Training eMEGASIM

Overview of actual simulation solutions

Outline

1. Company
2. Benefits of simulation
3. Model-based design
4. Real-time concepts
5. Hardware architecture
6. Software packages

Outline

1. **Company**
    - Introduction
    - Worldwide presence
    - Partial customer list
2. Benefits of simulation
3. Model-based design
4. Real-time concepts
5. Hardware architecture
6. Software packages

Introduction

Corporate

- Established in 1997
- Headquarters Montreal, QC, Canada
- Over 160 Employees
- More than 600 customers worldwide
- More than 20% of turnover invested in R&D

Products

- Faster than real-time Parallel simulation
- Rapid Control Prototyping simulation
- Controller Hardware-In-the-Loop simulation
- Power Hardware-In-the-Loop simulation

Main Markets

- **Power Systems**
    - Transmission, Distribution, Generation
    - HVDC & FACTS
    - Micro-Grids, Smart-Grids
    - Electromagnetic and electromechanical transients
- **Power Electronics**
    - Hybrid vehicles, More electrical aircrafts, electrical trains and ships, off-highway vehicles
- **Automotive and Aerospace**
    - Mechatronics and dynamic multi-domain simulators

Worldwide presence

Some customer references

REN Redes Energéticas Nacionais

Rte Réseau de transport d'électricité

Hydro Québec

国家电网 State Grid
中国电力科学研究院 China Electric Power Research Institute

EDF

Enel

Schneider Electric

ALSTOM

ABB

GE Energy

SIEMENS

KTH Vetenskap och Konst

Imperial College London

JRC European Commission

UCD Dublin

Politecnico di Torino

L2EP Laboratoire d'électrotechnique et d'électronique de puissance de Lille

Fraunhofer

Aalborg University Denmark

EPFL École Polytechnique Fédérale de Lausanne

The University of Nottingham
United Kingdom · China · Malaysia

Outline

1. Company
2. **Benefits of simulation**
   - Current challenges of power systems
   - Simulation goals
3. Model-based design
4. Real-time concepts
5. Hardware architecture
6. Software packages

Why real-time simulation ?

Provide with more high-end services

Growing complexity

More & more smart systems

Design safer systems

Combine many systems

Limited resources

Shorter deadlines

Difficult integration of many complex, smarter, safer systems

Simulation goals

Tests on the field are, by experience:

- Difficult to handle *(logistics, impacts, …)*
- Expensive *(time, resources, equipment, …)*
- Sometimes hazardous *(power systems, moving parts, …)*

Simulation tools allow:

- Verifications all along the project
- Early detection of errors *(design, implementation & integration)*
- Almost infinite test capabilities *(faulty cases, hazardous tests, …)*

Simulation goals

Reduce cost

- No need for a real system or prototype
- Detect faults earlier : the earlier the better !
- Minimize malfunctions after installation

Reduce delay

- Develop independently the HW and the SW of a controller
- Test systems independently in the lab with their simulated environment
- Reduce the rework activities with a progessive verification

Reduce risk

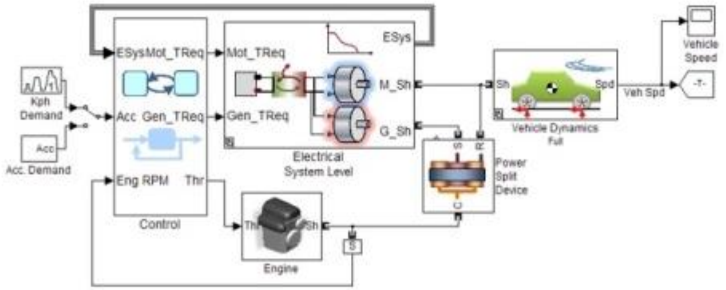
- Study a complex system in detail with simulation
- Better test coverage
- Test the system in faulty conditions in a safer way

Outline

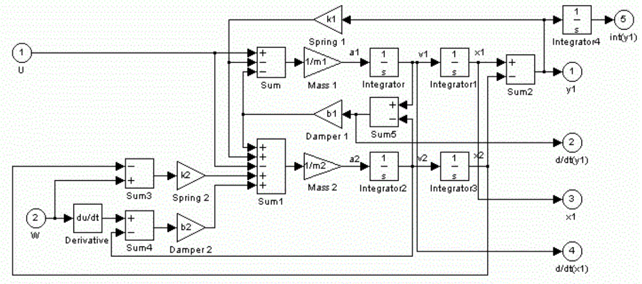
1. Company
2. Benefits of simulation
3. **Model-based design**
   - Model system with blocks
   - Applications
   - Real-time methods: MIL, RCP, HIL
4. Real-time concepts
5. Hardware architecture
6. Software packages

Model system with blocks

Physical models

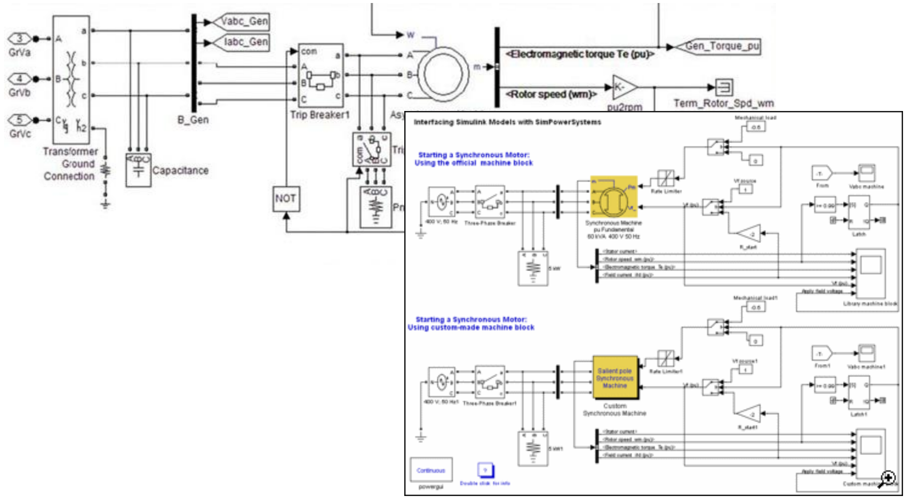


Algorithms / Control strategies



Real-time simulator

Power systems

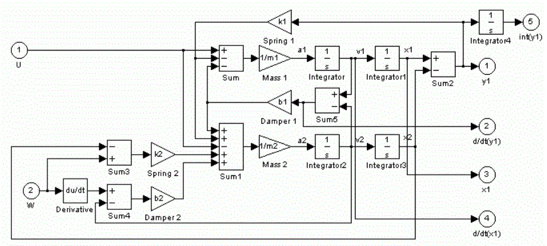


Code

```
# ------------------------------------------------------------
## if the script is executed (not imported)
if __name__ == "__main__":

    ## Connect to a running model using its name. The system
    ## control is release
    systemControl      = 0
    modelName          = 'acquisition1'
    modelPath          = ''
    exactMatch         = 0
    returnOnAmbiguity  = 0

    instId, modelState = \
        OpalApiPy.ConnectByName(modelName, modelPath, exactMatch,
                                systemControl, returnOnAmbiguity)
    print "The connection with '%s' is completed." % modelName

    try:
```

Model system with blocks

1. Design of the model

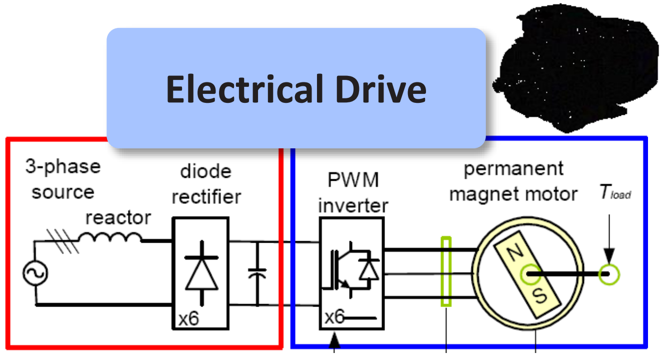


2. Model execution on RT simulator

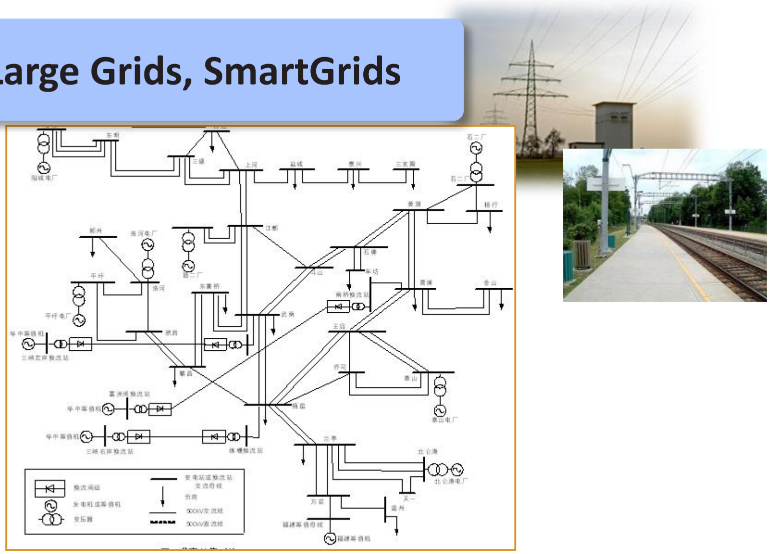
3. Tests with hardware in the loop

Applications

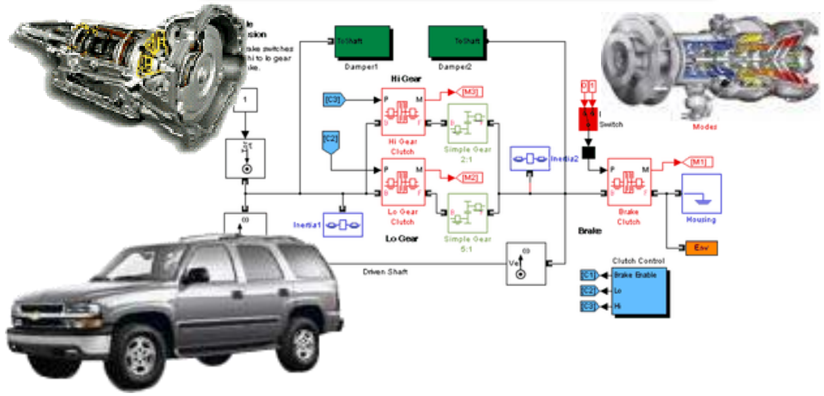
Electrical Drive



Large Grids, SmartGrids



Mechanical Systems

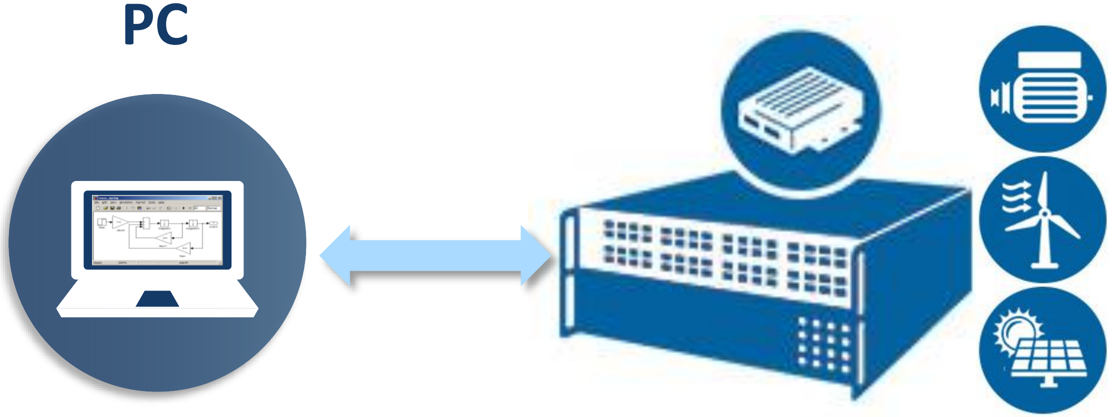


Model-In-the-Loop

Proof of concept
Functional description
Preliminary design phase

Real-time simulator
(simulated controller + plant)

PC

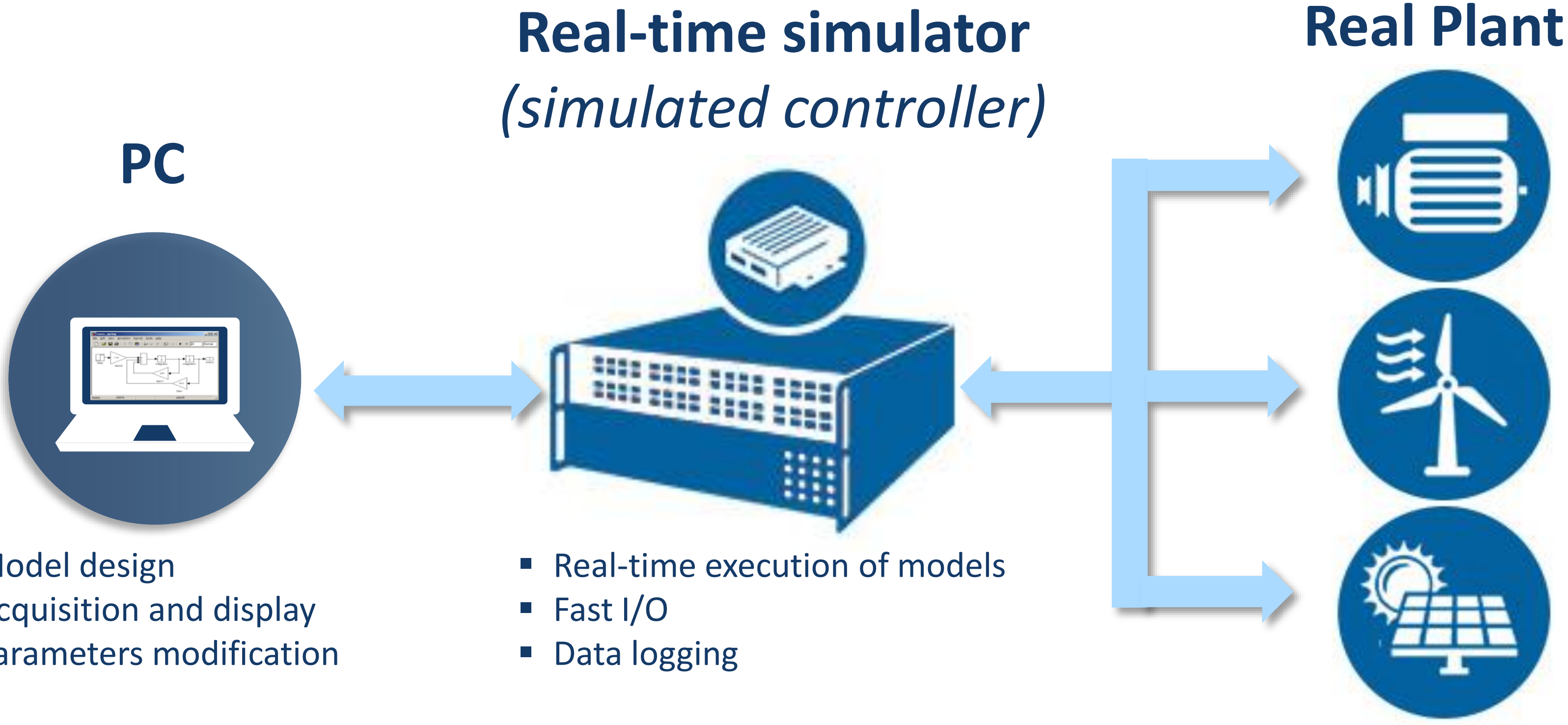


- Model design
- Acquisition and display
- Parameters modification

- Real-time execution of models
- Fast I/O
- Data logging

Rapid Control Prototyping

Test of the control algorithm
Detailed design of controller
Tuning of controller algorithm



- Model design
- Acquisition and display
- Parameters modification

- Real-time execution of models
- Fast I/O
- Data logging

Control Hardware-In-the-Loop

Test of the integrated controller
Safe conditions
Unlimited fault studies

Real-time simulator
(simulated plant)

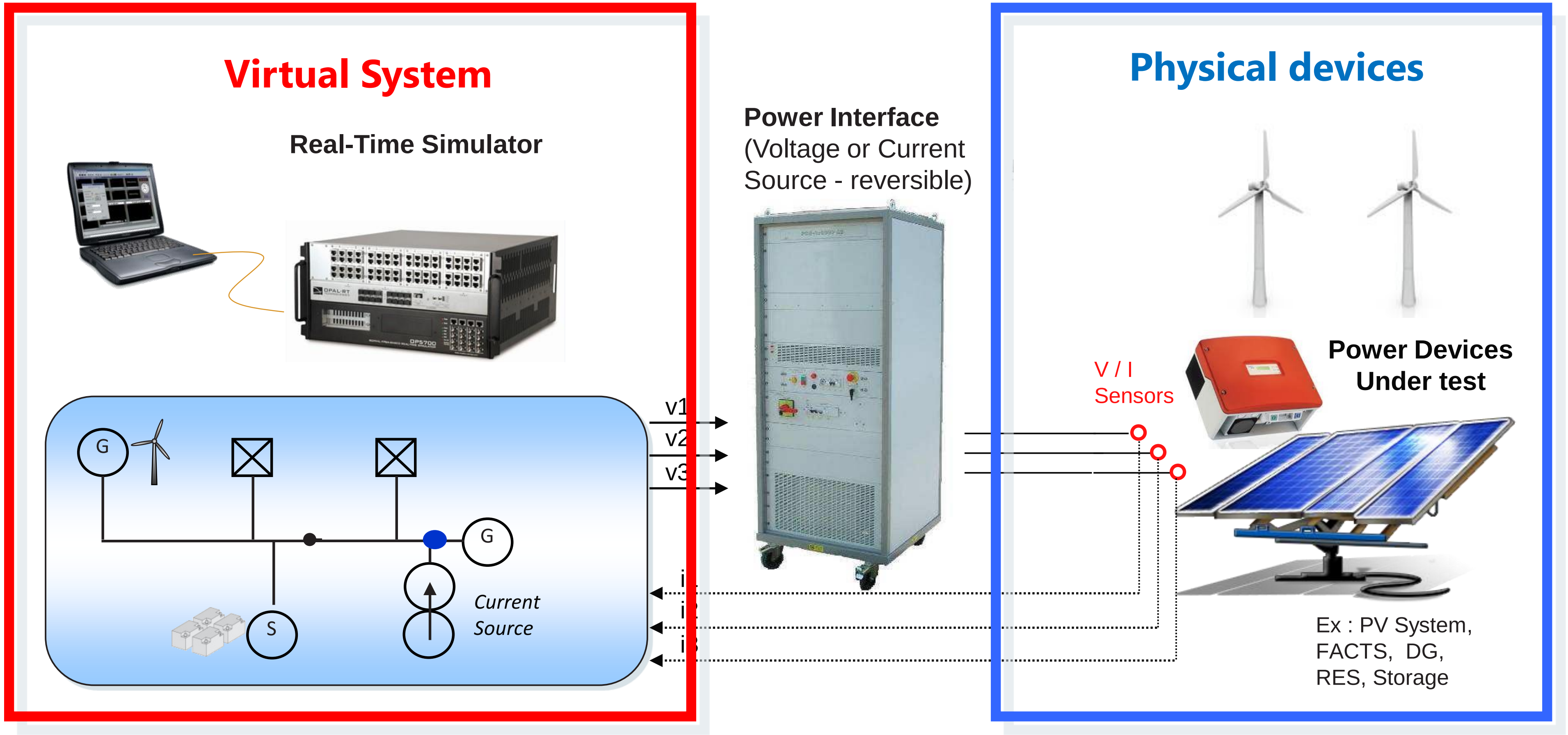
PC

Real Controller

- Model design
- Acquisition and display
- Parameters modification

- Real-time execution of models
- Fast I/O
- Data logging

Power Hardware in-the-loop



Outline

1. Company
2. Benefits of simulation
3. Model-based design
4. **Real-time concepts**
5. Hardware architecture
6. Software packages

Real-time concepts

What is **real-time** ?

- Give the good *result*
- At the right *time* !

A real-time system is not necessarily *very fast*

- Only ***fast enough***, depending on the application

Dynamic examples:

- Microseconds (10^{-6} s) for electromagnetic transients
- Milliseconds (10^{-3} s) for mechanical time responses
- Seconds for temperature control

Real-time concepts

Real-time:

- is required when real hardware is connected to the simulation
- ensures coherent time responses : determinism
- allows the simulation to lure the real hardware

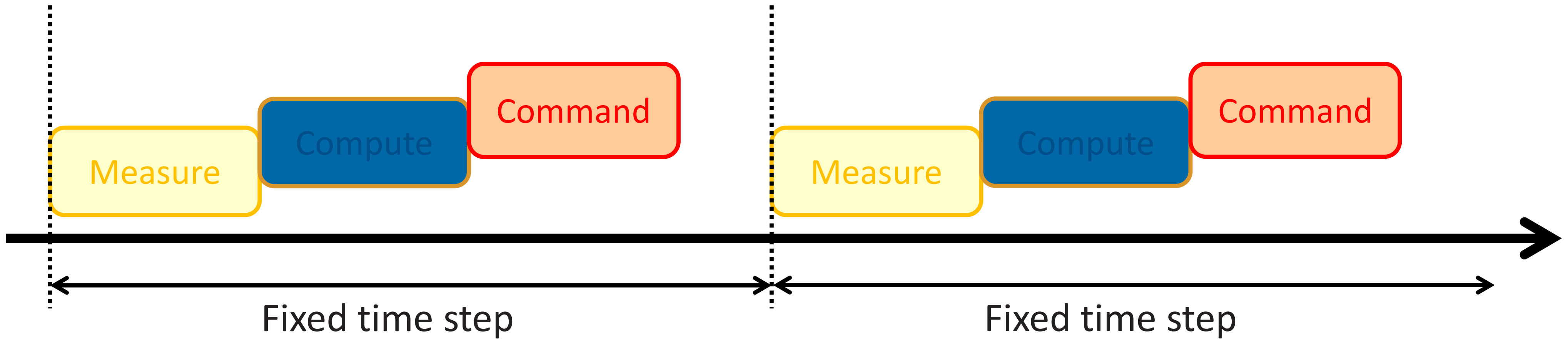
Real-time concepts

Controller

Controlled system

Real-time concepts

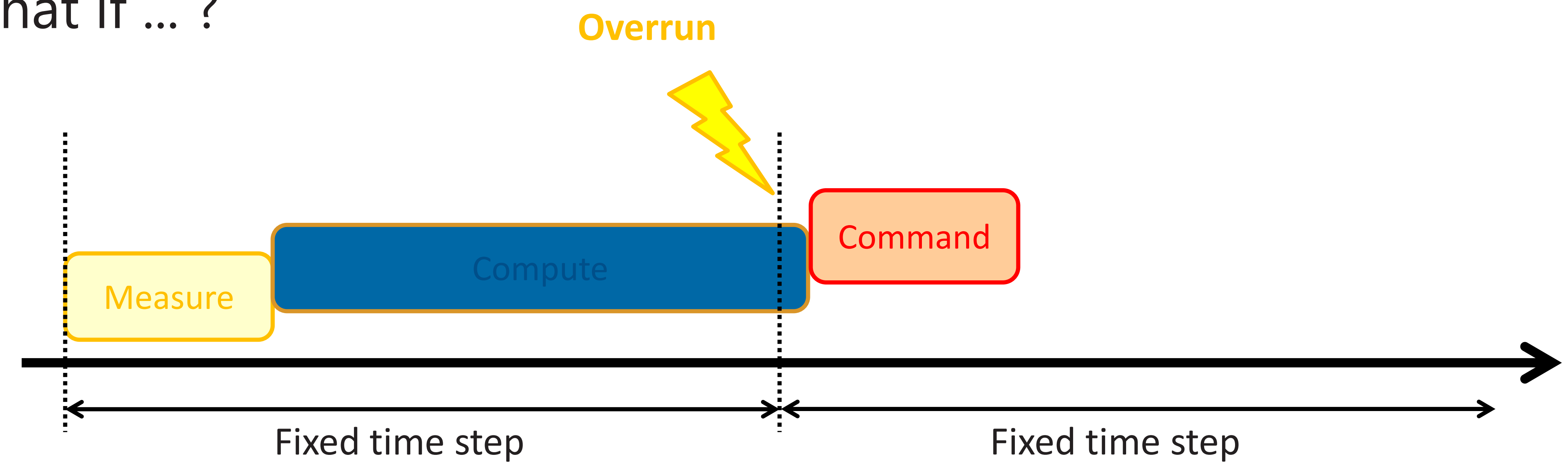
What is ***real-time simulation*** ?



The controller needs to take into account measurements, compute the control algorithm and generate commands within a fixed amount of time.

Real-time concepts

What if … ?



Too late… Real-time is not respected. The controlled system may not behave as expected.

Outline

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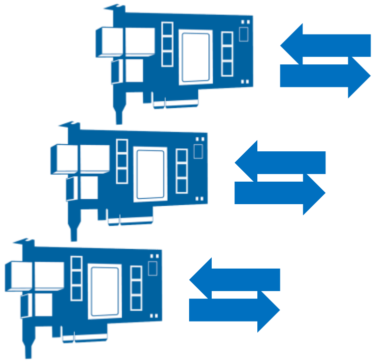
5. **Hardware architecture**
   - General architecture
   - Partial hardware list
   - Multiple-unit configuration
6. Software packages

General architecture

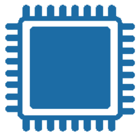
Host PC
Model edition
Simulation management
Graphical interface

RT Simulator
Model execution
Data logging
I/O management



FPGA & I/O boards
Interface with real devices

Ethernet
Link between host PC and simulator



Multiple-core CPU
Model computation

Partial hardware list

OP5600

Features

- Up to 4, 8, 16 or 32 INTEL® CPU cores
- Rack-mountable format 19” (4U)
- PCIe slots for connection with expansion units
- Support of communication boards *(IEC61850, C37.118, MODBUS, CAN…)*
- XILINX® FPGA with up to 8 I/O boards
- Designed for offline & real-time simulation

Partial hardware list

OP4510

Features

- 4 INTEL® CPU cores
- Compact format (2U)
- PCIe slots for connection with expansion units
- Optional SFP (optical fiber) connectors
- XILINX® FPGA Kintex 7 with 4 I/O boards

Partial hardware list

OP4200

Features

- Xilinx Zynq® (ARM® core + Kintex-7 FPGA)
- Compact format, portable device
- Communication: CAN, SFP, RJ45, JTAG, RS232
- 4 I/O boards (analog & digital channels)
- Connectors for I/Os: DB37, SMA, Screw, Fiber

I/O Boards

Analog outputs

- 16 channels
- [-16V; +16V]
- DAC: 16-bits, 1 Msps

Digital outputs

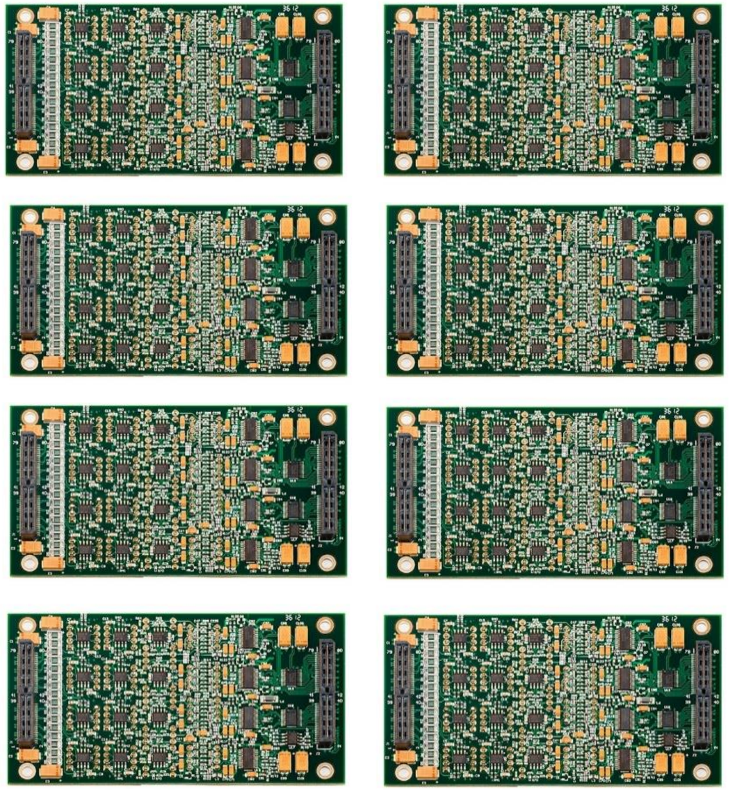
- 16 channels PWM
- 16 channels Static digital
- « ON »: 5 to 30 V

Analog inputs

- 16 channels
- [-20V; +20V]
- ADC: 16-bits, 2 Msps

Digital Inputs

- 16 channels PWM
- 16 channels Static digital
- « ON »: 4 to 50 V



Up to 8 boards per real-time computer

Third-party I/Os

Communication protocols

- IEC 61850: GOOSE & Sample Value modes
- IEC104
- DNP 3.0
- TCP/IP Ethernet
- RS232 & RS485
- CAN
- Modbus

Third-party hardware

- High Voltage Interfaces
- Synchronization with GPS (1PPS, IEEE1588, IRIG-B)

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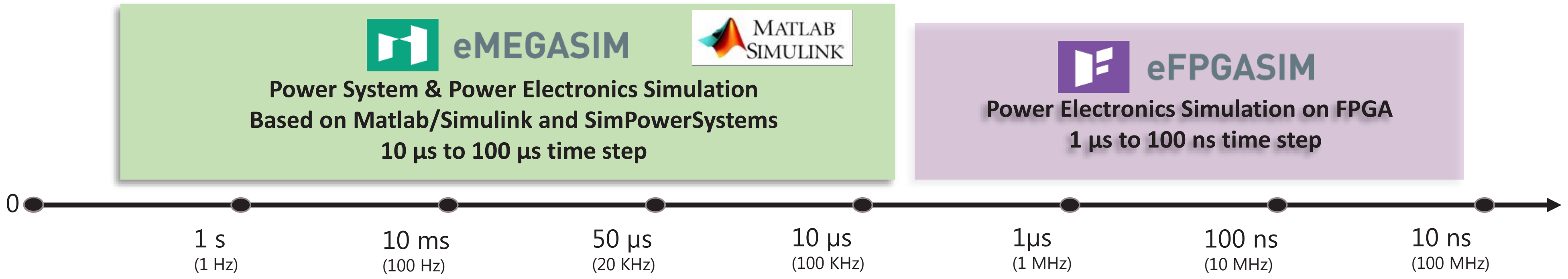
6. **Software packages**
   - Overview
   - eMEGASIM
   - eFPGASIM

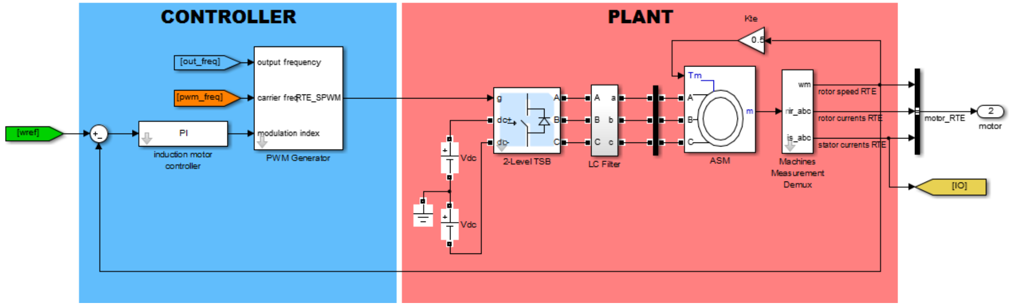
Overview

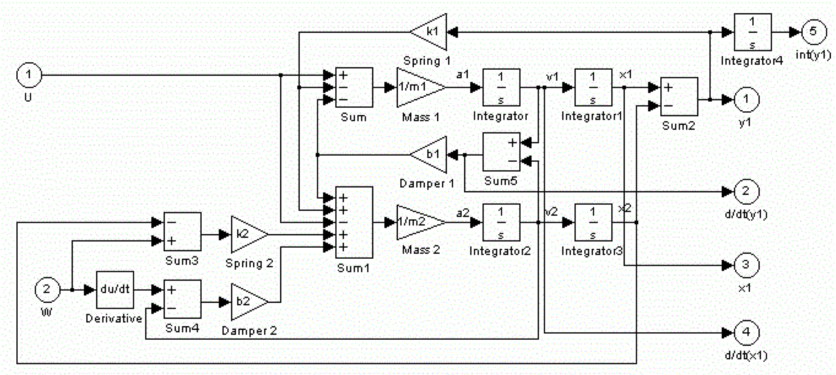


Period (frequency) of the simulated transient phenomena

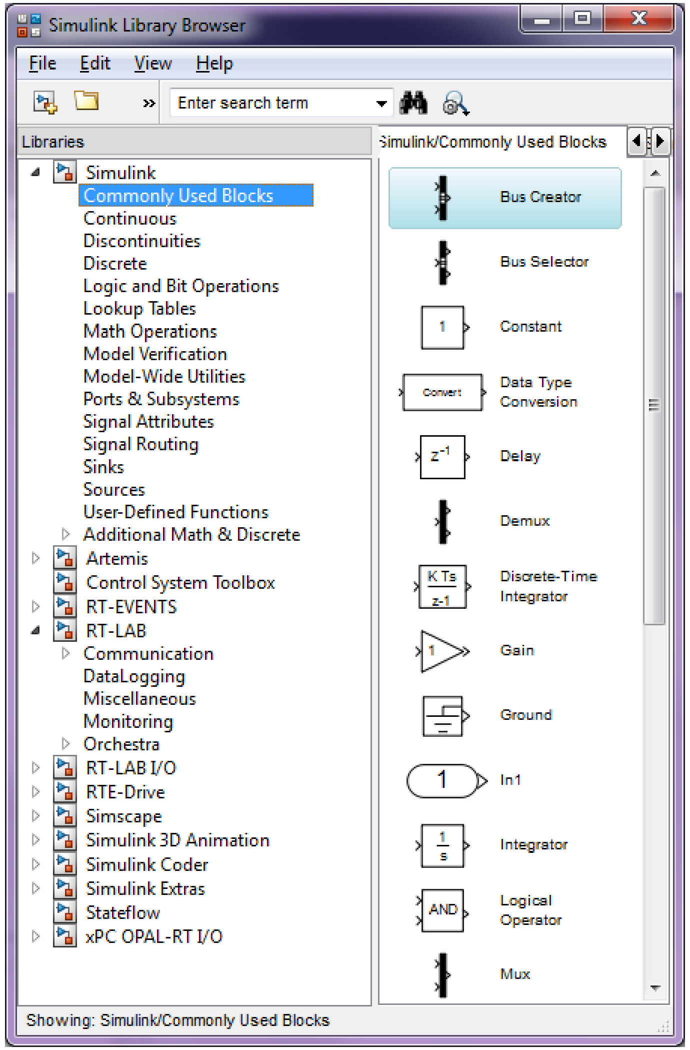
eMEGASIM

- Fully integrated with Simulink®/SimPowerSystems®/SimScape®
  - Power systems models
  - Power electronics models
  - Physical models (mechanical, hydraulic…)
  - Control algorithms
- Real-Time Electromagnetic Transient Simulation
- Around 120 nodes per CPU core at 50 µs
- Data logging, Visualizations & Fault Analysis

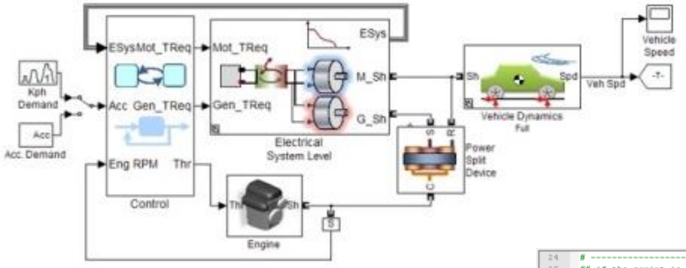




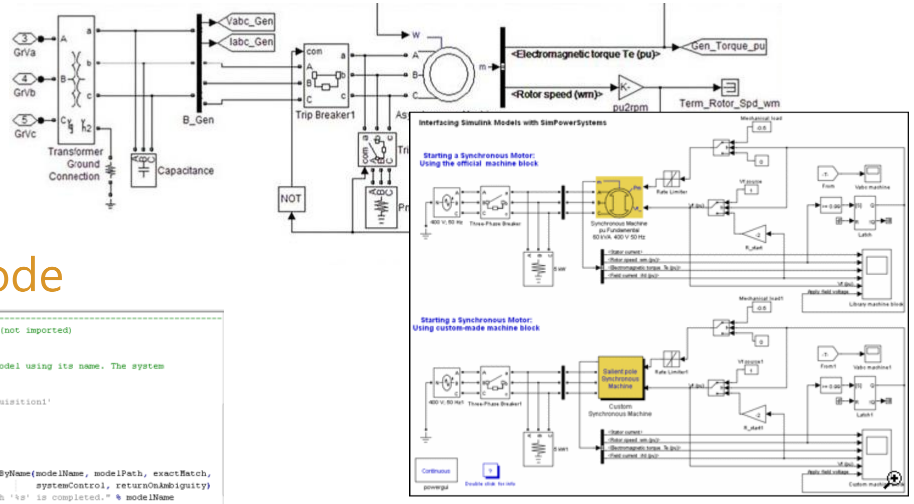
eMEGASIM



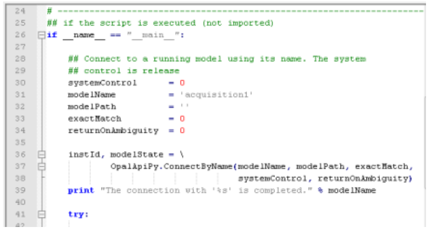
Physical models



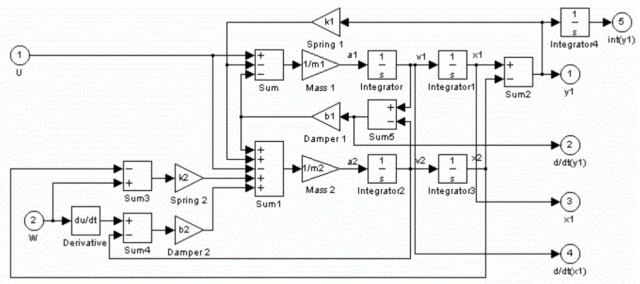
Electrical systems



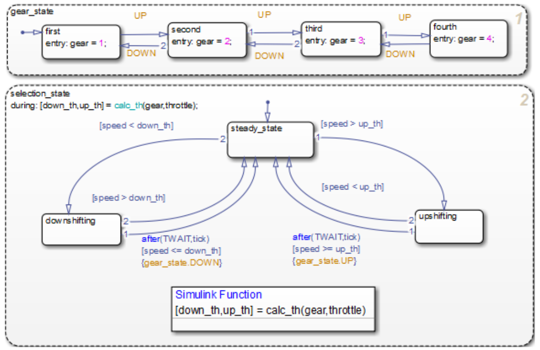
Code



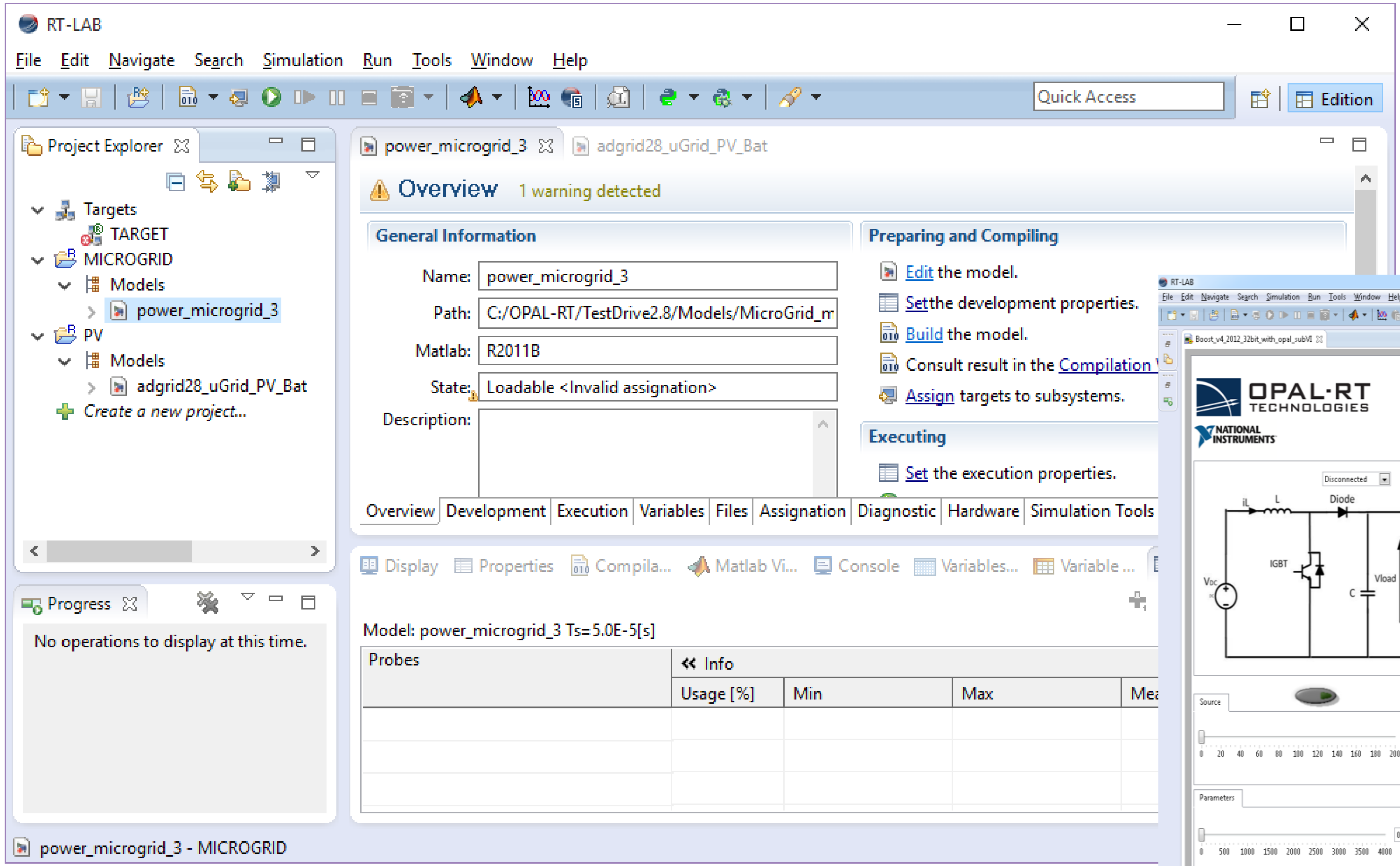
Algorithms

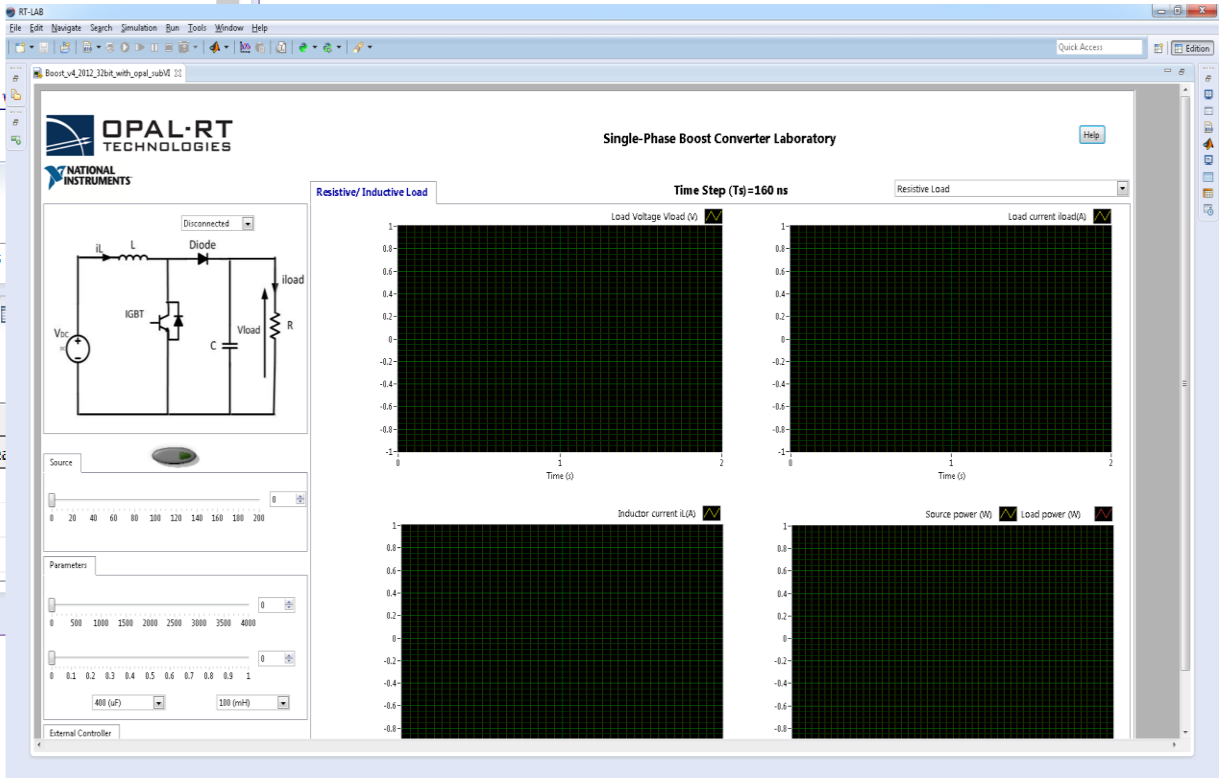


State diagrams



eMEGASIM


RT-LAB
File Edit Navigate Search Simulation Run Tools Window Help
Quick Access
Edition
Project Explorer
Targets
TARGET
MICROGRID
Models
power_microgrid_3
PV
Models
adgrid28_uGrid_PV_Bat
Create a new project...
power_microgrid_3
adgrid28_uGrid_PV_Bat
Overview
1 warning detected
General Information
Name: power_microgrid_3
Path: C:/OPAL-RT/TestDrive2.8/Models/MicroGrid_m
Matlab: R2011B
State: Loadable <Invalid assignation>
Description:
Preparing and Compiling
Edit the model.
Set the development properties.
Build the model.
Consult result in the Compilation
Assign targets to subsystems.
Executing
Set the execution properties.
Overview Development Execution Variables Files Assignation Diagnostic Hardware Simulation Tools
Progress
No operations to display at this time.
Display Properties Compila... Matlab Vi... Console Variables... Variable ...
Model: power_microgrid_3 Ts=5.0E-5[s]
Probes
Info
Usage [%] Min Max Mea
power_microgrid_3 - MICROGRID


OPAL-RT TECHNOLOGIES
NATIONAL INSTRUMENTS
Single-Phase Boost Converter Laboratory
Help
Resistive/ Inductive Load
Time Step (Ts)=160 ns
Resistive Load
Disconnected
Diode
IGBT
iload
Vload
R
C
L
Source
Parameters
Load Voltage Vload (V)
Load current iload(A)
Inductor current iL(A)
Source power (W)
Load power (W)
Time (s)
External Controller

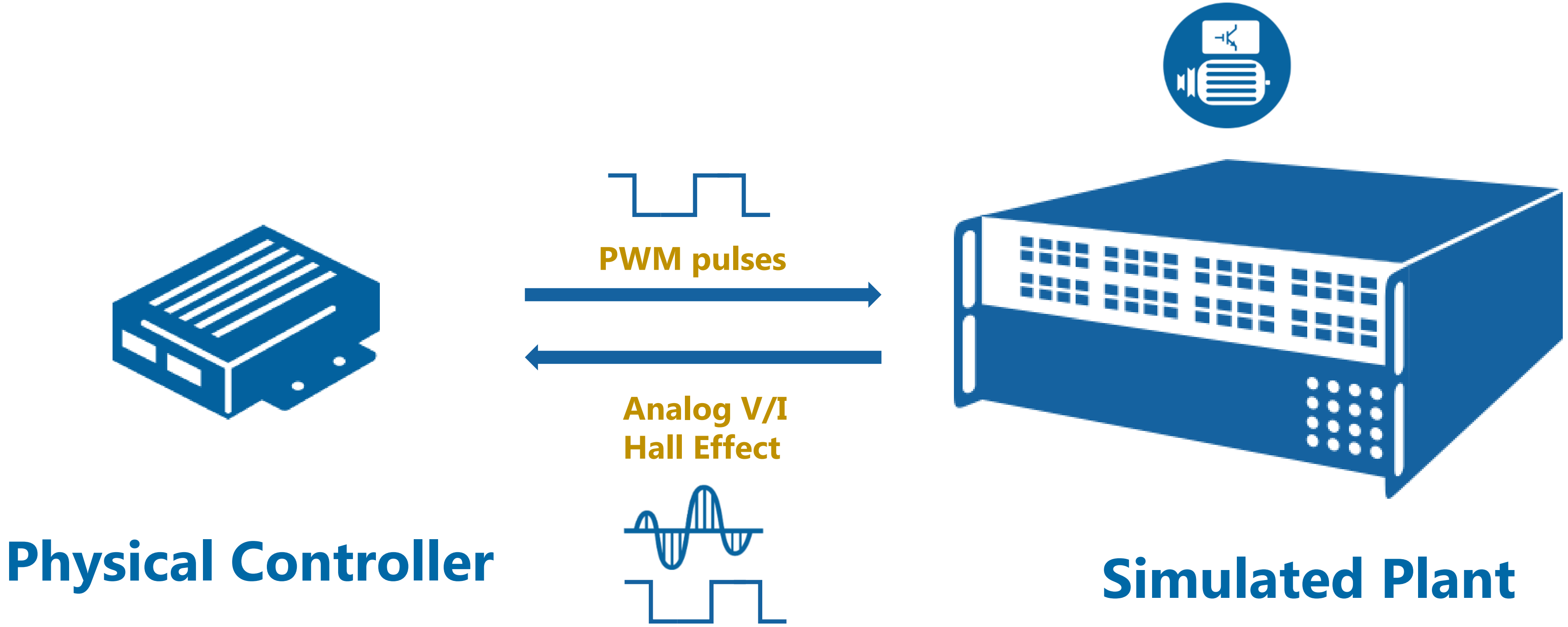
eFPGASIM

- HIL : a real controller is connected to the simulated plant (electrical circuit). Simulation has to be as fast as possible.

eDRIVEsim™ Simulator

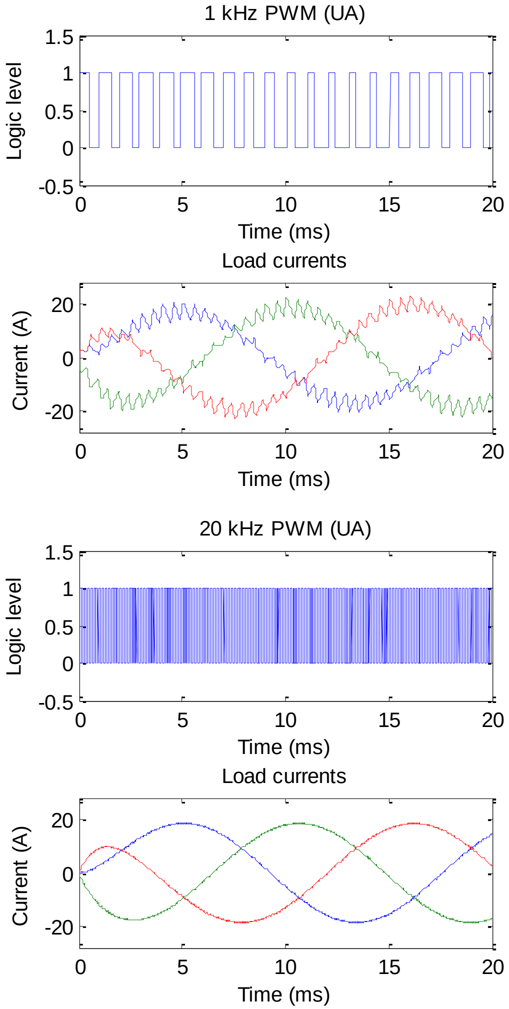
eFPGASIM

- HIL : a real controller is connected to the simulated plant (electrical circuit). Simulation has to be as fast as possible.



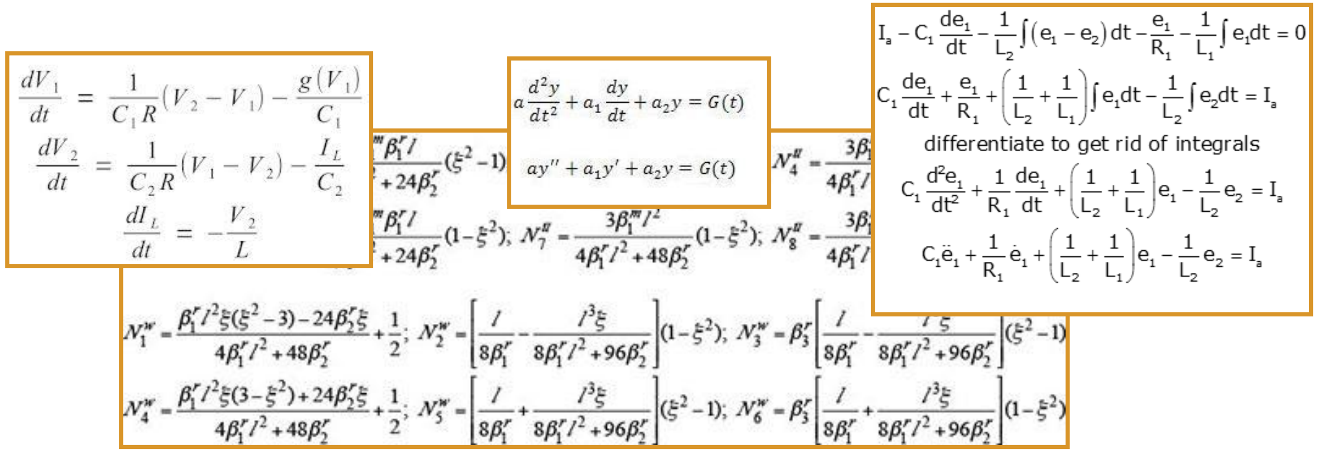
eFPGASIM

- High switching frequencies (10 to 100 kHz)
- Benefits of higher switching frequencies : higher power density, lower THD
- But : very challenging for real-time simulators, which must achieve time steps below 1 µs



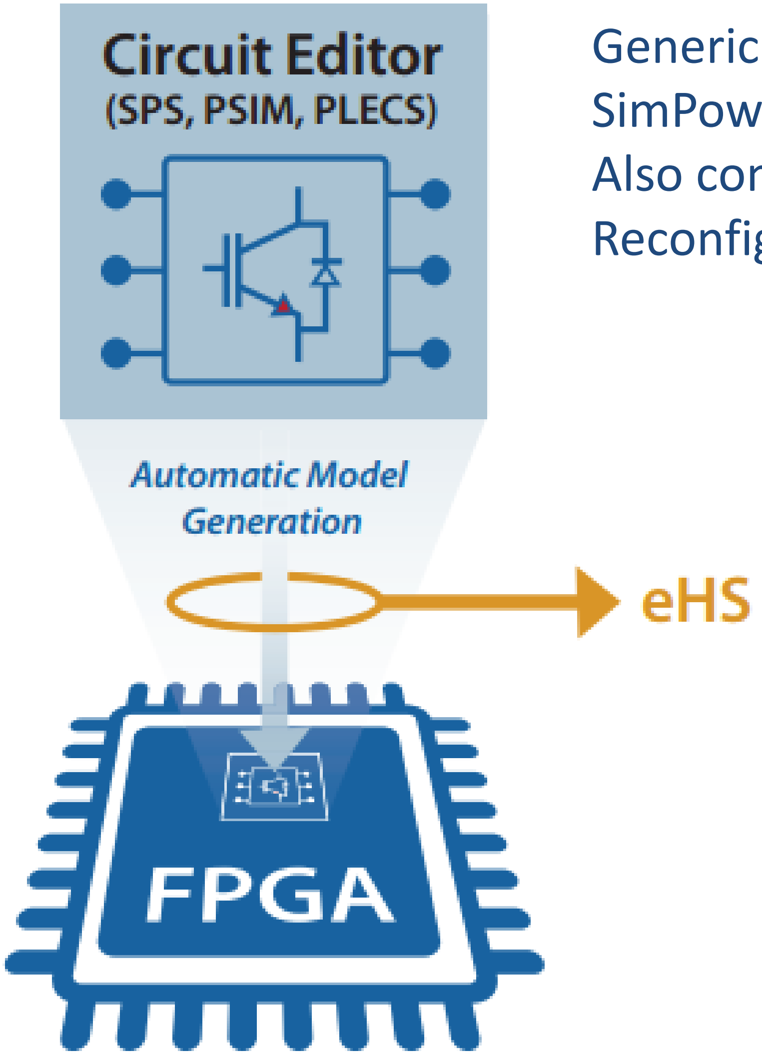
eFPGASIM

- To meet timing requirements, FPGA-based real-time simulation is an effective solution
- But : implementing and solving differential equations on FPGA is tricky and requires advanced FPGA programming skills



eFPGASIM

Generic Power Converter solver on FPGA
SimPowerSystems model editor interface
Also compatible with PLECS and PSIM
Reconfigurable from Host PC without reprogramming the FPGA



Automatic generation of electric circuit model:

- No mathematical modeling
- No FPGA expertise
- No VHDL programming
- No need for Xilinx Blockset or other Xilinx FPGA tools

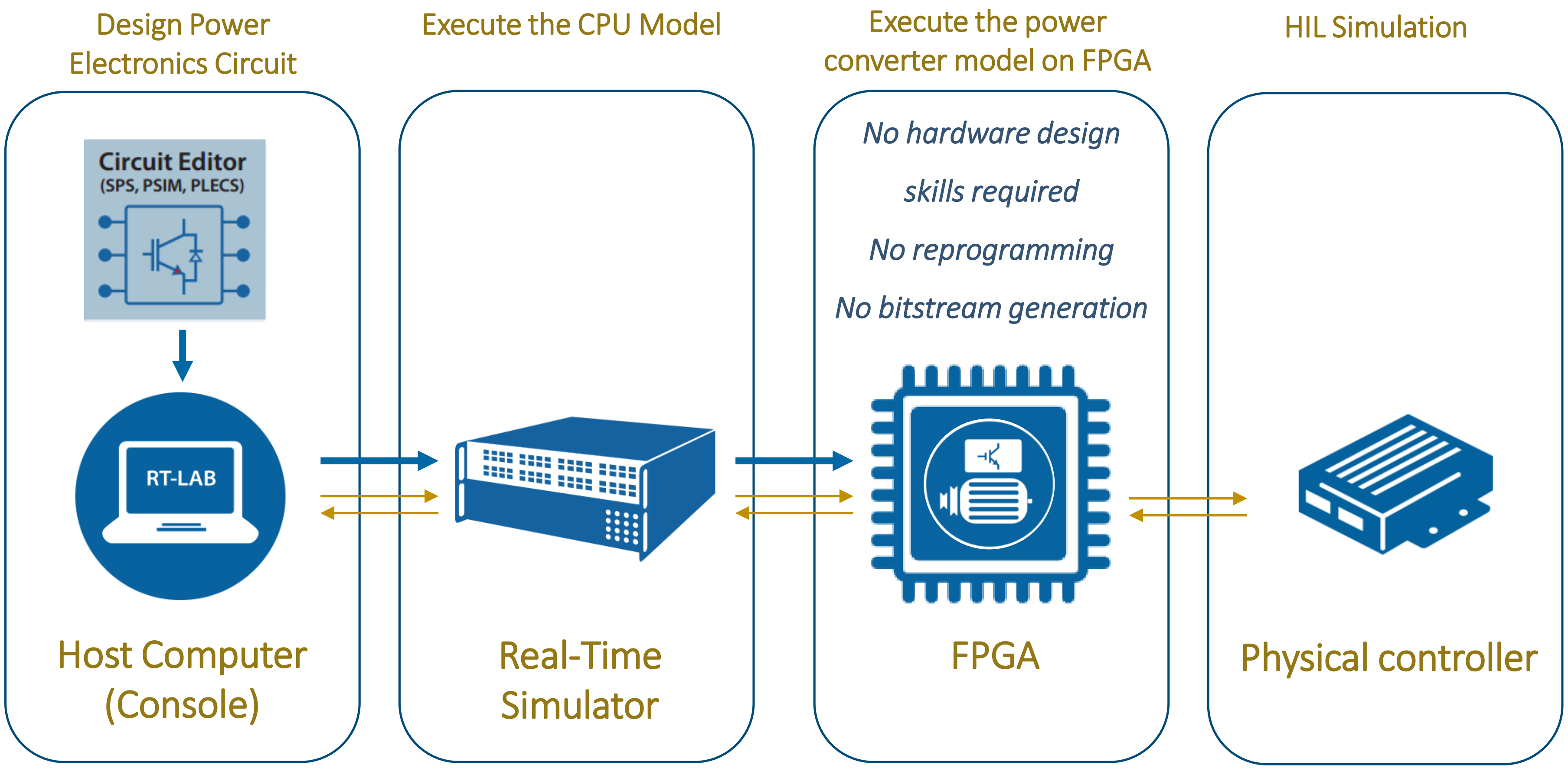
eFPGASIM

Benefits for your projects

- Time saving: Your model is directly executed from RT-LAB to OPAL-RT chassis FPGA board
- Easy to use: No FPGA expertise nor VHDL programming required
- High power computation with power converters models up to 72 switches and model time step below 1us

Characteristic	**3rd Gen**
Max. number of inputs (sources)	32
Max. number of outputs (measurements)	32
Max. number of switches	72 *(more to come !)*
Max. number of LC	150
Max. number of R	Unlimited
LCA capability	Yes
Computing power	24 GFLOPS
Scenario support	Up to 1024

eFPGASIM



Design Power Electronics Circuit
Execute the CPU Model
Execute the power converter model on FPGA
HIL Simulation
Circuit Editor
(SPS, PSIM, PLECS)
RT-LAB
No hardware design skills required
No reprogramming
No bitstream generation
Host Computer (Console)
Real-Time Simulator
FPGA
Physical controller

Questions

Questions ?