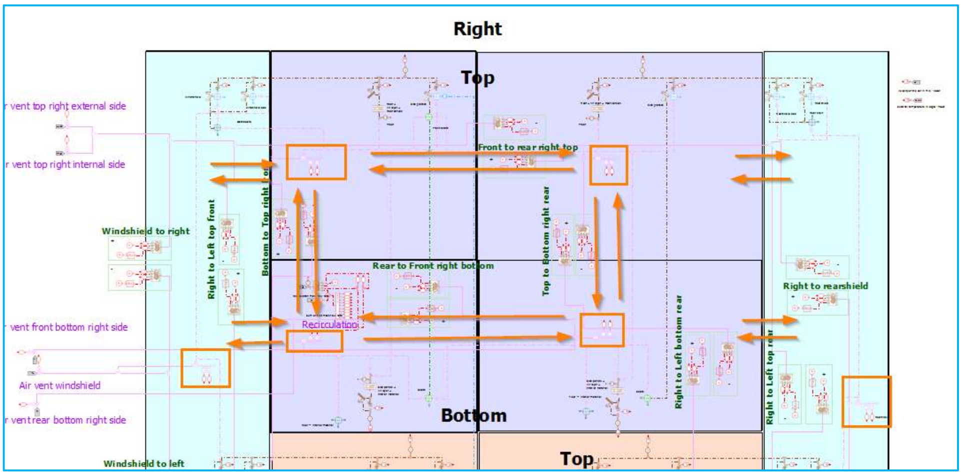

Figure 2-25 Siemens 1D cabin model with 10 volumes

The 3D model is used to calculate internal flow, as illustrated in Figure 2-26, meaning flow between 10 volumes and also convective heat exchange coefficient on walls.

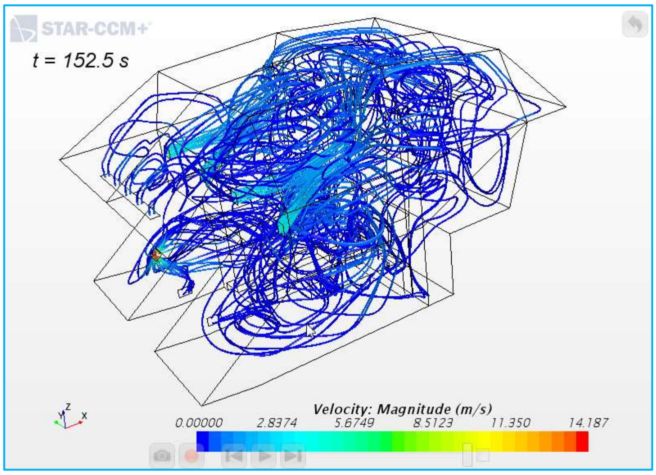

Figure 2-26 internal flow from simplified 3D cabin model

Data exchange occurs between Simcenter Amesim model and CFD model (STAR-CCAM+):

- 1D model supplies wall heat dissipation and air vent air flow
- 3D model supplies convective heat exchange coefficient and internal flow between volumes

This process is automatized thanks to a dedicated utility called embedded CFD.

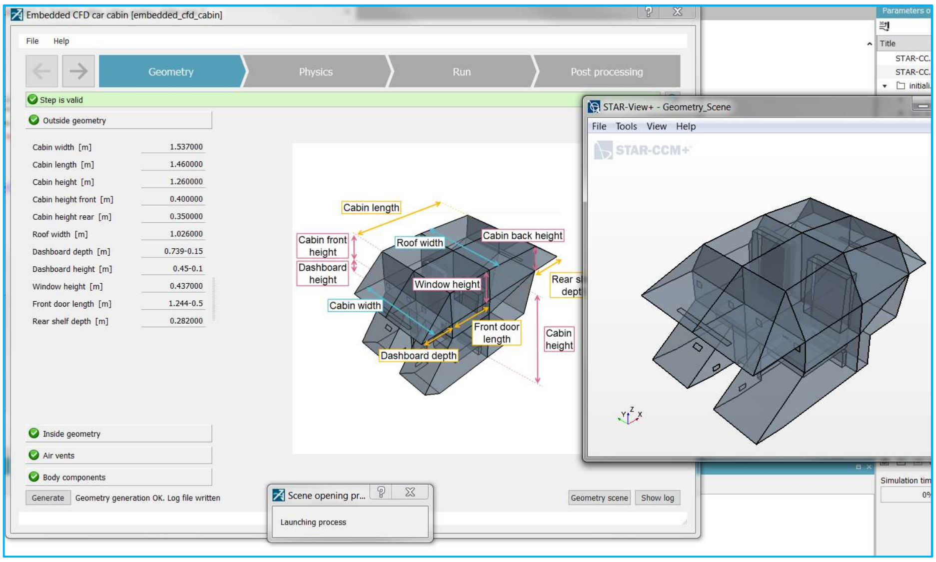

Figure 2-27 Siemens embedded CFD utility for cabin

Furthermore simplified 3D model could be replaced by using real 3D model directly coming from CAD, as illustrated in Figure 2-27. In this case 1D & 3D model could piloted with script on HPC, but 3D model call will be handle in the same way.

2.2.2 RT-SAS (VOLVO) thermal models

2.2.2.1 Objectives

The emergence of hybrid and electric trucks brings new opportunities and constraints for thermal management system design and optimization. Therefore advanced models need to be developed with several levels of fidelity to be used in the different phase of complete vehicle development. These models will be used as support to concept choice decision in early phases, and as optimization tool during development and verification.

Objectives of these subsystem models are multiple, and will depend on the project development phase:

- Cooling & heating capacity needs in early phase;
- Multiple topology evaluation
- System sizing optimization
- Virtual System integration and evaluation;
- Early state control development;

These models will be integrated in an overall methodology whose aim is to converge, step by step, to the most relevant and optimized complete vehicle thermal management system, taking into account and balancing many aspects such as battery lifetime, vehicle performances and efficiency over vehicle lifetime.

2.2.2.2 Coolant circuit

The coolant is used for the transfer of calories in the different component, as illustrated in Figure 2-28.

- Some components need to be cooled or heated via the coolant.
- Some components, like heaters, are used to heat the coolant.
- Others components like radiator, are used to cooled the coolant.

So the coolant layout is designed and tuned to fulfill coolant flow and pressure in the different components, using different branches, electro valves and pumps.

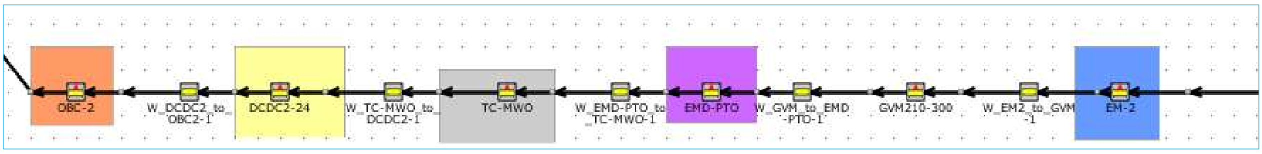

Figure 2-28 Example of eComponent branch coolant layout used at RT-SAS (VOLVO)

2.2.2.3 Cooling model

The cooling model is based on the concept shown in the Figure 2-29. Addition or rejection of heat is taken into account to estimate the temperature of the coolant at different points in the circuit.

Figure 2-29 : Low Temperature radiator with electrics fans

2.2.2.4 Battery model

The current battery model, as shown in Figure 2-30 is a macroscopic one, considering battery as a mass with thermal inertia and thermal links with coolant, ambient air. Heat dissipation is simulated by external data

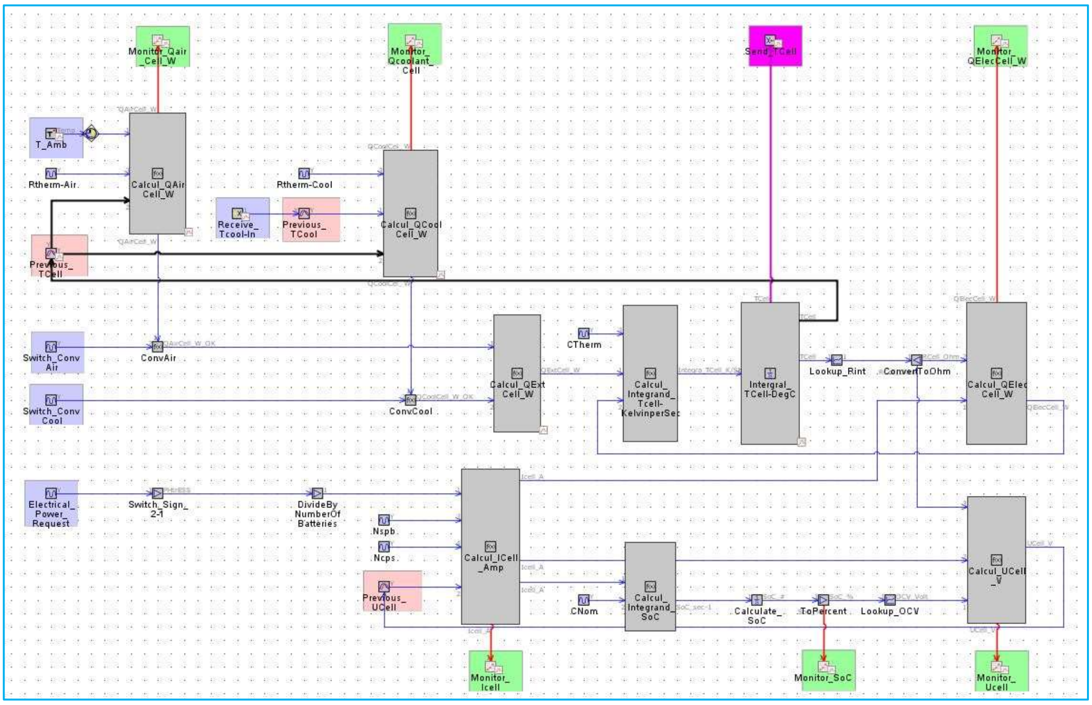

Figure 2-30: e-Trucks battery

Further detailed model will be developed within OBELICS collaborative project, among those:

1. Simplified heat balance model with electric power input, ambient conditions including heat rejection based on efficiency map
2. Improved thermal model with electric power input, ambient conditions including heat rejection based on efficiency map, predicting cell temperature.
3. High fidelity model with more details on cell efficiency, battery thermal model including degradation model.
4. High speed model with degradation, thermal model and protection strategy for control strategy optimization and considering co-simulation approaches for partner model integration.

2.2.2.5 Inverter model

Inverter model includes a pressure drop for coolant model. Several levels of fidelity are required for the heat transfer model to be included in the complete vehicle thermal management model, among those:

1. Simplified heat balance model with electric power input, ambient conditions including heat rejection based on efficiency map
2. Improved thermal model with electric power input, ambient conditions including heat rejection based on efficiency map, predicting core temperature.
3. High fidelity model with more details on inverter thermal model including temperature prediction model for sensitive components.
4. High speed model thermal model and protection strategy for control strategy optimization including also co-simulation approaches for partner model integration.

2.2.2.6 Accessory model

Accessories are modeling as pressure drop and heat addition or rejection. Inputs are coming from suppliers or tests. Several level of fidelity is required for the heat transfer model to be included in the complete vehicle thermal management model:

1. Simplified heat balance model with electric power input, ambient conditions including heat rejection based on efficiency map
2. Improved thermal model with electric power input, ambient conditions including heat rejection based on efficiency map, predicting core temperature.
3. High fidelity model with more details on inverter thermal model including temperature prediction model for sensitive components.
4. High speed model thermal model and protection strategy for control strategy optimization including also co-simulation approaches for partner model integration.

2.2.2.7 Cabin subsystem

The model realizes a heat balance at the cab level. It takes into account energy (heat) provided by the cooling system via the cab heater, air conditioning system via the evaporator, as well as heat exchanges to ambient (connection to ambient and sun load),as illustrated in Figure 2-31.

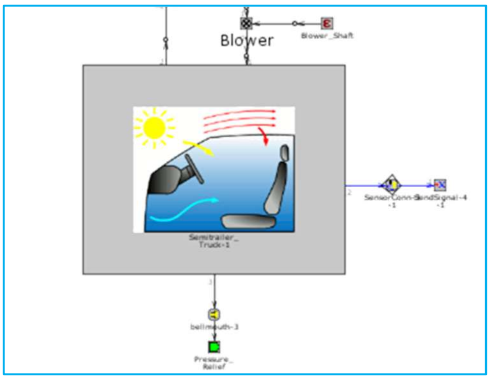

Figure 2-31: Cab simplified thermal model

Several levels of fidelity are required for the heat transfer model to be included in the complete vehicle thermal management model:

1. Simplified heat balance model based on ambient conditions taking into account heat provided by the thermal management, the driver and the environment (ambient and sun load)
2. Improved thermal model predicting cab average temperature.

2.2.2.8 Electric heater model

Electric heater model is a simple electric resistance in the coolant. That means a pressure drop view for coolant model and heat addition for cooling model.

2.2.2.9 Heat pump sub model

Heat pump will be considered as subsystem of the complete thermal management system to reduce complexity. Interface are properly defined in order to reach the right level of fidelity depending on the phase of development (from heat sink/source in very early phase to black box model for control strategy verification & tuning)

2.3 Chassis integration models

New flexible transmission 1D models and chassis models are being integrated into the drive and providing the parameterization flexibility enabling the optimal performance trade-off between gear ratios, drive operations, brake blending and longitudinal damping for energy recovery performance and comfort.

2.3.1 Siemens chassis model

2.3.1.1 Objectives

Objective of such subsystem is to supply several level of modeling from 1D with degree of freedom until 2 or 3 degree of freedom model, function of the level of accuracy based on development cycle of the vehicle.

2.3.1.2 1D chassis model

This model is the most functional one based on few input parameter. It is composed of vehicle model and transmission, as illustrated Figure 2-32.

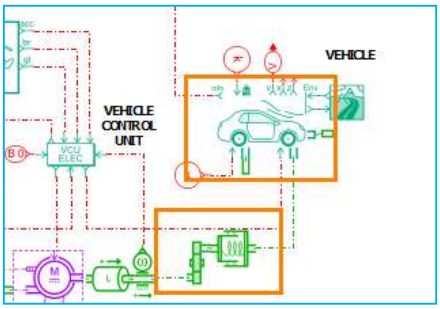

Figure 2-32 Siemens 1D chassis model

The 1D vehicle model needs few parameter like weight and aerodynamic and rolling coefficients, as illustrated in Figure 2-33.

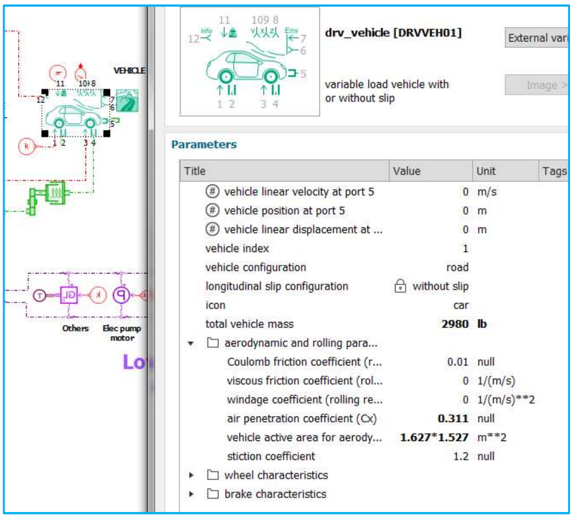

Figure 2-33 Siemens 1D vehicle model

Transmission is only composed of a reducer connecting motor to wheel and gear ratio is the only parameter, as illustrated in Figure 2-34.

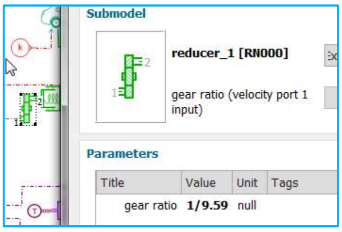

Figure 2-34 Siemens 1D reducer model

Furthermore reducer could also be easily replaced by 2/3 gear transmission to optimize operating point of electric motors.

Nevertheless such level of modeling could be also very useful even for 4 wheel independent drive architecture in early design phase, as illustrated in Figure 2-35.

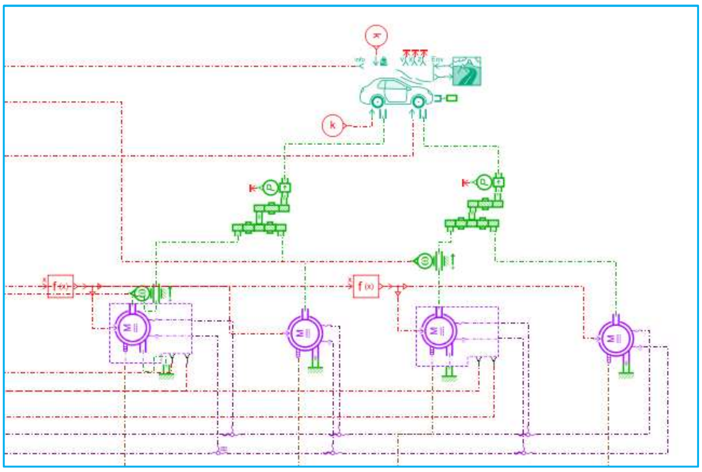

Figure 2-35 Siemens 1D chassis model for 4 wheel drive

Such model are useful if few parameter are available and if motor is directly connected to 1 shaft. Nevertheless if advanced steering model or electric vehicle with several motor connected to wheels, refined model of chassis should be considered.

2.3.1.3 2D/3D chassis model

For more advanced simulation taken the steering and/or all 4 wheels independently, 2D &3D chassis are available. For example if electric vehicle is driven by 4 motors, it’s important to study vehicle dynamics effect. Nevertheless models should be limited in term of parameter, because such model are used in predesign phase.

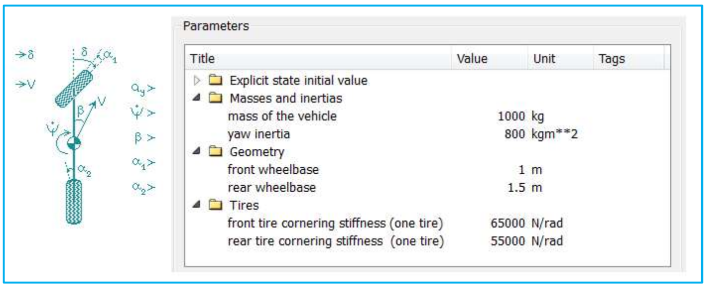

Figure 2-36 Siemens 2D chassis

2D model is useful to only add steering effect on 1D model whereas 3D model allow user to connect separate driving torque on each wheel, as illustrated in Figure 2-36 and Figure 2-37.

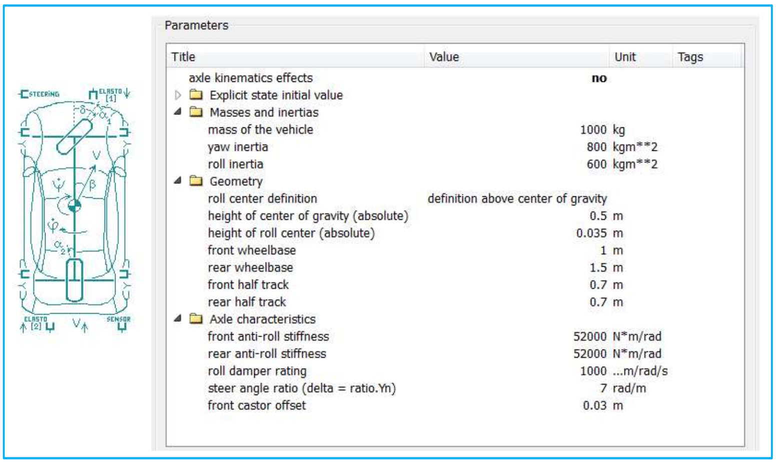

Figure 2-37 Siemens 3D chassis

With this 1st model of vehicle dynamics, some animation could be available to visualize the vehicle behavior on the road, as illustrated in Figure 2-38.

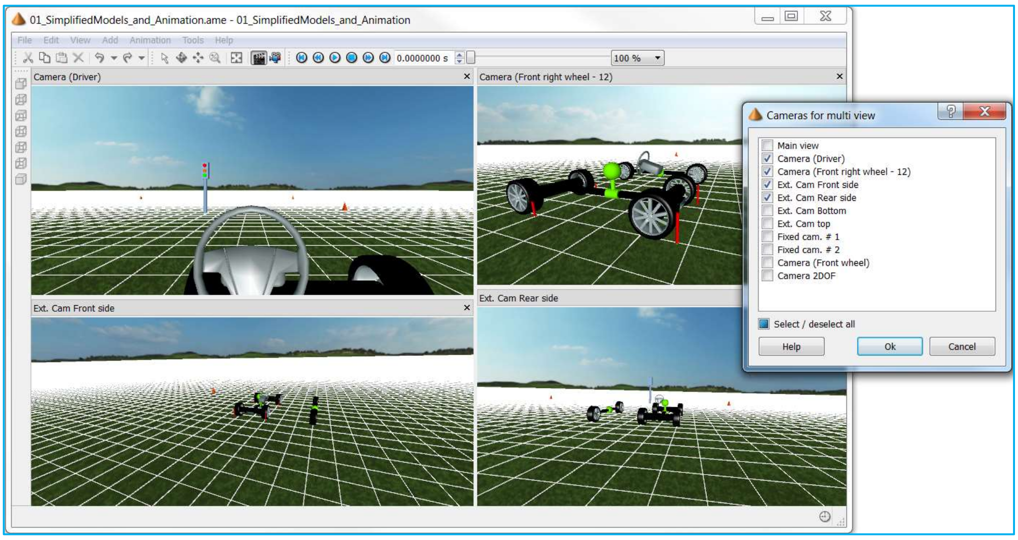

Figure 2-38 Siemens 3D chassis visualization with 3D animation

2.4 Power distribution and auxiliaries

New on-board electric power distribution networks are able to represent complex electric interactions of distributed power systems and their performance impact. Those new electric networks will also integrate auxiliary electric piloted loads (steering, driving automation, other actuators…).

2.4.1 Siemens auxiliaries model

2.4.1.1 Objectives

Objectives of this subsystem is to identify all electric consumers independently when they are (or not) activated. These consumers are split in 2 parts based on their voltage, as illustrated in Figure 2-39:

- HV auxiliaries
- LV auxiliaries

HV auxiliaries are generally electric component with power higher than 1 kW, instead of LV components with limited power.

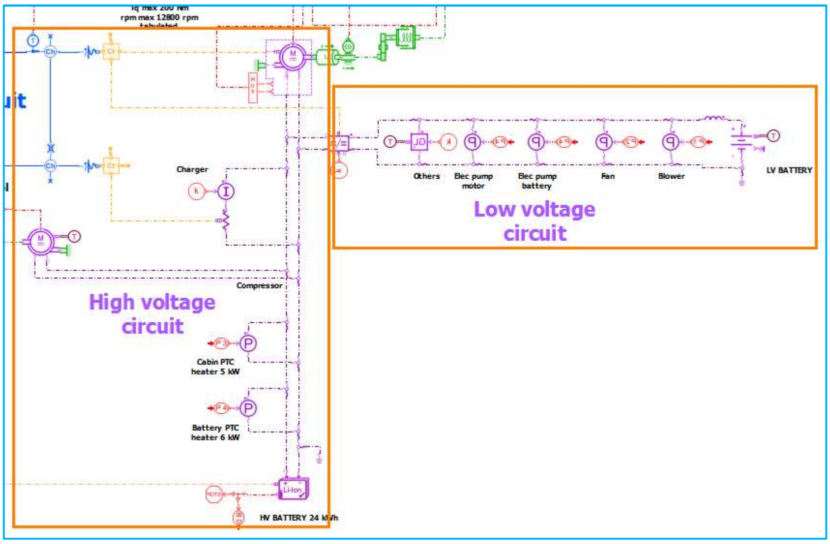

Figure 2-39 Siemens auxiliaries model overview

2.4.1.2 HV circuit

The high voltage circuit is composed:

- Motor (functional one which will replaced by more advanced model from WP2)
- Charger
- AC compressor
- Cabin PTC
- Battery PTC (functional one)

Charger is deactivated in this case but we can run scenario with charging phase if necessary and study the influence of battery cooling during such cycle.
Battery PTC and cabin PTC are connected to cooling and HVAC respectively, electric losses are directly transferred to HV voltage.
The electric motor of the compressor is controlled to supply correct speed in the compressor.

The HV battery is working with a rated voltage of 360V and is based on Li-ion chemistry.

2.4.1.3 LV circuit

The low voltage circuit is composed:

- Electric pump for motor cooling
- Electric pump for battery cooling
- fan
- blower
- others consumer (constant value of 200W)
- LV battery with rated voltage of 13.9V
- Converter DCDC

The converter DCDC is working with an efficiency of 95%, as illustrated in Figure 2-40. Refined model of converter could be integrated from WP2.

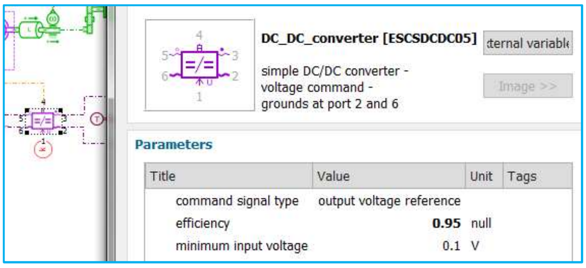

Figure 2-40 Siemens functional converter DCDC model

2.4.2 RT-SAS (VOLVO) auxiliaries models

2.4.2.1 Objectives

The objective of the auxiliaries' models is to access energy consumption during the cycle, this will influence hardware choice (battery size) and will change the control strategies during the cycle.

2.4.2.2 Description

The following subsystems will be integrated to the toy models. They are the most representative auxiliaries for distribution trucks:

- Air conditioning;
- Cabin;
- Garbage crusher;
- Heat pump;
- Fridge (for refrigerated freight).

The above-mentioned models will be provided possibly from other partners (e.g. Siemens). FMI/FMU Co-simulation interfaces will considered for partners model integration in VOLVO in-house vehicle simulation models. Energy consumption of the auxiliaries from the powertrain cooling system will be regarded internally at Volvo as part of the UC 2.4 which is working on the cooling system sizing.

2.5 Control strategies

Generic discrete models (Simulink, Amesim statechart/signal) expressing the key standard controls strategies (Traction control, braking, energy management, thermal management) impacting vehicle performances are being developed and standardized at IOs and parameter levels.

2.5.1 Siemens control

2.5.1.1 Objectives

Up to now control are developed with signal. Each component is controlled locally, but by end of project all will be managed under one control dealing with battery, motor, cabin…
Nevertheless more complex control could be implemented with statechart. Indeed when all thermal management will be implemented, more complex function can be easily handled with statechart utility.

2.5.1.2 Vehicle control unit

Motor torque is estimated thanks to vehicle control unit, based on several information. Up to now only output from driver and battery SOC are considered, as illustrated in Figure 2-41. But this control will be refined based on temperature of different electric component, like motor, compressor, battery…

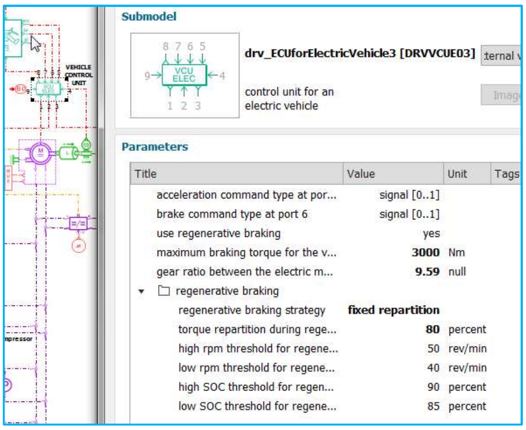

Figure 2-41 Siemens electric vehicle control

Battery could be reloaded during braking phase. In this case 80% of the braking torque request is used for battery loading. Dedicating braking strategies will be also integrated based on work from UNIFI

2.5.1.3 HVAC system control

Compressor speed is controlled to regulate cabin temperature (with fixed recirculation rate). This speed is then used to control electric motor of the compressor, connected to the HV circuit, as illustrated Figure 2-42.

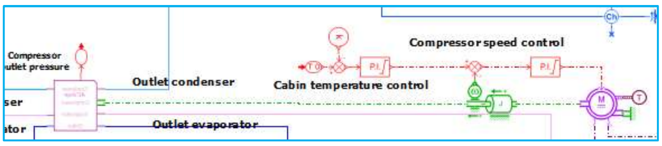

Figure 2-42 Siemens compressor control

The humidity rate of the cabin is also controlled thanks to a PTC, as illustrated in Figure 2-43.

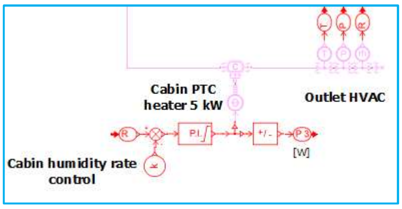

Figure 2-43 Siemens cabin PTC control

2.5.2 RT-SAS (VOLVO) control strategies

2.5.2.1 Objectives

The control strategies that will be implemented on the toy models will aim at decreasing energy consumption by means of:

- Controlling the electric machine(s) requests and abilities optimally;
- Perform thermal management;
- Optimize gearshifts.

2.5.2.2 Description

The controllers will be subjected to the following constraints:

- Thermal limitations;
- Battery degradation;
- Performance.

Additionally features like predictive information will be used in order to improve controls decisions. The control strategy will be model based when possible to increase model flexibility and scalability according to the different levels in vehicle modelling.

2.6 Brake and Brake Blending Models

In conventional ICE, vehicles, brake plant is devoted to safely control the longitudinal dynamic of the vehicle in partnership with the traction system. Conventional traction systems have limited dynamic performances, and also a differential allocation of controlled torques on wheels (Torque Vectoring) it's relatively difficult to be performed without increasing the complexity of powertrain layout.

For this reason, brake system is currently devoted also to the actuation of complex tasks dealing with the overall stability of the vehicle, being directly interfaced with ABS™, ESP-ESC™ systems and more generally to almost all the modern mechatronic systems that are currently aiming to control safety and performances of vehicle dynamics.

With the development of electric traction systems, designers have now the availability of motors allowing multi-quadrant operation (electric motors can be used to perform electric braking), high bandwidth (electric motors can regulate precisely their torque/speed behavior with very fast transients), torque vectoring (innovative powertrains including multiple controlled motors in order to differentiate torques applied on wheels respect to a desired control task).

Advantages of this innovative approach should be summarized in the following three points:

- increased efficiency and autonomy of vehicles (due to regenerative braking);
- higher performances of systems devoted to control vehicle safety and dynamics;
- reduced wear of conventional brakes including the reduction environmental impact in terms of produced by worn pads and discs.

Synergic and cooperative action of electric motors and conventional friction brake system involves the presence of devoted system able to properly manage the way in which the brake demand generated by a human or an autonomous driver is distributed between electric and mechanical brake systems (brake demand is also modified by on board subsystems devoted to vehicle safety such as ABS/EBD/ESC-ESP etc.)

This functionality is often called for both rail and road vehicles "Brake Blending" and it's often performed by specific control threads implemented on an ECU.

For this reason, a specific subsystem called Brake Blending Controller has been developed as visible in Figure 2-44. The modified (by brake blending logic) brake demand is actuated by a plant, which should remain, only in a short term scenario, a hydraulic one. The Brake Plant converts the desired brake demand in a corresponding braking action in terms of clamping forces and consequently of applied braking torques applied to wheels. In this document it's considered a dedicated "Brake Plant Model".

Finally, generated braking efforts should be applied on vehicle wheels by braking units, so it should be interesting to evaluate corresponding thermal behavior and wear of brake components according the simulated blending policy.

This is the aim of a third brake sub-model briefly called "Braking" in the scheme of Figure 2-44. "Braking" Model calculate energy flows across braking units and corresponding effects in terms of exchanged power, thermal and related properties as wear or friction coefficients of brake pads.

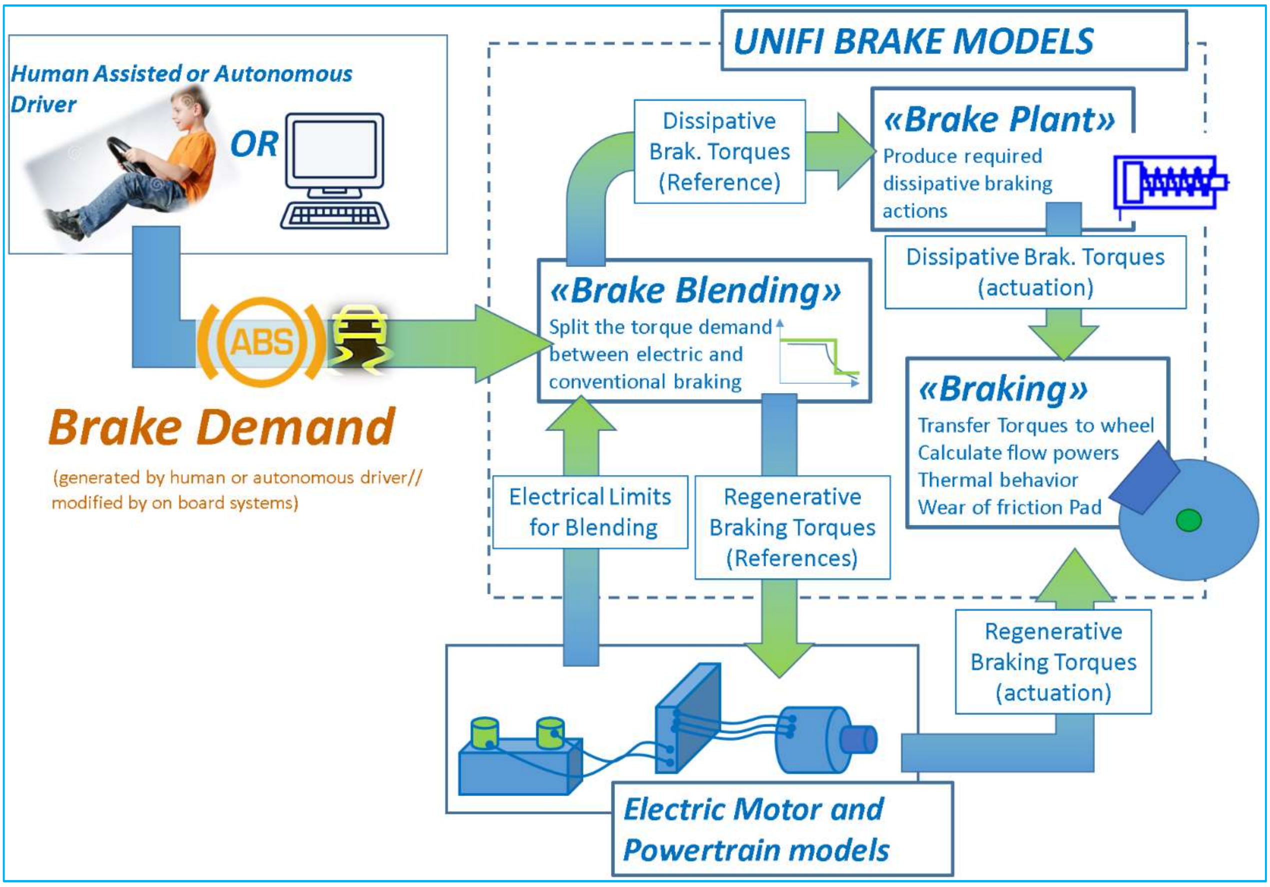

Figure 2-44 Brake Models introduced by UNIFI and their integration respect to the rest of the toy model

All the brake UNIFI Submodels are currently implemented in Matlab Simulink™, however models are assembled using basic signal blocks of the Simulink libraries in order to assure two main requisites:

- Portability: by assembling models with simple "base" instructions, it's assured a wide compatibility for most of the Real Time and Fast Simulation Targets used in the project. Also this is an important issue looking at the possibility of exporting brake models in FMI format in order to obtain a complete interoperability with different models produced by different partners of the project.
- Easy Cross-Validation/Code rewriting in different environment: adopted blocks and commands used to assemble the model in Matlab-Simulink are almost equivalent to the ones available in Siemens Simcenter Amesim™ ("Red" Signal Domain blocks) or even in free software like SCILAB. In this way it's quite easy to manually rewrite almost the same code using other simulation tools without incurring in relevant cross-validation problems that should be arise when the same code is manually transferred between different simulation environments.

2.6.1 "Brake Blending" Subsystem Model

2.6.1.1 Objectives

Aim of the "Brake Blending" model is to simulate the behavior of controller devoted to manage the synergic application or regenerative electric braking and the conventional dissipative one. The controller is designed to privilege the maximum efficiency and consequently the application of the maximum electric effort respect to power and current limits of both motor and energy storage systems. All these operations are performed without affecting vehicle handling, stability and safety performances in order to produce a negligible impact respect to the maneuver performed by a human driver (assisted by other mechatronics subsystems) or an autonomous one. A non-secondary advantage of extended brake blending is the reduction of wear of brake pads and discs and the corresponding improvements in terms of reliability, maintenance costs, reduced production of debris and brake related pollutants improving also the overall environmental impact of the vehicle.

2.6.1.2 Description

A simplified Toy implementation of the “Brake Blending” is currently shared on project portal as an open Matlab Simulink™ Model which is briefly described in Figure 2-45. In particular the model shown in Figure 2-45 is referred to the blending of electric and mechanical braking forces on a single motorized wheel. The implementation shown in Figure 2-45 should be summarized in the following steps:

1. ***Power and Current Limits***: according the state of traction and energy storage systems, the “Brake Blending” controller evaluates performance limitations in terms of maximum power and currents automatically selecting the most cautious/restrictive condition. Currently these electrical limitations are supposed to be read from an external vehicle data bus, being calculated by the corresponding interested control units (battery BMS, and/or motor Driver). However, if required by UCs partner it’s also possible to implement a local calculation of these electrical limits.
2. ***Torque demand creation:*** according brake and traction commands performed by vehicle driver a corresponding reference torque demand is evaluated.
3. ***Electrical Torque Saturation***: in order to maximize the usage of electric motors respect to conventional brakes, the torque reference is supposed to be entirely exerted by electric motors. Generated torque reference is saturated respect to known limitations of the electric plant previously calculated in point 1.
4. ***Calculation of residual Mechanical/Dissipative Braking Torque***: since the response of electric actuators is saturated respect to their known limits, in order to satisfy the required torque demand, the difference between desired braking torque and the one made available by electric actuators is calculated. This one is used to estimate the desired amount of braking torque that have to be delivered to the wheel by the conventional/mechanical brake plant to compensate limitations of the electric brake plant.
5. ***Dynamic Compensation***: since electric and mechanical brake plant should have a quite different dynamical behavior (specifically it’s supposed a faster electric plant), additional signal filters implemented in terms of transfer functions should be applied to the reference electric braking torque in order to compensate its faster behavior.

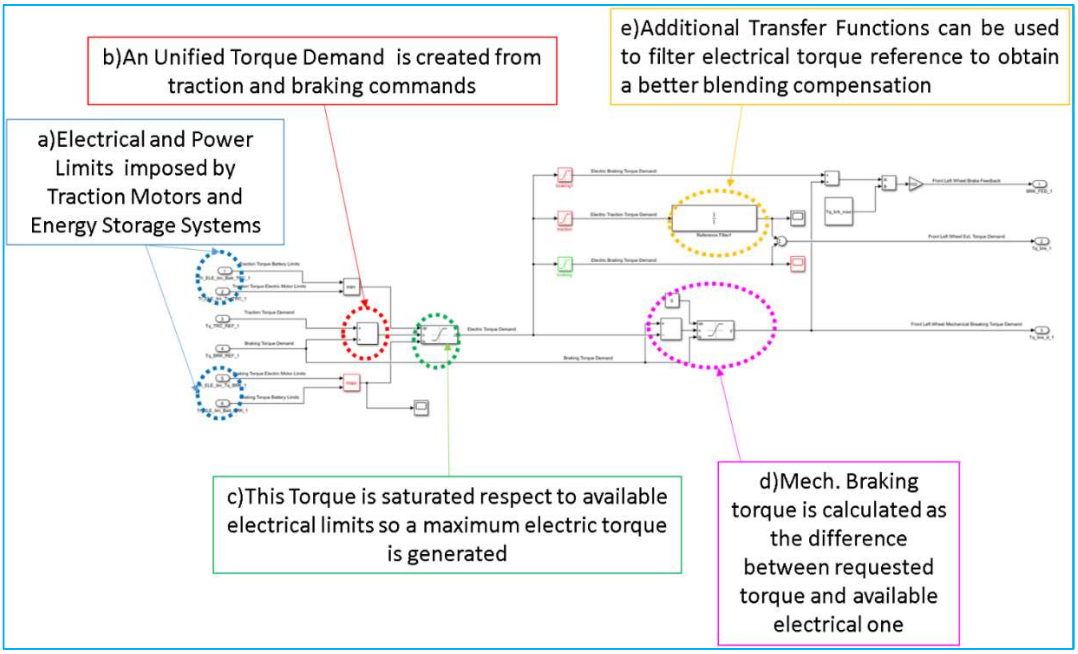

Figure 2-45 Equivalent implementation in Matlab Simulink™ (tested releases 2017a-2018a) of a toy model of the “Brake Blending”

The scheme of Figure 2-45 can be generalized to an entire vehicle by applying the same logic to each wheel.

In particular, if a wheel is not motorized, it's possible to reuse the same identical logic by coherently imposing "null" power/torque limits for electric torque. In this way, by working only on model parameters the same control logic can be extended to almost any powertrain, making easier the customization of this model for different UCs proposed in OBELICS project.

In Figure 2-46 an example of results concerning the blending action during a braking maneuver (initial speed 50m/s) is shown: since it's an iso-deceleration braking, elapsed time is substantially proportional to vehicle speed reduction. In order to show all the possible features of the proposed model simulation starts at a speed which is supposed higher respect to maximum speed allowed by the electric powertrain. In this conditions braking performance is assured completely by the conventional brake. As speed decreases, regenerative braking is activated. However brake application is saturated respect to both delivered power and torque.

At very low speed (few km/h) motor drivers are usually unable to perform electric braking efficiently, so it is supposed that the electric braking is de-activated and substituted by the conventional one. Behavior reproduced in Figure 2-46 is a qualitative representation of possible situations that can be simulated by the proposed controller acting on a motorized wheel.

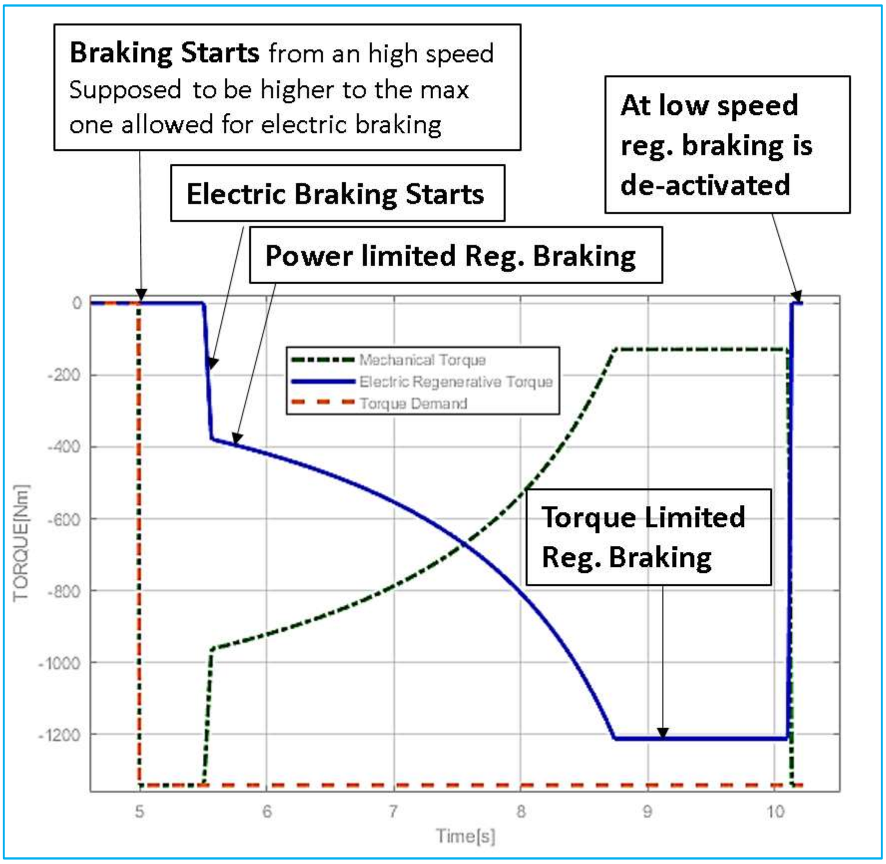

Figure 2-46 example of blending of brake torque applied on a wheel (toy example) during an emergency braking from an initial speed of 50m/s (toy example not referred to any UC with a very high deceleration corresponding to about 1G)

A full description of "Brake Blending" Sub-Model is provided in the Model Identity Card File available on OBELICS project site (excel file provide by all members according WP 3 Leader Specifications).

2.6.2 "Brake Plant" Subsystem Model

2.6.2.1 Objectives

Brake Plant Model has to reproduce the behavior of a real brake plant model: "Brake Plant" is intended as the plant which converts the brake demand (produced by the driver and corrected by various on board subsystem) in real clamping forces of brake pads able to produce the desired brake torques on wheels.
In few word "Brake Plant" represents the actuation of a brake demand reference produced by the human driver and/or by autonomous systems that are assisting, correcting or even substituting him.

The model has to reproduce some specific features in terms of dynamic response and known limitations, without introducing a too detailed modelling that should limit the applicability of the proposed approach to different UCs considered in the project and more generally to future applications which are currently in the development phase.

2.6.2.2 Description

Brake Plants currently adopted on road vehicles are mainly fluidic servo-amplification and actuation systems:

- Hydraulic plants: for small to medium size vehicles (motorcycles, cars and light vans/trucks)
- Pneumatic plants: for heavy, large or articulated vehicles (large trucks).

Some reference schemes taken from literature are shown in Figure 2-47 and Figure 2-48.

The pneumatic brake configuration is substantially similar to the classic UIC one[4]. UIC pneumatic brake is currently adopted in the railway sector. Even more complex plant configurations can be easily found in literature considering advanced or proposed innovative systems for future implementations.

In order to produce toy models of general use, the brake plant is analyzed in terms of functions that are performed by different subsystems and then translated in an equivalent functional model, visible in Figure 2-47.
Adopted model maintains only some limited physical features of the simulated plant:

1. ***Brake Demand Generation***: brake demand it's simulated as a converted and servo-amplified command signal which substantially represents a clamping force reference and consequently a torque one. For modelling purpose this stage should be considered a simple servo-amplification performed by a nonlinear amplifier with limited bandwidth.
2. ***Plant Configuration***: driver brake demand and more general the plant configuration would be affected by the action of mechatronics subsystems such as ABS or ESP/ESC that have to modulate the torque applied to wheels in order to preserve vehicle safety and stability. In a toy model all these complex functionalities are simulated in a simplified way by assuring the possibility of a direct access of external commands from on board systems to the valves that are controlling brake clamping units. According the current plant state (as example conventional braking or correction imposed by ABS/ESP systems) applied commands are filtered by different transfer functions that could be customized in order to reproduce the response of corresponding fluid components.
3. ***Brake Modulation***: clamping pressure applied to brakes is typically regulated by electro-hydraulic valves; valves are able to connect the controlled actuator with a pressure source or to discharge it. A single effect actuator controlled by a 3/3 valve (three ways, three states valve) is the best way to approximate plant response.
4. ***Brake Inexhaustibility***: Safety of the brake plant involves that the availability of supply pressure has to be assured in every working condition. This feature is important for mechatronics systems like ABS and ESP system whose fluid consumptions is sometime difficult to be evaluated, since their action often corresponds to complex regulation patterns. It should be noticed that for stability control systems brake torques have to be modulated also when it's not performed a braking maneuver by the driver. For this reason, real plants have additional capacities and feeding/pumping units to assure the pressurization of the plant in almost every condition.

For the purposes of the toy model, pressure sources are supposed ideals and inexhaustible. In future implementations, real pressure sources with programmable flow limitations, should be introduced.

[4] see all the fiches of the series UIC 54x-x

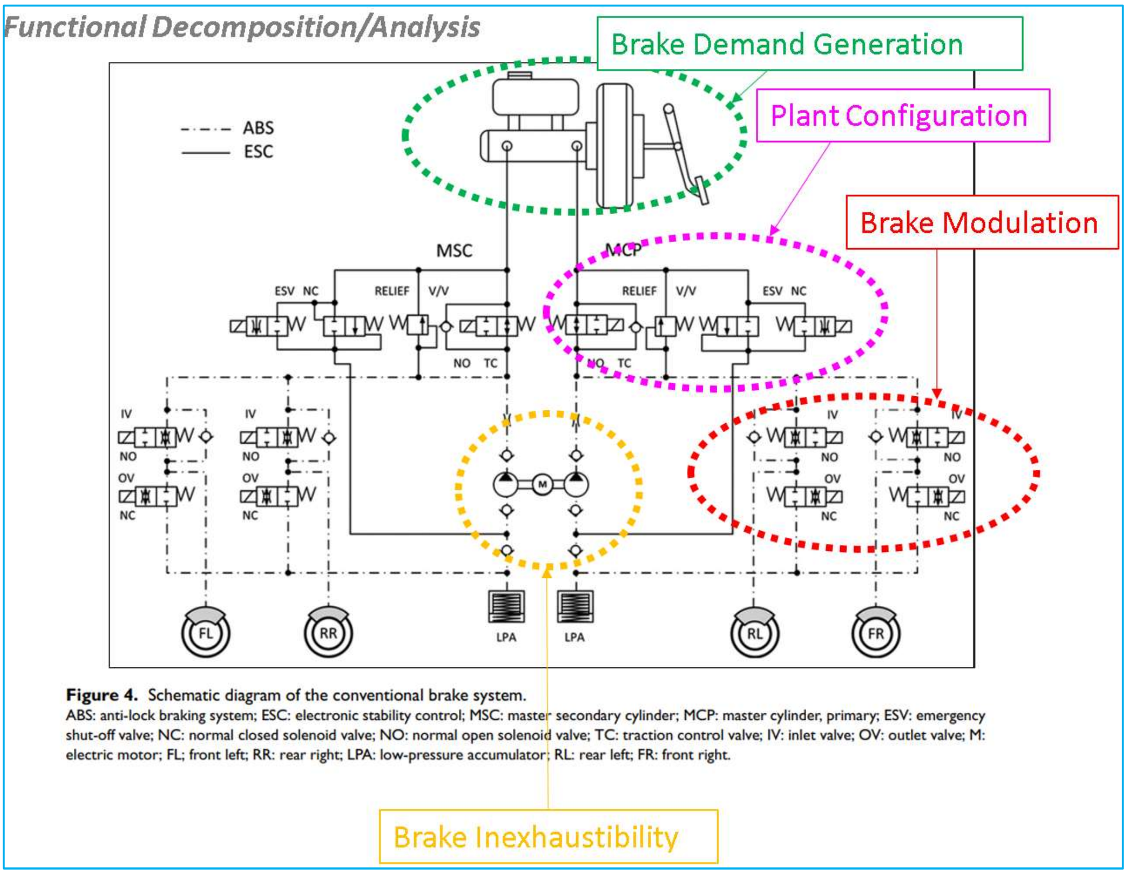

Figure 2-47 functional decomposition of a hydraulic braking plant of a car (Dzmitry Savitski, Valentin Ivanov, Klaus Augsburg, Barys Shyrokau, Robert Wragge-Morley, Thomas Pütz, and Phil Barber, The new paradigm of an anti-lock braking system for a full electric vehicle: experimental investigation and benchmarking Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering Vol 230, Issue 10, pp. 1364 – 1377,https://doi.org/10.1177/0954407015608548)

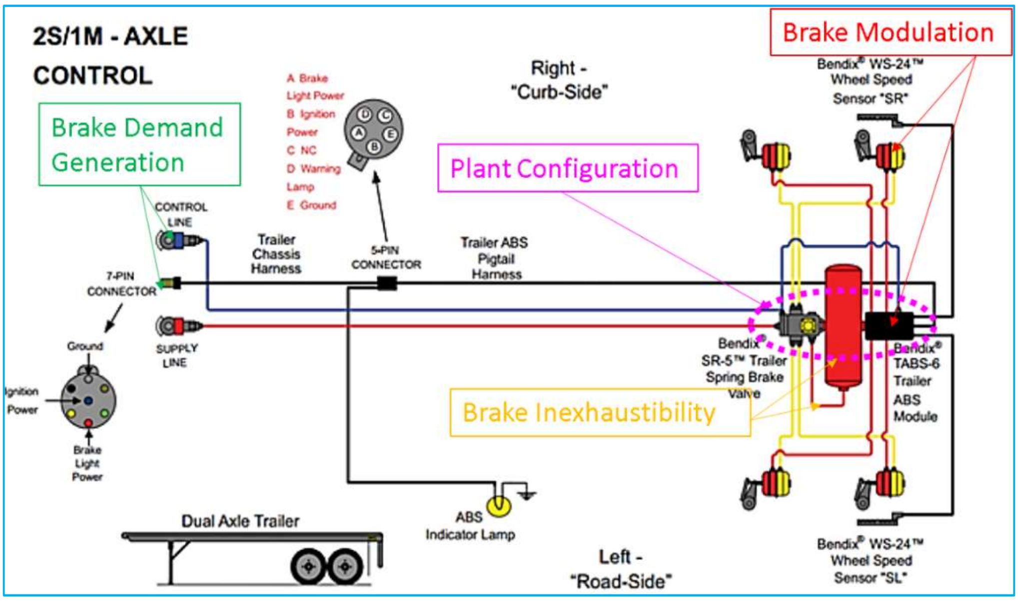

Figure 2-48 functional decomposition of a pneumatic brake plant of a heavy truck trailer (Bauer, F., et al. "Hardware-in-the-loop system for electro-pneumatic brake systems of commercial vehicles." The Dynamics of Vehicles on Roads and Tracks: Proceedings of the 24th Symposium of the International Association for Vehicle System Dynamics (IAVSD 2015), Graz, Austria, 17-21 August 2015. CRC Press, 2016.)

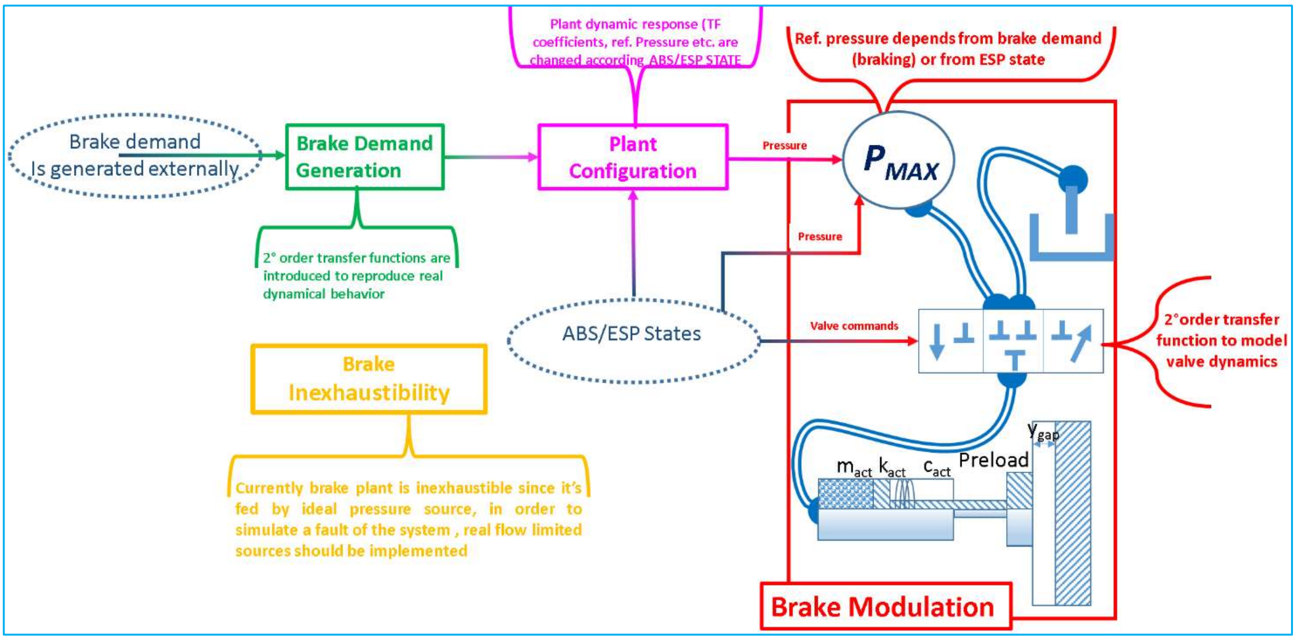

Figure 2-49 functional implementation of the brake plant adopted for the brake plant

2.6.3 "Braking" Subsystem

2.6.3.1 Objectives

Aim of the "Braking" subsystem is to simulate the application of both regenerative/electric and dissipative/mechanical torques to wheels. In this way, the sub-model is able to calculate power flows and corresponding energy integrals. Knowing the amount of dissipated energy on each wheel, the model is able to roughly calculate corresponding thermal and wear behavior of brake friction components (pads and discs).
Since brake friction factor depends from thermal and loading conditions, values of applied torques and dissipated energies should be corrected considering fading or more generally load-sensitivity of pads behavior.

In this way, the "Braking" Subsystem satisfies the objective of calculating performances of brake blending strategies in terms of efficiency, safety, improved environmental impact, considering also the volume of pollutant debris produced by wear of brake pads.

2.6.3.2 Description

In order to simplify the description of the model, mathematical symbols adopted in this document are the same that are indicated in the corresponding model identity card. The model identity card has to provide variable names that can be easily used also in the corresponding "code" of the simulation model. For this reason, adopted symbols are from a formal point of view a bit "rude" in order to avoid characters and operators that can be difficult to be directly used in a simulation code. For other variable and symbols that are not used as input-output variables in shared model identity cards, simpler and more formally elegant symbols should be adopted.
The simplified approach currently described in this document is also adopted in literature in handbooks (Genta, et al., 2007) and are still adopted in recent publications concerning thermal design of braking components.

"Braking" model" performs the following sub-functionalities that are described in the scheme of Figure 2-50:

- Thermal Behavior of Components: temperature of components is calculated;
- Wear of Components: model evaluates wear and volume of pollutant debris produced in the braking phase;
- Stability of friction-braking performances: torques applied to wheels are corrected taking count of the thermal behavior of friction components;

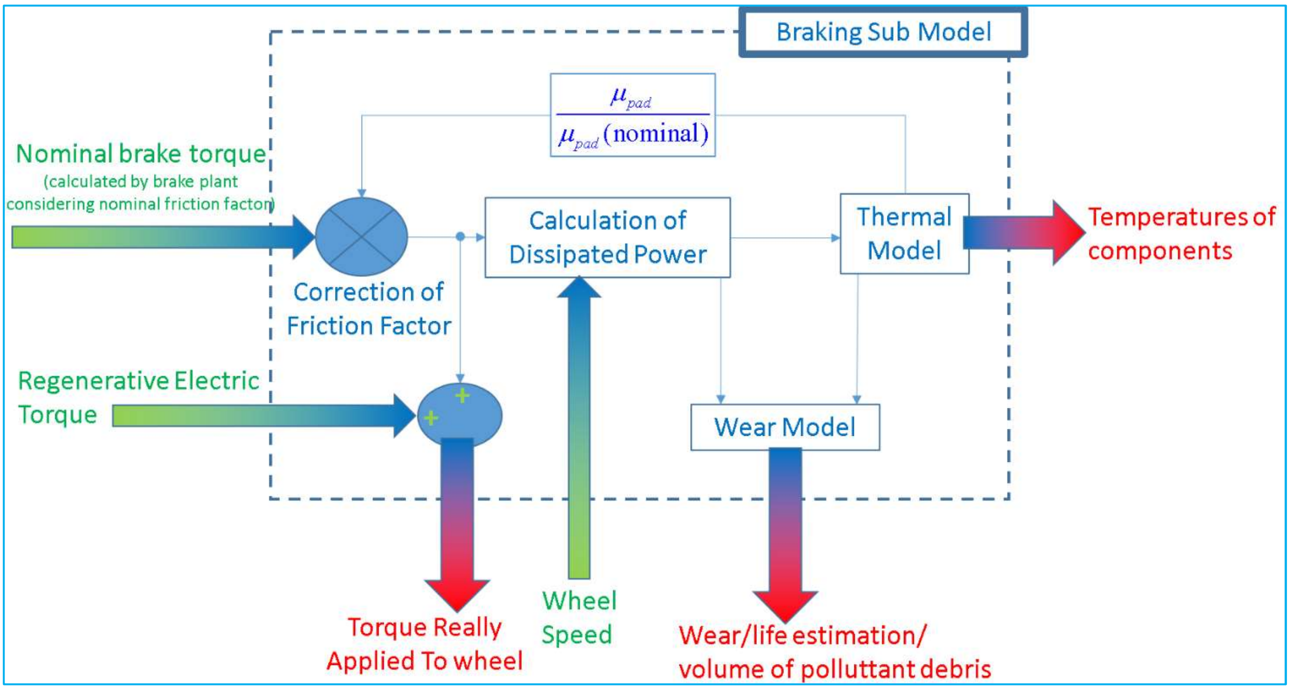

Figure 2-50 “Braking” sub-model functional scheme

2.6.3.3 Thermal Behavior of Components:

Being $Tq_{Br,d,i}$ the dissipative torque applied on the i-th wheel and $W_{w,i}$ the corresponding rotational speed, dissipated power on brake-components $W_{br,d,i}$ should be calculated according Equation 10.

Equation 10 $$W_{Br,d,i} = Tq_{Br,d,i} \cdot W_{w,i}$$

Energy is dissipated in the contact interface between pads and discs, so generated heat is transferred to both ones, being $Q_{pad,i}$ and $Q_{disc,i}$ respectively the heat flows transferred to pads and disc of the i-th wheel.
It’s possible to define a heat flux distribution coefficient γ (Equation 11) in order to roughly evaluate how transferred heat flow is divided between pads and discs. By adopting the coefficient γ, a decoupling of the two thermal systems (pads and the disc) is introduced, however this is an approximation commonly accepted in literature, as expressed in Equation 12.

Equation 11 $$\gamma = \frac{Q_{disc,i}}{Q_{pad,i}}$$

Equation 12 $$Q_{disc,i} = \frac{\gamma}{\gamma+1} \cdot W_{Br,d,i}; Q_{pad,i} = \frac{1}{\gamma+1} \cdot W_{Br,d,i}$$

Once inlet heat flows for each brake component are calculated, it’s possible to perform a rough evaluation of mean temperatures $T_{disc,i}$ (for disc) and $T_{pad,i}$ (for pads), solving corresponding lumped systems described by Equation 13 and Equation 14.

Equation 13 $$Q_{disc,i} = C_{disc,i} \cdot T_{disc,i} + \left(h_{convection,d,i} + h_{conduction,d,i} + h_{radiation,d,i}\right) \cdot \left(T_{disc,i} - T_{amb}\right)$$

Equation 14 $$Q_{pad,i} = C_{pad,i} \cdot T_{pad,i} + \left(h_{convection,p,i} + h_{conduction,p,i} + h_{radiation,p,i}\right) \cdot \left(T_{pad,i} - T_{amb}\right)$$

Cooling coefficients adopted in Equation 13 and Equation 14 are clearly variable and nonlinear. For this reason it’s possible to introduce calculated or tabulated relationships to evaluate exchange coefficients respect to relevant physical parameters (component temperature, disc angular speed, vehicle speed, etc.). A good reference followed for the current implementation is represented by the work of Stevens and Tirovic (Heat dissipation from

a stationary brake disc, Part 1: Analytical modelling and experimental investigations, 2018) & (Heat dissipation from a stationary brake disc, Part 2: CFD modelling and experimental validations, 2018).
Considering the importance of the heat distribution factor γ, also this coefficient should be tabulated respect to different working conditions according various models available in literature (commonly a constant mean value of gamma of about 4-5 is considered).

2.6.3.4 Wear of Components:

For the calculation of pad and disc wear rates, constant wear rate factors $K_{wear,pad}$ and $K_{wear,disc}$ are currently considered, as expressed in Equation 15 and Equation 16.

Equation 15 $$\boldsymbol{K_{wear,pad} = \frac{Vol_{pad,i}}{W_{br,d,i}}}$$

Equation 16 $$\boldsymbol{K_{wear,disc} = \frac{Vol_{disc,i}}{W_{br,d,i}}}$$

With more data from UCs partners, it should be possible to introduce tabulated relationships respect to typical input parameters (dissipated power, temperature, clamping pressure, etc.).

2.6.3.5 Stability of friction-braking performances:

Braking Performances clearly depends from pad friction factor μ_{pad}. Braking torques are currently calculated considering a constant value of μ_{pad}. However, “braking” model is able to roughly evaluate thermal behavior of pads, clamping forces and exchanged flow powers. As a consequence, it’s possible to introduce tabulated corrections of applied braking torques in order to simulate the typical dependency of friction factor respect to over-cited parameters.
Transients associated to large variation of μ_{pad} are quite slow since this feature is mainly dependent from thermal/energy related effects. So torque corrections performed to take count of friction fluctuations should be easily performed using the loop described in Figure 2-50 without producing appreciable numerical instability troubles or imposing numerically onerous integration frequencies.

2.7 Conclusion

All these subsystems offer new capability in term of modeling especially to assess new EV architectures and to consider more deepened integration. Braking is no more seen as “lost energy”, but as a source of energy if it’s correctly controlled. Thermal integration in early stage of the design process is mandatory due to its complex integration between all subsystems, especially through with balance between thermal comfort and reliability of electric component). Such new design issues are highlighted with toy model in next chapter.

3 Toy model integration

New models, tools and methods are able to support vehicle-level electric powertrain integration studies in a flexible and fast process and support new powertrain concepts, multiple configurations of physical and/or functional models and vehicle-level processing scalability to cover detailed to real-time compliant simulation using standardized model integration (Ponchant, et al., 2017).

3.1 Siemens integrated model

3.1.1 Description

This integrated vehicle model is based on Fiat 500e developed in context of UC2.5, as illustrated in Figure 3-1. Focus of this mode is the thermal behavior and its impact on vehicle range. Input parameter are estimation up to now and model will be refined later during the project.

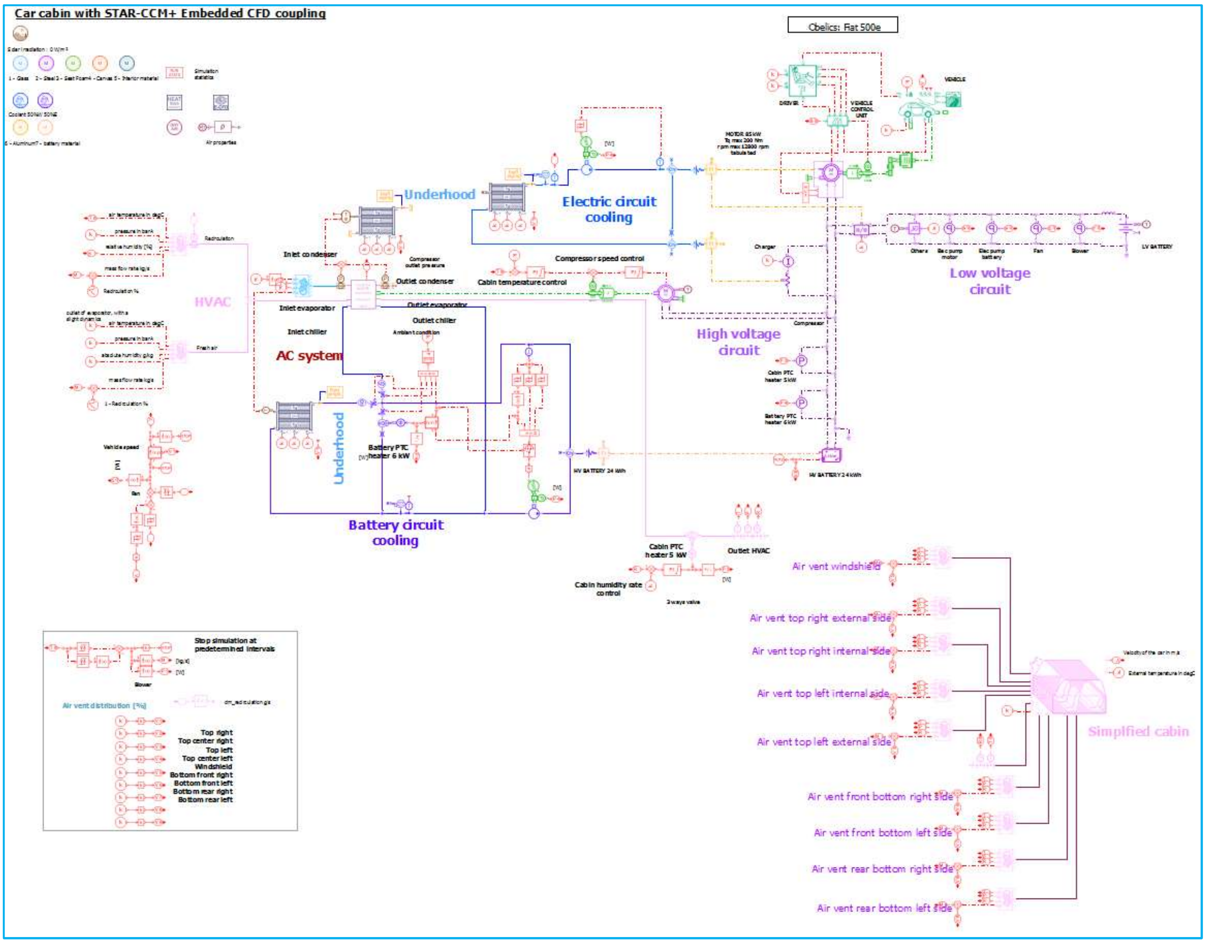

Figure 3-1 Fiat 500e integrated vehicle model

Model is composed of different subsystems described in previous section. 3D calculation can be launched during the whole simulation, based on some condition:

- Under-hood
  - $|V_{ve} - V_{ref}| > 5\ m/s$ with V_{ref} last saved vehicle speed at the 3D calculation
  - Fan activated; position 0 - 1 – 2
- Cabin
  - HVAC blower position change

Thermal subsystems have impact on vehicle range for several reasons:

- PTC activation
- AC Compressor activation
- Cooling pump activation
- Influence of temperature on the electric component (motor and battery)

So thermal effect cannot be neglected on electric vehicle.

3.1.2 Results

Model has been run on new driving cycle called WLTC, which is the new European standard, as illustrated in Figure 3-2.

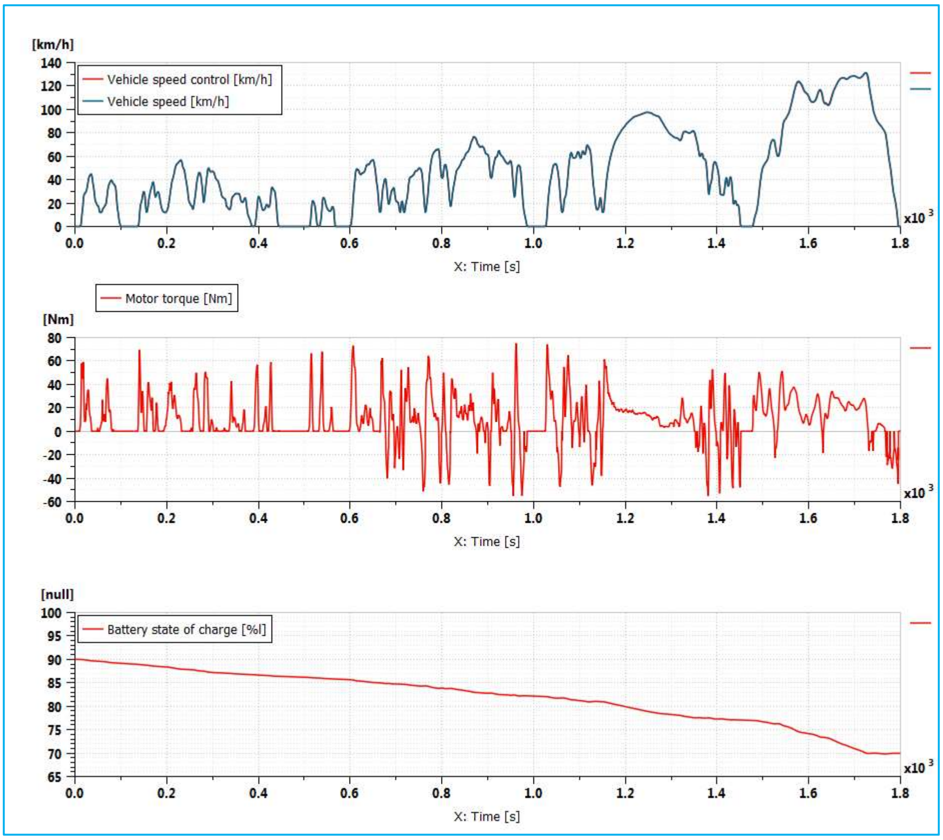

Figure 3-2 Fiat 500e main results

We can notice motor I used to load battery (negative torque) when battery SOC achieved 85%.

Influence of each electric consumer could be identified especially the ones linked to thermal subsystem, as illustrated in Figure 3-3.

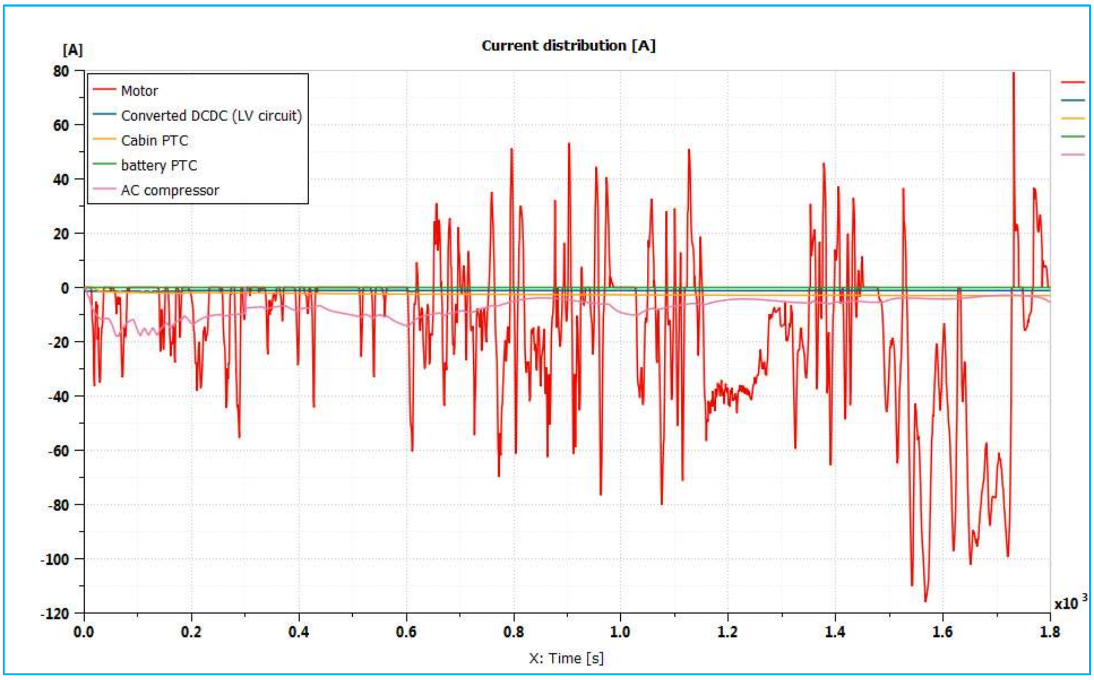

Figure 3-3 Fiat 500e current distribution

We can notice AC compressor contribution is not negligible at the beginning of the scenario, because cabin has to be cooled down. When target temperature is reached its contribution is much lower.

Thermal management of the electronic component such as motor, inverter and/or battery could be studied by integrating all interaction between under-hood flow or cabin comfort request, as illustrated in Figure 3-4.

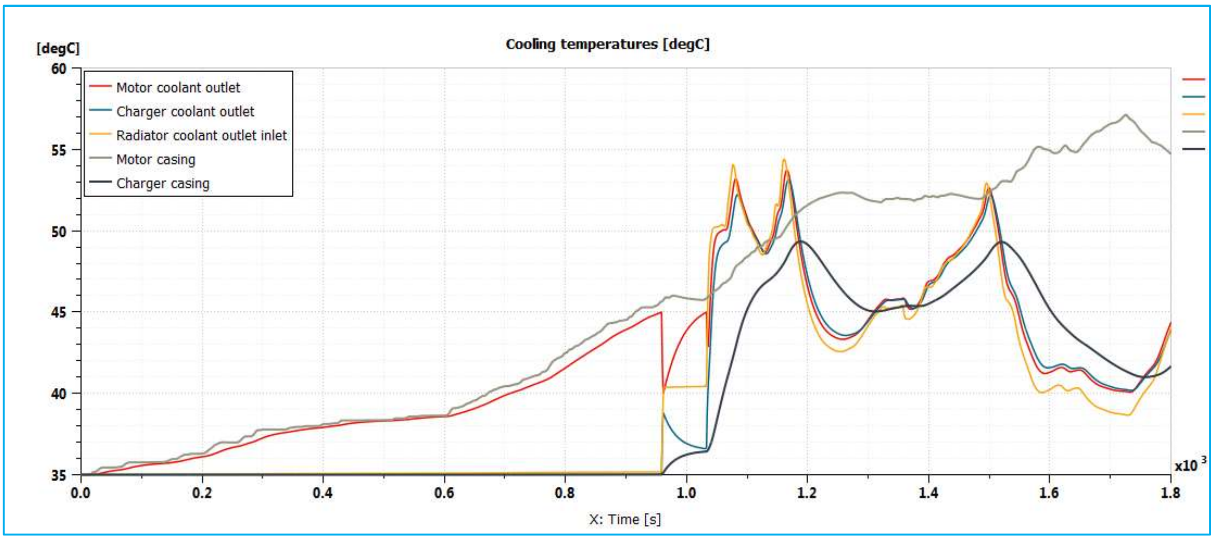

Figure 3-4 Fiat 500e elec. Component temperatures

The battery temperature is cooled down until achieving 25 degC. Then pump is stopped and chiller is no more used in order to reduce the compressor power, as shown in Figure 3-5.

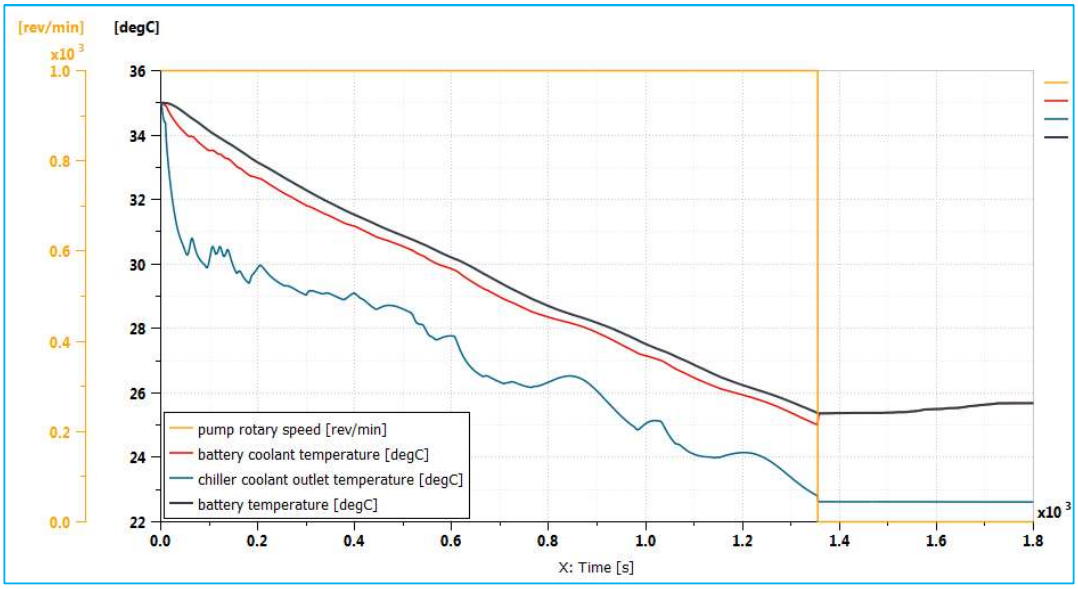

Figure 3-5 Fiat 500e battery temperature

Function of the vehicle speed or the fan activation, CFD model is called, as illustrated in Figure 3-6.

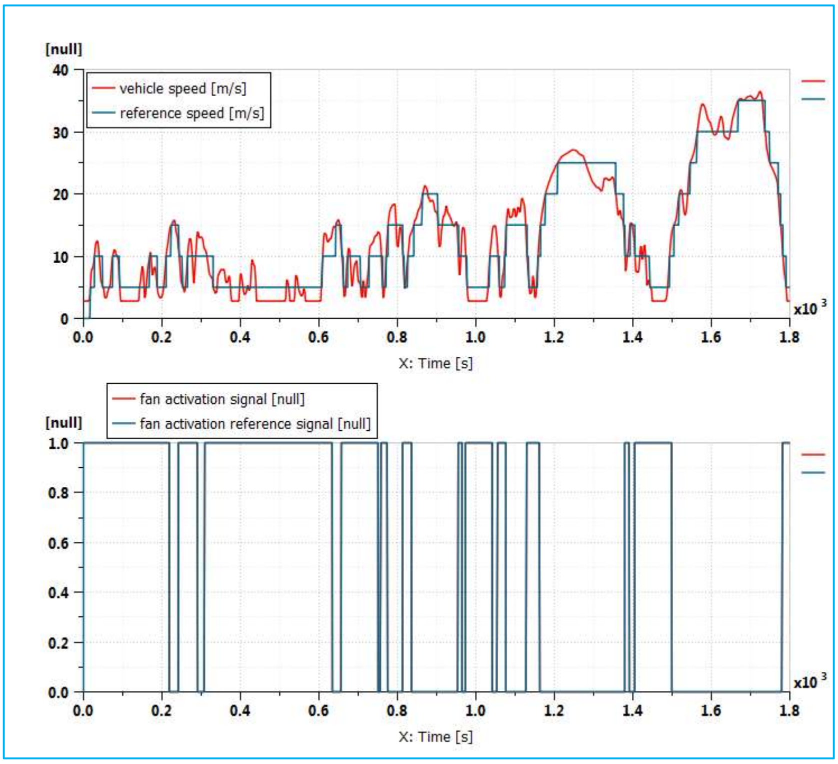

Figure 3-6 CFD model call, based on control signal

As information[5] mean air velocity on heat exchanger is calculated based on velocity map generated with CFD, as illustrated in Figure 3-7.

[5] Not used for heat flow rate calculation

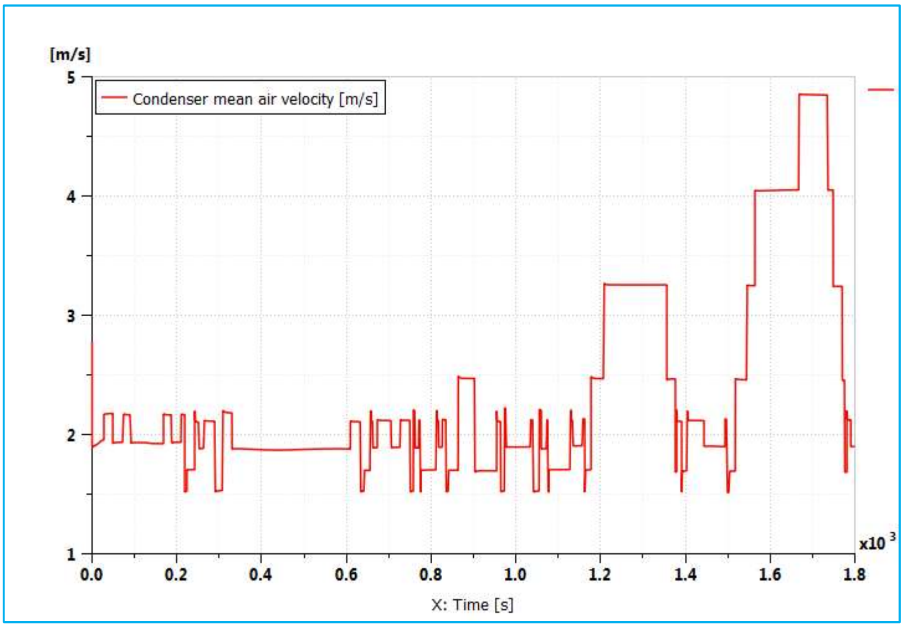

Figure 3-7 mean condenser air velocity

Such methodology allows user to run 1D/3D coupling model with quite fast simulation time for a complete driving cycle. In this example, overall simulation lasted around 3h30 with 84 CFD calls.

Temperature gradient within the cabin could be analyzed thanks to the smart 1D/3D coupling, which is relevant for control strategy (recirculation, compressor…, as illustrated in Figure 3-8.

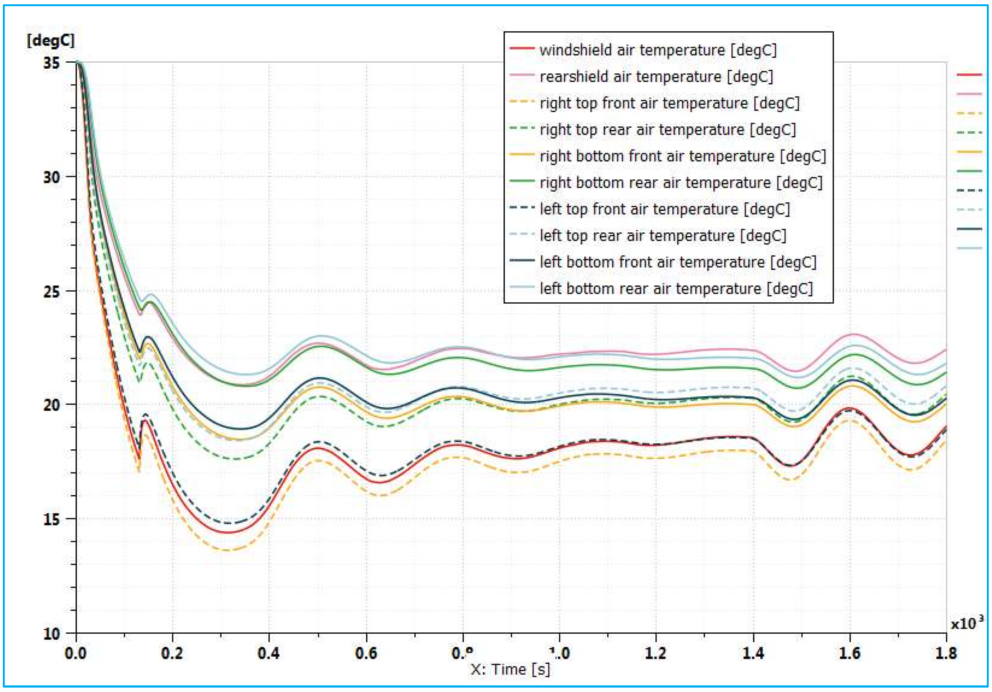

Figure 3-8 temperature distribution in cabin

We can notice the Left bottom front air temperature is used for control, because recirculation flow is coming from this area. With such approach, we clearly see the temperature difference between colder part (top front & windshield) and hottest part at the bottom rear, with an estimated temperature difference of ¾ degC.

3.2 RT-SAS (VOLVO) integrated model

3.2.1 Main objectives

The "toy" models described here will be used firstly to analyse vehicle performance for different powertrain topologies (architectures), architectures for example with single or multiple electric drive axles, and different component performance specification to support the development of an electric truck dedicated to multipurpose commercial application (refuse, distribution, distribution with fridge, …); on the other hand these models will also support thermal management system development along the design process with vehicle level analysis. Therefore, these models need to be flexible enough to allow seamless integration of scalable vehicle sub-system models without requiring extensive modelling adaptation and parameterization.

The first toy model is adapted from the existing VOLVO in-house integration tool, which is dedicated today mainly to detailed system design integration, in order to support faster high level powertrain system design analysis targeting robust concept selection and optimized sizing for a set of vehicle applications, scenario and vehicle performances metrics (vehicle attribute requirements). This toy model allows vehicle simulation with different levels of scalability, as illustrated in Figure 3-9, it can take into account complete powertrain and cooling system modelling for detailed integration analysis as well as running the vehicle with high level powertrain characteristics (limitations at the wheel) to enable early torque, power and energy requirement analysis.

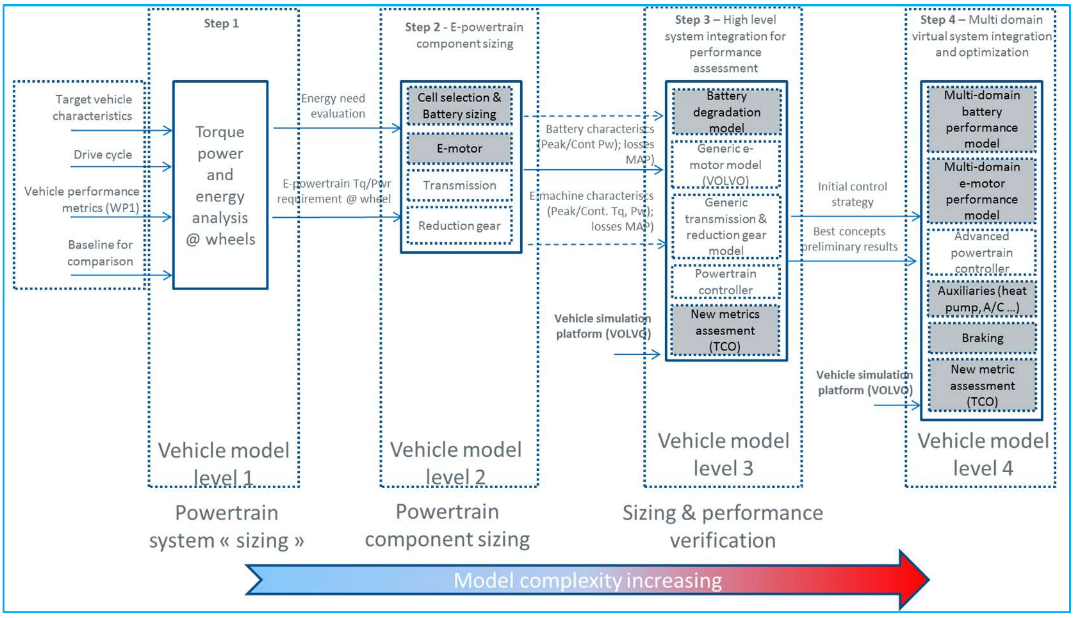

Figure 3-9: Description of models used in each step of the methodology.

The second toy model will focus on virtual assessment of vehicle thermal management system considering complete vehicle system simulation. The aim of this model is to enable thermal management system concept exploration, system development including design optimization, controller development and calibration, complete system virtual verification with drive cycles derived from real driving conditions. This toy model allows vehicle simulation with different levels of cooling system model scalability.

3.2.2 Toy model for powertrain concept design analysis and optimization in early project phase

3.2.2.1 Model description

This model will be developed considering similar vehicle model architecture and modelling guidelines (Vehicle Modular Architecture standard – VMA) in order to keep continuity in the simulation environments between these new integration tools for early powertrain concept analysis and the current in-house simulation platform supporting project design phase and product development. This model consists of the following subsystem models integration:

- Road and environment sub-system model
- Driver sub-system model
- Vehicle sub-system model

Figure 3-10 provides a description of this model at the top level.

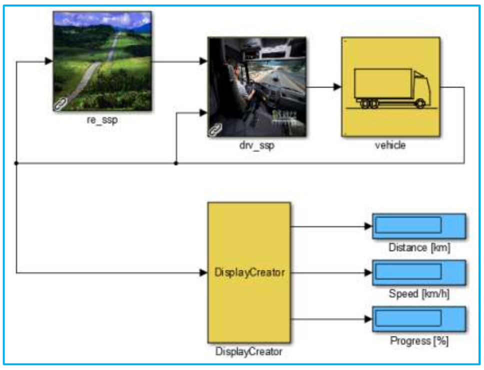

Figure 3-10 Toy model description at top level

The proposed modelling guidelines allow a vehicle model scalability to cover high level powertrain system simulation for new concepts exploration, powertrain systems performances requirement definition (torque, power and energy requirements) in relation to the operating scenarios and vehicle-level electric powertrain integration studies of key systems in a flexible and fast process for component performances specification and powertrain performances assessment with vehicle level simulation. The purpose of this model is to quantify energy consumption and autonomy. The following subsystem will be included for these integration analyses with "simplified" models:

- Electric components: battery, electric machine and inverter systems
- Control strategies: energy management, powertrain and brake blending strategies
- Thermal systems
- Auxiliary systems

3.2.2.2 Results

Figure 3-11 below corresponds to a vehicle simulation with ASTERICS cycle using the first toy model that only consider the high level characteristics of the powertrain (level 1), it shows the impact of the powertrain design parameters on performance, in this case it is considered maximum torque and power at the wheels of 24kNm and 240kW respectively.

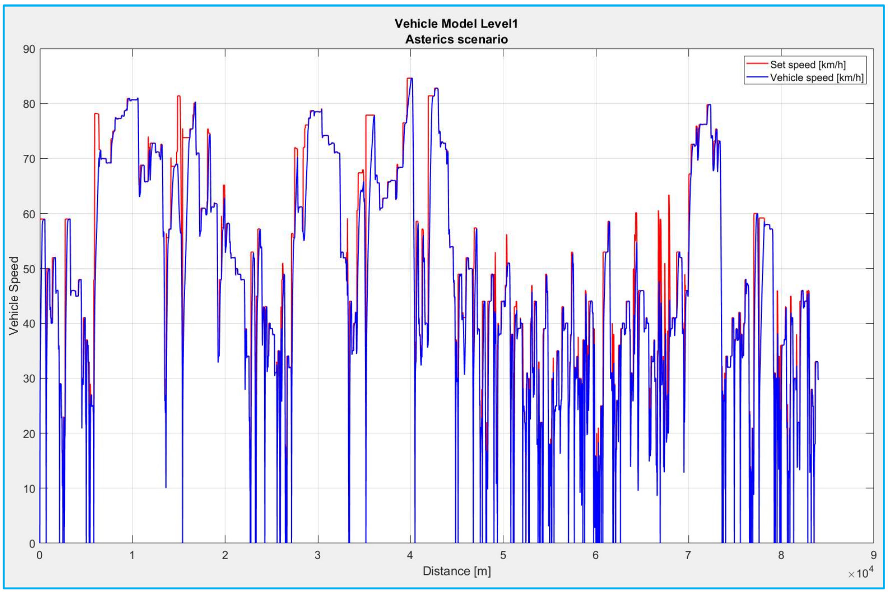

Figure 3-11: Level1 model simulation on ASTERICS cycle.

From this toy model one can analyse torque and power request at the wheel from a cycle, and use this data to size the powertrain correctly. It is also possible to analyse energy requirements at the wheel, what can be used to size battery systems and give an initial guess on cooling requirements. Figure 3-12 shows the torque at the wheels envelope and the actual operating points inside the envelope.

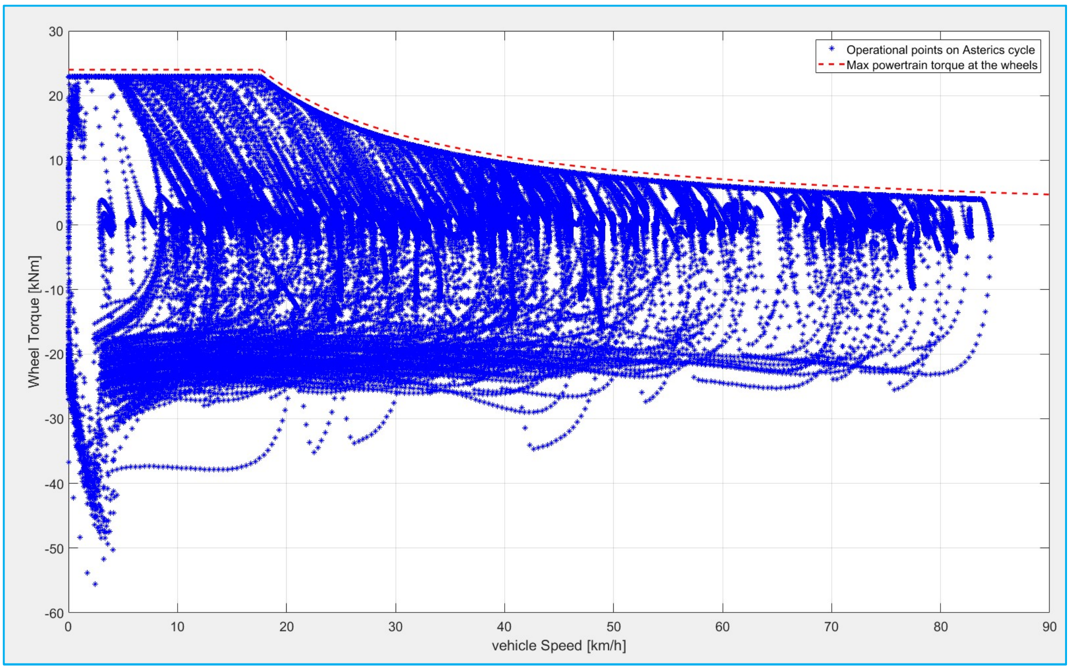

Figure 3-12: Maximum torque envelope with operational points for ASTERICS cycle.

With toy model level 1 it is also possible to analyse duty cycle power demand, and understand for how long a certain power demand is requested during the cycle which can help sizing the peak and continuous requirements of the powertrain. Figure 3-13 shows a histogram of power demand for ASTERICS cycle.

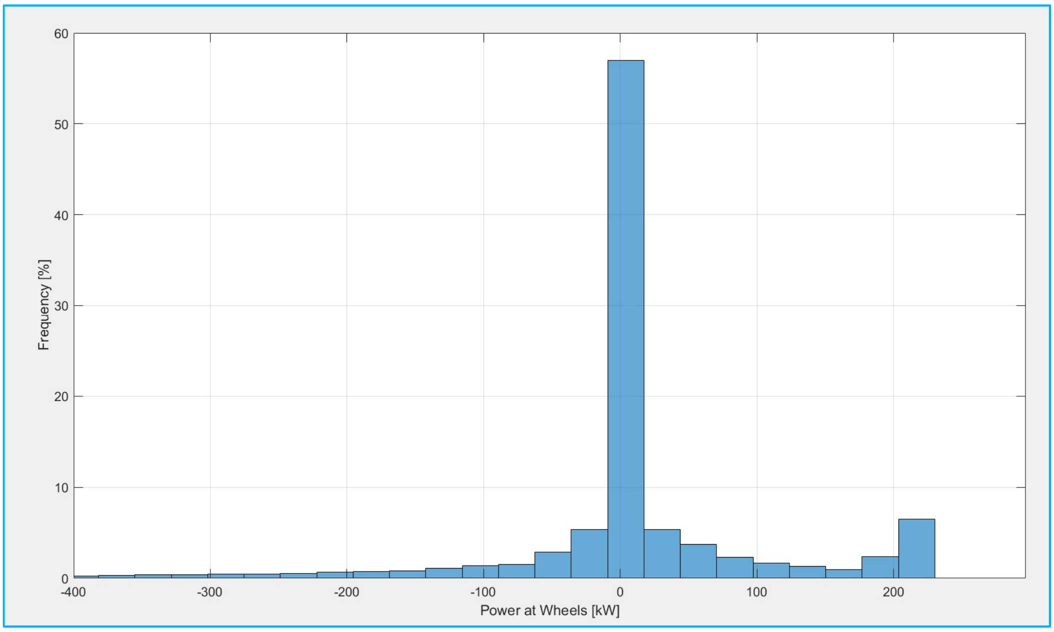

Figure 3-13: Histogram of power request at the wheels for ASTERICS cycle.

3.2.3 Toy models for vehicle thermal management system optimization

3.2.3.1 Model description

In this model the goal is to simulate the complete vehicle thermal management system and it impacts on driveline performances, as illustrated in Figure 3-14. The powertrain model is coupled with different scalable thermal management system models, co-simulation interface will be explored to allow detailed thermal management system integration (with third party software). These models will be used in several development steps from early phase up to final design and verification, with the aim to link thermal management system performances to overall vehicle performances

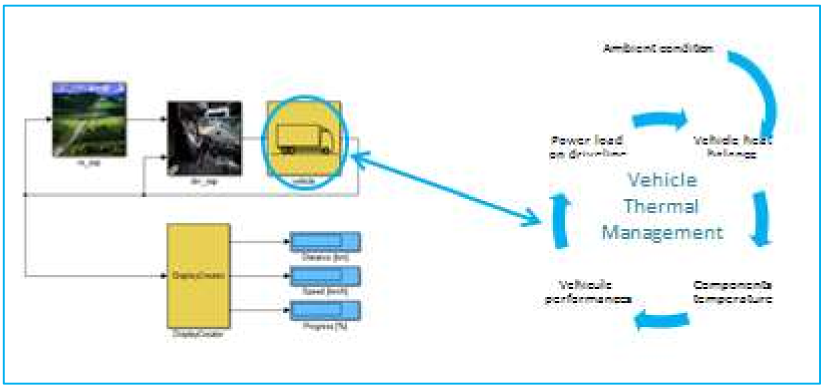

Figure 3-14 Toy model description for vehicle thermal management

3.2.3.2 Results

Figure 3-15 below illustrates the temperature of several electric components on a reference drive cycle. Components temperature remains in a reasonable temperature window allowable the maximum performance.

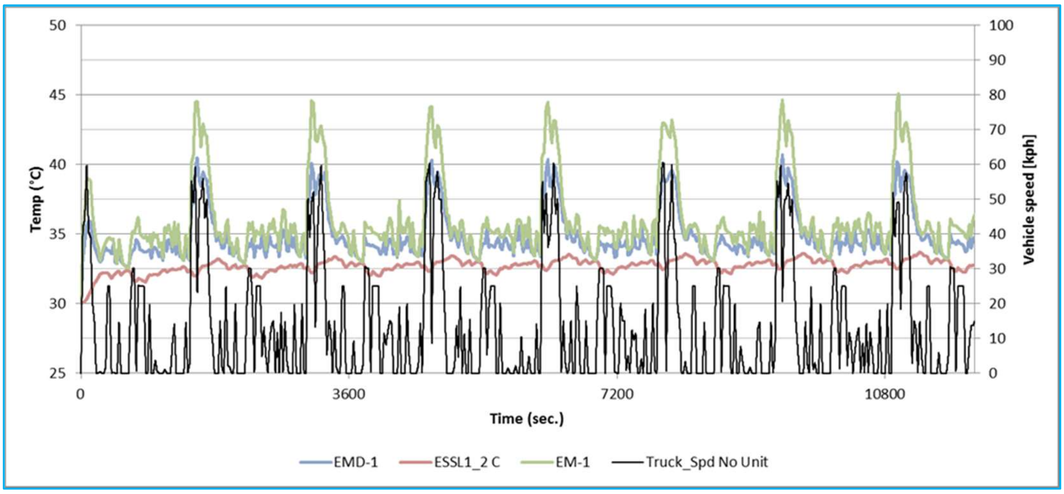

Figure 3-15 Temperature results on a typical drive cycle

Figure 3-16 shows the temperature range in which the electric components are working. It gives statistics information about the time spent close or over the temperature limit, bringing opportunity for optimization.

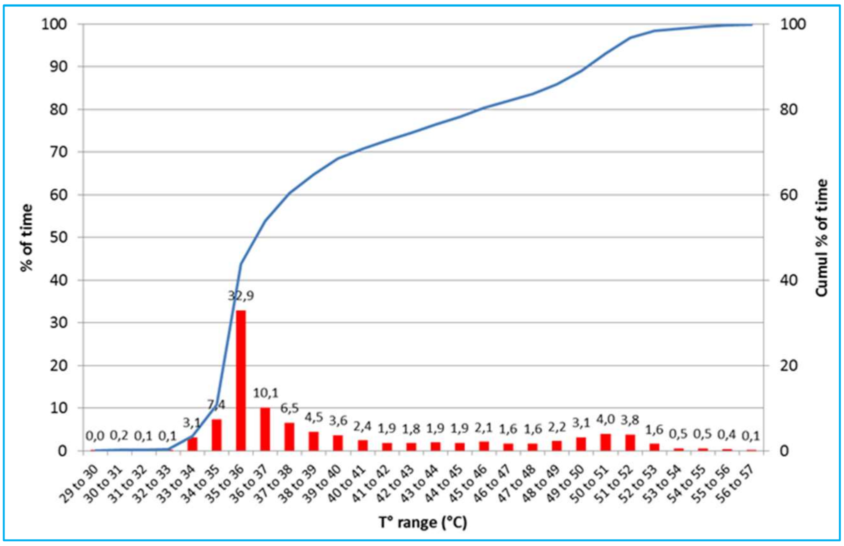

Figure 3-16 Temperature statistics on a typical drive cycle

4 Conclusions

This document describes several components and their capability to support electric vehicle development by allowing interaction between multi-physical subsystems, especially through thermal components. These interactions has been highlighted in some example thanks to toy models. Thermal behavior is critical in electric vehicle and a deeper understanding is mandatory, which is highlighted with 1D/3D smart coupling in order to integrate interaction of electric components on their design phase. Energy management is also a key point in electric vehicle and braking system has to be considered in such complex control to enhance the range of vehicle by allowing new strategy for brake blending control. The architecture of electric vehicle is now free from conventional chassis and new one could be easily assessed, like 4 wheel drive (one motor per wheel) architecture.

Toy models are highlighted such complex integration which will be used in other Work Packages of the OBELICS project to reduce and enhance to overall EV design process through different use cases:

- Validation of electric component design (WP2)
- Virtual testing for specific component (performance, reliability safety on more realistic test cases (driving cycle, real driving cycle…) (WP5)
- Validation of advanced control on real time platform, by considering all power flow, especially with refined brake blending strategies (WP4)
- Enhanced thermal management with complete understanding of integration between subsystems (WP6)

5 Abbreviations and definition

ABS	AntiBlockierSystem
AC	Alternative current
ACEA	European Automobile Manufacturers' Association
CAD	Computer Assisted Design
CFD	Computational Fluid Dynamics
DC	Direct Current
EBD	Electronic Brakeforce Distribution
ECU	Engine Control Unit
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
IM	Induction machine
ITEA	Information Technology for European Advancement
LV	Low Voltage
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
WRSM	Wound Rotor Synchronous Motor

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Partner no.	Partner organization name	Short Name
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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
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17	University of Surrey	US
18	Das Virtuelle Fahrzeug Forschungsgesellschaft mbH	VIF
19	Vrije Universiteit Brussel	VUB

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