Powerful Advanced N-Level Digital Architecture
for models of electrified vehicles and their components

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Publishable Executive Summary

The PANDA project aims at using the W-model approach, which relies strongly on virtual design and test methods, to reduce the electrified vehicles time-to-market. The project proposes a standard efficient virtual and real testing method of electrified vehicles and will provide a Cloud library of functional models to be accessible by multiregional companies [PANDA 2020]. By improving the virtual and HiL testing efficiency of components, this methodology and tools should significantly reduce the overall development time of new products, and vehicles.

This deliverable sums up the work done on some other deliverables, with a final comparison between virtual testing of the demo-car [Panda D4.5], HiL testing of the battery [Panda D5.1], HiL of the e-drive [Panda D5.2], HiL of the e-subsystems [Panda D5.3] and the real testing of the physical demo-car.

The virtual testing of the demo-car using the EMR formalism has demonstrated a good correlation with the demo-car physical tests, both with simcenter AMESIM© and MATLAB/Simulink©.
HiL testing of different powertrain components such as the battery or the e-drive also demonstrated a good correlation with the simulation, while giving much more flexibility than an in-vehicle testing.
HiL testing have also been performed using real-time cloud computation, showing a great potential for multi-partners projects, were a physical component and the rest of the model could be in different locations.
The conclusion of this deliverable is that replacing part of the real testing by simulation can lead to 4 to 20 times less development time for each prototype iteration. Simulation is also extremely efficient to develop the EMS (Energy Management Strategy) of a hybrid electric vehicle thanks to a lower simulation time than real time testing. For the HiL testing, the time benefits from the integration and the test itself may not be much faster than on the vehicle, but it has other advantages. Testing a full vehicle on a bench is much more difficult and time consuming than testing a single component, with the rest of the vehicle modelled. It is also a much more flexible solution, since any virtual component can be changed between two runs in a few seconds. HiL testing is also compatible with cloud computing, which enables at the manufacturer to test its new component in its own facility, while the rest of the model is run by the OEM and stays confidential.

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1. Introduction

The objective of the PANDA project is to provide a disruptive and open access model organization for an easy interconnection and change of models in the development process of electrified vehicles [PANDA 2020]. The model organization is based on EMR (Energetic Macroscopic Representation) formalism [Bouscayrol 2012]. The formalism is implemented in the 1D simulation tools, MATLAB-Simulink© and Simcenter AMESIM© [PANDA 4.1], an industrial simulation tool used in automotive industry. Models necessary for building a vehicle simulation were developed by PANDA partners in WP2 [PANDA 2.1], WP3 [PANDA 3.1] and WP4 [PANDA 4.1]. They developed multi-scale multi-domain models based on EMR formalism that can be introduced in a simulation architecture of an electrified vehicle [PANDA 1.2]. The methods has been validated on 3 references vehicles: a BEV [PANDA D4.3], a FCV [PANDA D4.4] and a P-HEV [PANDA D4.5]. Moreover, the developed models have been used for HiL testing of the subsystems of the P-HEV for the work package WP5: HiL testing of the battery [PANDA D5.1], HiL testing of the e-drive [PANDA D5.2] and HiL testing of the e-subsystems [PANDA D5.3].

This report is dedicated to the analysis of the data obtained during the project through the work package WP5. By comparing virtual, HiL and real testing of different components, we will be able to demonstrate the potential of using more simulation in the product and vehicle development phase.

The studied vehicle is a Peugeot 308 SW with a gasoline engine and an automatic gearbox. It was retrofitted by VALEO into a plug-in hybrid electric vehicle (P-HEV). This vehicle includes, in addition to the conventional powertrain, two electric machines and their control electronic (e-drives), a 48V battery, an on-board charger and an electronic control unit (ECU) containing the energy management strategy (EMS).

We will first compare the results from the demo-car with its virtual testing, then with HiL testing before reaching the conclusion.

2. Demo-car presentation

This section aims to present the demo-car of VEEM, which is the P-HEV reference vehicles of PANDA for both virtual and real testing. More details can be found in [PANDA 4.5]. As the development of new vehicle is a complex task, this section deals with the industrial constraints in such a development and the complexity of the different task to manage in the case of an innovative hybrid vehicle.

2.1. Powertrain components

The studied P-HEV is a retrofit of a gasoline car. Two electric drives, a high-power battery and an on-board charger have been added to the thermal vehicle (Figure 1). The main characteristics of this vehicle are provided in Table 1.

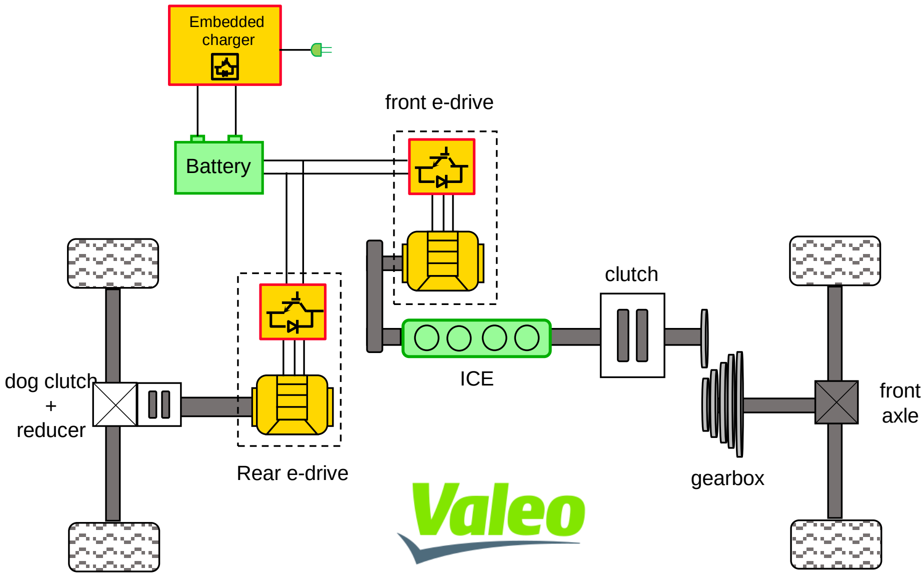

Figure 1: Structural description of the P-HEV

Table 1: Main characteristics of the P-HEV components

Component	Characteristics
Engine	Gasoline (Peugeot engine type EB2DTS) 1.2 l turbo 3 cylinders Maximal power of 96 kW at 5500 rpm Maximal torque of 230 Nm from 1750 rpm
Traction battery	Rated voltage of 44.4 V Rated capacity of 111 Ah Maximal Current of 600 A Operating voltage: 36 V to 51 V Operating temperature: – 30°C to 60°C Water cooled system
Six-speed gearbox (front axle)	Automatic gearbox Ratios with mechanical differential (final drive): [17.8 8.9 5.75 4.25 3.14 2.47]
Front e-drive	48 V Claw pole machine Air cooled system VSI of 48 V DC Rated power of 4 kW
Rear e-drive	48 V permanent magnets rotor synchronous machine Water cooled system

	VSI of 48 V DC Rated power of 25 kW
One-speed gearbox (rear axle)	Ratio of 18.15 Dog clutch for disconnection Integrated mechanical differential (final drive)
DC/DC power converter	48V / 12V converter Maximal power of 1.8 kW
On-board AC/DC charger	230V / 48V converter Maximal power of 2.5kW

It can be noted that different versions of the demo car have been realized, as usual in automotive industry, for progressive integration of various components and for continuous improvements. The demo-car 5 is the reference vehicle for the PANDA project (Figure 2).

Figure 2: Pictures of the final demo-car 5 (Top) and the rear e-drive on the vehicle (Bottom)

2.2. Vehicle modes

As in most hybrid vehicles, it is possible to select a specific operating mode in the demo-car.
On this vehicle, the selection is done via a tablet and a dedicated Android application. Communication with the vehicle is carried out via WIFI with a CAN <-> WIFI gateway integrated into the vehicle CAN and Hybrid CAN network. The tablet is located in the vehicle and the dashboard near the driver for an easy reach (Figure 3).

The vehicle modes available are as follows:

- **Conventional:** by default, the vehicle operates in the conventional way, without hybrid functions. The front machine is still used as an alternator to supply the electric loads.
- **Hybrid**: the vehicle operates in hybrid mode. The strategy distributes the driver torque set point optimally between the traction components.
- **Electric Vehicle**: the thermal engine is forced off, and only the rear e-drive machine is used to move the vehicle.
- **AWD** (All wheel drive): the vehicle operates with the thermal engine and the rear e-drive electric motor permanently (front e-drive machine in generator mode to limit battery discharge)

- **Sport**: same as AWD with maximal torque settings on the rear e-drive machine to improve vehicle performance as much as possible.
- **Regen**: enables or disables regenerative braking in each mode listed above.

Figure 3: Screenshot of the HMI interface during driving

The usual mode for a hybrid vehicle is the hybrid mode, where the EMS decides how to split the power between the ICE and the electric machines to optimize the mid-term fuel consumption.
It is possible to realize such strategy with different levels of complexity, and optimization.
The most basic one is a RBS (Rule Based strategy) using very simple rules to decide how to split the power. This is the original strategy implemented in the vehicle by Valeo. It can be described as follows:

- Pure electric drive when the power demand is below a threshold and the battery SOC above another. Only the rear electric machine is used.
- ICE driven mode, where the ICE and front electric machine are used. Depending on the SOC, the front electric machine can be used to charge the battery.

An initial target of this project is to use the EMR to develop an optimized strategy that can be used on both the model and the actual vehicle. Unfortunately, as the demo-car was not available for final validation of the actual model, control and EMS, only simple EMS are used in this report. Experimental validation has been only provided for pure electric mode and pure thermal mode. Experimental measurements for hybrid modes was planned but delayed due to the COVID-19 crisis. Anyway, a simple EMS will validate the principle of virtual testing of a P-HEV. Advanced EMS has been developed, but will be tested in the demo-car later.

2.3. HMI feedback

The HMI (Human Machine Interface) makes it possible to display in "real time" different information to the driver:

- Thermal engine Power (kW)
- Front e-drive and rear e-drive electric machines power (kW)
- Battery SOC (0-100%) and thermal availability (thermal rate 0-100%)
- Accelerator pedal and brake pedal position (0-100%)
- Gear lever position (PRND)

2.4. Vehicle instrumentation

All significant powertrain data are going through the vehicle CANs. The original CAN contains all the conventional powertrain data (ICE, vehicle …) while the hybrid CAN contains data for all the added components.

This data is recorded using Vector CANalyzer tool and can then be analyzed using the same software on the computer. An example is provided in Figure 4.

2.5. Integration results

All the electrical subsystems have been integrated on the demo-car. Figure 4 shows the results of this work of implementation and progressive testing.

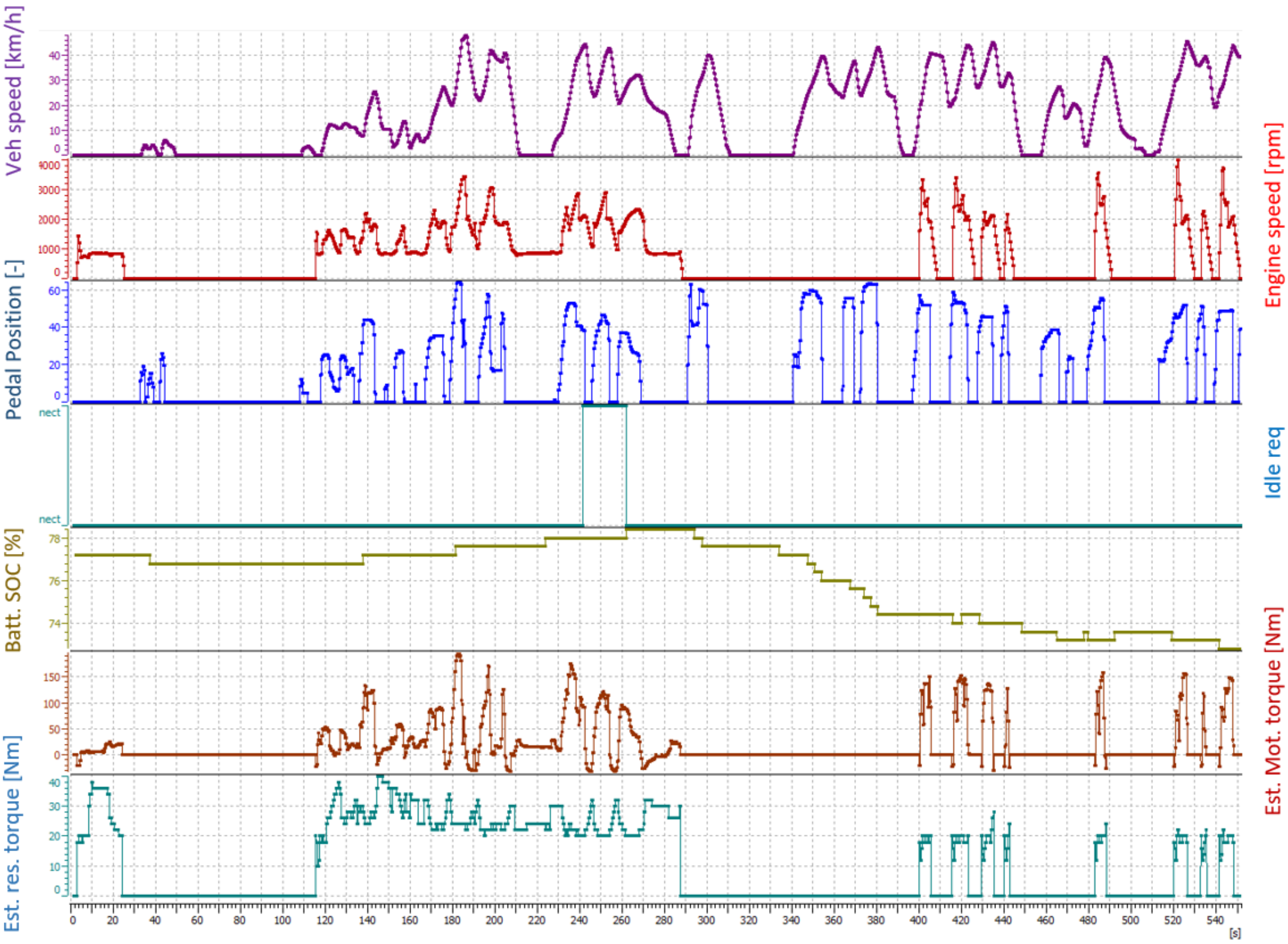

Figure 4: Visualization of data acquisition on the demo-car

3. Virtual testing

In this section, the main results on virtual testing (pure simulation) are reported for the P-HEV. More details can be found in [PANDA D4.5]. The PANDA project aims to develop a cloud of models for virtual and real testing (Figure 6).
The model organization is firstly reminded. The simulation in Simcenter AMESIM© and in MATLAB/Simulink© are then briefly described. The validation using experimental results are presented. Finally, the development time of the digital twin of the studied P-HEV is discussed.

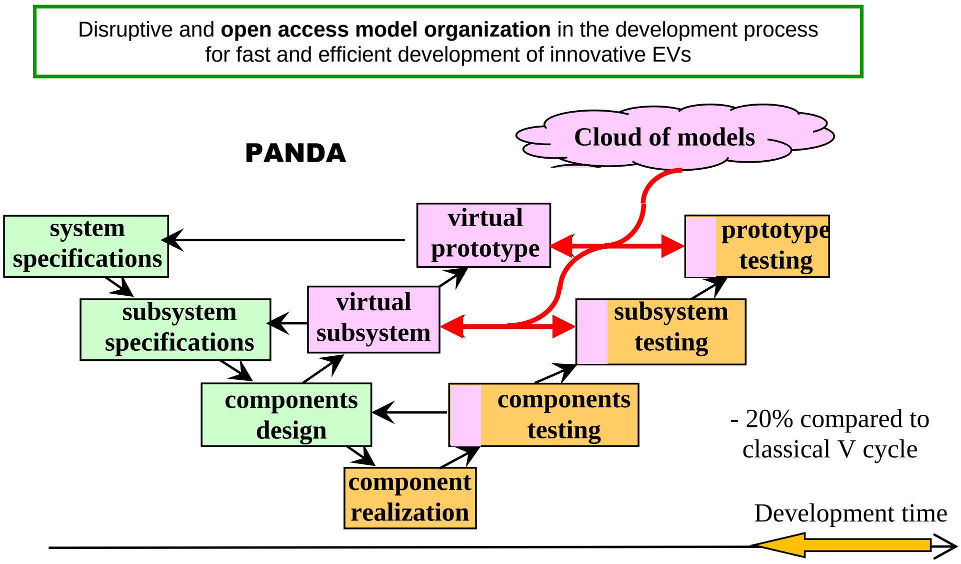

Figure 5: Subsystem testing in PANDA method.

3.1. EMR and control of the P-HEV

The EMR of the P-HEV is presented in [Tournez 2021] (Figure 6). Its design is detailed in the PANDA report on the virtual testing of the P-HEV [PANDA D4.5]. The physical part of the model is represented by the orange pictograms and the power flows by the links between them.

- Mechanical coupling between the front e-drive and the ICE
- Mechanical coupling between the front and rear e-drive
- Electrical coupling between the battery and both e-drives e-drive
- Mechanical coupling between the powertrain and the mechanical brake subsystem.

The modelling of all these parts and interactions is enabled by the EMR formalism. The control scheme (blue pictograms) is systematically deduced from the EMR of the system regardless of its complexity. The EMS (Energy Management Strategy) has then to manage the energy distribution between the different parts, by acting on the coupling elements. The EMS is a key point of the vehicle management to ensure the desired driving condition while minimizing the fuel consumption and pollutant emissions. Different EMS have been proposed in [PANDA D4.5].

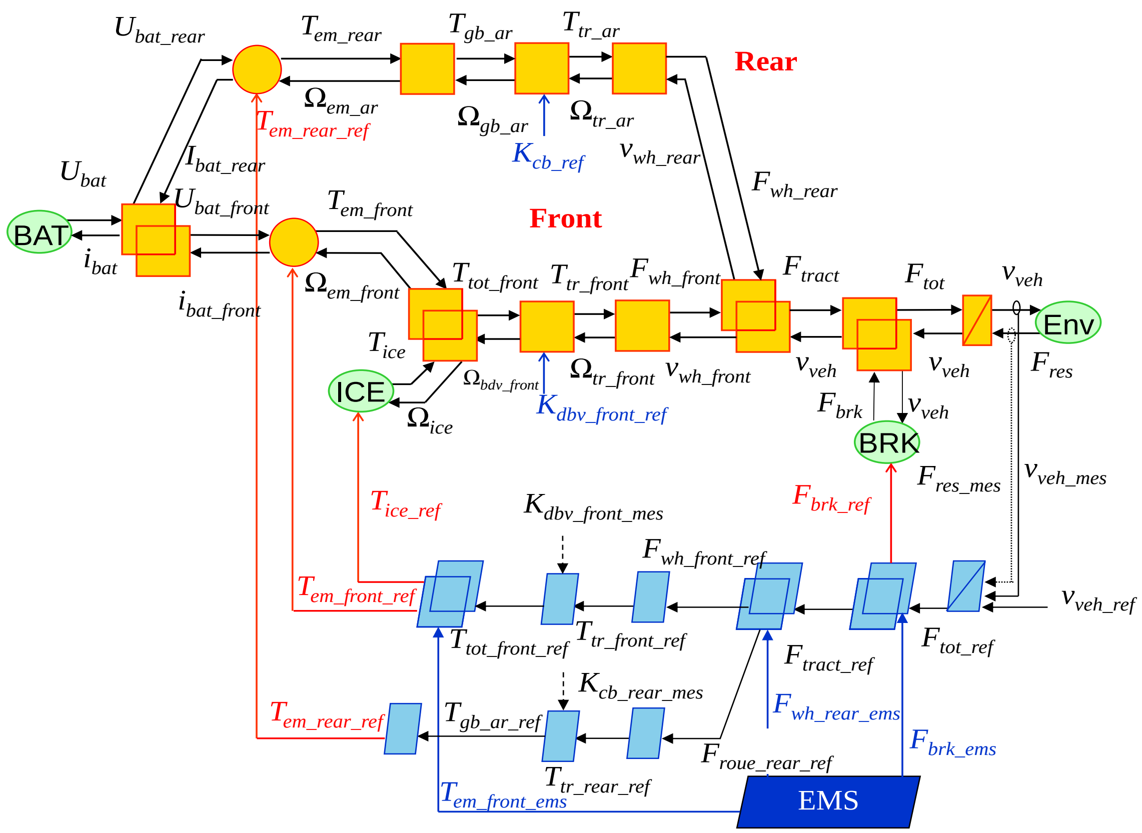

Figure 6: EMR and control of the studied P-HEV.

3.2. Simulation of the studied P-HEV

The EMR and control of the studied P-HEV has been achieved in two simulation packages from EMR libraries: MATLAB/Simulink © and Simcenter-AMESIM ©. It demonstrates the flexibility and adaptability of EMR to different simulation environment.

Moreover, different model levels of the battery [PANDA D2.1] and e-drive [PANDA D3.1] have been tested. This has been made possible and easy thanks to the fixed inputs and outputs imposed by the EMR. All the simulation details are reported in [PANDA D4.5]. Only the main principle and results are reported in this deliverable.

3.2.1. MATLAB/Simulink©

An EMR library for MATLAB/Simulink © has been developed by L2EP / Univ. Lille since 2000 [EMRwebsite 2022]. From the EMR and control of the P-HEV, the simulation is developed in a systematic way (Figure 7).

3.2.2. Simcenter AMESIM ©

An EMR library has been developed by Siemens in Simcenter AMESIM© for the PANDA project [PANDA D4.1]. The combined components, control and EMS give the full vehicle model, presented in Figure 8.

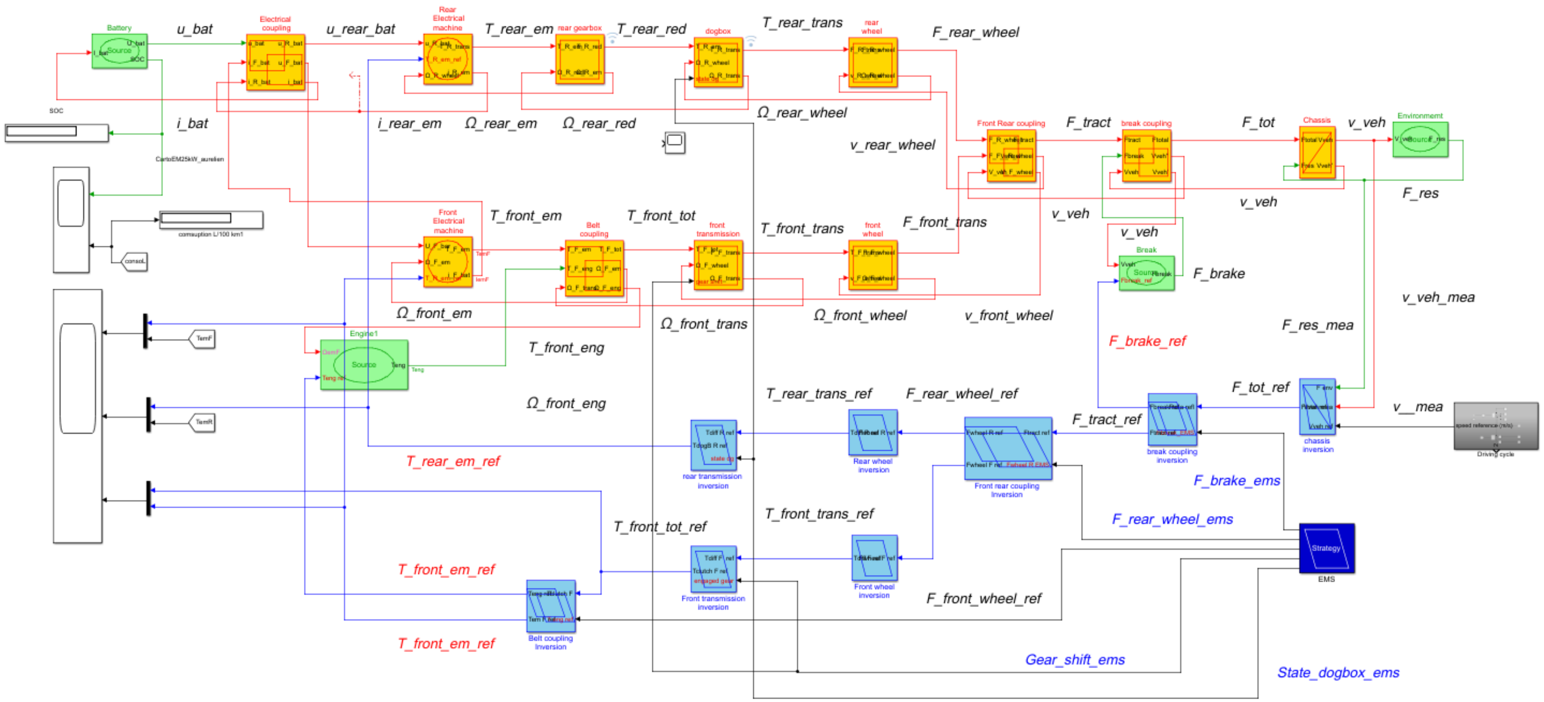

Figure 7: EMR and control of the P-HEV on MATLAB-Simulink©

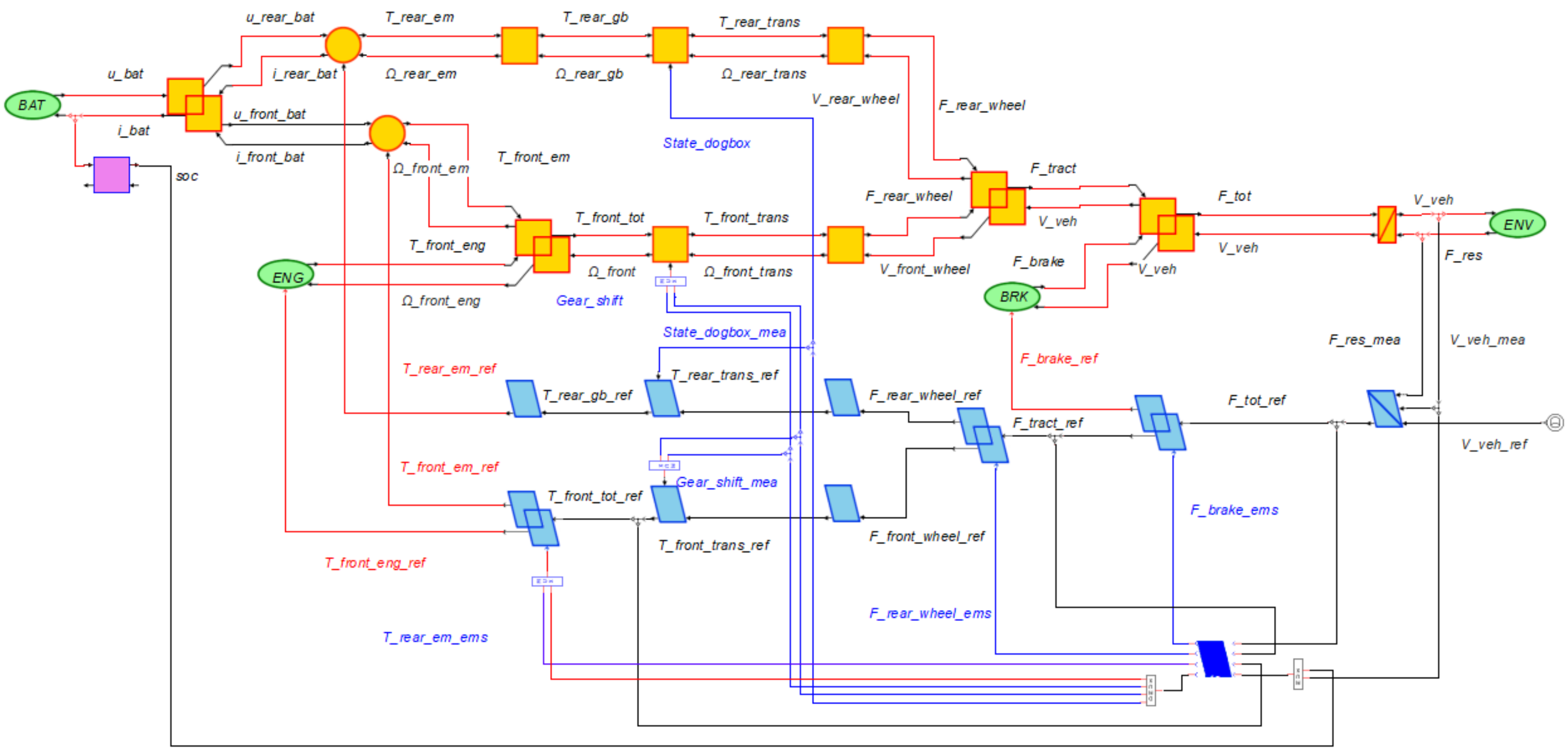

Figure 8: EMR of the P-HEV in Simcenter AMESIM©

3.3. Simulation validation

Both simulations environment have been compared using the WLTC driving cycle, with the same fixed step solver (ODE 1 Euler - 1ms time step) and the same ruled-based EMS. Both simulations give the same results. Therefore, the comparison between the measurement and simulation will be based only on the Simcenter AMESIM© model.

The comparison against the demo-car measurements was split in two parts, a pure electric mode and a pure thermal mode.
As an example, some results of a pure electric driving cycle using the rear e-drive is provided in Figure 9. The velocity profile measured on the vehicle is used as input for the simulation. Subfigure 9.a shows a near perfect correlation between the measured and simulated rear e-drive speed. Because of important data missing from measurements (road slope for instance), the torque input used is based on the estimated e-drive torque instead of the vehicle acceleration. Figure 9.b shows a good correlation between measured and simulated current, leading to an overall energy consumption accuracy of 94% (Figure 9.c). More tests are provided in [PANDA 4.5].

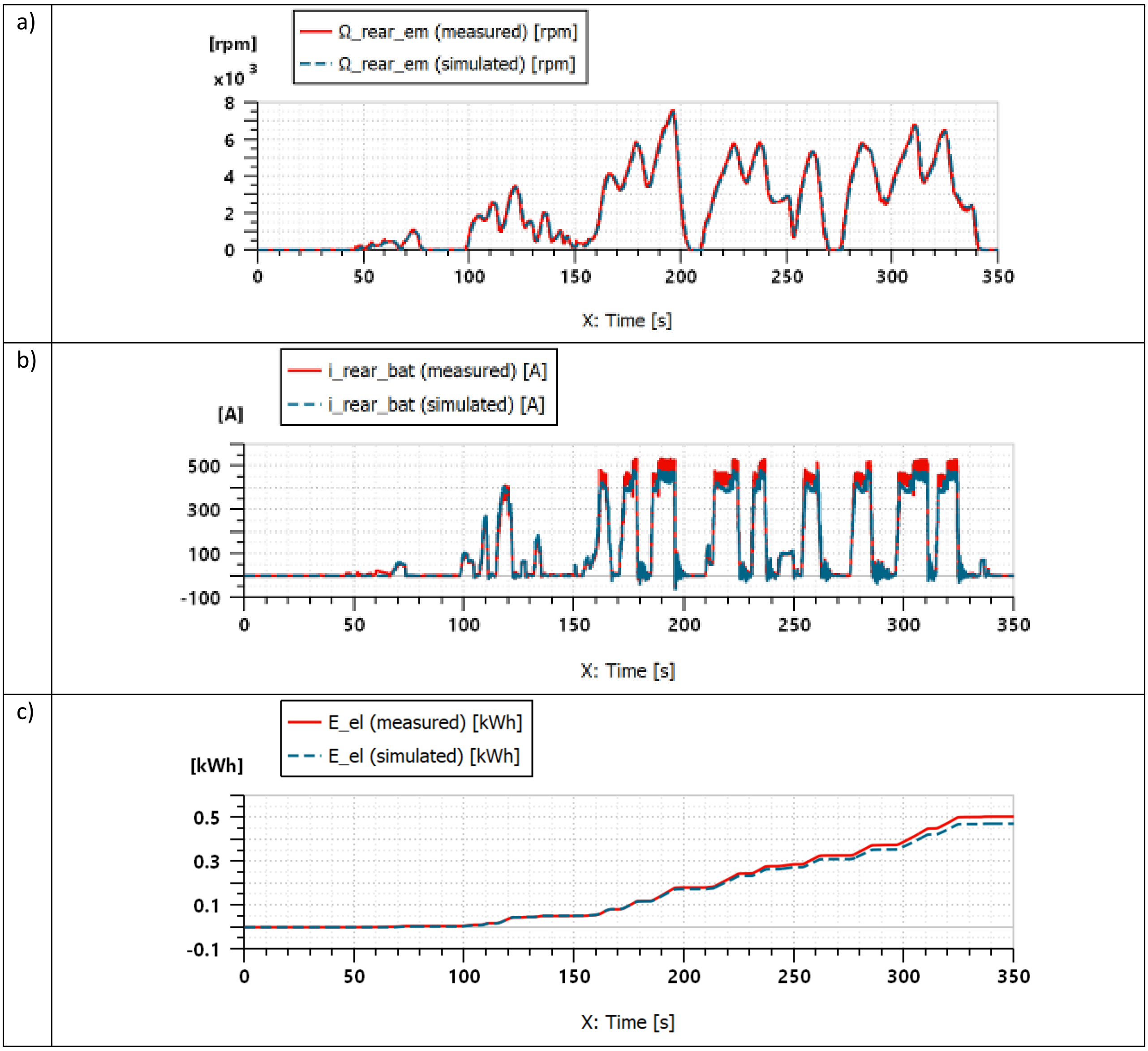

Figure 9: Pure electric drive demo-car comparison with simulation

a. e-drive rotational speed - b. battery current - c. energy consumption

Unfortunately, it has not been possible to validate the whole model in hybrid mode because the EMS developed on simulation was not integrated to the vehicle. The vehicle availability for the project was limited, and the integration itself is a time consuming operation.

3.4. Analysis of the simulation development

From the experience on the P-HEV, the development of the simulation model and control of level 1 [PANDA D3.1] is estimated around 1 person.month, for a senior scientist with the expertise on the process and the right models. The development of an efficient Energy Management Strategy (EMS) is also time consuming and is estimated around 1 person.month with the EMR formalism. It includes the development of an off-line optimal EMS, derivation of a real-time suboptimal EMS and validation by simulation.

Of course, development of more detailed models increases the development time. These developments excludes the development of an EMR library in an appropriated software. The training time in EMR and library development will be estimated in the deliverable D6.4 impact analysis.

We estimated approximatively 4 hours for the simulation data analysis of one scenario. This time increases up to 2 days when a new EMS is required (if any powertrain component is changed for instance).

Thanks to the method high flexibility, changing a sub-model from one level of complexity to another has very little impact on the development time. Therefore, the EMR organization enables a seamless change of the models. Only the computation time will be changed, because the simulation step should be adapted to the model level.

For example, for a level 1 e-drive model is used, a simulation step of 100ms is sufficient. For a level 2 e-drive model, the simulation step must be reduced to 1ms (in case of a fixed-step method). Thus, the computation time will be approximatively 100 time slower.

4. Real-testing of components of the studied P-HEV

In this section, the main results using real testing for components and subsystems of the P-HEV are reported. The HiL testing of a battery [PANDA D5.1], an e-drive [PANDA D5.2] and the e-subsystem [PANDA D5.3] have been achieved using the simulation model of the P-HEV computed in real-time.

The main results of these tests are reported in this deliverable. More details can be found in the related deliverables.

4.1. HiL principle

Compared to pure simulation (virtual testing), HiL testing (real testing), replace one simulation model by a physical component [Maclay 1997] [Bouscayrol 2011]. A power interface system is inserted between the component under test and the other components that are simulated in real-time [PANDA D1.4].

The selection of the power interface system is an important step, because it should be as transparent as possible for the physical component. Its response time must be lower than the one of the device under test and of the simulated part. The system under test must "believe" it is really connected to the other parts. These power interfaces are defined from the inputs and outputs of the border between the system under test and the simulated parts, thanks to the EMR organization.

The simulated part should be computed in real-time to interact with the subsystem under test as in real life. A high-power computation ECU should then be used. In the PANDA project, Typhoon has developed a specific ECU. This real-time simulator uploads the model from Simcenter AMESIM ©, converts it in Typhoon language, and computes this model in real-time. This conversion is facilitated by the EMR organization that imposes the inputs and outputs for all the subsystems. Moreover, EMR is based on the exclusive integral causality, which makes EMR-based models have low computation time compared to a structural based model [PANDA D1.2].

In addition to standard HiL, cloud-based HiL testing have also been achieved for the battery [PANDA D2.2] and for the e-drive [PANDA D3.3]. One part of the simulation is computed in real time in the local Typhoon ECU and one part is simulated by Simcenter AMESIM © in the cloud. This decomposition of the real-time simulation is again facilitated by EMR organization.

4.2. HiL testing of a new battery

In this part, the Blueways battery has been tested using stand-alone HiL testing [PANDA D5.1]. A power supply is used as power interface (Figure 10).
The full simulation model is uploaded to the cloud and translated in Typhoon language. Then the battery model is removed and the model is interconnected to the power interface, which supplies the battery during the test.

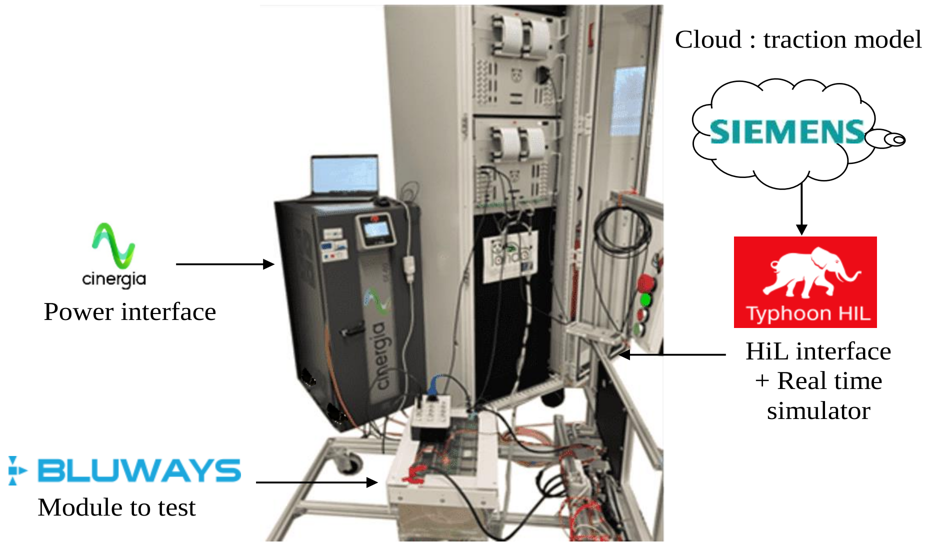

Figure 10: HiL test bench for battery testing

The HiL tests have been realized for WLTC class 3b driving cycle (Figure 11). The current requested or supplied by the battery is calculated in real-time in the model and imposed by the power interface to the battery (Figure 12). The battery voltage (Figure 13) and temperatures are measured on the physical battery. The estimated SoC is shown Figure 14. In [Panda D4.5] we demonstrated that the simulated P-HEV model is well correlated with the actual demo-car.

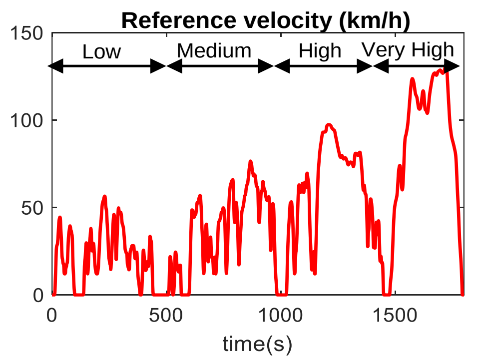

Figure 11: WLTC class 3 reference speed

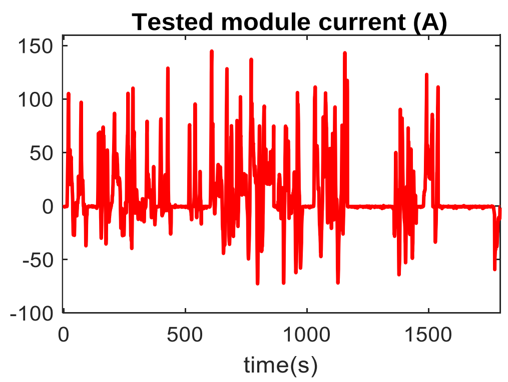

Figure 12: Experimental battery current

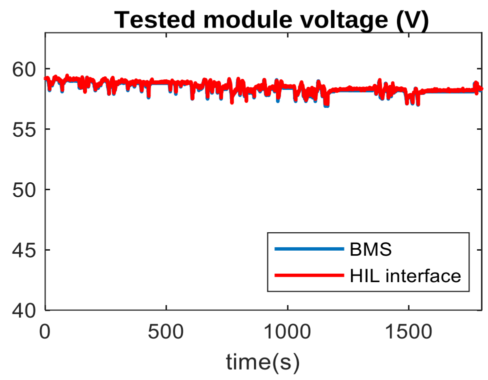

Figure 13: Experimental battery voltage

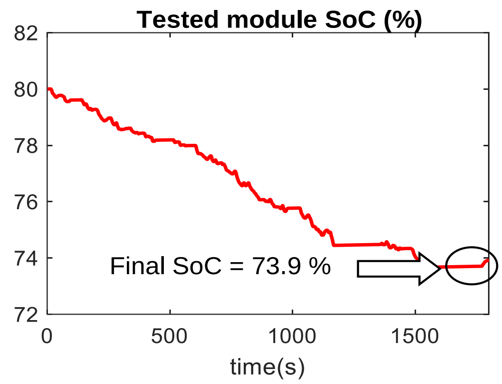

Figure 14: Experimental battery SoC

4.3. HiL testing of an e-drive

In this part, the rear e-drive is tested at VEEM with another e-drive as power interface [PANDA D5.2] (Figure 15). Since no Typhoon ECU was available at VEEM, a dSPACE autobox has been used as a real-time simulator. The simulation model has been converted in MATBLAB/Simulink© from the Simcenter AMESIM© simulation, then compiled and flashed into the dSPACE using existing Simulink/dSpace compilation tools. This development has been extremely quick thanks to the EMR organization.

The dSPACE ECU interacts with the Valeo ECU (containing the e-drive control) using a CAN CAN/CAN FD protocol. More details can be found in [PANDA D5.2]

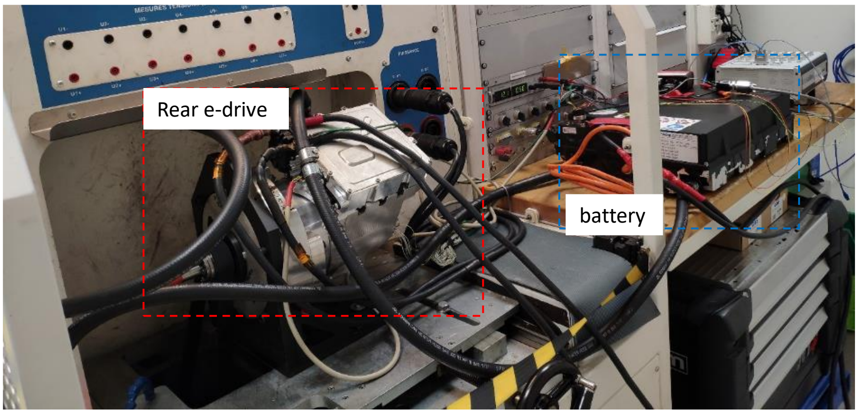

Figure 15: HiL testing of the rear e-drive at VEEM

The simulated model input is the WLTC class 3b driving cycle (Figure 16 – f). The rotation speed (a), torque (b), current (d), and voltage (e) measured on the e-drive has been plotted as well as the simulated battery SoC (c). The e-drive has thus been tested as it was really connected to the vehicle powertrain.

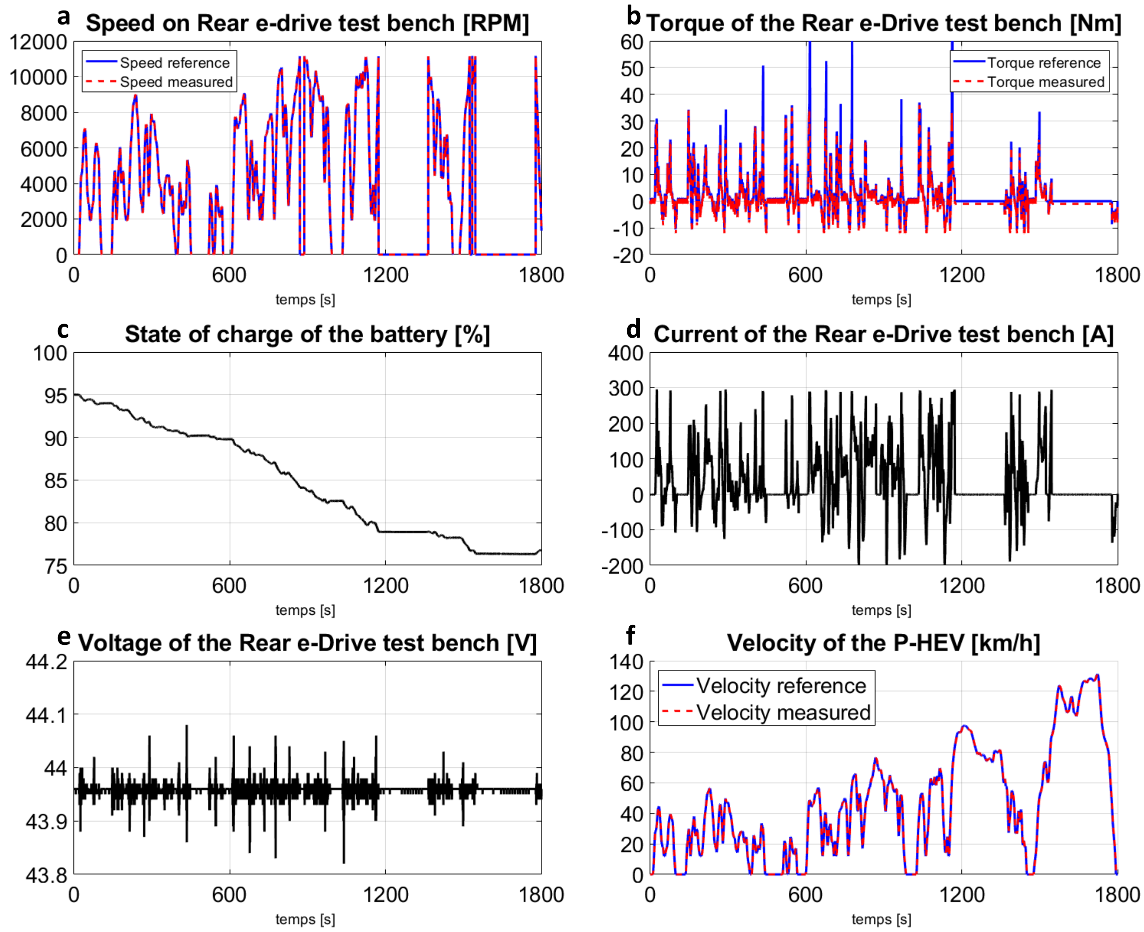

Figure 16: Experimental results of the HiL testing of the rear e-drive:
a. rotation speed - b. torque - c. SoC, - d. e-drive current - e. e-drive voltage - f. vehicle velocity

It can be noted that a reduce-scale HiL test has been realized at ULille using another e-drive, as intermediary step [PANDA D5.2].

4.4. HiL testing of the complete e-subsystem

In this part, both e-drives are tested in the eV platform of L2EP, as it was not possible at VEEM [PANDA D5.3]. In this case, Typhoon ECU is also used for both stand-alone and cloud-based HiL testing. Since VEEM e-drives where not compatible with ULille benches, an equivalent e-subsystem has been carried out with the e-drive of ULille. The aims was to demonstrate the possibility of this kind of test thanks to PANDA's methodology.

Two emulation drives (load e-drives) are connected to their respective e-drives under test (Figure 17). Both load e-drives and tested e-drives are controlled using a dSPACE controller board. The Typhoon ECU is dedicated to the real time simulation of the mechanical transmission, the ICE and the vehicle dynamics of the P-HEV. A CAN network interconnect both ECUs. The experimental set-up is described in Figure 18.

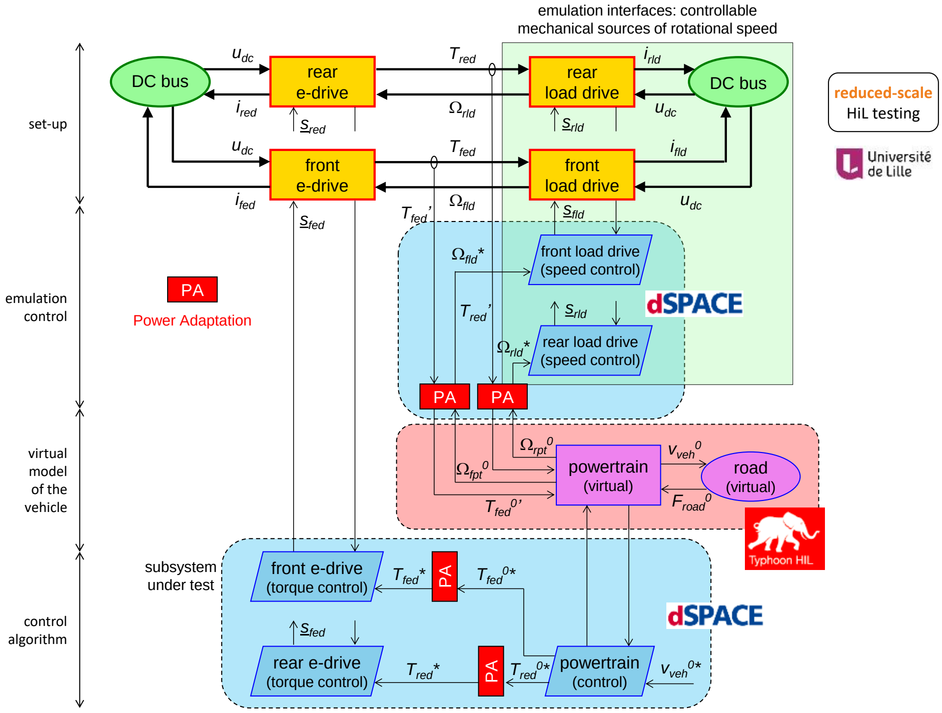

Figure 17: Organization of HiL testing of the complete e-subsystem at ULille

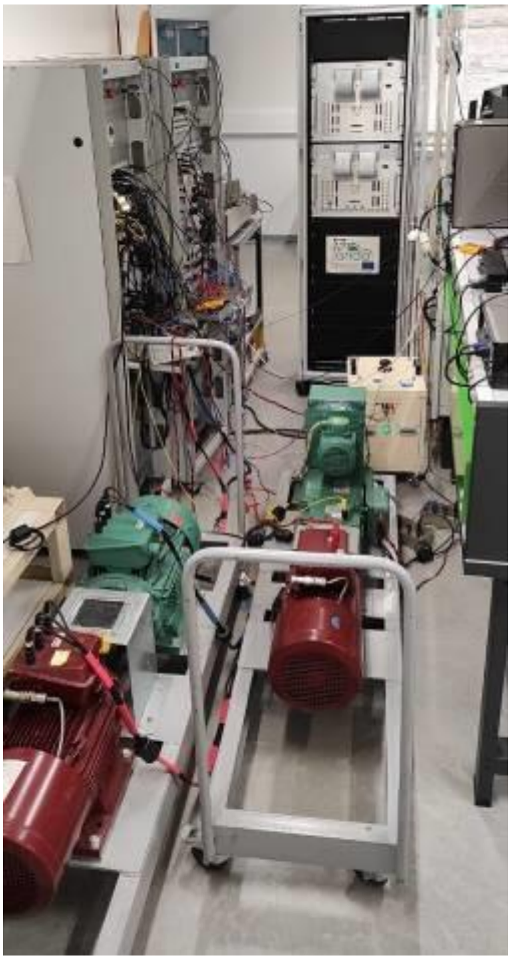

Figure 18: Experimental set-up of the HiL testing of the e-subsystem at ULille

The WLTC class 3b driving cycle has been fed to the model, which in turn sent the torque and speed set points to the e-subsystem. The variables of both e-drives were measured and can be seen in the Figure 19 (first 600 s of the WLTC). As the e-drives under test are not the same e-drives in the demo-car, it was not relevant to compare the HiL and demo-car measurements. This test was still necessary, because it demonstrates the ability to test the e-subsystem.

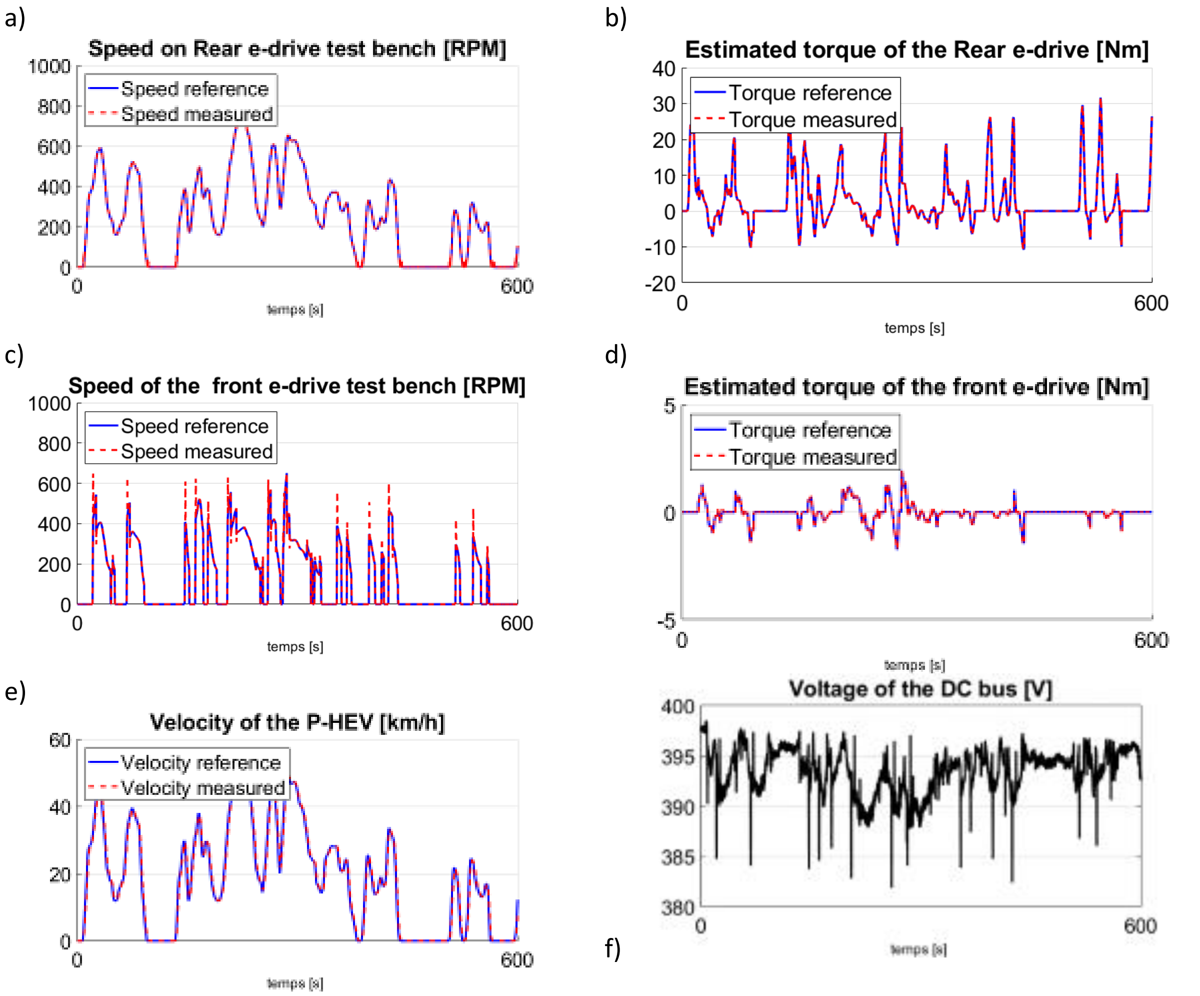

Figure 19: Experimental results of the HiL testing of the e-subsystem (first 600 s of WLTC):
a. rear e-drive speed - b. rear e-drive torque - c. front e-drive speed - d. front e-drive torque - e. vehicle velocity - f. DC bus voltage - g. battery current - h. battery SoC.

4.5. Analysis of the HiL testing

It is firstly assumed that the experimental testing bench is already set up as follows:

- the power interface is already operational (including its control),
- the communication protocols are already operational and pre-programmed,
- the real-time ECU is operational,
- All the necessary sensors are already available.

From the project experience, we estimate it takes 1 to 2 full days to prepare the bench with the tested subsystems (battery, e-drives, …)

- installation of the tested subsystem (battery, e-drives) on the test bench
- adaptation of the model to real time
- signal routing (measure, reference)
- security update (current, voltage)
- update of the interface

Because the test is run in real-time, the global test time depends on the reference cycle. For the WLTC Class 3, the duration is 1800s (30 minutes) for one test.

5. Potential benefits of increased simulation use

This section aims to analyze the development time potential gain using more simulation and HiL testing. As a demo-car was already developed by VEEM, the study is focused on the gain for an update of the demo-car by new components. Indeed, at the final stage of the vehicle development, several vehicle prototypes are used to test progressively different versions. This stage is very time consuming as for each prototype, it includes the component integration in the vehicle, the vehicle preparation with sensors, the driving tests and data analysis.

5.1. Comparison of components on the demo-car

At the beginning of the project, the P-HEV demo-car e-drive was of lower power (15kW). Then it was replaced by a new, more powerful e-drive of 25 kW. This change makes an excellent example of a demo-car between retrofitted with the latest prototype iteration. It gave us some crucial information about the effort and duration of such operation. As the real development contains confidential data, only an approximate estimation of the time reduction using simulation or HiL will be provided in this subsection.

Different component sizing can be easily done using simulation if the models are accurate enough. With our current model level in the P-HEV simulation, the experimental comparison with a real e-drive shows an accuracy of 94% [PANDA D4.5]. At this point, we estimated that such accuracy was good enough for a general sizing of the powertrain. If necessary, more precise models can be developed using advanced modelling methods [PANDA D3.3] while keeping the EMR philosophy using the same inputs and outputs.

Considering the development time of the simulation model of the complete P-HEV traction system, the comparison of different e-drives can be achieved in simulation around 4 times faster than an equivalent comparison on the demo-car

Moreover, another battery has been tested in simulation to evaluate its benefits against the current one. As the P-HEV model was already developed, this comparison with another component was made just by changing the battery parameters in the model and launch the simulation. In that second case, the comparison took at least 20 times less time than an equivalent physical swap in the democar.

If other components and subsystems would be changed, the simulation can be a valuable decision tool to have good results without significant time.

It demonstrates the potential time-saver of the digital twin provided by simulation. It is well known that in the automotive industry, many prototypes must be built, integrated and tested in a more complex environment before it reaches the final product state. With a simulation being 4 to 20 times faster than measurements, any prototype replaced by simulation brings a significant development time reduction.

5.2. Development of Energy Management Strategy

The Energy Management Strategy (EMS) is a key point for P-HEV to reduce the fuel consumption. At first, a basic EMS has been implemented and tested on the demo car. This EMS has been used to validate the vehicle model [PANDA 4.5]. From this model, an optimal EMS has been realized using off-line Dynamic Programming and a WLTC driving cycle to set a benchmark.
From that optimized but theoretical EMS, other sub-optimal EMS have been proposed thanks to the high flexibility of the simulation. Unfortunately, these real-time EMS have not been implemented on the demo-car due to a lack of time.

For each different versions of the demo-car, the EMS should be updated with the new components. In simulation, such update takes a few hours, while on the vehicle an EMS update can take several days.
In the H2020 project VISIONxEV [Tatschl 2022], the development of efficient EMS is reduced by 25% using advanced models. This figure only considers the development of the first EMS. However, for each prototype version, a new EMS must be developed. Thanks to the high flexibility of the models and a systematic method for the EMS development, we can consider that the development time of all the EMSs can be reduced significantly compared to traditional methods with an in-vehicle tuning of some parameters. This point is specifically achieved by using EMR, which is dedicated to the control organization of energy conversion systems [Bouscayrol 2012], which specific emphasis on EMS design [Pam 2017] [Horrein 2019] [Nguyen 2019] [Castaings 2020], these last 5 years.

5.3. HiL testing of the battery

The battery of Blueways has been tested using the real-time model of the P-HEV, both in stand-alone HiL testing [PANDA D5.1] and cloud-based HiL testing [PANDA D2.2]. It should be noted that cloud-based HiL has been achieved with a cloud server in Paris and experimental set-up in Lille and in Brussels.

5.3.1. Stand alone HiL

Stand-alone HiL test allows testing the real battery before its insertion in the vehicle prototype, reducing the testing time. The time to implement the battery in the real vehicle is replaced by the time to implement the battery on the HiL set-up. The integration of the component itself is not necessarily faster, but it is much easier to perform various tests with the HiL than the demo-car. It also allows changing any simulated component (e-drives …) quickly to see its impact on the battery. A 50% reduction of the testing time can be reached [OBELICS 2021].

5.3.2. Cloud-based HiL

Cloud-based HiL testing can use a common real-time model between different industrial partners to ensure a common development or a fair comparison. For example, the battery can be tested at the battery manufacturer in collaboration with the OEM. At the reception of the battery, the OEM can perform the same tests to validate the setup, and then run its own tests with confidence. In that case, the initial tests can be made by Blueways and the reception test by VEEM, before the integration into the vehicle. By anticipating some problems, the testing time in the vehicle will thus be reduced.

5.4. HiL testing of the e-drive

The e-drive of VEEM has been tested using the real-time model of the P-HEV, in stand-alone HiL testing [PANDA D5.2]. In that case, as VEEM generally use MATLAB/SIMULINK © instead of Simcenter AMESIM© for simulation and dSPACE instead of Typhoon ECU, the simulation model has been redeveloped in MATLAB/Simulink© with has a dedicated compiler to dSPACE. Thanks to the EMR organization, this translation step has been achieved in a very fast way. This experience demonstrates the flexibility of the PANDA method for different software packages and real-time simulators / controller boards. It can also be noticed that cloud-based HiL testing of other e-drives has been also achieved in [PANDA D3.3]: cloud server in Brasov (Romania) and experimental set-up in Cluj Napoca (Romania); cloud server in Paris (France) and experimental set-up in Lille (France).

5.4.1. Stand alone HiL

Stand-alone HiL testing can be used to test the real e-drive before its insertion in the vehicle prototype, reducing the testing time. The initial target was to run both the HiL testing and the demo-car along a WLTC cycle, using a dynamometer test bench for the democar. Unfortunately, due to the COVID crisis, the experimental test with the demo-car has been delayed several time. Indeed, performing measurement on a vehicle bench is complex. The vehicle must be available and ready to run and the bench must be booked several weeks or months ahead. Then the actual tests can take a few days. Sadly, the right time to perform these measurements never occurred after the 1st Covid outbreak.

On the bright side, this demonstrates quite strongly the interest of HiL testing platform to replace demo-car testing during the development process. In the OBELICS H2020 project [OBELICS 2021], the use of HiL testing of e-drive has led to a reduction of the e-drive development time by 50%. From the experience of PANDA, this reduction can be confirmed.

5.4.2. Cloud based HiL

The cloud-based HiL testing aimed to test an e-drive, equivalent to the actual VEEM one, in the P-HEV environment. Indeed, because VEEM did not have the Typhoon ECU connected to the cloud, this HiL testing has been achieved on the eV experimental platform of ULille with different e-drives but with the Typhoon ECU and the cloud connection using Simcenter AMESIM ©. Of course, it is not possible to compare the results with the demo-car measurements because of the different e-drives. However, the principle of a cloud-based HiL testing of the e-drive has been demonstrated. As discussed in the PANDA meetings, we could imagine a common cloud and model between VEEM (e-drive supplier) and RTR (e-drive users), used to better prepare the e-drive development and reduce the testing time at the reception by the OEM. In that way, the testing time of the e-drive in the vehicle will thus be reduced.

5.5. HiL testing of the e-subsystem

The e-subsystem of the P-HEV (battery and the 2 e-drives) have been tested in stand-alone HiL at the ULille platform, using equivalent e-drives [PANDA 5.3]. Unfortunately, as stated in the previous subsection, as the e-drive are different from the ones in the vehicle, the accuracy of this kind of HiL testing cannot be evaluated.

Regardless of this specific point, the successful test of several components within a HiL test demonstrates the feasibility and potential of the method. Because the battery HiL testing [PANDA D5.1] and the e-drive HiL testing [PANDA D5.2] had already achieved, the real-time models, the real-time simulator, the power interface were already developed. It has allowed this third HiL testing to be carried out quickly. The PANDA method consists in a uniform organization of the models that enables a high flexibility for moving to one HiL testing to another. In XILforEV H2020 project, the use of remote HiL testing has estimated a reduction of 50% of the testing phase [Ivanov 2022]. This gain seems in agreement with the studies in PANDA.

6. Conclusion

The P-HEV demo car of VEEM has been used as reference vehicle for the PANDA project. First, a virtual model has been developed using Simcenter AMESIM © and the EMR library. This digital model has been partially validated by comparison with experimental tests on the demo-car. In a second test, a new battery, one e-drive, and an equivalent e-subsystem have been studied using HiL testing and real-time models of the P-HEV from the developed model in Simcenter AMESIM © and also in MATLAB/Simulink ©. Unfortunately, without proper dynamometric test bench results, it was not possible to make an accurate and fair evaluation of the HiL accuracy against the demo-car.
In this report, it has been shown than virtual or HiL testing allows to test and compare quickly, accurately and efficiently a large number of components, before the actual integration in the vehicle.
Since testing a new component in a demo-car is extremely time consuming, virtual and HiL testing contribute to a significant reduction of the development time for the components and the vehicle. Moreover, the capability of cloud-based HiL testing of components has been demonstrated thanks to the PANDA methodology. Common models and common cloud between OEM and suppliers could be a relevant way to increase the reliability of the component development and to reduce the number of tests at reception, thus the number of test on the vehicle prototype.

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Table 2: Project Partners

#	Type	Partner	Partner Full Name
1	UNIV	ULille	Université de Lille
2	IND	SISW	Siemens Industry Software SRL
3	UNIV	VUB	Vrije Universiteit Brussels
4	IND	VEEM	VALEO Equipement Electriques Moteur SAS
5	UNIV	UTCN	Universitatea Tehnica Cluj Napoca
6	SME	TY	Tajfun Hil (Typhoon Hil)
8	UNIV	UBFC	Université Bourgogne Franche-Comté
9	SME	UNR	Uniresearch BV
10	IND	RTR	Renault Technologie Roumanie
11	SME	Bluways	BlueWays International bva
12	IND	TUV	TUV SUD Battery Testing Gmbh

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Appendix A – Abbreviations / Nomenclature

Table 3: List of Abbreviations / Nomenclature

Symbol / Shortname	
BMS	Battery Management System
CAN	Controller Area Network
CPU	Central Processing Unit
DP	Dynamic Programming
ECU	Electronic Control Unit
EM	Electric Machine
EMR	Energetic Macroscopic Representation
EMS	Energy Management Strategy
HMI	Human Machine Interface
ICE	Internal Combustion Engine
P-HEV	Plug-in Hybrid Electric Vehicle
PMSM	Permanent Magnets Synchronous Machine
PWM	Pulse Width Modulation
SOC	State of Charge
WLTC	Worldwide Harmonized Light Vehicle Test Cycle