# Sizing of an electric powertrain using a hybrid model combining Simcenter Amesim and Modelica components

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**During the 0D/1D modelling phase of an engineering project, the combination of several approaches can facilitate the design stage. This paper presents a hybrid model of an electric powertrain using Simcenter Amesim and Modelica components. The process of validating the design of an electric powertrain subsystem in a vehicle system simulation is also presented. The aim is to illustrate the benefits of the combination of Modelica's acausal modelling approach and Simcenter Amesim's causal modelling approach.**

## I. Nomenclature

| | | |
|---|---|---|
| MBD | = | Model Based Design |
| BEV | = | Battery Electric Vehicle |
| EV | = | Electrical Vehicle |
| MSL | = | Modelica Standard Library |
| PWM | = | Pulse width modulation |

## II. Introduction

In numerical modeling and simulation, the notion of causality allows the sequencing of physics modelling equations in a logical order adapted to the computer. It also provides them with the necessary path to solve the system of equations. It consists of designating the input and output variables of a model and each of its sub-models. As a result, this sequence creates a causal relationship between inputs and outputs.

When the causality is not imposed, and an algorithmic and symbolic process enables the generation of the required computational sequence, the modeling approach is called acausal model. In this case, the physical connection ports have no pre-defined inputs or outputs before their association.

Multi-physics modeling and simulation software programs are either causal or acausal. Nowadays, this difference relates only to the modeling aspect. In Simcenter Amesim, it is possible to use commercial Simcenter Amesim causal libraries using the bond graph concepts and Modelica acausal libraries in the same platform, which allows the modeler to have this extra degree of freedom and to symbolically process the equations before simulation.

For each approach there are benefits and drawbacks. Therefore, we decided to merge these two approaches during the modeling phase of an electric powertrain. In this article we present a hybrid model - Simcenter Amesim based and Modelica based - and the benefits of this hybrid approach.

This study presents the modeling and simulation activities performed within the Simcenter Amesim platform for what concerns multi-domain system simulation. A first model of an Electrical Vehicle (EV) is depicted, including a detailed model of inverter circuit to model their high frequency behavior. A second model is built where the inverter system is using an acausal approach thanks to the Modelica language. Finally, conclusions will be presented comparing both approaches.

## III. Amesim model introduction – EV

For this work, an Electrical Vehicle (EV) has been modeled using Simcenter Amesim. The Fig. 1 shows the sketch with the different components used to model the electrical vehicle.

The Simcenter Amesim model can be used to support the Model Based Design [1, 2] at different parts of a BEV design project: Definition of requirements, preliminary designs of subsystems (as battery and electric machine), validation sizing of subsystems, etc.

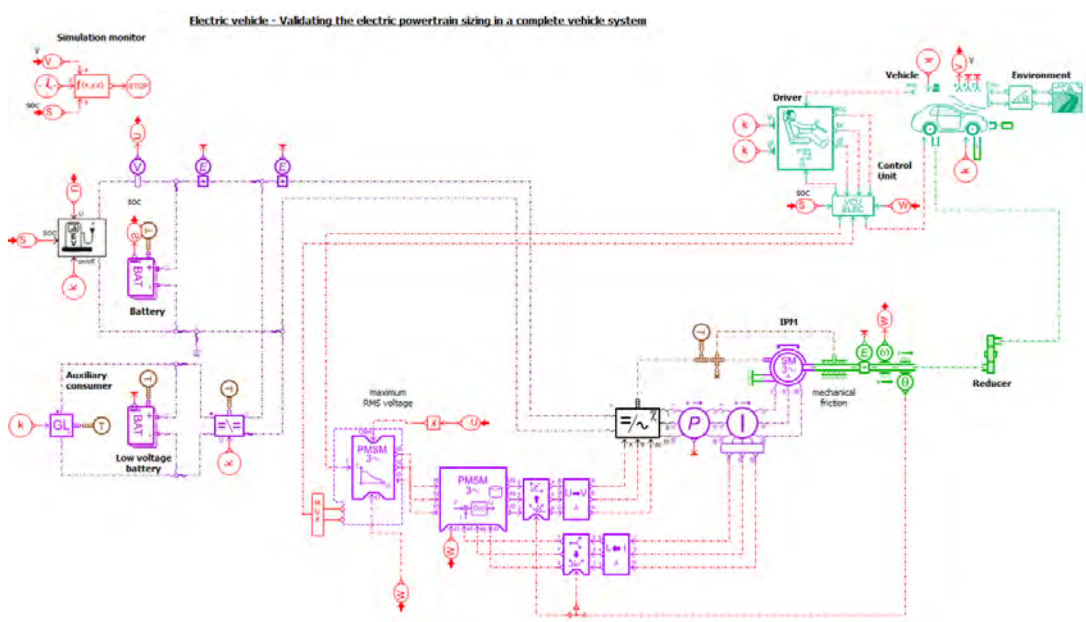


Fig. 1: Electrical Vehicle

The model is composed of a vehicle dynamic model, driven model as well as the reducer mechanical system. The reducer system is connected to an electrical motor model, a switched 3 phase PWM inverter model and a quasi-static battery model. A battery charger system is included to model the charging phases of the vehicle.

As you can notice, there is a focus on the electrical system of the EV system. For that, more detailed approach has been used on the modeling of that sub-system. The goal of this EV model is to validate:

- The electrical motor behavior in the EV integration

- The control system of the electrical motor

For this last objective (validation of the control system of electrical motor), is necessary to simulate high frequency effects on the electrical system. In order to "capture" the behavior needed for this goal, the model design engineer can select between all available level of models inside Simcenter Amesim libraries (Electric Storage library, Electrical Static Conversion library, Powertrain library, etc.). The following Fig. 2 shows the different levels of modeling for each subsystem and the selection done for this work.

| | Electric motor | Inverter | Battery | Gearbox | Chassis |
|---|---|---|---|---|---|
| Level 1 | Static | Balanced | Generic battery | Ratios efficiency | One inertia |
| Level 2 | Quasi-static | Average | Advanced model (semi-empiric) | Flywheel inertia | 3 DoF (2D) |
| Level 3 | Dynamic | Switched | Advanced model (semi-empiric) + thermal | Detailed rotary stiffness and inertia | 18 DoF (3D) |
| Level 4 | Cooperation with FEM | | Advanced model (semi-empiric) + aging | | |

Fig. 2: Models proposed in Simcenter Amesim libraries - Selection of complexity this EV model

Once, the model is done in Simcenter Amesim, the user can select the operational context where the system will operate. For this work, an acceleration from 0 to 100 km/h will be defined as cycle mission.

Most of the icons visible on Fig. 1 represent a physical model of a component such as an electrical motor, a battery, or a reducer. In some cases, for the sake of the model understanding, super-components are used: they encapsulate part of the model in a block, structuring the model from a functional point of view. Here the inverter system is modeled inside the super-component depicted in Fig. 3.

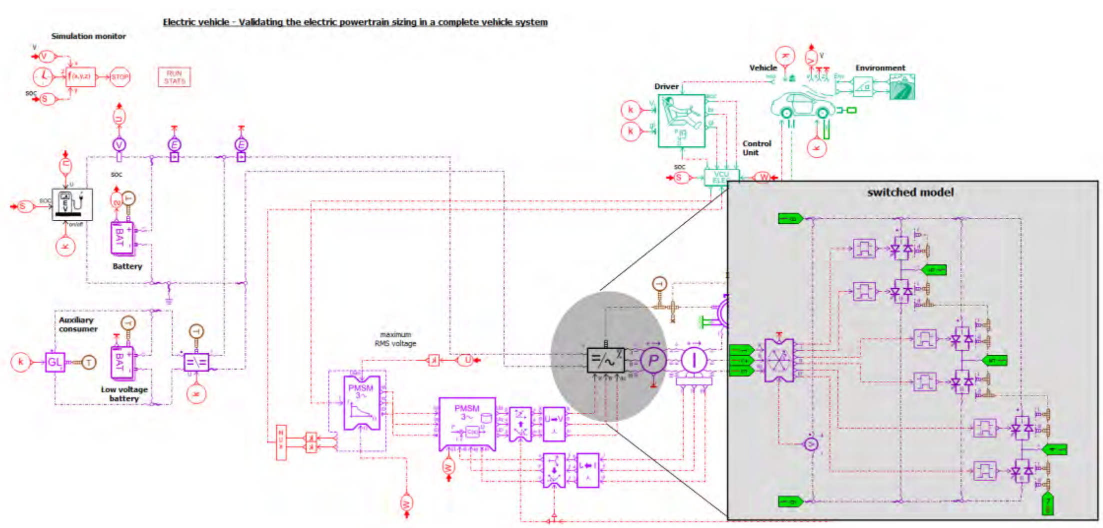


Fig. 3: Overview of switched inverter model in super-component

Inside the super-component a very detailed 3-phase PWM inverter has been modeled. The inverter is modeled using the switched approach, where all high frequency effects related to the inverter are modeled.

### A. Inverter component characterization

The 3 phase PWM inverter is composed of 3 switched inverter arms. These models will take the conduction and switching losses of the model into account in a quasi-static way.

The switching frequency and conduction characteristics will also have an impact on the phase voltage delivered to the machine. Fig. 4 shows the switched inverter model done using Simcenter Amesim standard components.

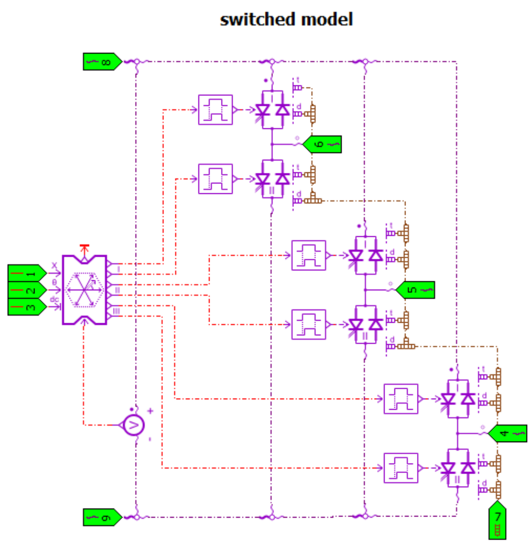


Fig. 4: Switched inverter model

The switched inverter model is composed of several inverter arms and is modeled as one Simcenter Amesim component as showed in Fig. 5. This way to model it allows fast and accurate simulations. However, the architecture is fixed for the arm modules.

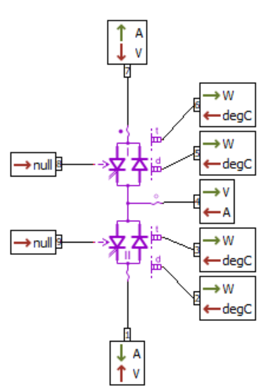


Fig. 5: Switched inverter model

Each module consists of a transistor and an antiparallel diode where the considered conduction characteristic of the 2 modules is summarized in Fig. 6

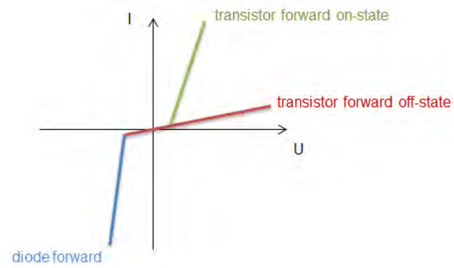


Fig. 6: Considered conduction characteristics

This model computes the thermal aspect of the chips and the semiconductor characteristics as a function of temperature. The electro/thermal coupling is then fully taken into account.

## IV. Modelica model

We use the MSL 3.2.2 - Electric Switch and diode - to model the 3 phase PWM inverter composed by 3 switched inverter arms. With the help of the Simcenter physical ports this Modelica bloc can be connected to the previous model and replace the Simcenter Amesim inverter model, as showed in Fig. 7. Behind the scene here, the Modelica bloc is based on the FMI 2.0 standard, created automatically in model exchange with a Simcenter Amesim specificity because it is possible to connect also physical ports to this customized FMU.

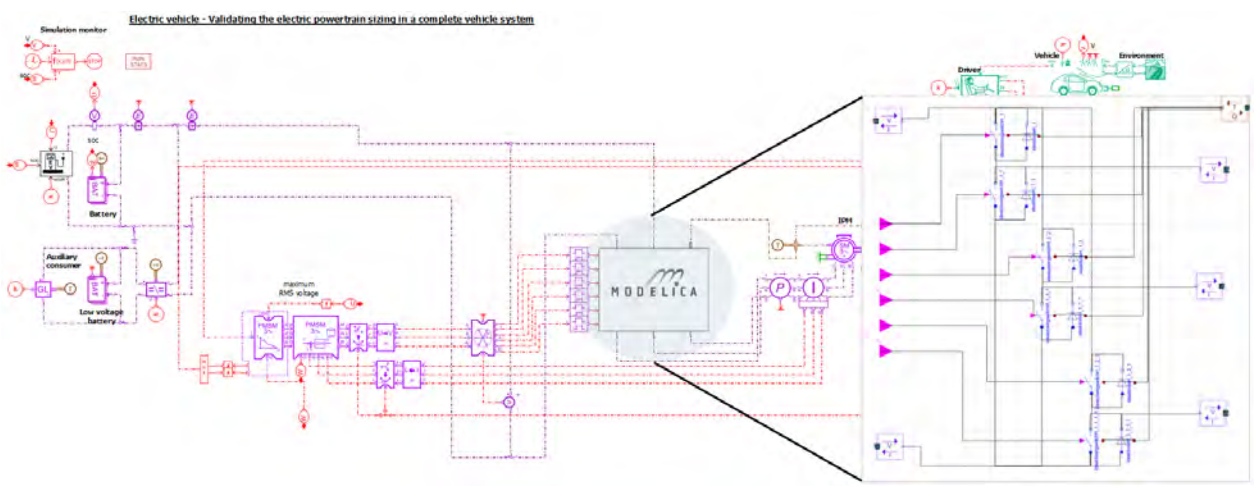


Fig. 7: Overview of a switched inverter Modelica model

The MSL diode takes conduction and voltage drop characteristics into account, but the switch does not. And neither component takes switching losses into account. So, these components, unlike the ones presented previously, are not well suited for thermal modeling and will be less accurate for power flow estimation.

But they are the required level for control validation, to quickly test innovative inverter architectures or observe the impact of high switching frequencies on the powertrain.

## V. Comparison two approach

The comparison is carried out during the modelling phase, the analysis of the results and the performance analysis.

### A. Modeling phase

During the modelling phase of the homogeneous model, we must deal with the causal aspect and the concepts of bond graphs. Especially for the inverter model, the arms composed by two modules introduce some complexities due to its sequencing. A specific analysis must therefore be done in order to have an equivalent sub-model integrating causality and ready to user for final users. With this approach, the more the number of modules increases by arms, the more delicate and time-consuming the analysis and modelling can be.

For the heterogenous model, the inverter model created thanks to the MSL easily by ignoring the causality aspect, even if the number of modules is increased in each arm. This Modelica approach can save a lot of time regarding the Simcenter Amesim homogenous approach.

### B. Results

The two models presented give the following results. Fig. 8 shows the results at the boundaries of the permanent magnet synchronous machine (PMSM) for 0.2 seconds of simulation. As shown, the heat power, the current (A) and the voltage (A), received by the PMSM are exactly the same regardless of the approach chosen.

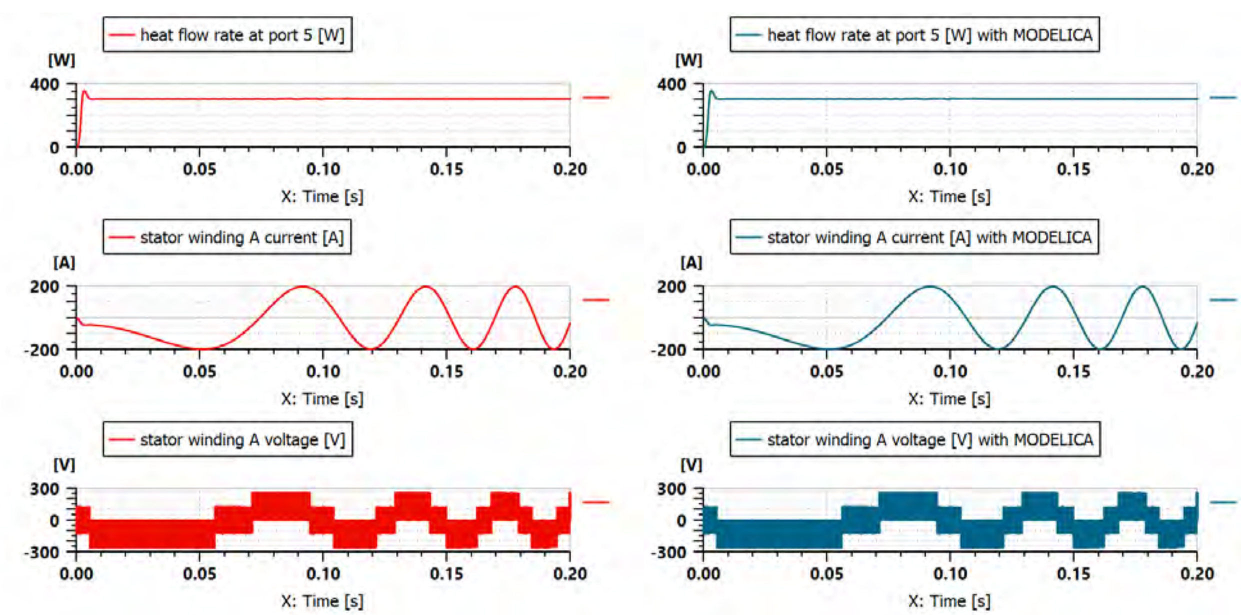


Fig. 8: Simulation results from homogenous (left) and heterogenous (right) models for 0.2 seconds.

Fig. 9 shows the simulation results of the velocity of the vehicle, the state of charge of the battery and the machine electromagnetic torque during 10 seconds of simulation. As shown, the results are the same for both approaches.

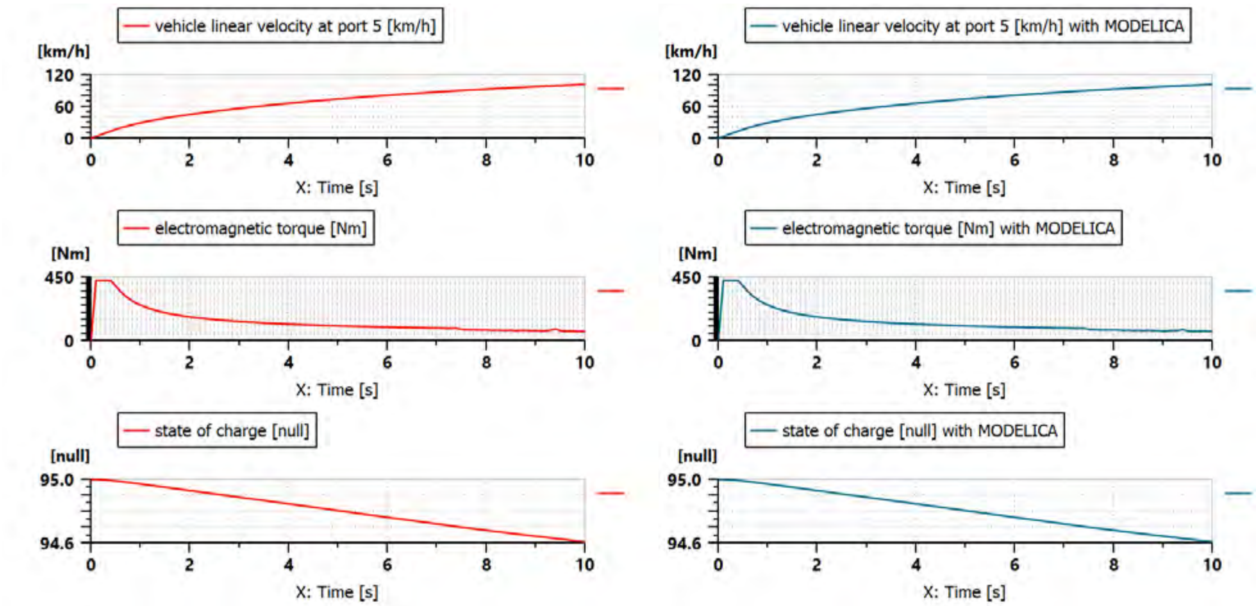


Fig. 9: Simulation results from homogenous (left) and heterogenous (right) models for 10 seconds.

### C. CPU comparison

To finish the comparison between the two approaches, the Fig. 10 presents the CPU times. As shown, the heterogenous model decreases the performance of the simulation by almost 20% compared to the homogenous model. This can be linked to the Modelica approach integrating an automatic model reduction procedure as opposed to the causal approach of the Simcenter Amesim. Indeed, during the translation phase of the Modelica code, a symbolic processing made by the compiler occurs. This phase translates the code into a procedural code that serves to facilitate function evaluations to be called as the software works through each time step.

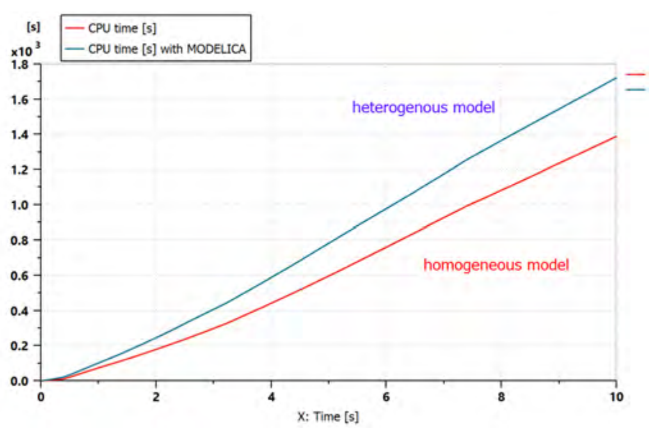


Fig. 10: CPU time comparison

## VI. Conclusion

The inverter arm models provided in the Electrical Static Conversion (ESC) allow for fast and accurate simulations. But this fast performance comes at a cost: the architecture is fixed for the arm modules. This is where the Modelica solution can be complimentary. The architecture of each module can be quickly and easily modified in Modelica, since causality aspects will be dealt with by the compiler. This can be useful, for example, if we want to design an inverter with a higher current by putting several transistor/diode modules in parallel. In Amesim we could model this new design by using equivalent parameters, calculated using the updated Modelica model, though Software Based Characterization (SBC). This makes sense because the native Amesim model will still outperform the Modelica model in terms of CPU time. This shows that both approaches make sense and are complementary in creating new electrified powertrains.

## References


[1] Sebastian Ciceo, Yves Mollet, Mathieu Sarrazin, Herman van der Auweraer, Claudia S Martis. Model-Based Design and Testing for the Energy Consumption Analysis of the Electric Vehicles

[2] Sebastian Ciceo, Yves Mollet, Mathieu Sarrazin, Johan J. C. Gyselinck, Herman van der Auweraer, Claudia S. Martis. Model-based design and testing for electric vehicle driveability análisis.