Hardware-In-the-Loop simulation: hybrid locomotive Energy Storage System behavior tests

Dr. Tony LETROUVE, Dr. Julien POUGET
SNCF Innovation & Research Dep., MEGEVH network,
1. HIL simulation interest and structuring problematic

2. Power HIL simulation of PLATHEE locomotive

3. Conclusion and outlooks
HIL simulation interest and structuring problematic
- Actual approach -

- Customer needs
- Sizing and power flow studies
- Prototype elaboration
- Prototype development
- Prototype behavior validation
- Feasibility response

- Direct validation of component behavior in real time on vehicle,
- Components homologation (hardware),
- All physics phenomena are taken into account.
- Actual approach -

Customer needs

Sizing and power flow studies

Prototype elaboration

Prototype development

Prototype behavior validation

Feasibility response

Cumulative dev. cost

Time to market

Sizing

Prototype

- Complex to develop, more than one prototype needed,
- Time needed,
- The development Cost is exponential with the time on prototype,
- A lot of resources are needed (prototype, staffs and tracks availability),
- unrepeateable tests,
- Security and fault tolerance tests are made on-line.
Adding intermediary steps:
- Reduce the time on prototype (reduce the cost and time of development),
- Virtual homologation of some subsystems ahead of time.

Solution: simulation?
HIL simulation: hybrid locomotive ESS behavior tests

Adding simulation -

- Customer needs
- Sizing and power flow studies
- Simulation
- Prototype elaboration
- Prototype development
- Prototype behavior validation
- Feasibility response

Time to market

Component library development using EMR (common tool, formalism unification, easy to share, ...)

Cumulative dev. cost

Sizing Sim. Proto

- Prototype debugging ahead of time (ex. control),
- Easy to use,
- Quick development,
- Availability,
- Repeatable tests.
- Adding simulation -

- Customer needs
- Sizing and power flow studies
- Simulation
- Prototype elaboration
- Prototype development
- Prototype behavior validation
- Feasibility response

- Time to market

Cumulative dev. cost

- With Simulation
- Actual approach

- ✔ Models validity range,
- ✔ virtual homologation complicated,
- ✔ real time portability of the control?
Customer needs
- Sizing and power flow studies
  - Simulation
  - Prototype elaboration
  - Prototype development
  - Prototype behavior validation
  - Feasibility response

Solution: « SuperModel » development?

→ How many development time? All interaction are they taken into account?
« HIL simulation : hybrid locomotive ESS behavior tests »

- Battery test example -

- Development time? Computation time?

- ✓ ageing?
  ✓ temperature?
  ✓ EMI?
  ✓ Etc.
No more model dependency: real power part

- Battery test example -

Energy management

Control & Energy management

Upstream system

voltage

current

+ INTERFACE

- INTERFACE

Battery

EMR'15, Lille, June 2015
« HIL simulation : hybrid locomotive ESS behavior tests »

- HIL simulation -

EMR’15, Lille, June 2015
Customer needs

Sizing and power flow studies

Simulation

Control development

Simulation HIL

RT control validation and power subsystems validation

Prototype behavior validation

Feasibility response

Reduce development time,
Financial benefits (mobilization et component deterioration),
Security et quality tests (fault tolerance tests),
Repeatable tests,
Virtual homologation available.
Power adaptations? (Signal)

Voltage

Measures
(Power) (Signal)

Current

Upstream system

Control & Energy management

Emulated models (signal)

Can EMR help to structure the different parts of a HIL simulation?
Power HIL simulation of PLATHEE locomotive
**Drawbacks:**

- **No energetic storage** for traction or auxiliaries,
- Diesel engine is **uninterrupted** (Auxilairies, etc.),
- Diesel engine is not always in its **maximal efficiency point**.
Objectifs:

✓ Defining a structured experiment for Energy storage tests,
✓ Validation of the real time portability of the developed control and EMS,
✓ Subsystem tests (nominal and fault tolerance) in a controlled environment before full prototype implementation.
Objectifs : ✓ Defining a structured experiment for Energy storage tests,
✓ Validation of the real time portability of the developed control and EMS,
✓ Subsystem tests (nominal and fault tolerance) in a controlled environment before full prototype implementation.
« HIL simulation : hybrid locomotive ESS behavior tests »

Power HIL simulation structure -
Power HIL simulation structure -

System under test

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCs</td>
<td>Source cells</td>
</tr>
<tr>
<td>Bat</td>
<td>Battery</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal combustion engine</td>
</tr>
<tr>
<td>Aux</td>
<td>Auxiliary system</td>
</tr>
<tr>
<td>EMS</td>
<td>Energy management strategy</td>
</tr>
</tbody>
</table>

Diagram showing the simulation structure with various components and their interconnections, including power flows, control signals, and energy management strategies.

- ICE
- Brak
- Env
- DCM
- Wh.
- SM
- DC Bus
- SC
- Bat

Components and their interactions are detailed in the diagram, showing the system's power simulation structure for hybrid locomotive ESS behavior tests.
HIL simulation: hybrid locomotive ESS behavior tests

Power HIL simulation structure:

System under test

ICE

Generator Strategy

EMS

Driving Strategy

Brak

Aux

Bat
« HIL simulation : hybrid locomotive ESS behavior tests »

- Power HIL simulation structure -

EMR’15, Liège, June 2015

Experimental test bed

Real-time simulator

System under test

Reduced-scale

Power adaptation element
HIL simulation: hybrid locomotive ESS behavior tests

- Experimental setup and results

1 – Same EMS than Prototype:

 Models validation

![Graphs showing various parameters such as voltage, power, current, and other metrics over time.](image)

- 2 x OP5600 real-time simulator
- 48V Battery pack
- 48V Maxwell Supercaps
- 400W controllable voltage source
2 – New EMS and studies outlooks:

→ Fair strategies comparison (maintenance, component behavior, fuel, ...)
Conclusion and outlooks
EMR as a structuring tool:

- Such a complex system and experiment needs methodology: EMR,
- Integral causality allows to use description and control part in real time.

Reduced-scale Power HIL simulation

- Reduce the cost and time to market of new developments,
- Do not required any prototype component,
- Quick development and adjustment possibility,
- Interface systems behavior validation,
- Prepare experiment for full-scale.

Outlooks

- fault tolerance tests and control robustness,
- full-scale HIL simulation,
- implementation on prototype.
Thanks for your attention!
Dr. Julien POUGET
SNCF, Innovation & Research Dept., MEGEVH, France
PhD in Electrical Engineering at University of Franche-Comte, Belfort
Research topics: optimal design, modeling, control and energy management applied in railway hybrid energy systems (electrical and diesel locomotive, electrical and thermal building and railway network)

Dr. Tony LETROUVE
SNCF, Innovation & Research Dept., MEGEVH, France
PhD in Electrical Engineering at University of Lille & PSA (2013)
Research topics: EMR, HIL simulation, Energy Management, Prototyping