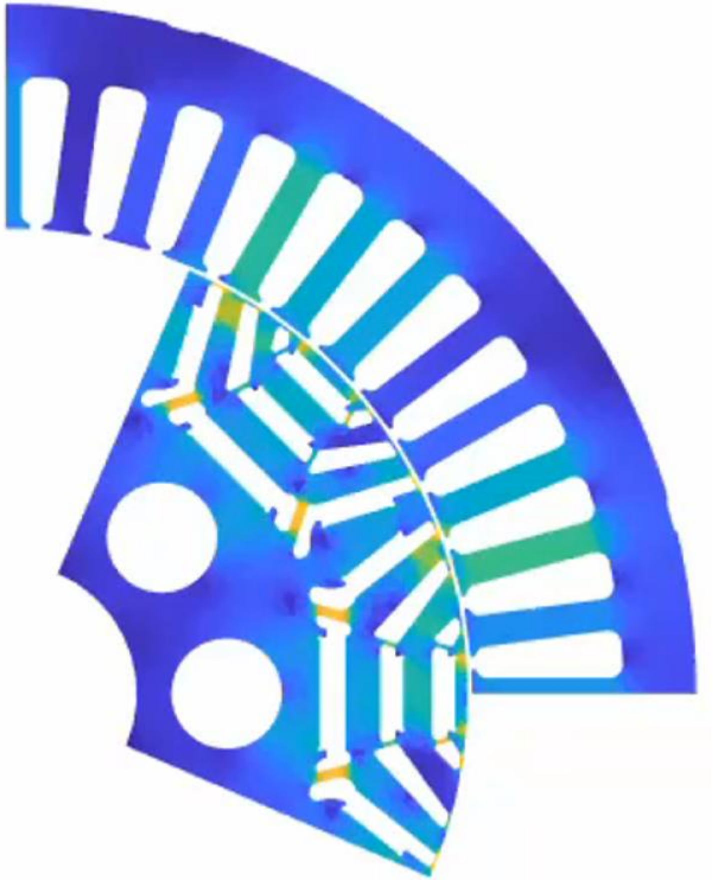
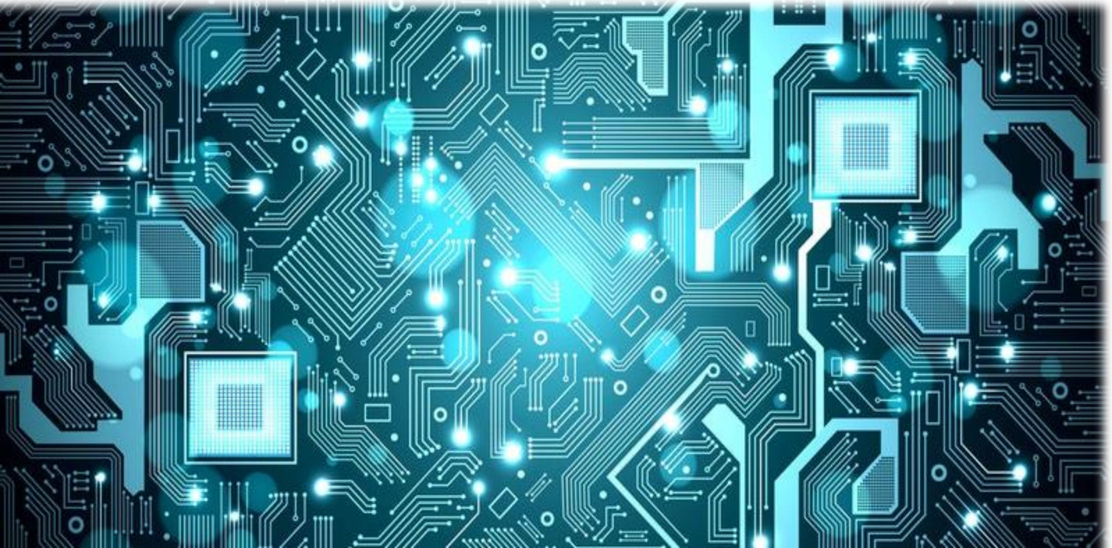


E-DRIVE CONTROLS TOOLCHAIN FOR ACCELERATED DEVELOPMENT

2024/10/08



FABIEN VIDAL-NAQUET

ifp Energies nouvelles

CARNOT ifpen Transports Energie

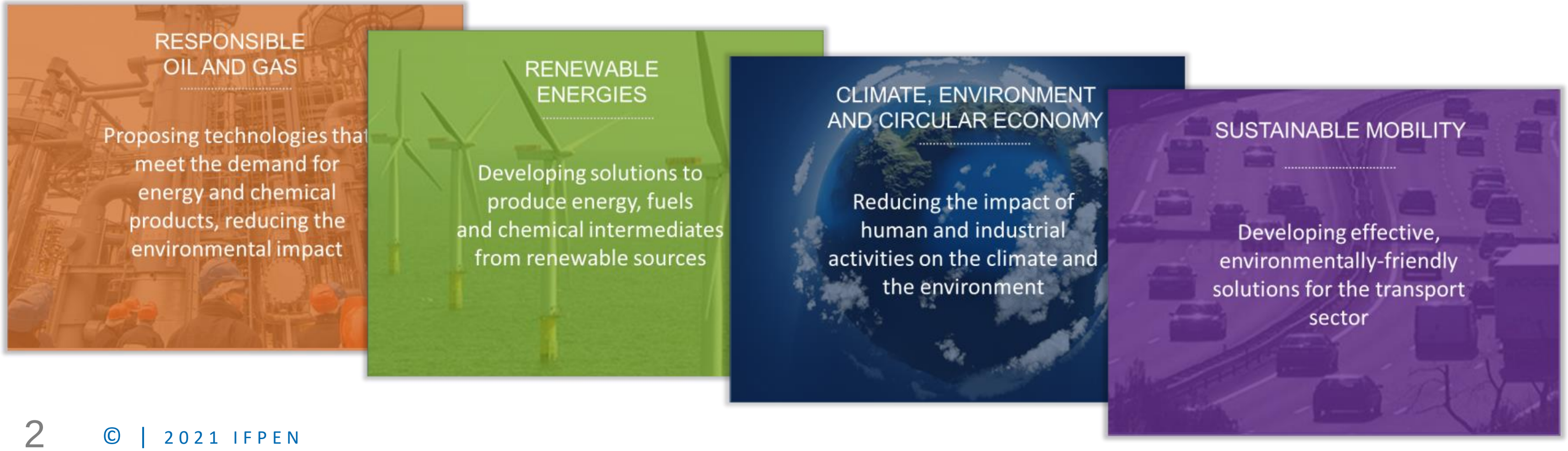
RESEARCH & TECHNOLOGY ORGANIZATION (RTO)

A public sector **R&I** body

A **training** center

An industrial **group**

An international scope in the fields of energy, transport and the environment



1,530 people

1,078 engineers and technicians dedicated to research

3rd public research centre for patents

Sustainable mobility

ELECTRIC SYSTEMS DEPARTMENT

Specify and propose innovative electric systems

Design and build the electric and power electronics components

Control and optimize the electric systems on their whole operating area

Evaluate and validate the electric systems on dedicated experimental facilities

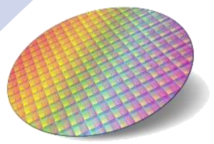
Carnot ifpen Transports Energie

RESEARCH & TECHNOLOGY ORGANIZATION
ELECTRIC SYSTEMS DEPARTMENT

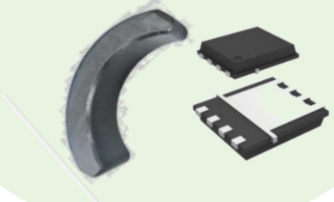
Sustainable mobility

Partnerships

Materials



Advanced components or on shelf



Parts design

→ Active parts (Radial, Axial…)

→ Power stages (SiC/GaN)

→ e-Motors (48-800V)

→ Inverters

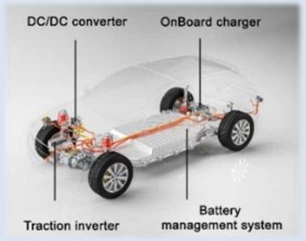
→ Fuel Cell DC/DC

TRL 7

eDrive Systems

→ For xEV

→ For FCEV



TRL 9

Partnerships

Custom markets

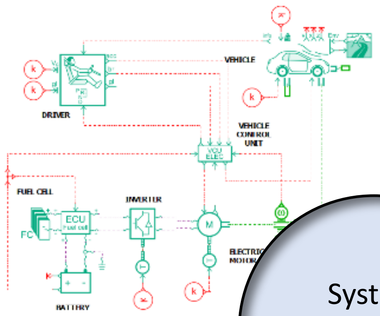
Inverters for bench testing

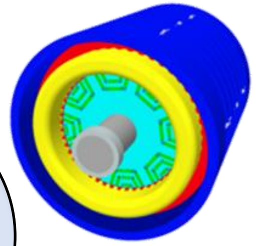
Industrial support

Towards automotive traction and fuel cell applications

Skills available with <100 people

Sustainable mobility





ELECTRIC SYSTEMS

System analysis and simulation

Motors design and simulation (EM, thermal)

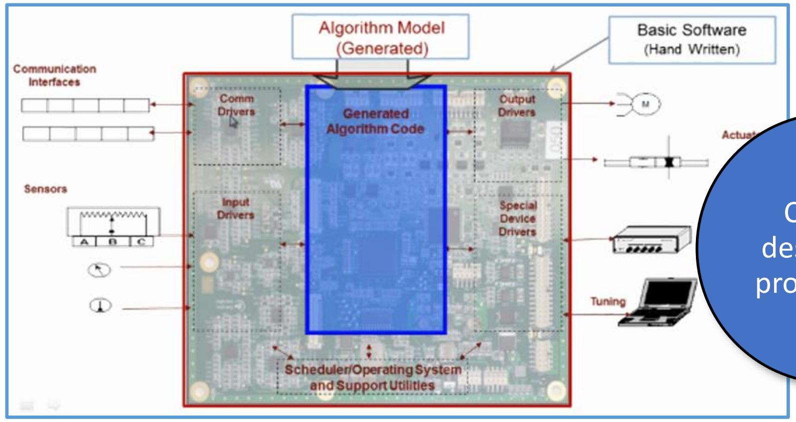
Electronics design and simulation (EM, thermal)

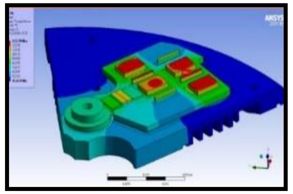
Mechanical design

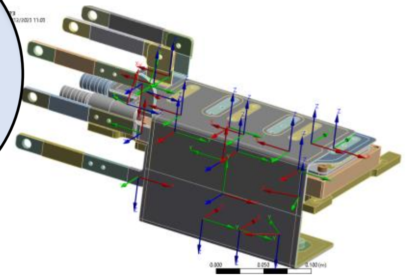
Electric motor and electronics prototyping

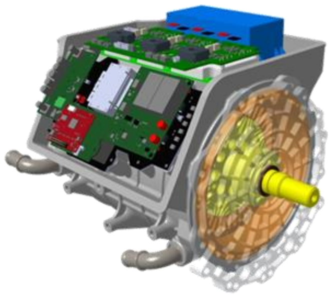
Control design and prototyping

Experimental validation









INTRODUCTION

Sustainable mobility

What?

→*IFPEN has developed a unique chain of software tools to support innovation in power electronics and electric motors.*

→*With full vertical integration, from finite element data processing to high-power bench testing, IFPEN drastically reduced its own development times and those of its partners.*

Why?

→*IFPEN has an agile controls team supporting a great number of innovation projects*

- But too much time was spent on repetitive tasks, impeding our ability to innovate on controls

→*Available solutions did not match **our** needs :*

- Solutions like those based on AUTOSAR are too heavy and expensive

- Solutions like dSpace cannot be fully integrated and are expensive too

INTRODUCTION

Sustainable mobility

IFPEN developed a **Full Control Toolchain** for e-Drives

→ *To drastically reduce software & control development lead time*

→ *To provide ambitious & innovative solutions making sense for industrial applications*

INTRODUCTION

Sustainable mobility

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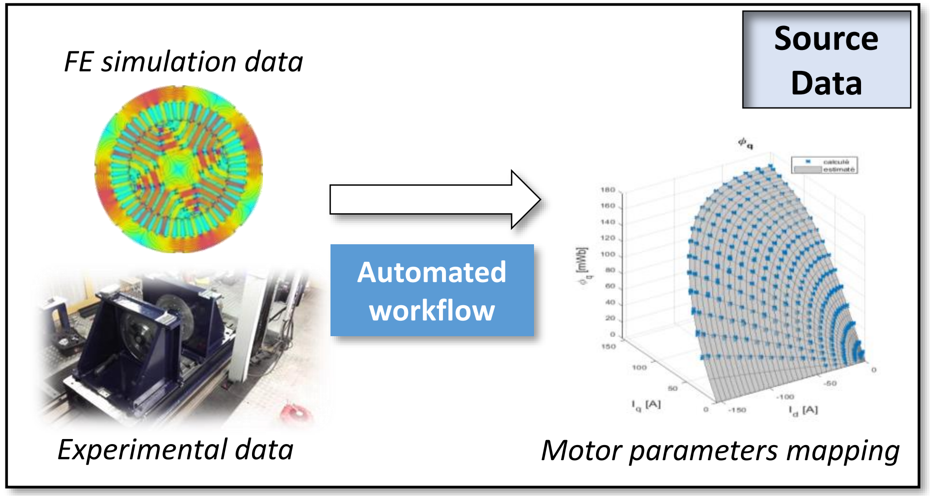

Start from data processing

INTRODUCTION

Sustainable mobility

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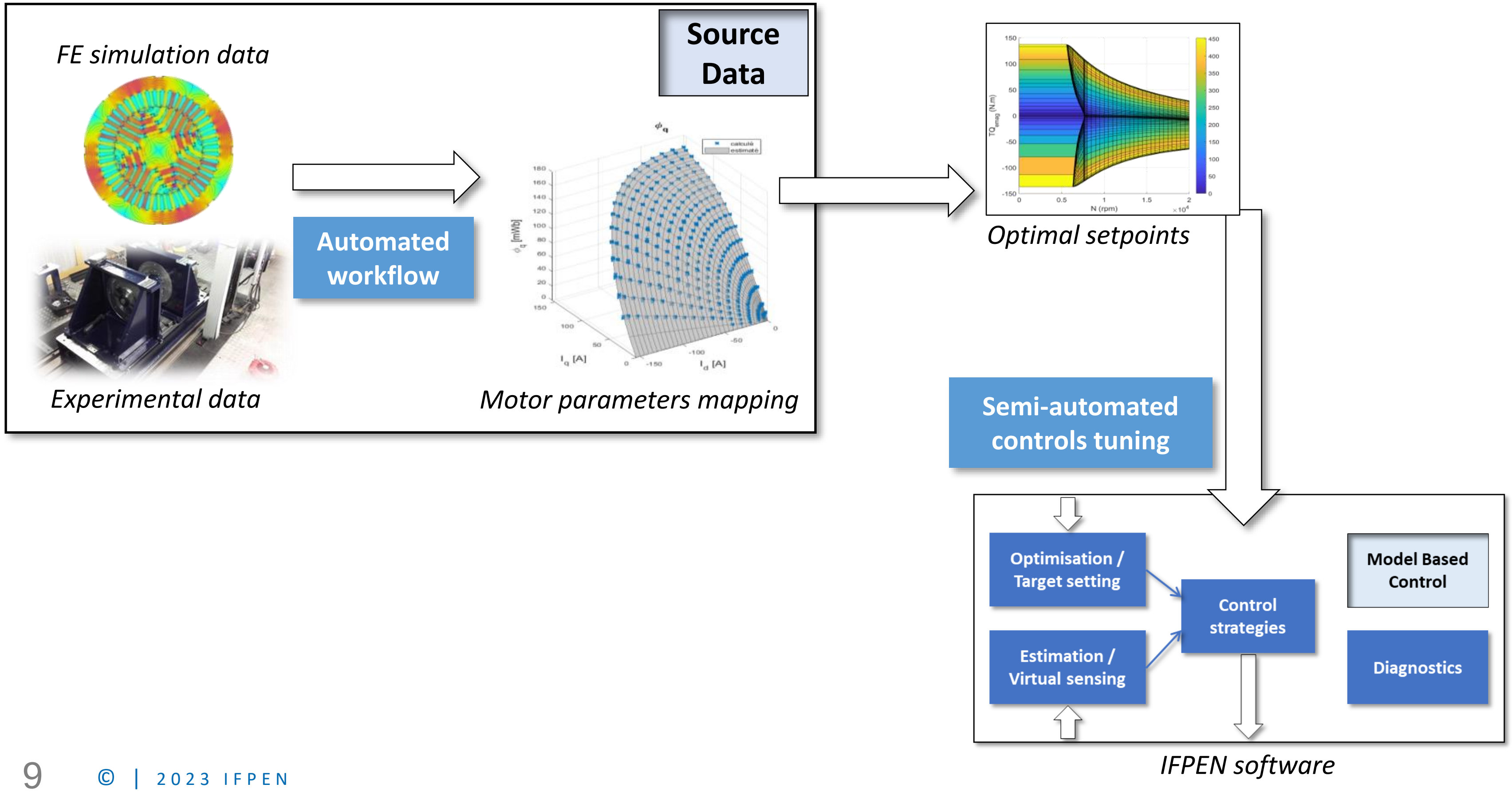

To quickly setup controls

INTRODUCTION

Sustainable mobility

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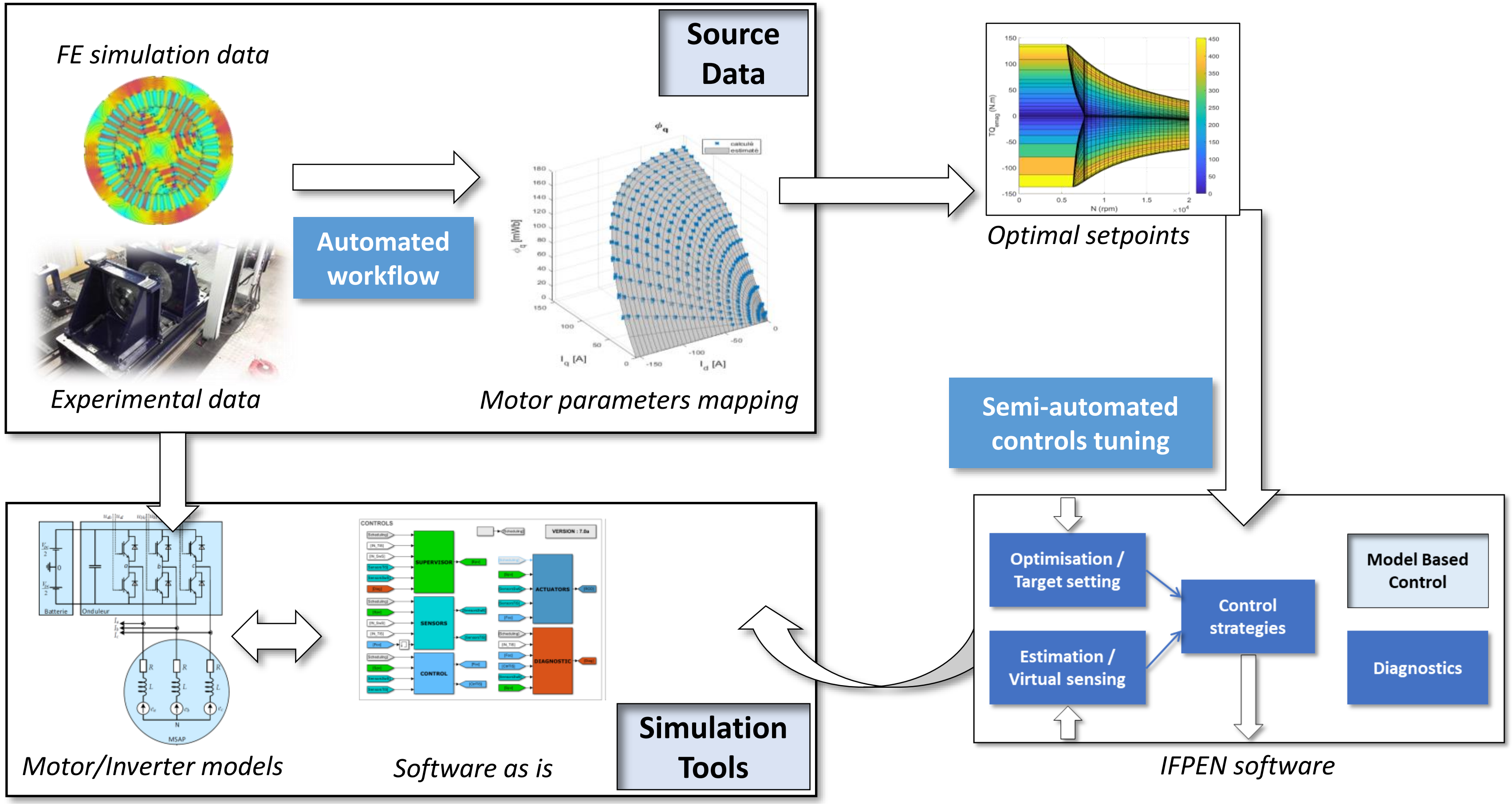

For simulation applications

INTRODUCTION

Sustainable mobility

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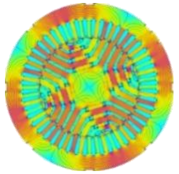
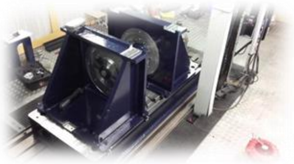
Source Data

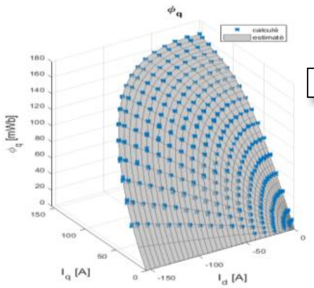
FE simulation data



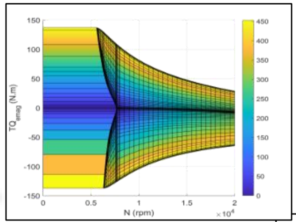


Experimental data

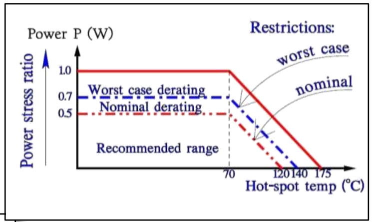
Automated workflow



Motor parameters mapping



Optimal setpoints



System limitations

Semi-automated controls tuning

Monitored params & variables selection

Optimisation / Target setting

Estimation / Virtual sensing

Control strategies

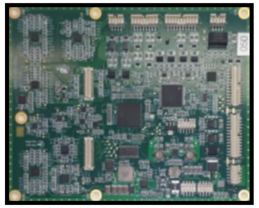
Model Based Control

Diagnostics

IFPEN software

Automated code generation

Practical application



IFPEN CPU board with embedded firmware

And for experimental applications

INTRODUCTION

Sustainable mobility

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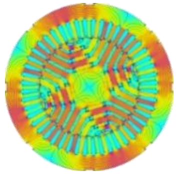
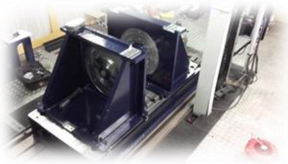
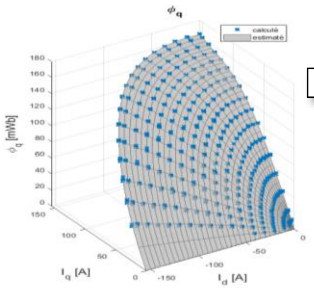


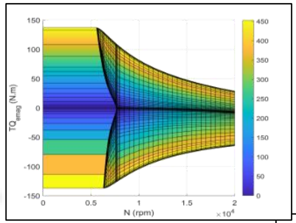


Experimental data

Automated workflow



Motor parameters mapping



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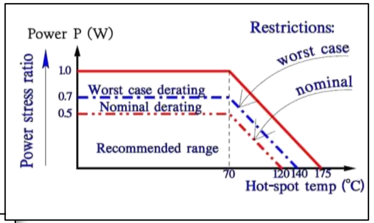

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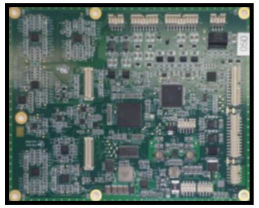
IFPEN software

Automated code generation

Practical application

Targeted system

IFPEN inverter



IFPEN CPU board with embedded firmware

And for experimental applications

SUMMARY

Sustainable mobility

I) Software calibration and generation

II) Software experimental validation

III) Software simulation tools

SUMMARY

Sustainable mobility

I) Software calibration and generation

II) Software experimental validation

III) Software simulation tools

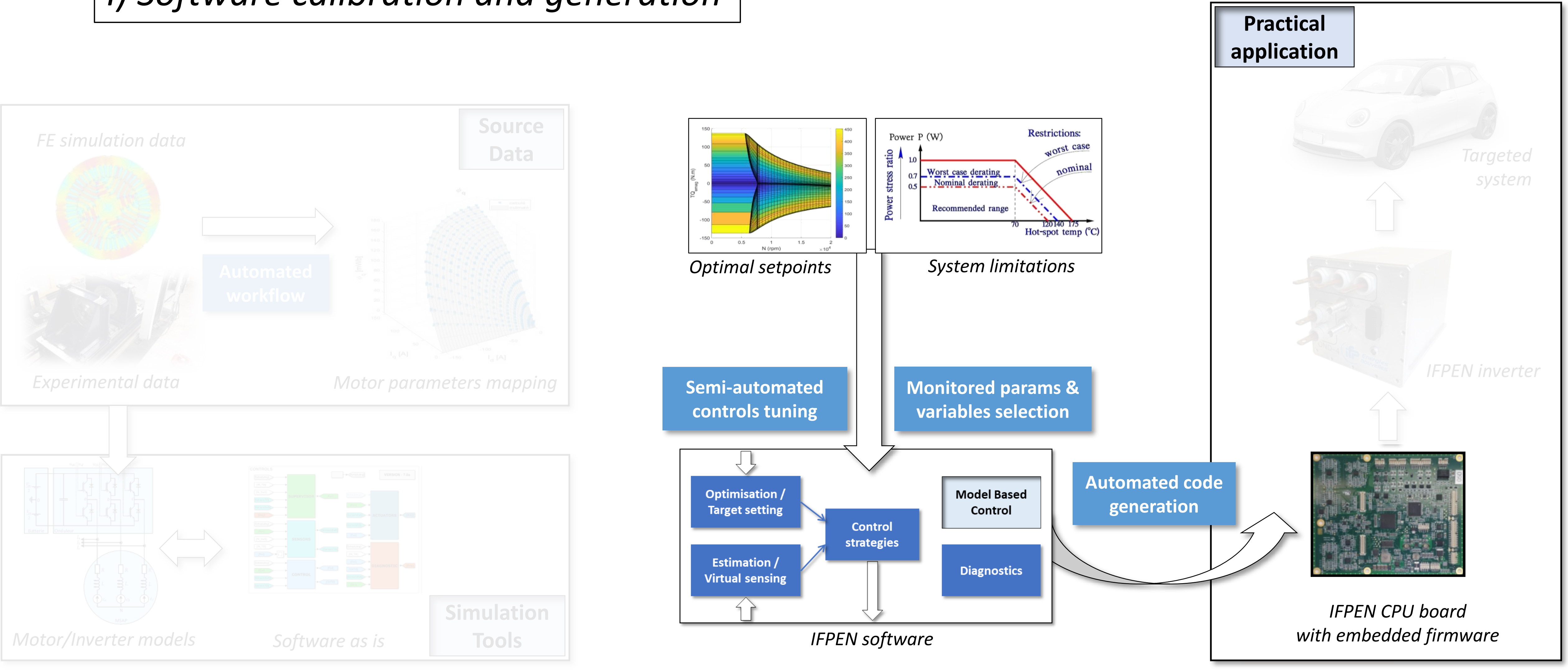
ifpen Transports Energie

Energies nouvelles

I) SOFTWARE CALIBRATION AND GENERATION

Sustainable mobility

I) Software calibration and generation



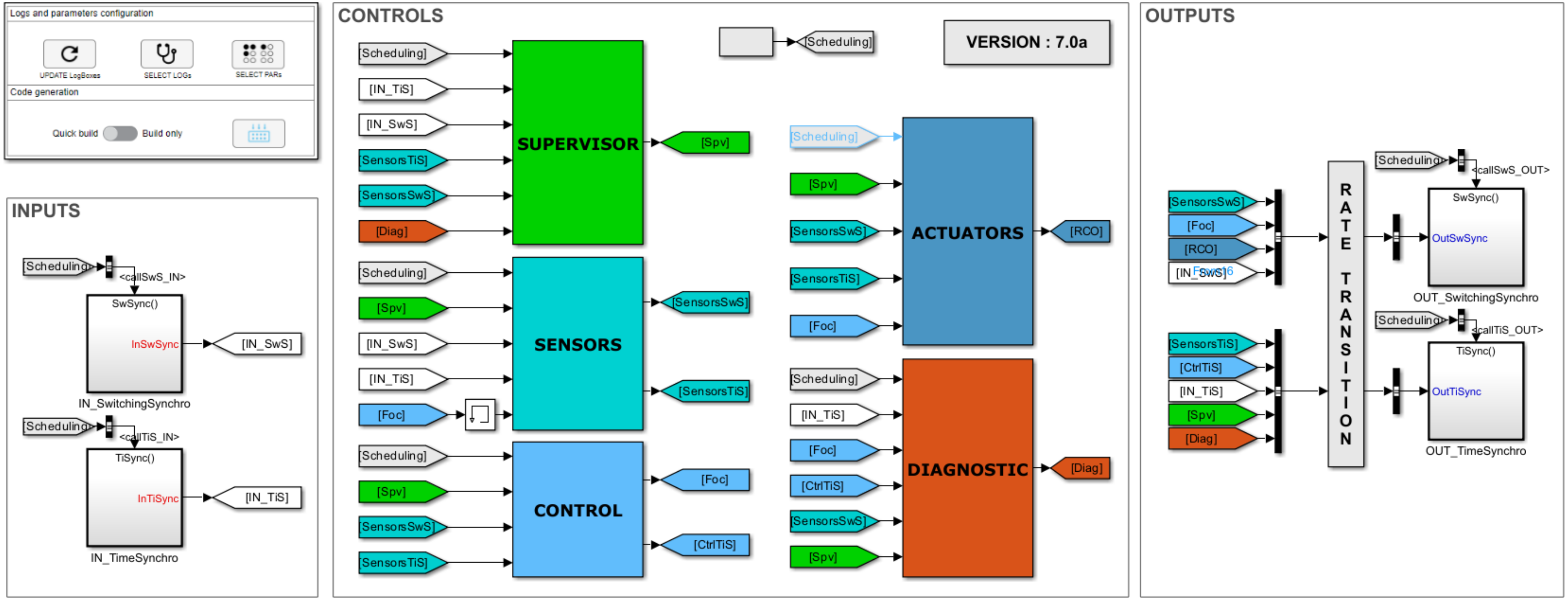
I) SOFTWARE CALIBRATION AND GENERATION

Sustainable mobility

The **toolchain** is articulated around control algorithms in Matlab/Simulink

→*Easy coding facilitates quick development*

→*A single engineer can seamlessly setup his system before operating it*

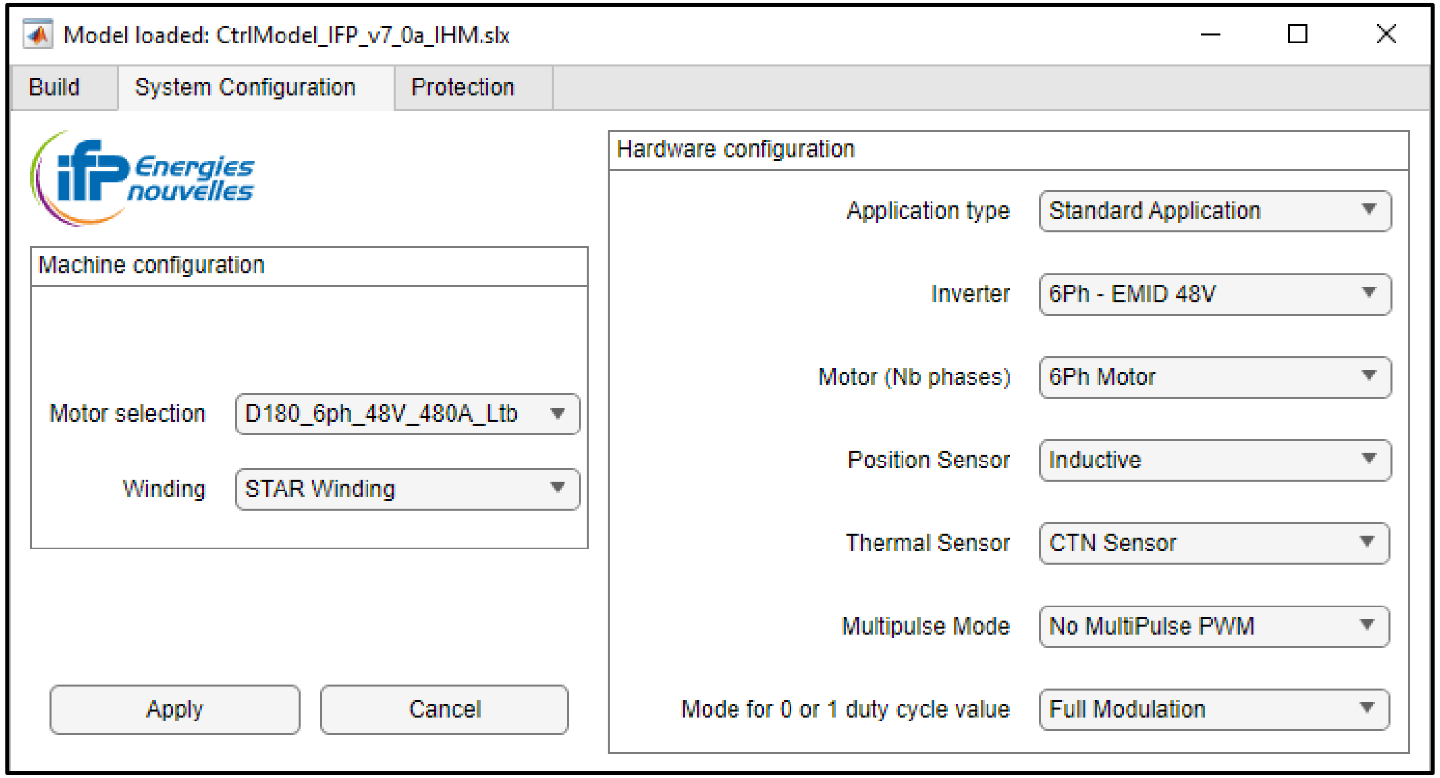


I) SOFTWARE CALIBRATION AND GENERATION

Sustainable mobility

System setup is fully done from an App and in-house blocks

→*To select any IFPEN-made inverter targeted and motor calibration*



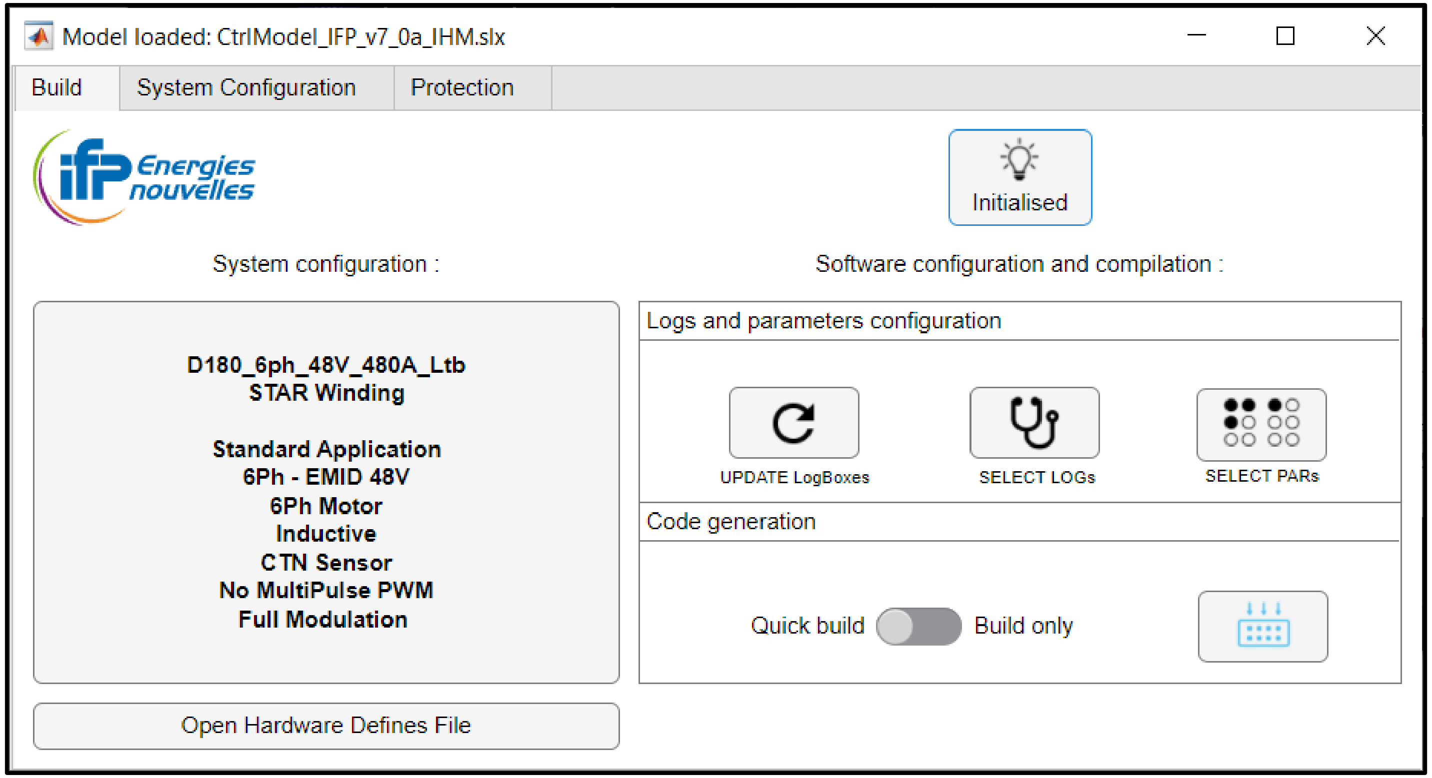
I) SOFTWARE CALIBRATION AND GENERATION

Sustainable mobility

System setup is fully done from an App and in-house blocks

→*To select any IFPEN-made inverter targeted and motor calibration*

→*To manage relevant parameters and signals before code generation*



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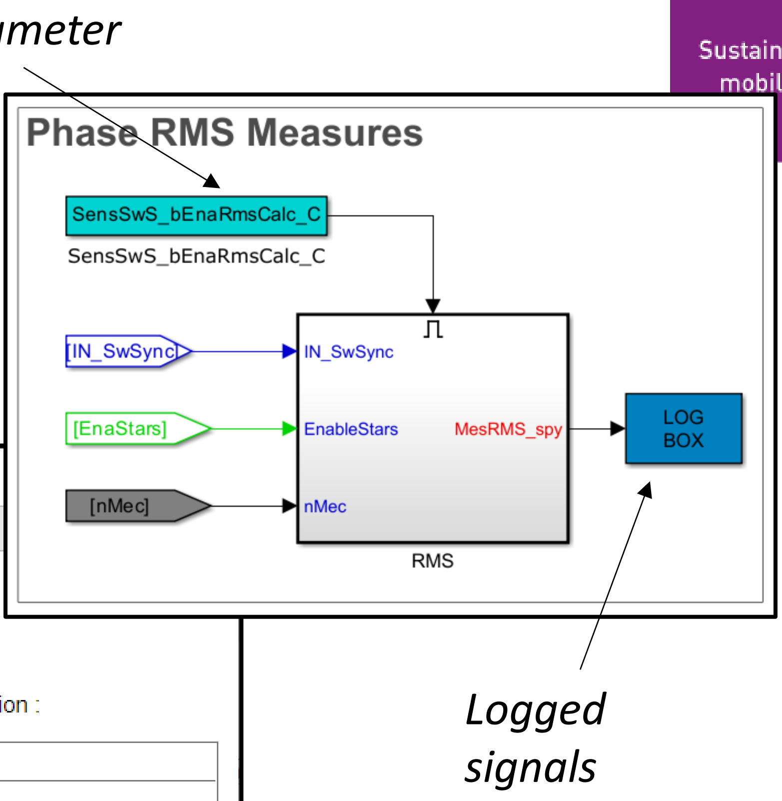

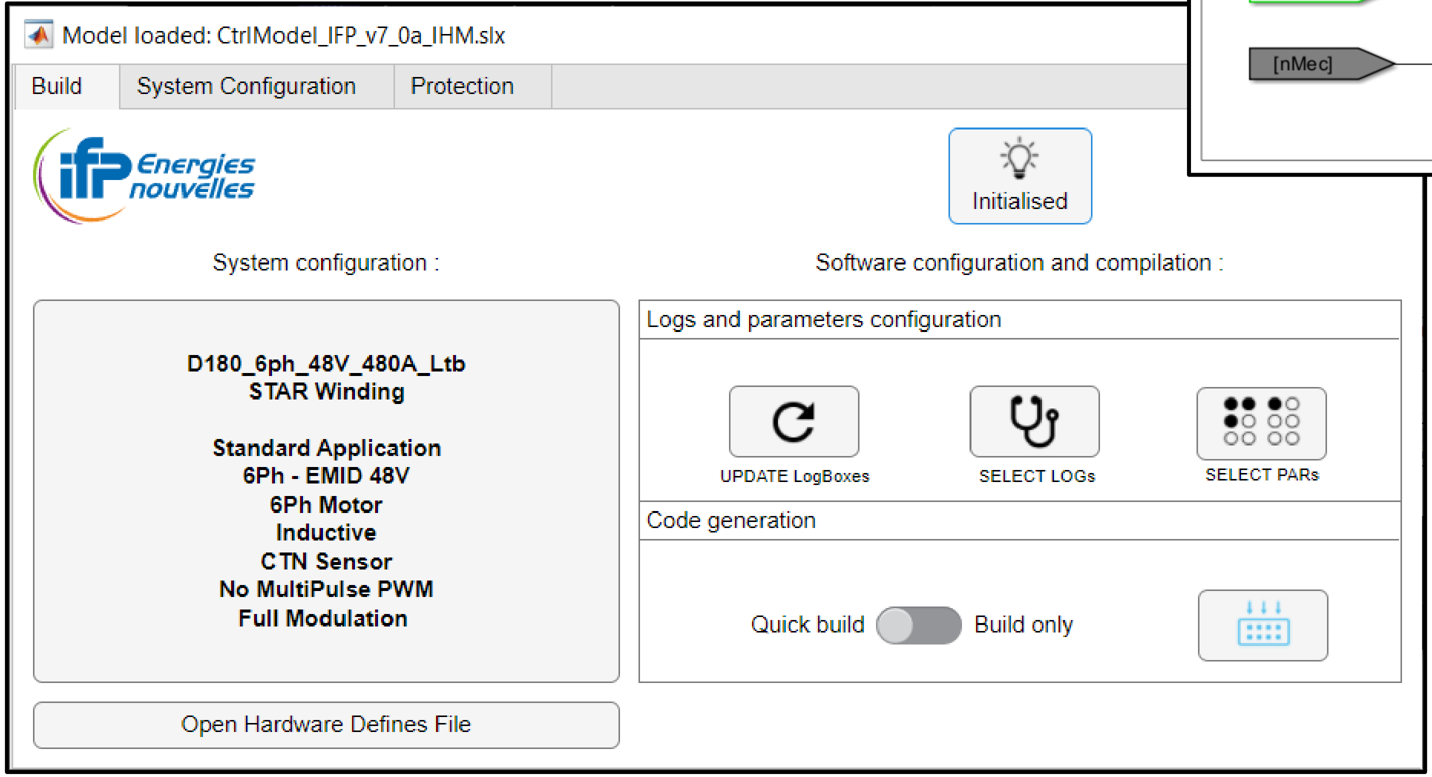

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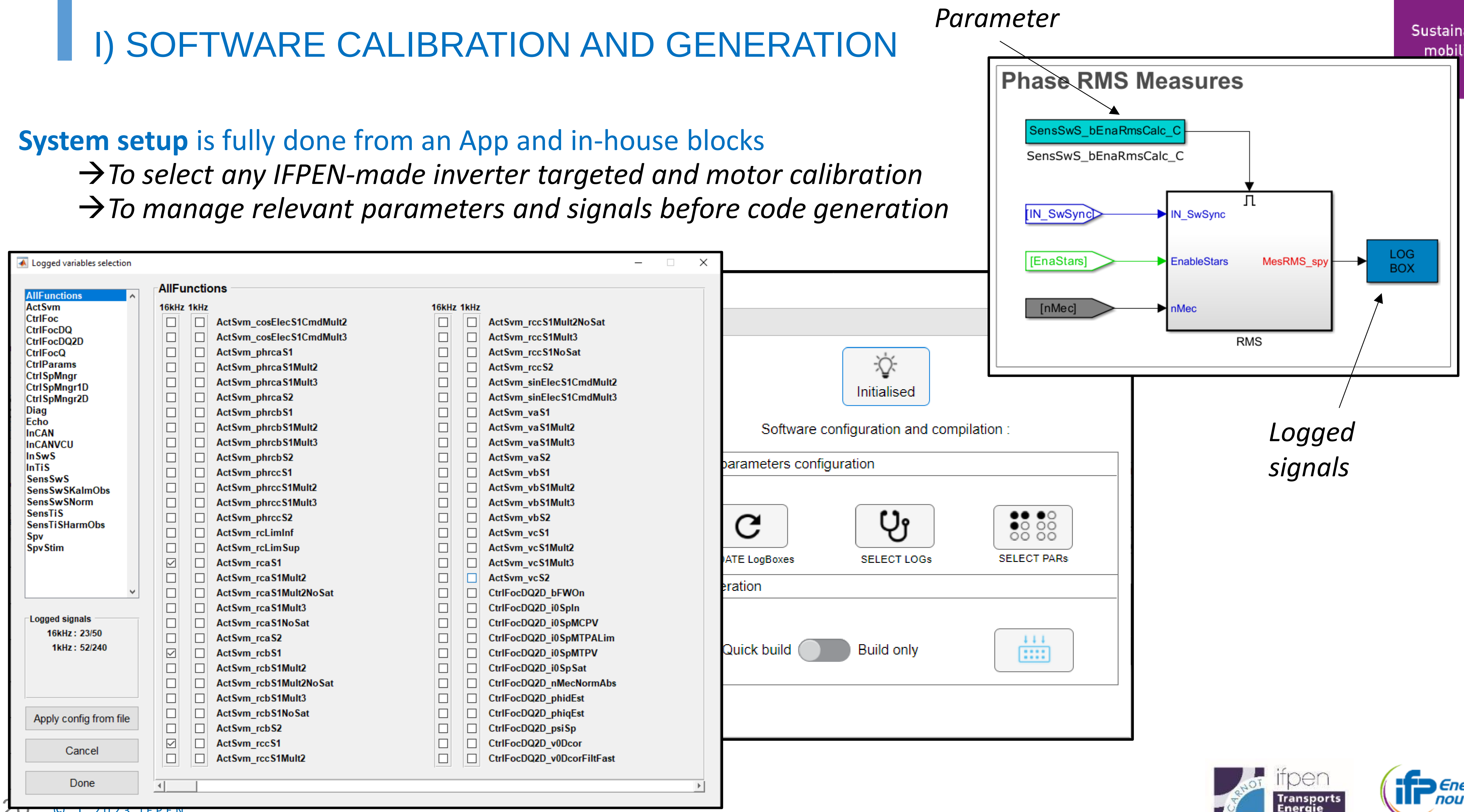
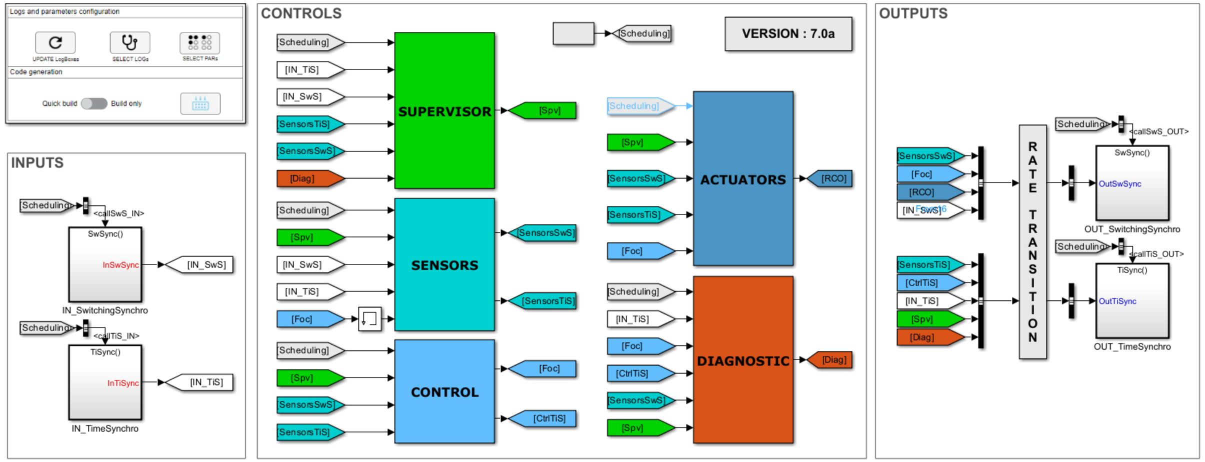


I) SOFTWARE CALIBRATION AND GENERATION

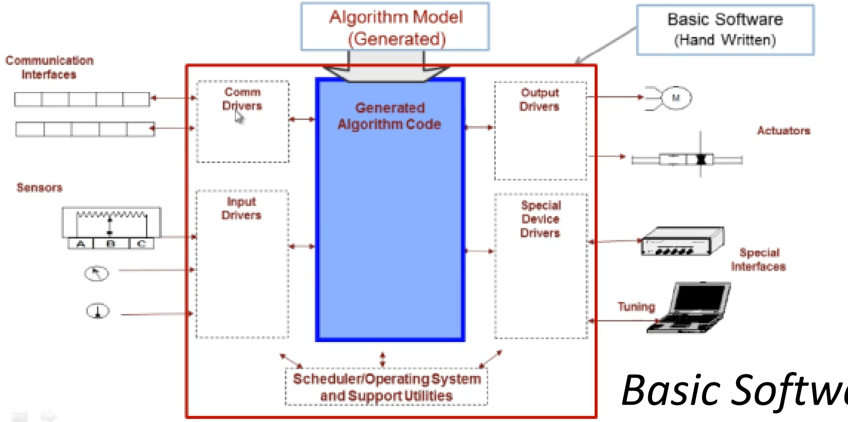
Sustainable mobility

All steps of **code generation** are driven from the App

→ *From Simulink code generation to flashing firmware in the inverter*

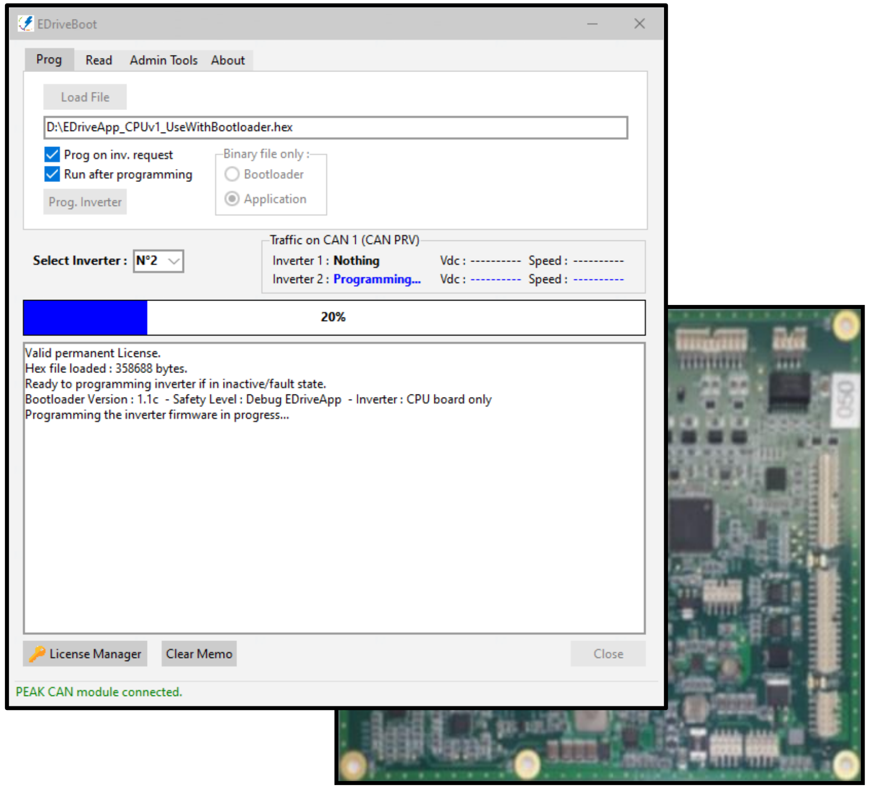


Controls



Basic Software

Code generation and update is done in less than 5 minutes



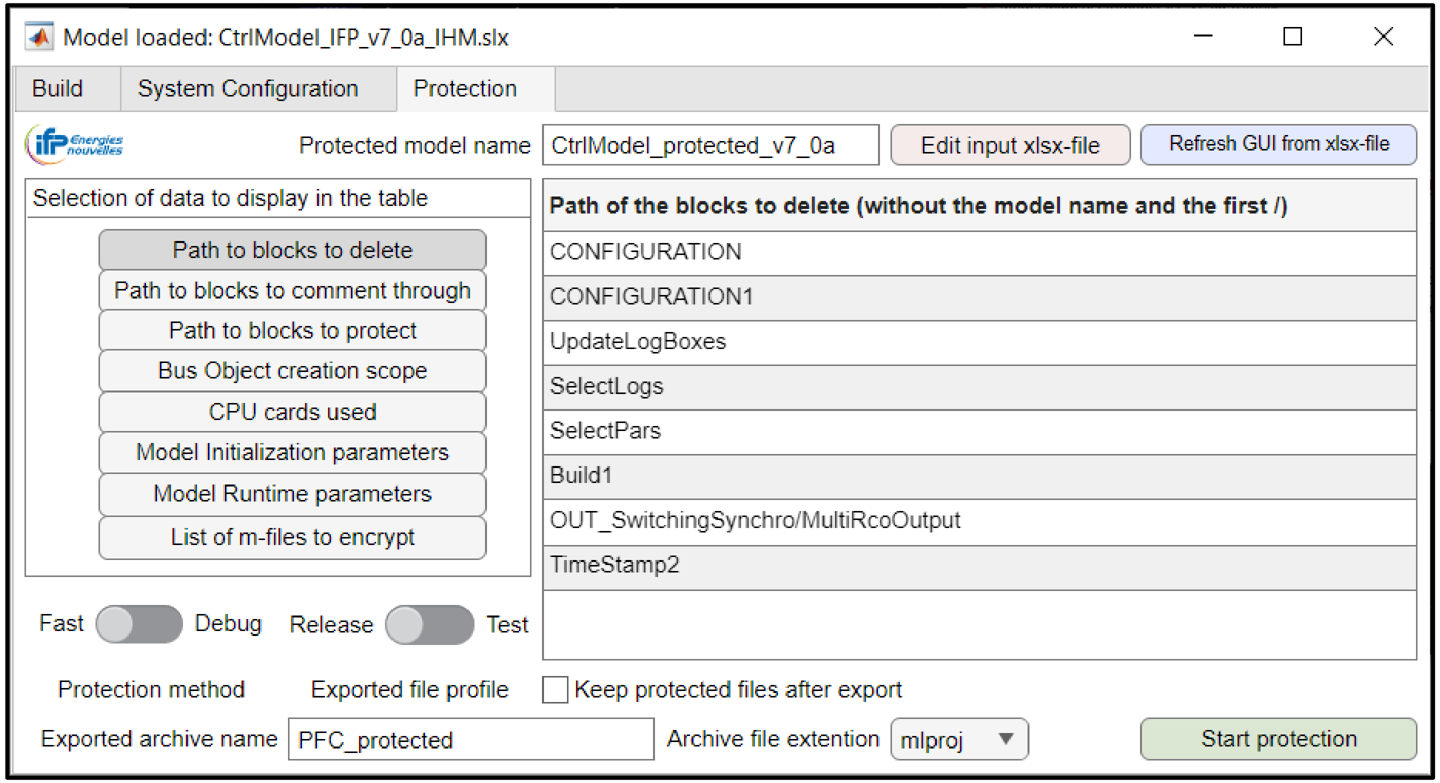
I) SOFTWARE CALIBRATION AND GENERATION

Sustainable mobility

All steps of **code generation** are driven from the App

→ *From Simulink code generation to flashing firmware in the inverter*

→ *Including an option to fully/partially protect our code for external use*



Automatic model reference creation
→ share .slxp files

SUMMARY

Sustainable mobility

II) SOFTWARE EXPERIMENTAL VALIDATION

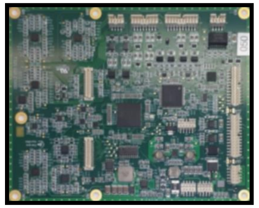
Sustainable mobility

II) Software experimental validation

Practical application

Targeted system

IFPEN inverter



IFPEN CPU board with embedded firmware

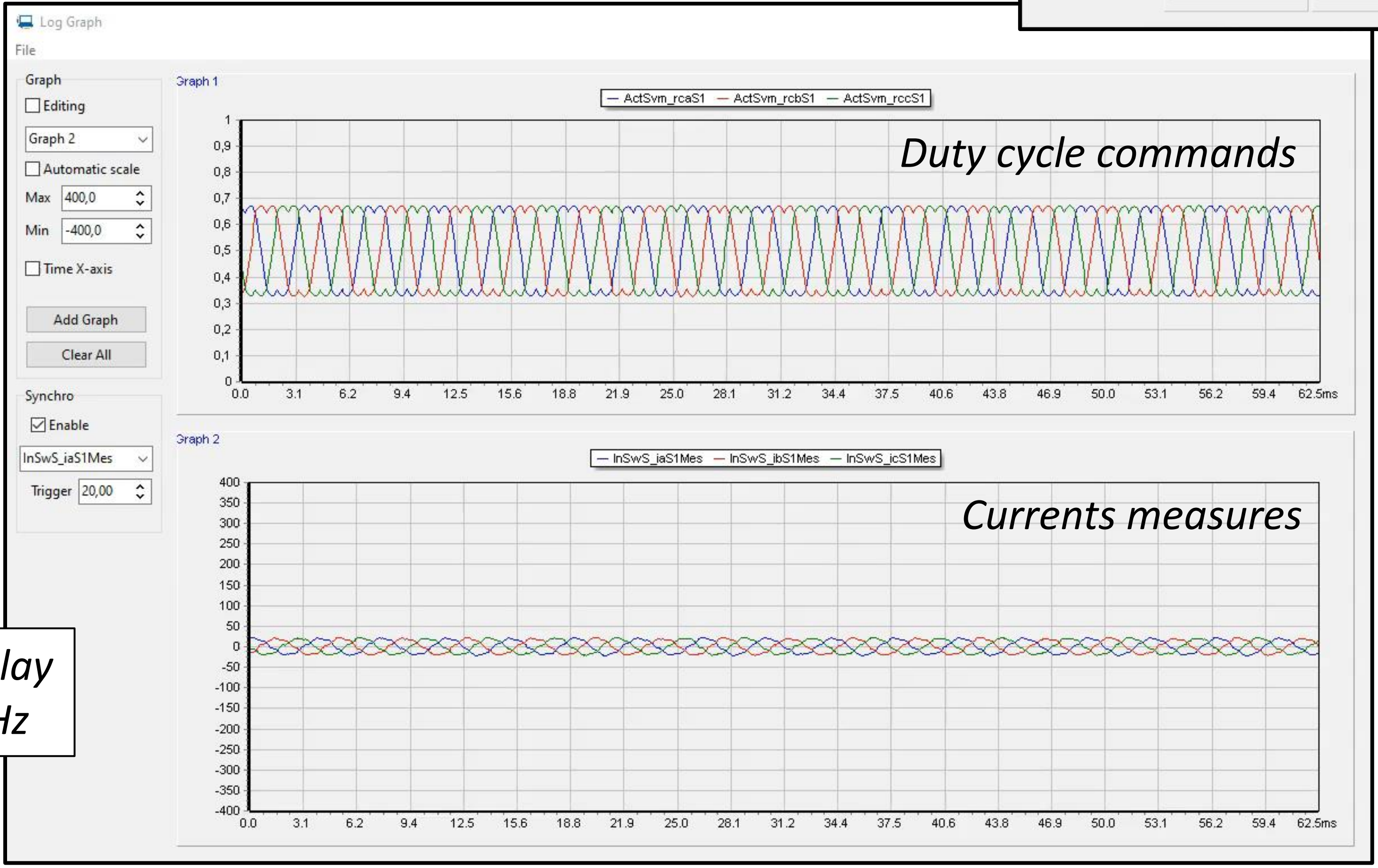
II) SOFTWARE EXPERIMENTAL VALIDATION

Sustainable mobility

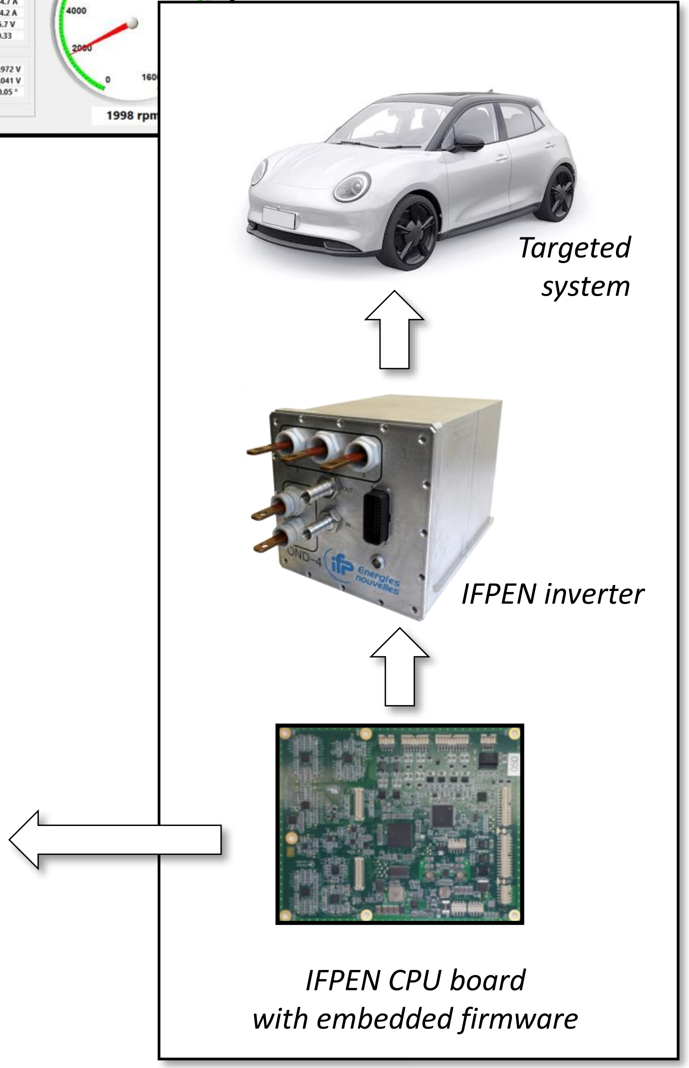
The toolchain includes a practical **Human Machine Interface**

→*Automatically adapted to signals and parameters selected*

→*Easy to edit for fast-prototyping*



Live display @20+ kHz



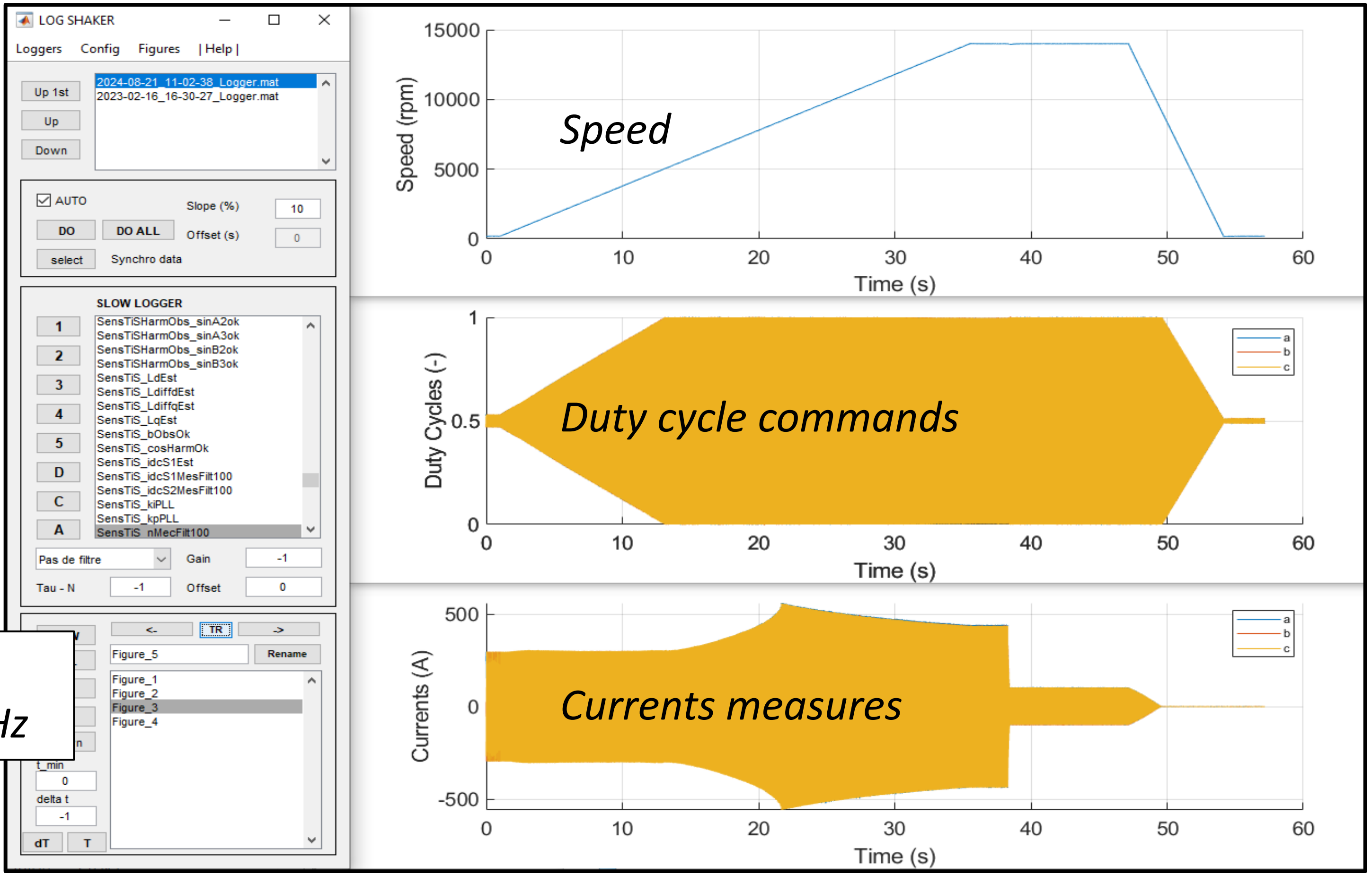
II) SOFTWARE EXPERIMENTAL VALIDATION

Sustainable mobility

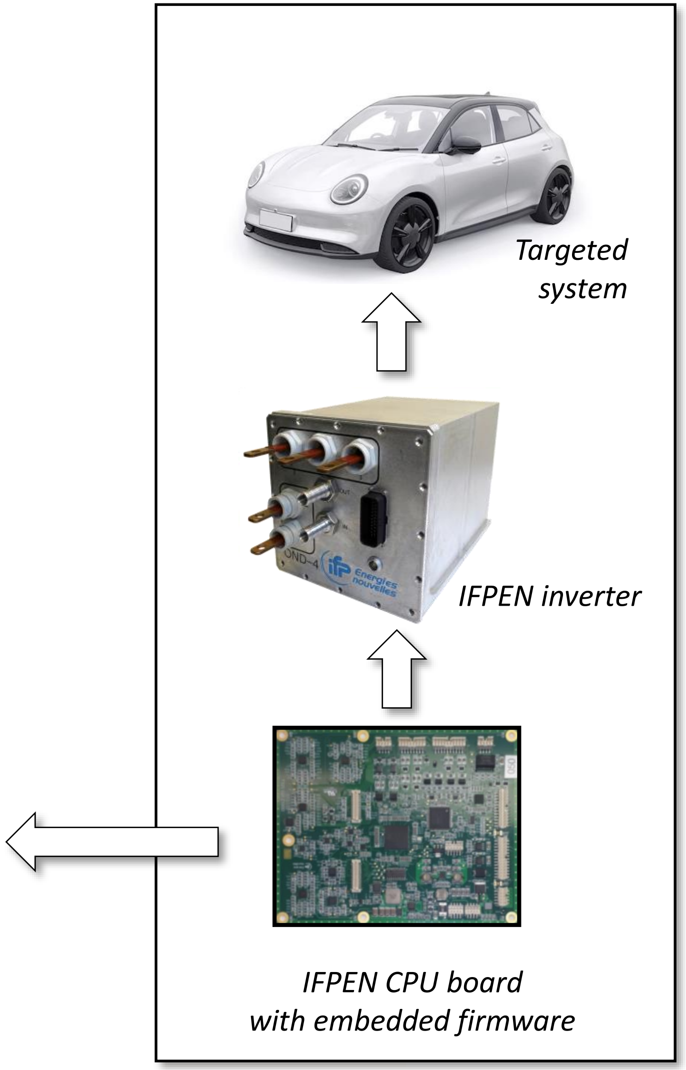
The toolchain includes also a dedicated **signals analysis tool**

→*A dataset & display setup manager*

→*With synchronization, filtering and correction functions*



Analysis @20+ kHz



II) SOFTWARE EXPERIMENTAL VALIDATION

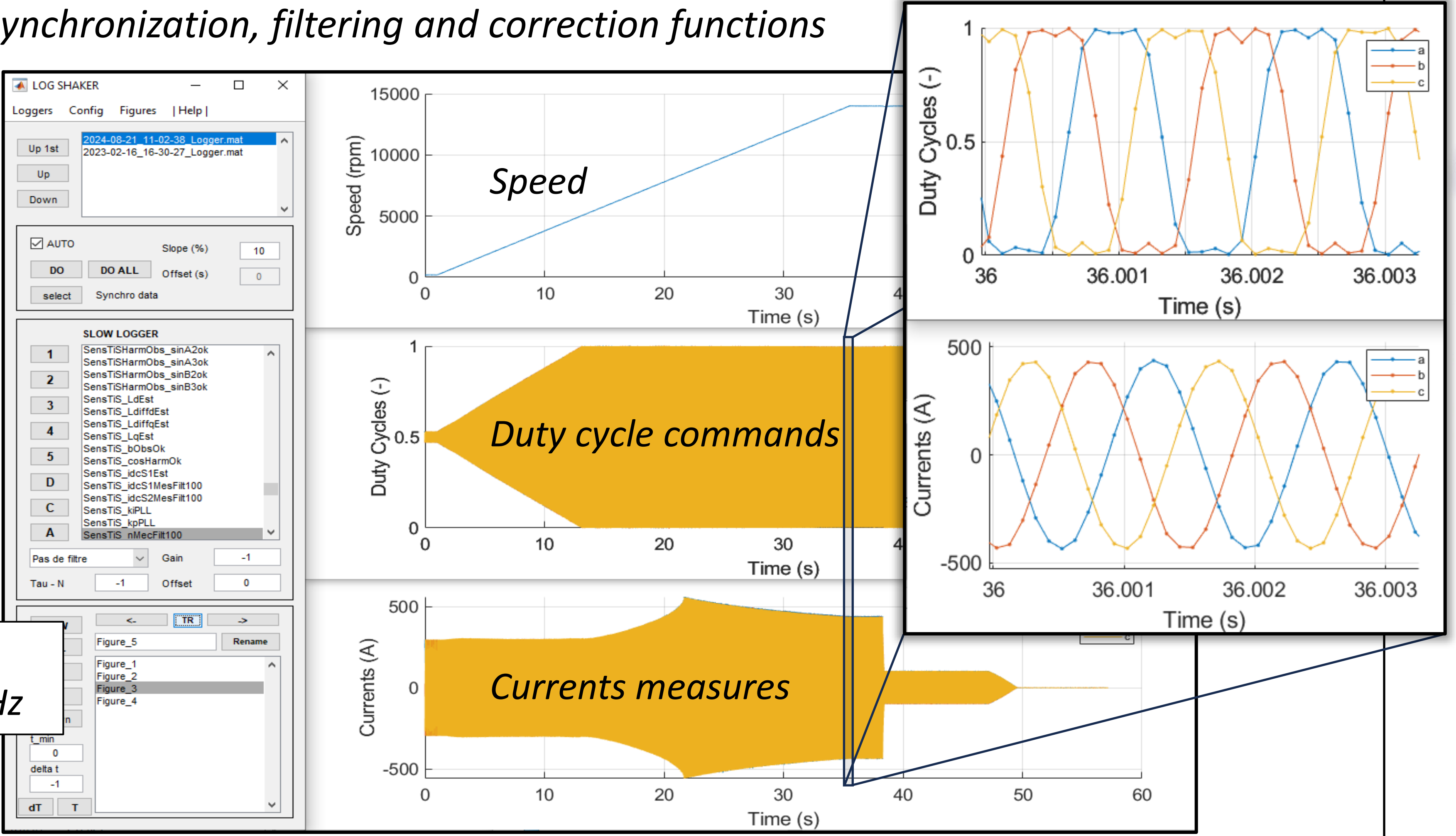
Tens of signals logged
@ 20+ kHz
without duration limits

Sustainable mobility

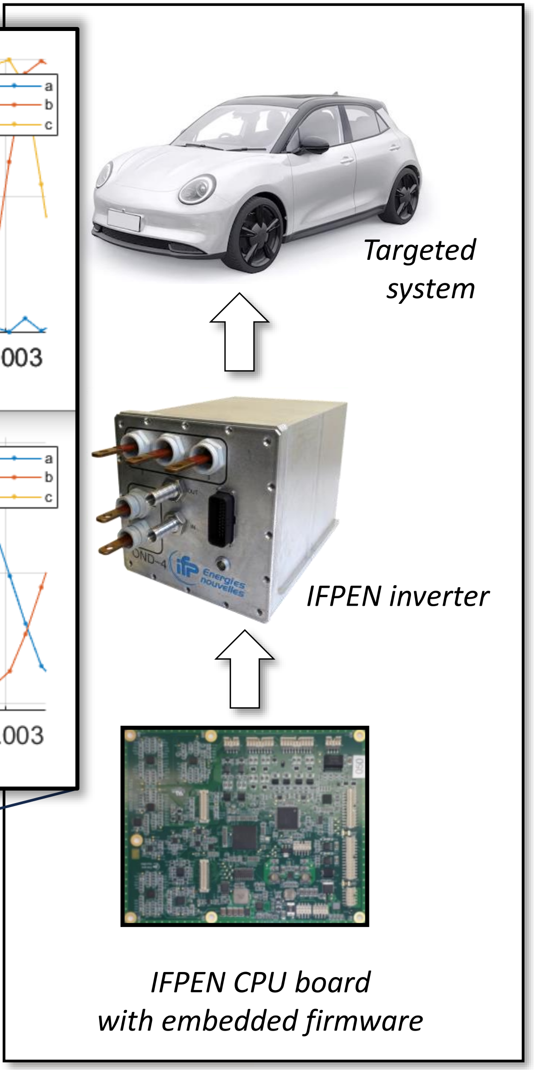
The toolchain includes also a dedicated **signals analysis tool**

→*A dataset & display setup manager*

→*With synchronization, filtering and correction functions*



Analysis
@20+ kHz



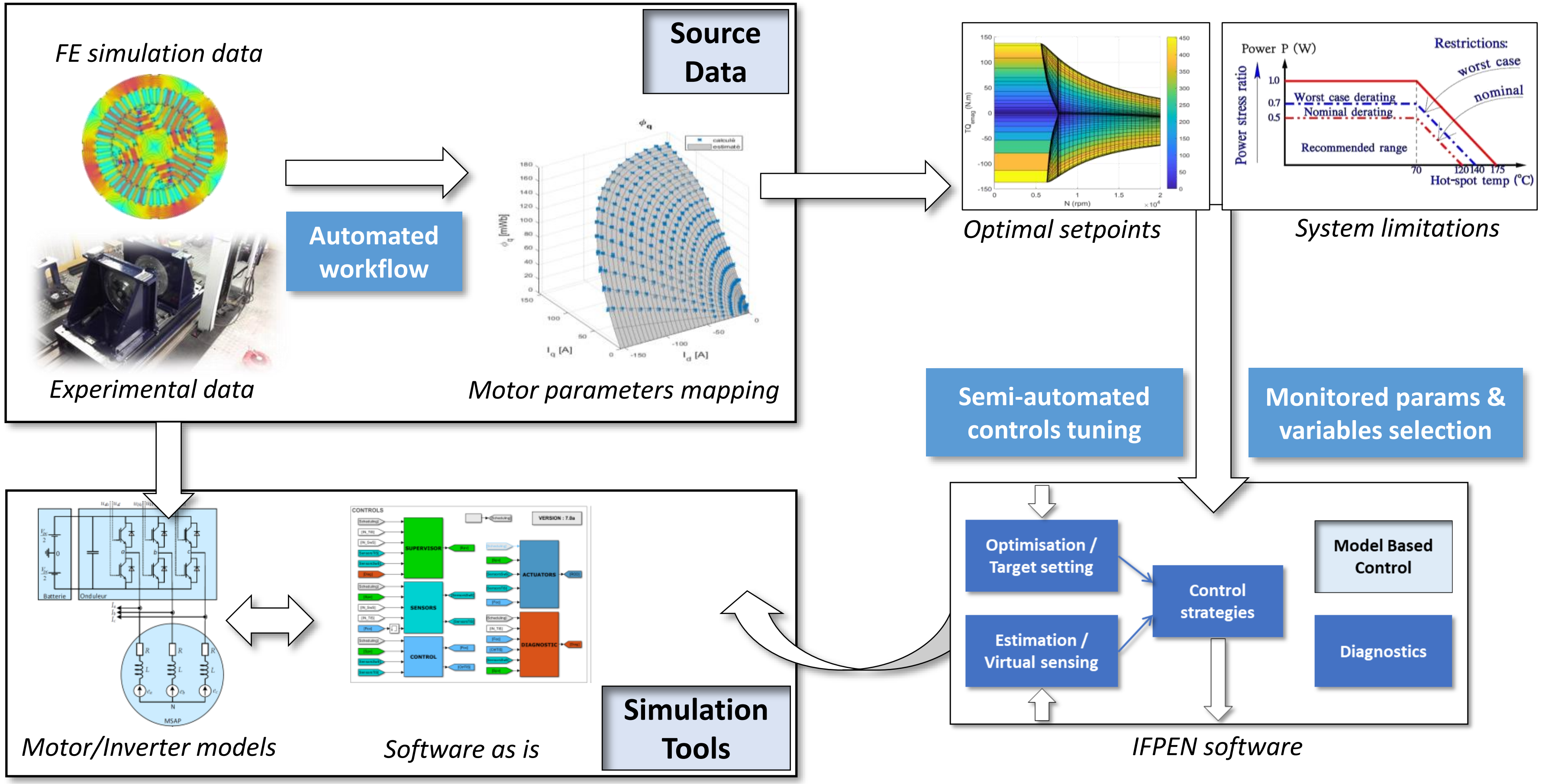
SUMMARY

Sustainable mobility

III) SOFTWARE SIMULATION TOOLS

Sustainable mobility

III) Software simulation tools

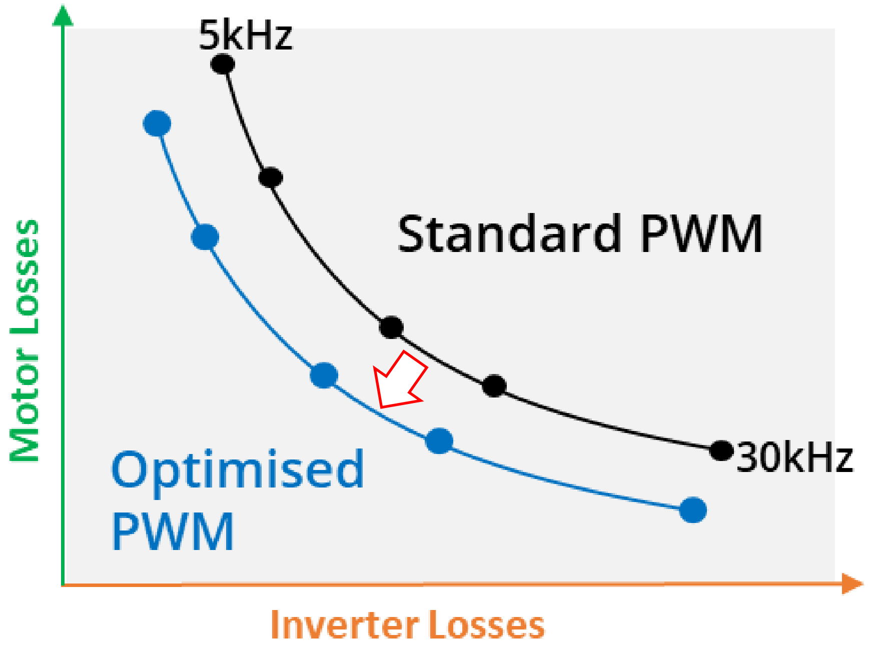


Sustainable mobility

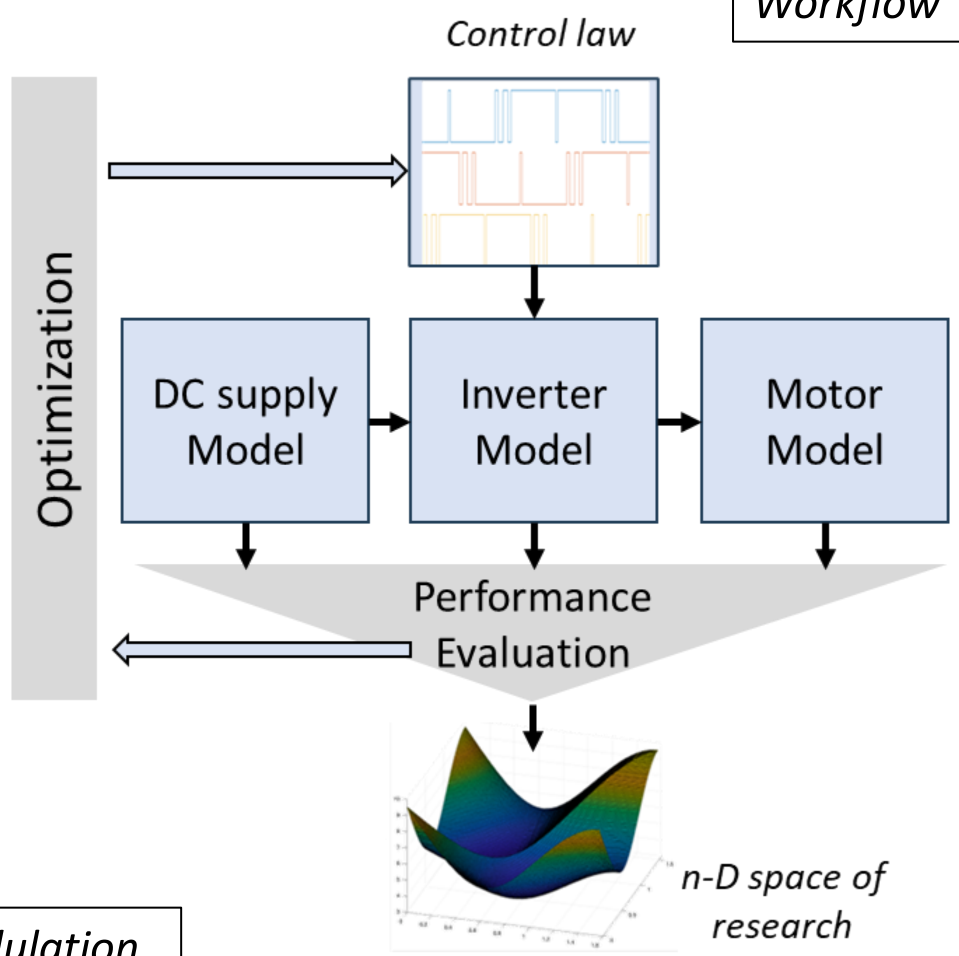
The objective is to **replace control laws bench evaluation with simulation** as much as possible

→ *Performance criteria : efficiency under constraints (DC ripple, NVH, Torque ripple, CPU load, etc.)*

→ *Usually evaluated on the bench due to system complexity, but degrees of freedom are too numerous*

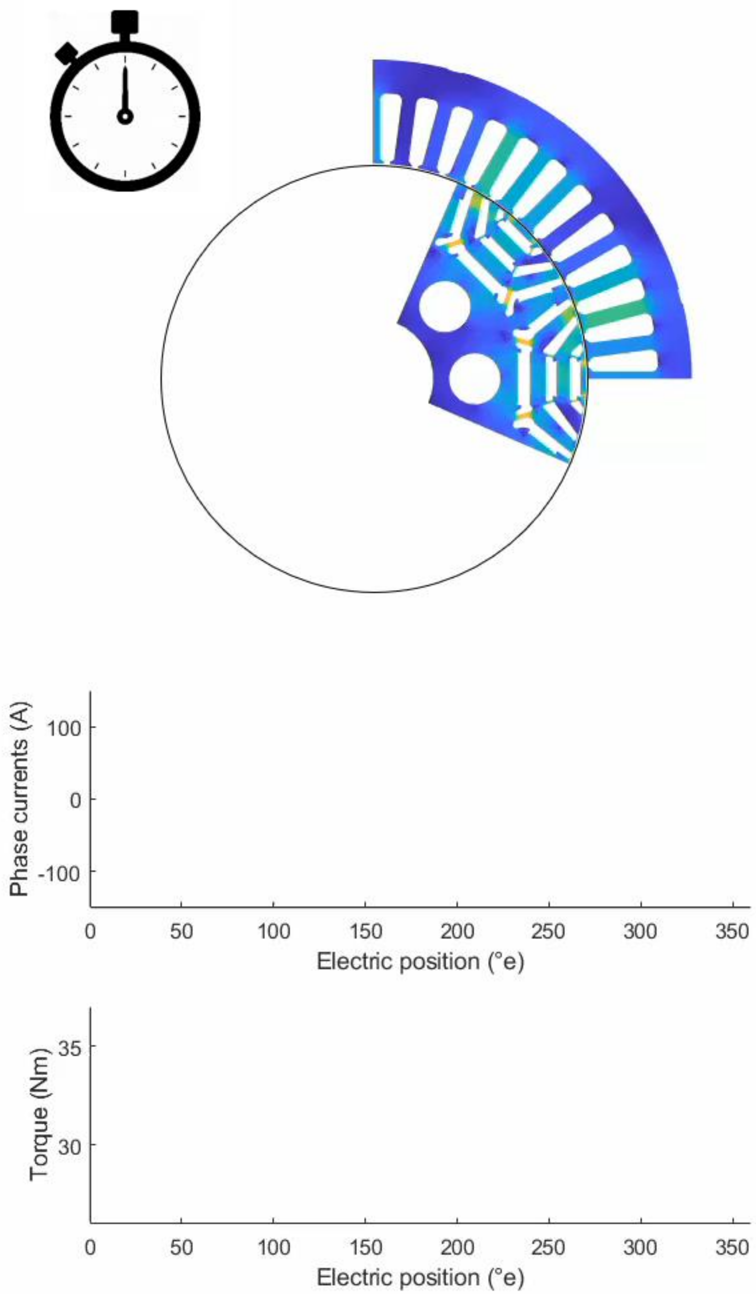


Optimization Workflow

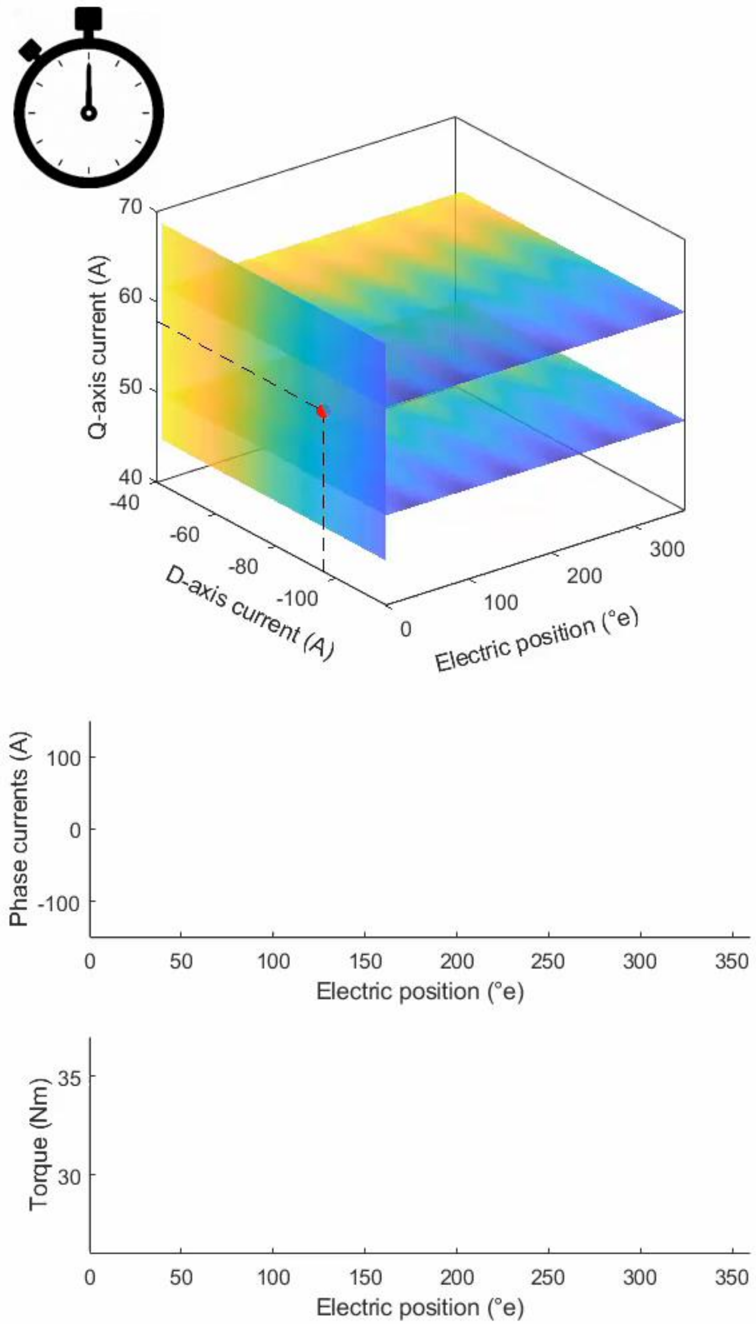


NB : PWM = Pulse Width Modulation

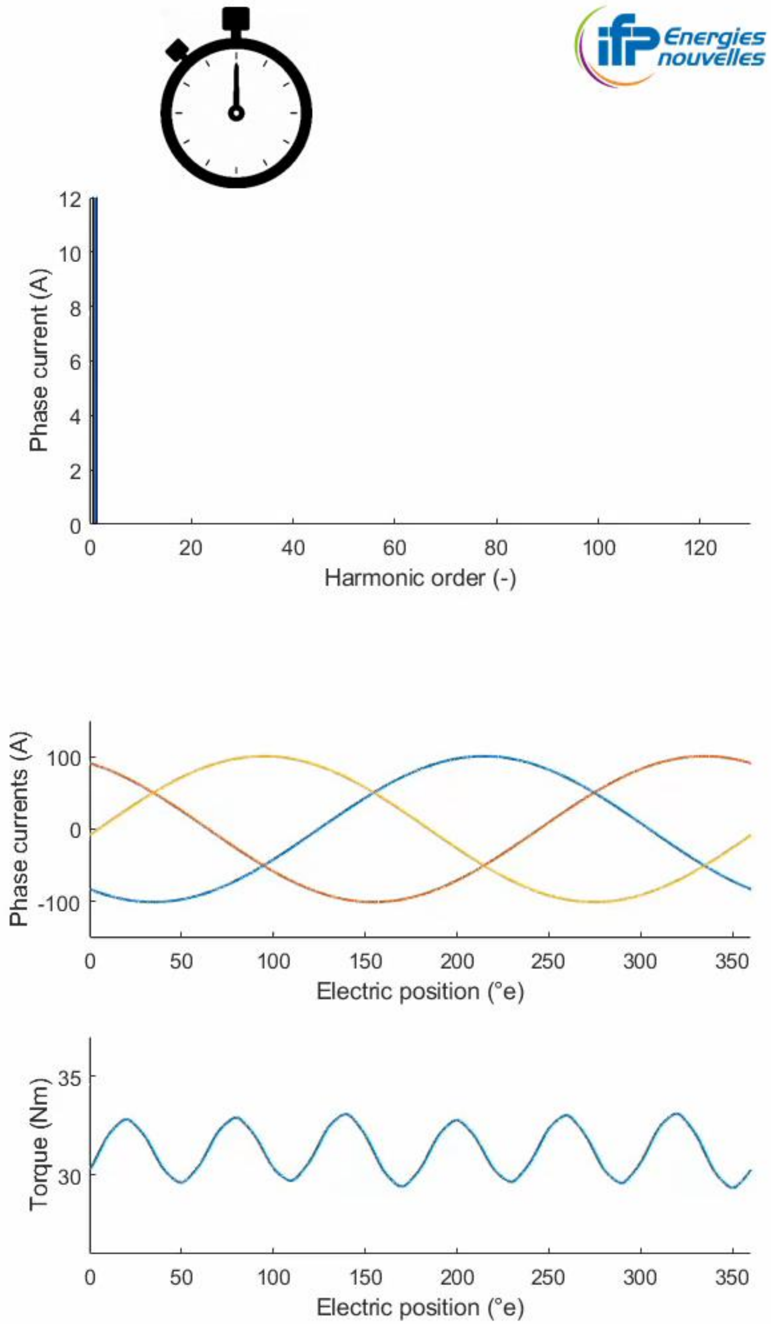
Finite Elements



Time-based reduced model



Frequency-based reduced model



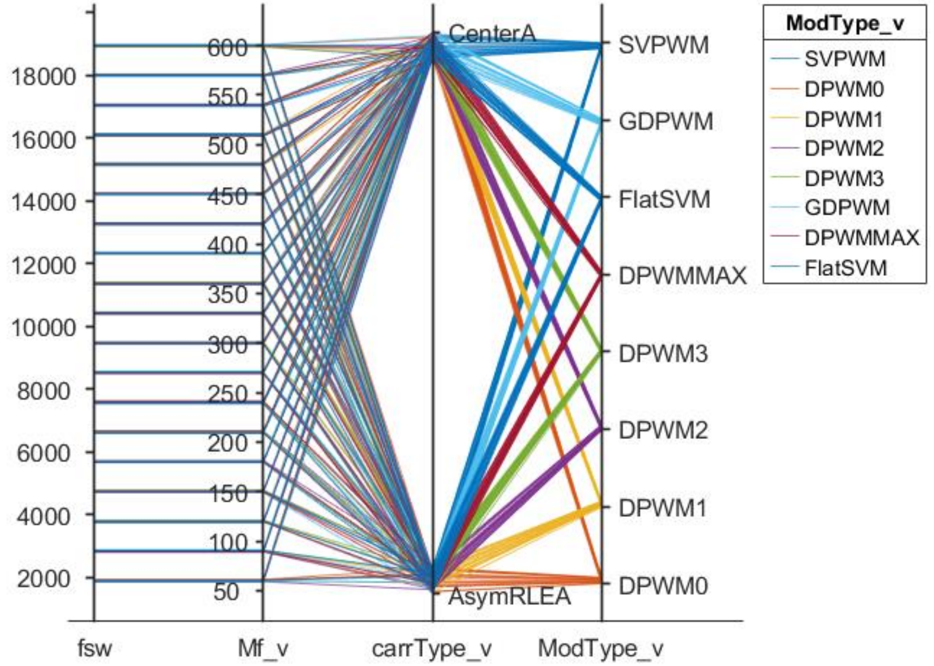
III) SOFTWARE SIMULATION TOOLS

Sustainable mobility

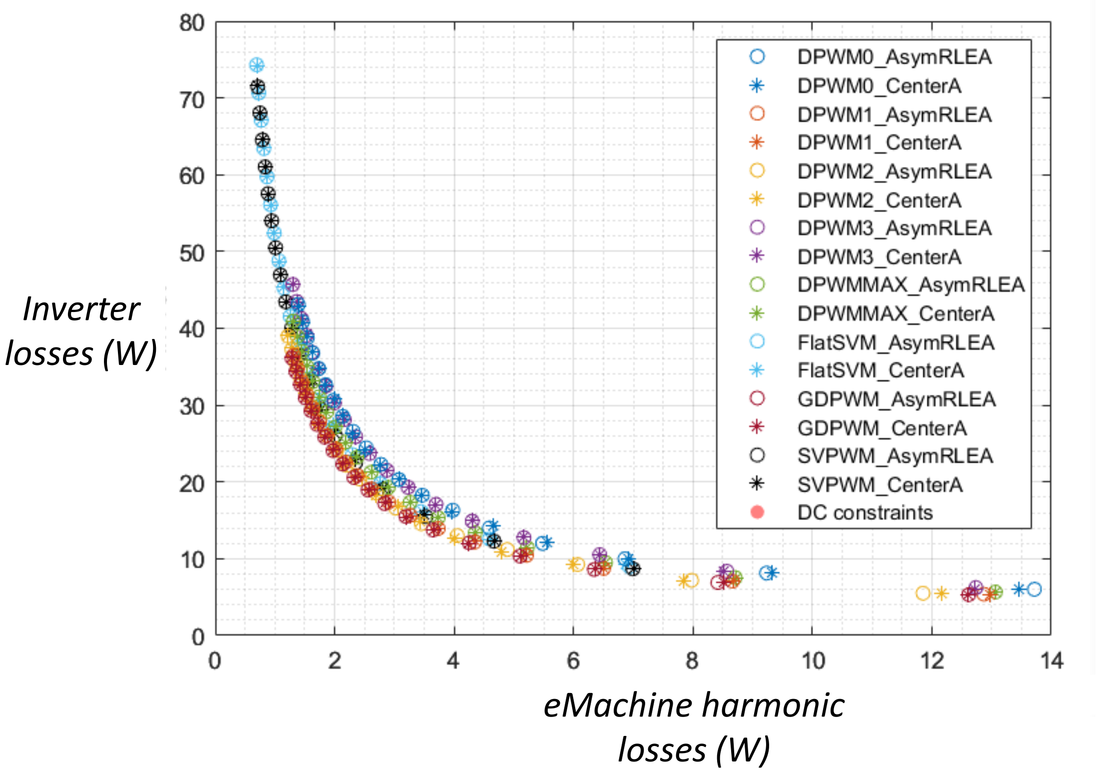
These models are used in our **optimization** process

→*We now use our fast-computing models to evaluate a great number of configurations efficiently (~50000 evaluations/hour)*

Configurations evaluated



Resulting Pareto front



CONCLUSION

Sustainable mobility

Achievements

→*An efficient workflow tailored to our needs, and advanced modeling of physics, are leveraged to develop innovative control strategies*

→*Within 5 years with a controls team of 3 people (now 5)*

- *70+ CPU boards made and integrated in 10 different IFPEN prototype inverters*
- *60+ different electric motors driven with these, often for 24/7 bench tests*
- *20~ patents filed for innovative motor control solutions*

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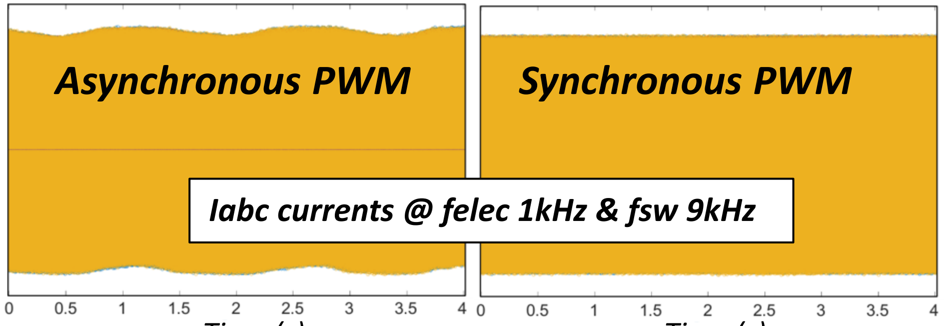
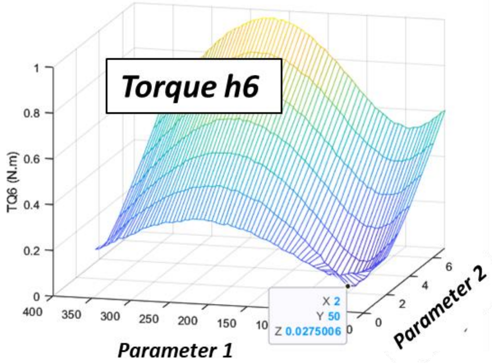
→ Synchronous PWM

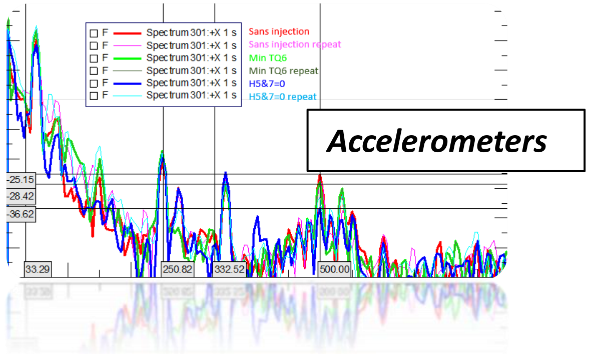
- *Efficient overmodulation : power ↗↗*
- *Lower frequency @ high speed : losses ↘*
- *DC bus ripple mitigation : Capacitors volume ↘*



→ Harmonics injection

- *For compensation of torque harmonics and airgap radial forces : material cost ↘*
- *Operational in steady-state and during speed transients*





CONCLUSION

One step further : Gen2 SiC inverter dedicated to motor bench testing

→*Objective: support motor and control technology development for industrial partners*

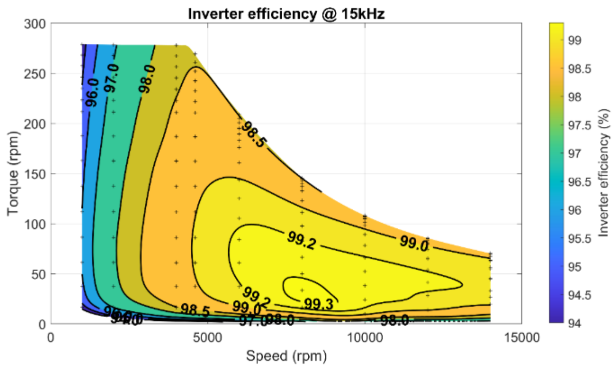
→*Method: a versatile, high-performance inverter, marketed in partnership with ALPHEE Engineering*

→The inverter

- *Delivers 500 Arms and operates up to 50 kHz*
- *Benefits from efficient calibration and unique control methods for motor characterization*
- *Features our latest advances in controls: synchronous motor control, current injection for NVH reduction, etc.*

→The partnership

- *Launched in early 2024, it has led to the manufacture of 6 SiC inverters*
- *The SME Alphée handles manufacturing, marketing, commissioning and after-sales service.*



Peak power	320 kW
Continuous power	250 kW
Max current	500 Arms
Efficiency	99% on wide area
DC Voltage	500 - 800V
Switching frequency	5 – 50 kHz

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