IEEE COMPEL 2013
The 14th IEEE Workshop on Control and Modeling for Power Electronics (COMPEL)

IEEE Advancing Technology for Humanity

OPAL-RT

From Imagination to Real-Time

Real-Time Simulation of Renewable Energy Systems Using RT-LAB

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Introduction

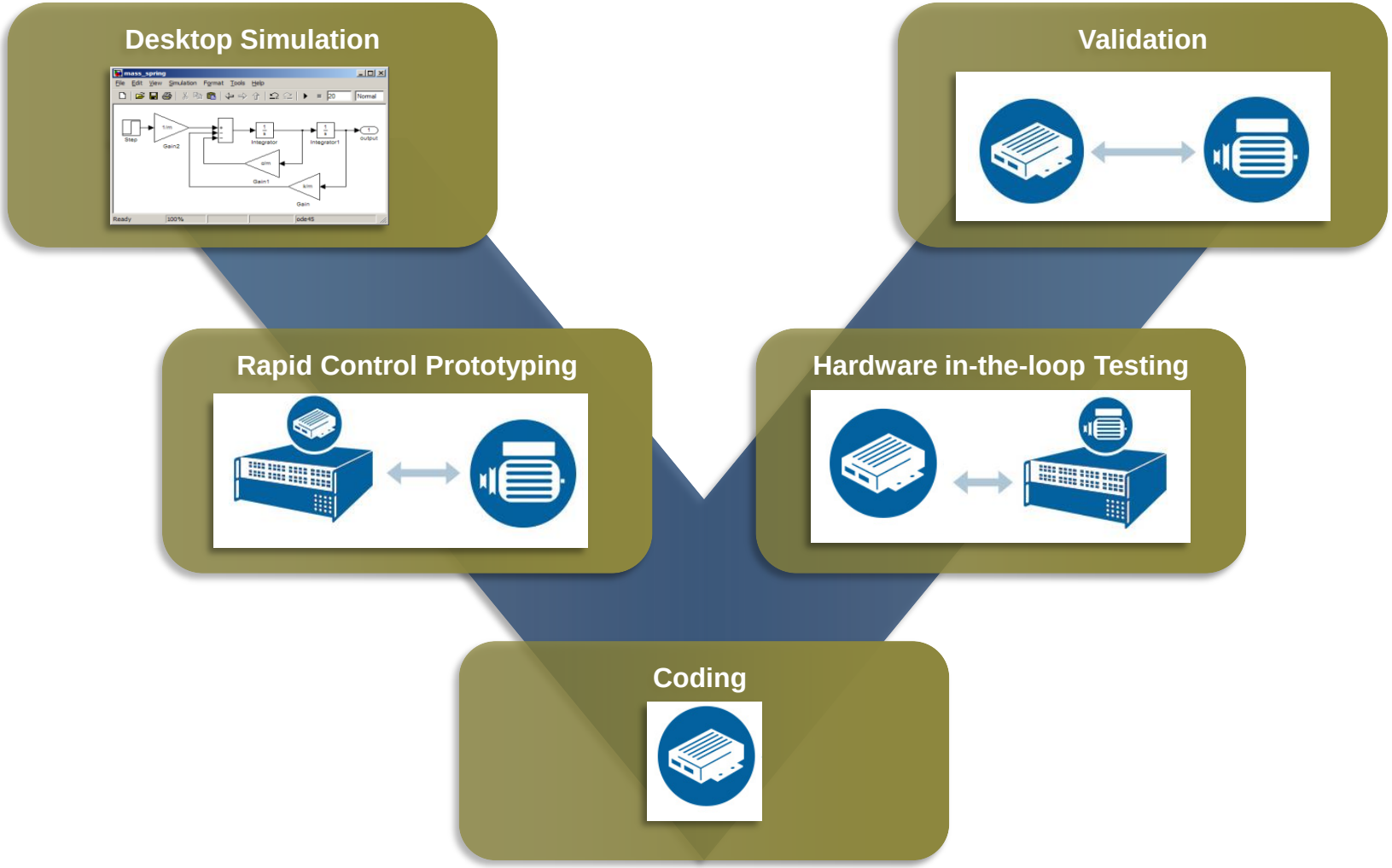
- **When we think about environment and energy, we think:**
  - Electric Vehicle
  - Hydro Power
  - Wind Power
  - Photovoltaic Power
  - Renewable Energies

- **Power Engineers think about:**
  - How to control
  - How to bring this technology quickly to market
  - How to distribute power
  - How to interconnect

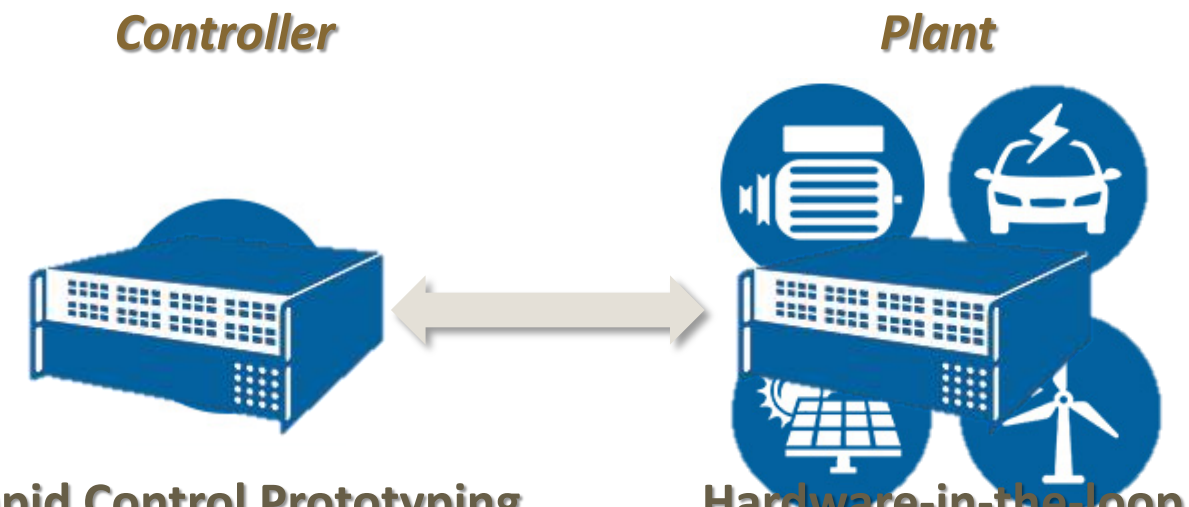
Outline

- Context
- Modelling Challenges for Renewable Energy Systems
- Solution
- Specialized models
- Summary

Context : Real-Time Simulation Helps in Development Process



Context : Controlled System, and Real-Time Simulation

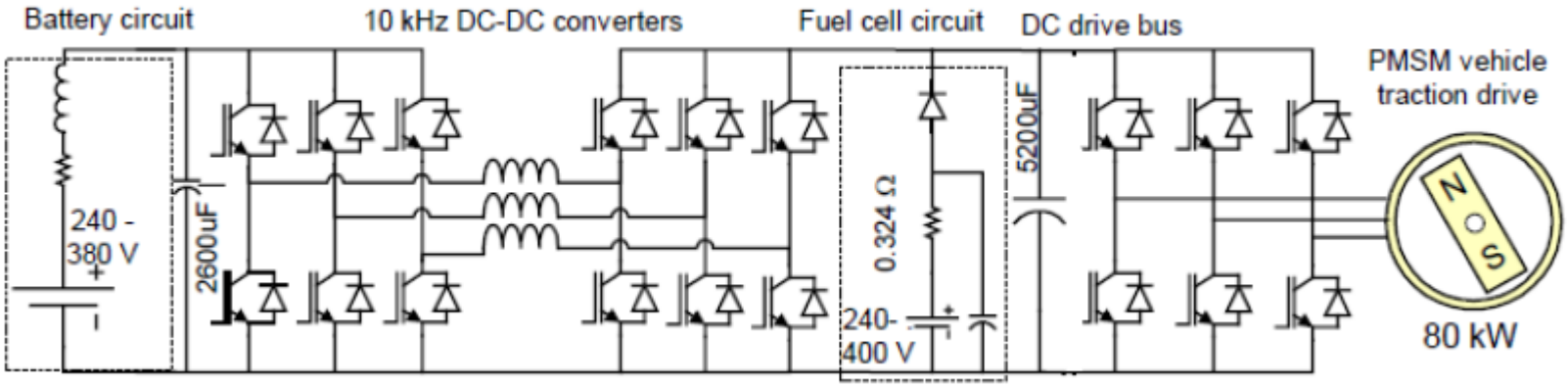


Renewable Energy Systems

- **Electric Drive for Hybrid Electric Vehicle and Electric Vehicle**
- **Modular Multilevel Converter (MMC) for HVDC Connection**
- **Wind farms, Photovoltaic Systems to Grid Connection**

Challenges for Electric Drive

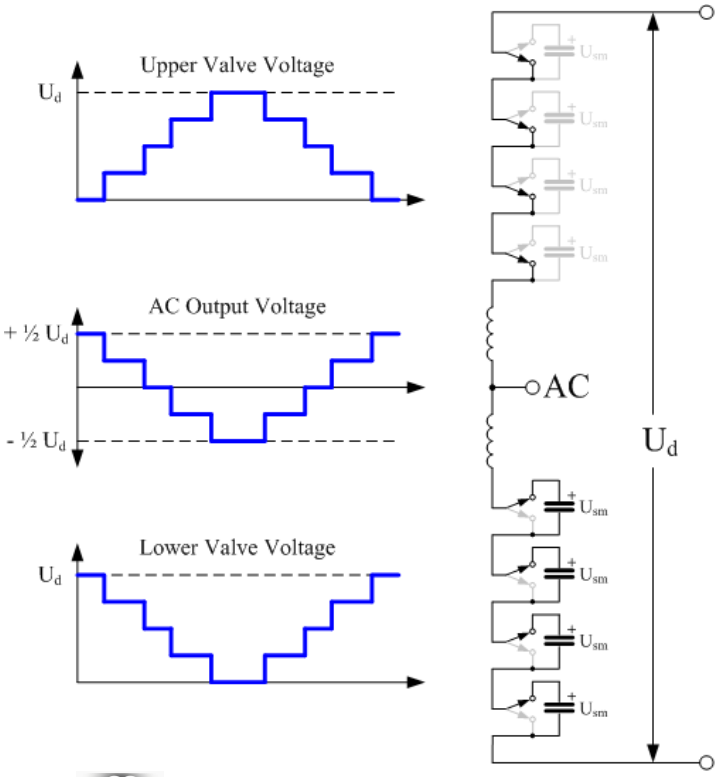
- **Example figure : PMSM motor for electric vehicle model**



- **Reduce latency**
  - Protection – Fast response needed
  - High speed – Fast rotating machine
  - Precision – Position of the rotor

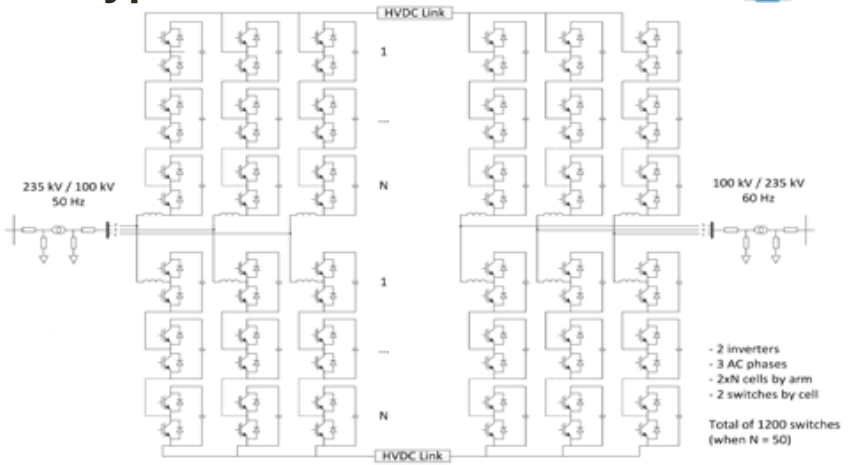
Challenges for Modular Multilevel Converter

- **Large number of Inputs/Outputs managements**

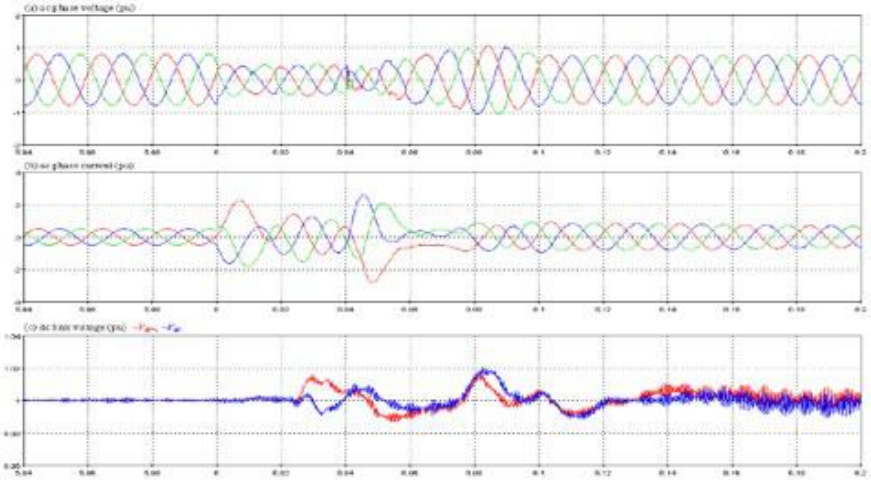


 Wikipedia

- **Typical MMC HVDC circuit**

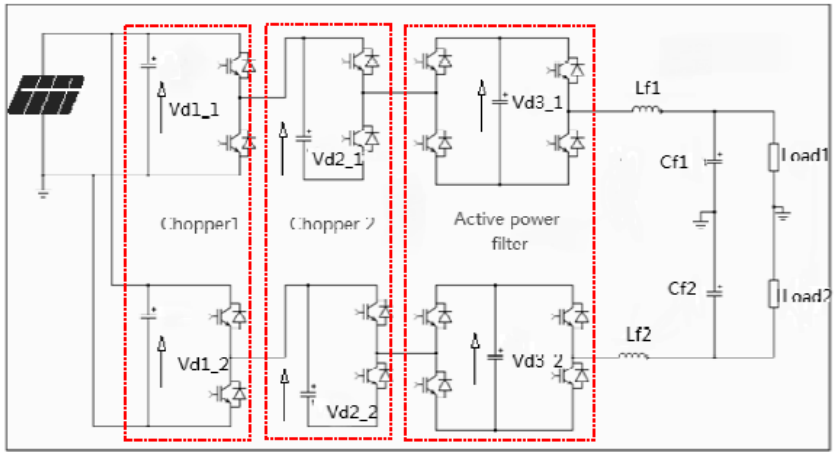


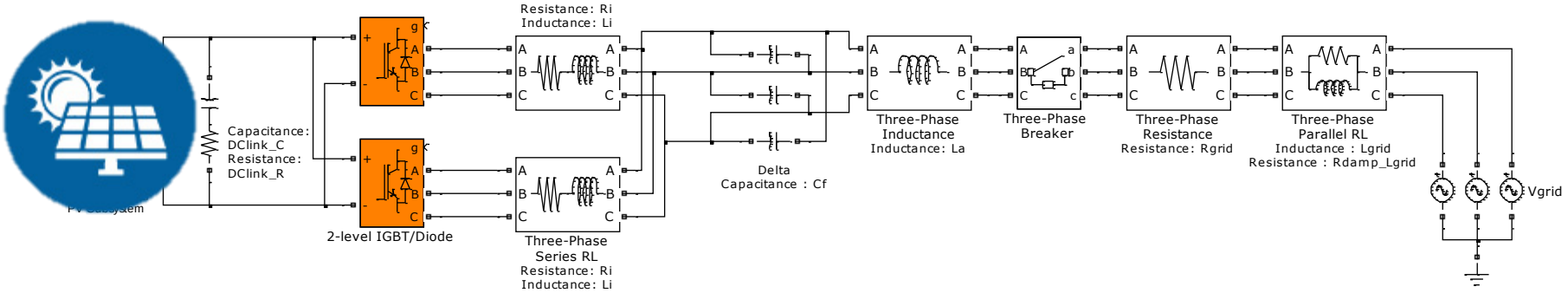
- **MMC response to a short circuit fault at transformer primary side**



Challenges for Micro-Grid

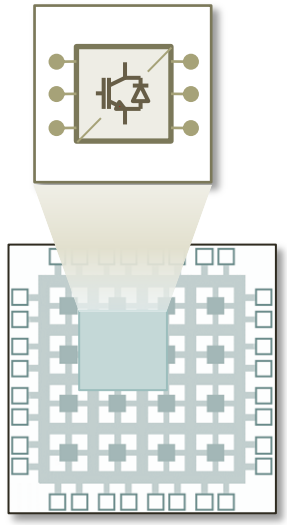
- **Numerous converters**
- **Fast switching**
- **Short Transmission Lines**





Solution : FPGA-based simulation

- **Low Latency**
- **High resolution – Small Time Steps**
- **Non-averaged model**
- **Fault capabilities**
- **Transient analysis**
- **Higher Harmonics effect**



FPGA-based Simulation with eHS

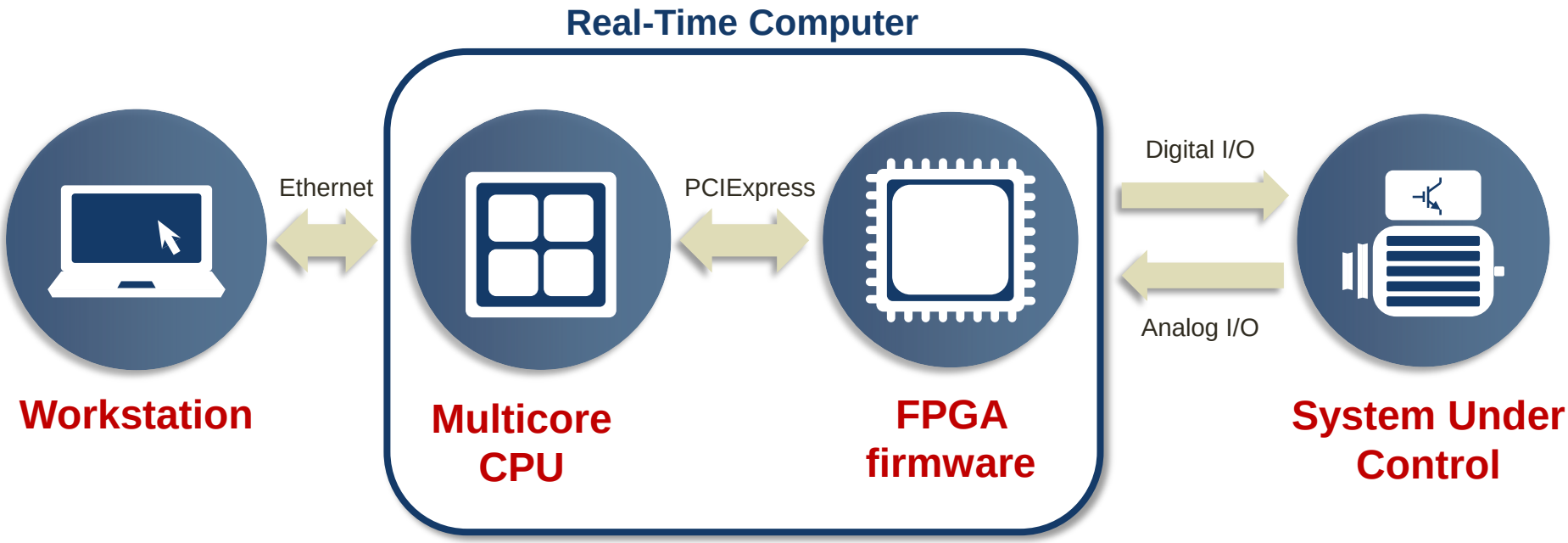
Difficulties

- **FPGA are more difficult to program Modeling via Block Diagram**
- **Generating bitstream is long (typical: 120 min +)**
- **Flashing FPGA firmware is long ~15 mins**

Want

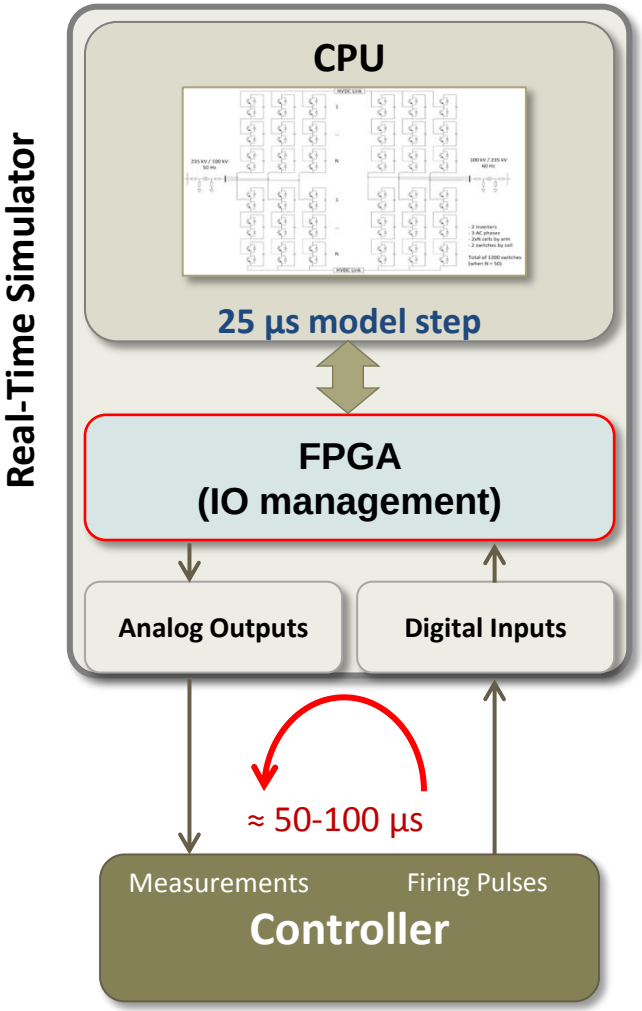
- **Easier to program**
- **Flexibility**
- **Save bitstream generation time**
- **Save reprogramming time**

Fast and versatile architecture

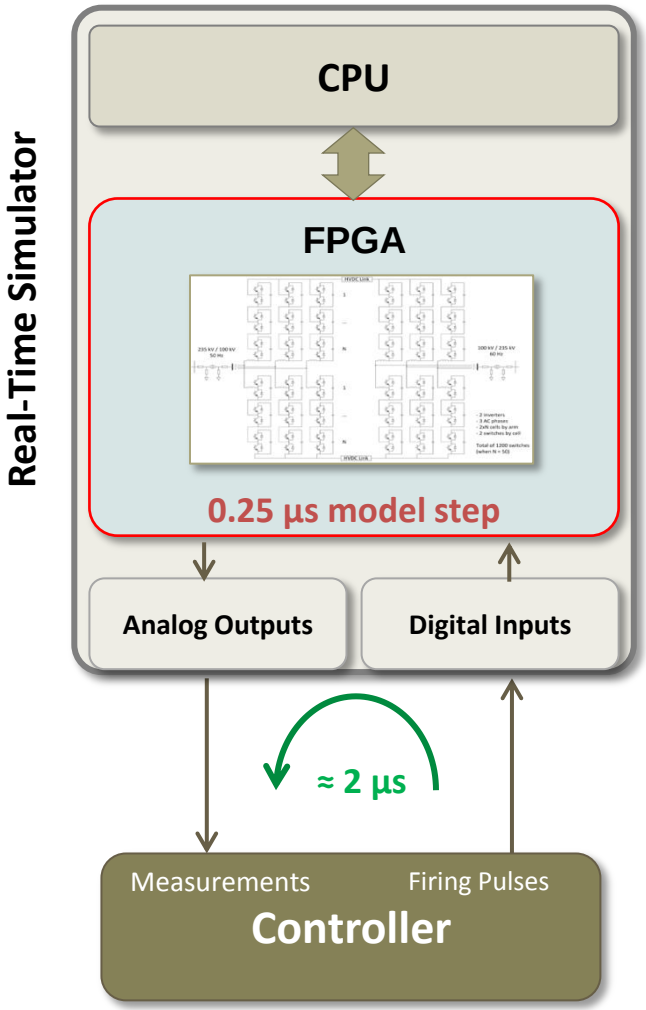


CPU and FPGA-based Simulation Platform

CPU-Based Simulation

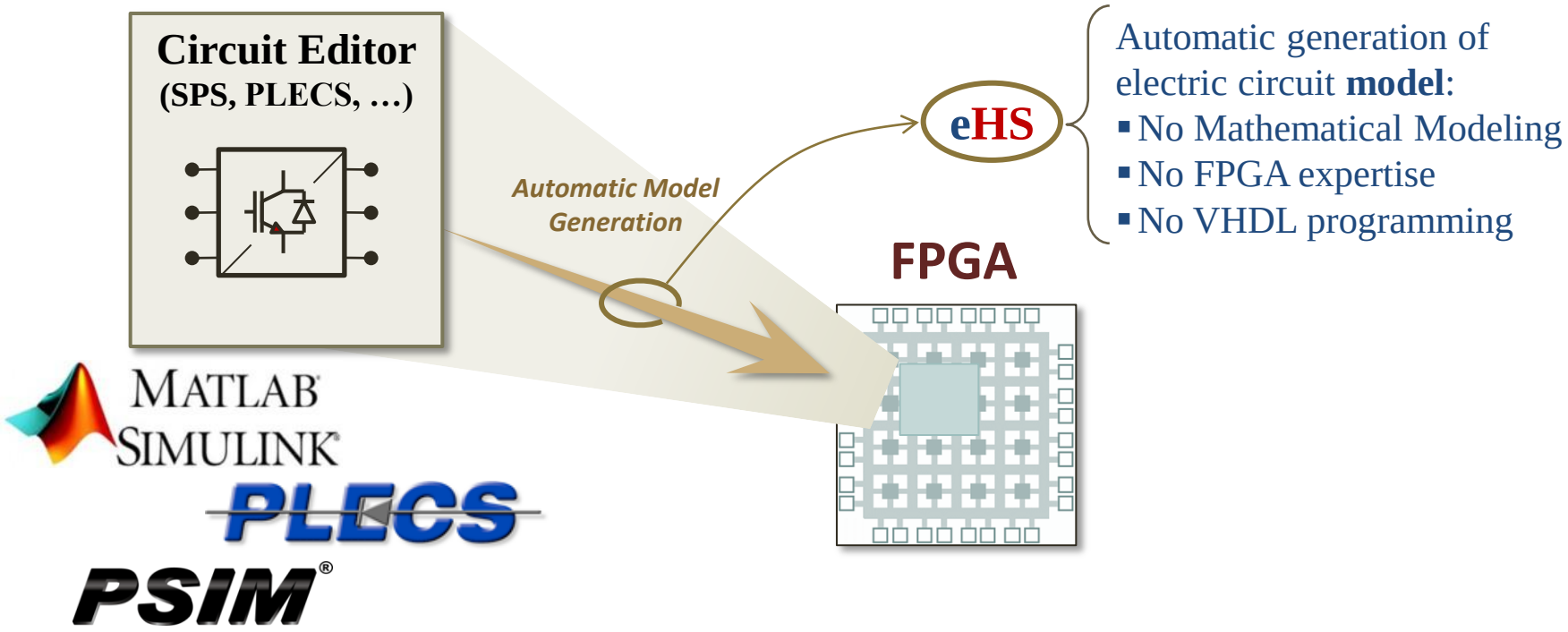


FPGA-Based Simulation



eHS Key Features

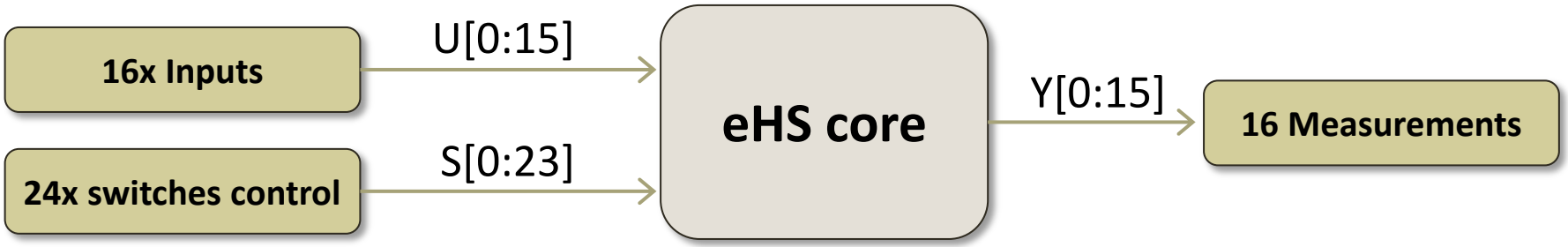
- **eHS (electrical Hardware Simulation) solver**
  - Generic Power Converter solver on FPGA
  - SPS model editor interface (Soon with PLECS, PSIM and EMTP-RV)
  - Reconfigurable from Host PC without reprogramming the FPGA
  - Simulation in off-line mode with eHS nodal solver within Simulink



eHS Nodal Solver

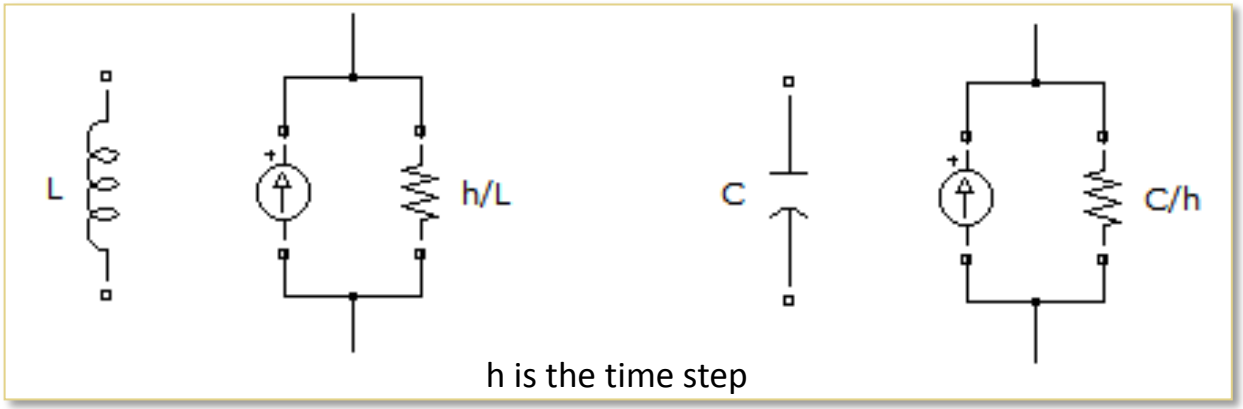
- **eHS uses the modified nodal analysis approach**
  - It solves a admittance matrix to find the voltage at each node and the current from each sources.
  - The admittance matrix does not need to be re-computed for each switch status
  - Simulated model topology and parameters can be modified without recompiling the bitstream
- **The maximum size of the circuit is determined by the number of inputs, switches and reactive components**

- **Currently, the maximum number of components is :**
  - 16 inputs (voltage/current sources)
  - 16 outputs (voltage/current measurements)
  - 24 switches (IGBTs, breakers, etc)
  - 60 non-switching devices (ie. L and C) – unlimited resistors



Switch Model in eHS

- **eHS method replaces switches by:**
  - either a very small inductance when conducting
  - or a very small capacitor when not conducting



- **This method is called the fix-Y because the admittance matrix does not change when a switch changes state.**

Switch Model in eHS

- **For the matrix to remain the same upon switching event, the following equation must remains true**

$$Gs = {}^{h}/_{L} = {}^{C}/_{h} \qquad \text{where } h \text{ is the time step}$$

- **When building the nodal matrix a value between 10 and 0.001 has to be set to represent a switch. This determines the value of the inductor and the capacitor representing the switch.**

$$L = {}^{h}/_{Gs} \qquad C = h \times Gs$$

- **For example, a time step 100ns and a Gs=1, the switch will be represented by the following inductance when conducting or the following capacitance when non-conducting.**

$$L = {}^{h}/_{Gs} = {}^{100ns}/_{1} = 100nH \qquad C = h \times Gs = 100ns \times 1 = 100nF$$

- **Ideally, we need a very small inductor and a very small capacitor to represent a ideal switch. Depending of the circuit topology, the best result is obtained by optimizing the value of Gs and compare results with conventional off-line software.**

FPGA-based Simulation with eHS

Difficulties

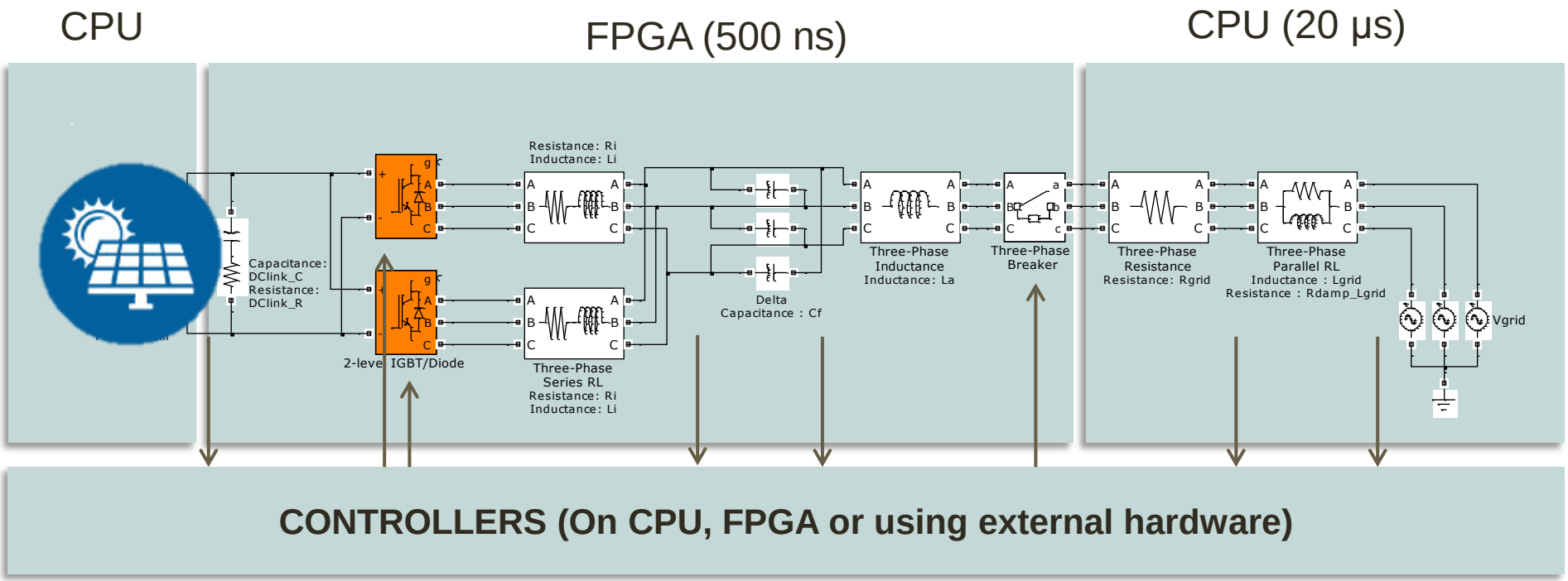
- **FPGA are more difficult to program**
  Modeling via Block Diagram
- **Generating bitstream is long**
  (typical: 120 min +)
- **Flashing FPGA firmware is long**
  ~15 mins
-

Want

- **Easier to program**
- **Flexibility,**
  freedom to change circuit topology
- **Save bitstream generation time**
- **Save reflashing time**
- **On-line modification of circuit parameters**
- **On-line modification of circuit topology**

Real-Time eHS Simulation Examples

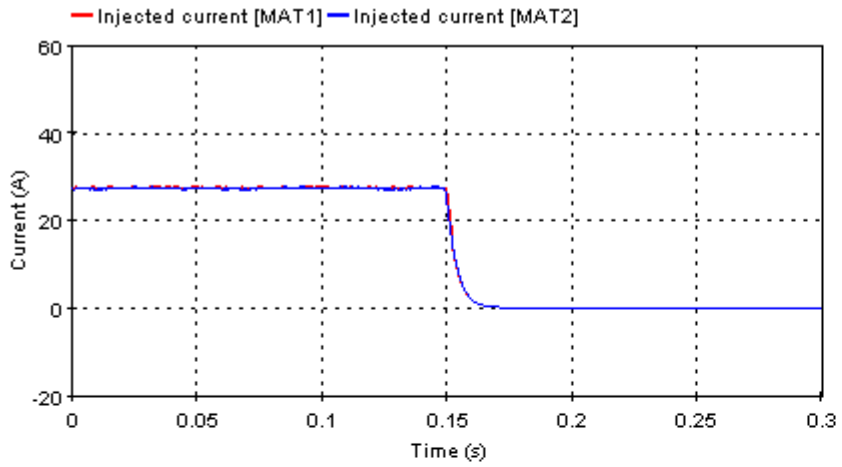
- **eHS model : PV connected to grid.**

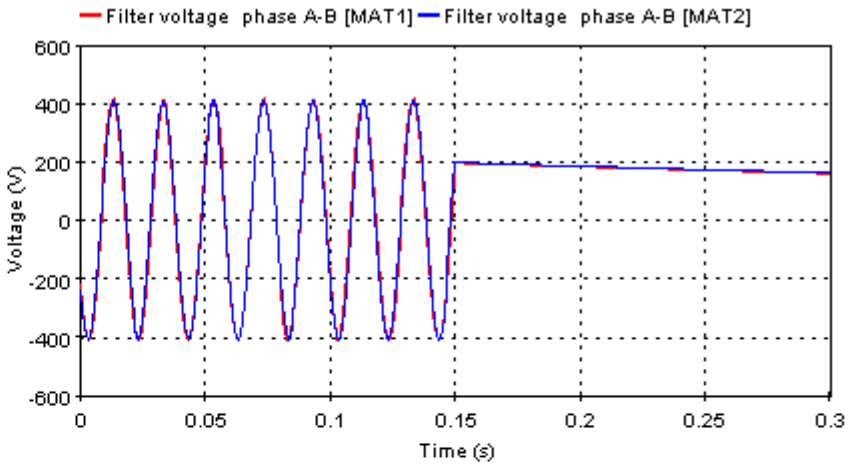


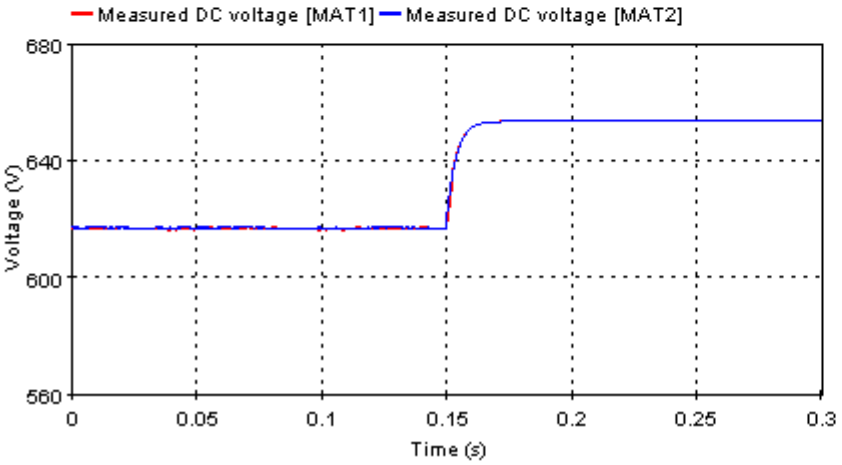
- **Time Step = 500ns**
- **4 sources inputs (1 DC from PV, 3 phases AC from Grid)**
- **16 voltage and current measurements,**
- **15 switches (2x 2level inverters & 3phase breaker)**

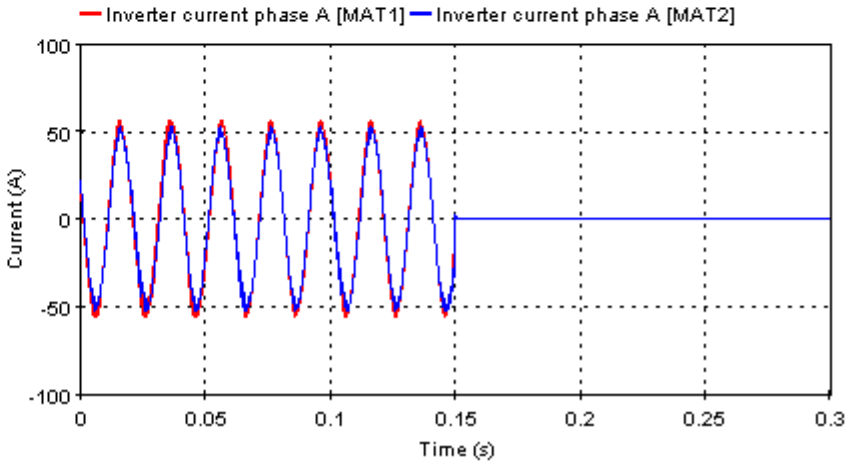
Real-Time eHS Simulation

- **Results for PV model**



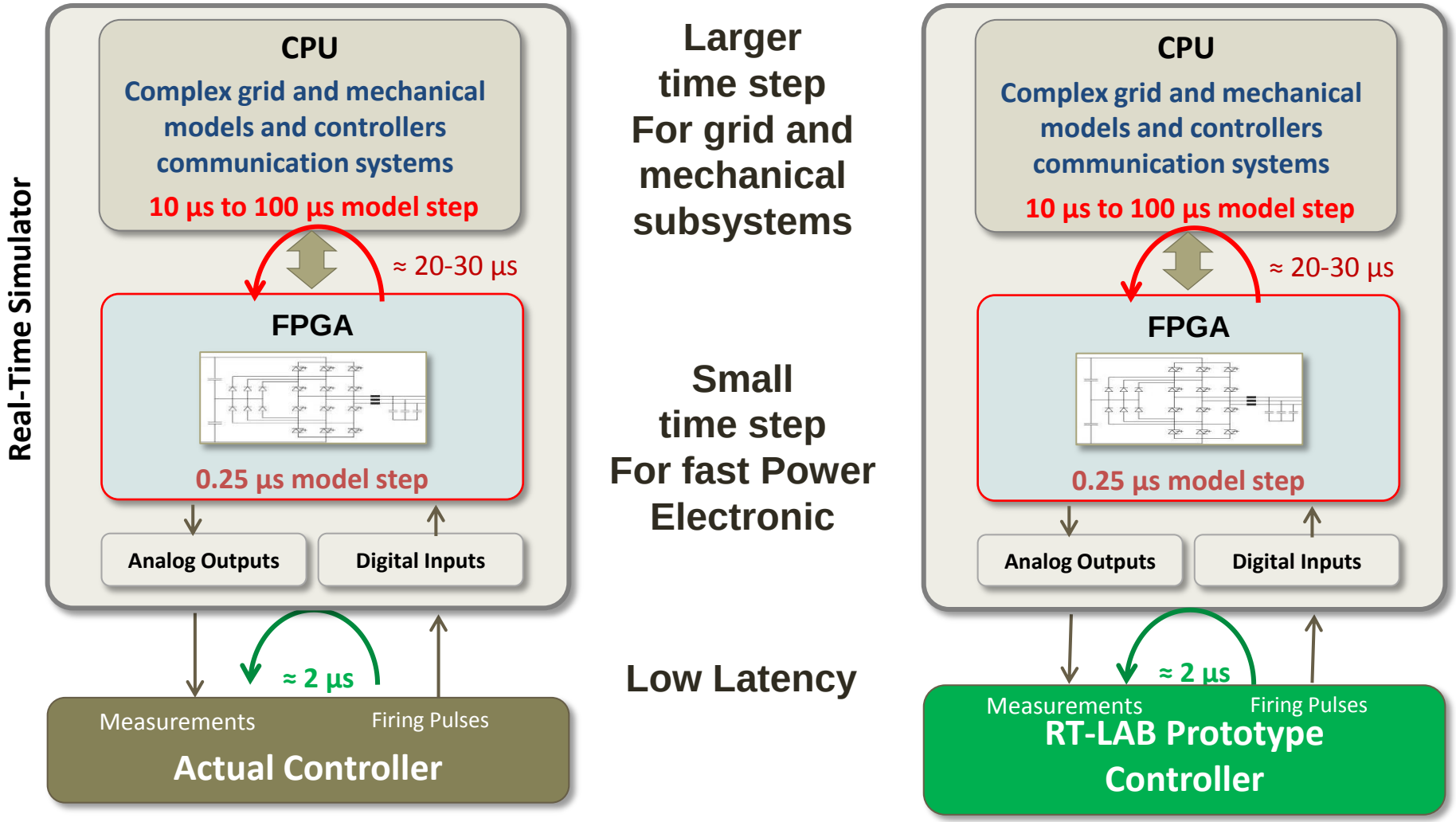






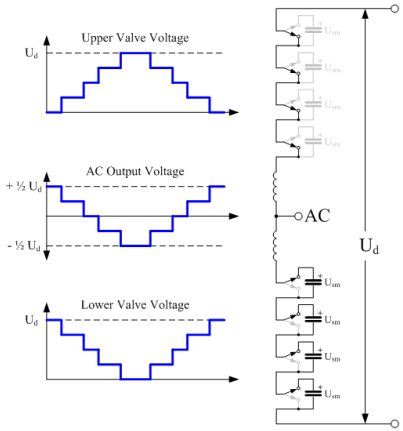
Mixed CPU-FPGA-based Multi-Rate Simulation Platform

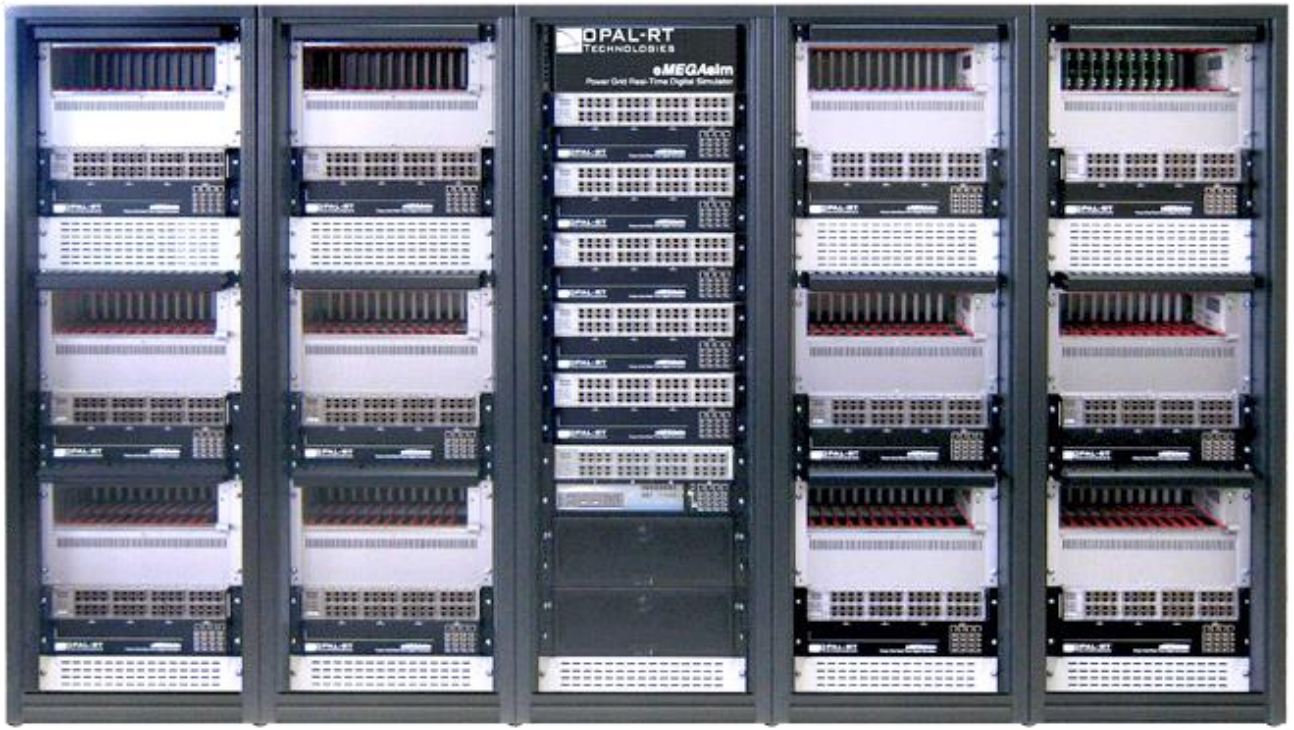
- **Standard architecture of OPAL-RT RT-LAB simulator and RCP system**



Specialized Models

- **MMC Solver**

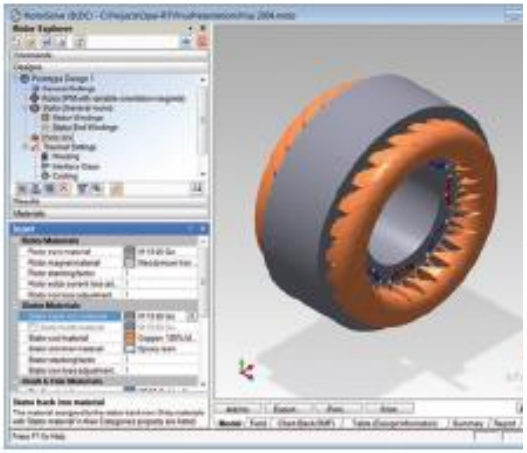




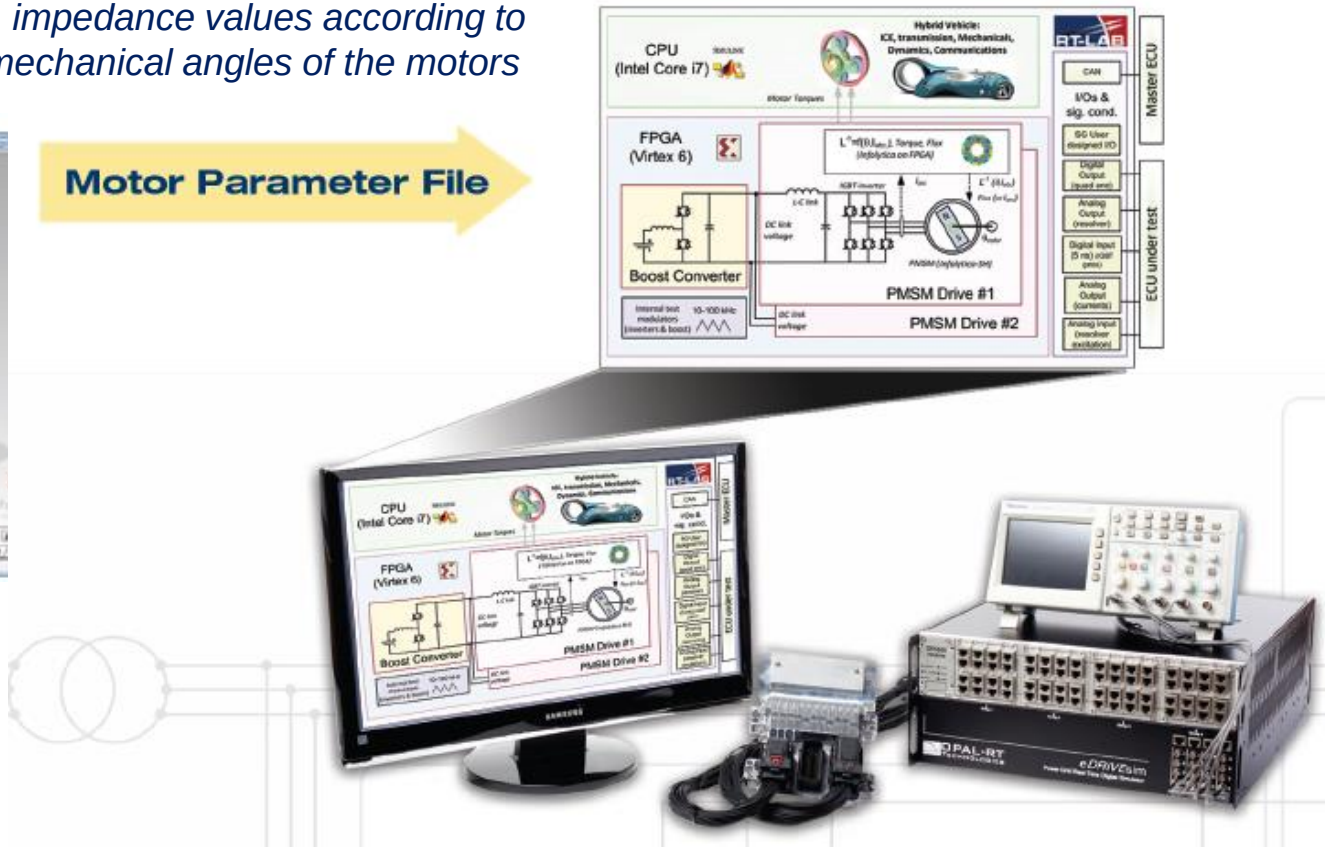
Specialized Models

- **Motor model on FPGA**
  - Using Finite Element Analysis (FEA) modeling approach:
    - Such as JMAG-RT and MotorSolve

Flux, impedance values according to the mechanical angles of the motors

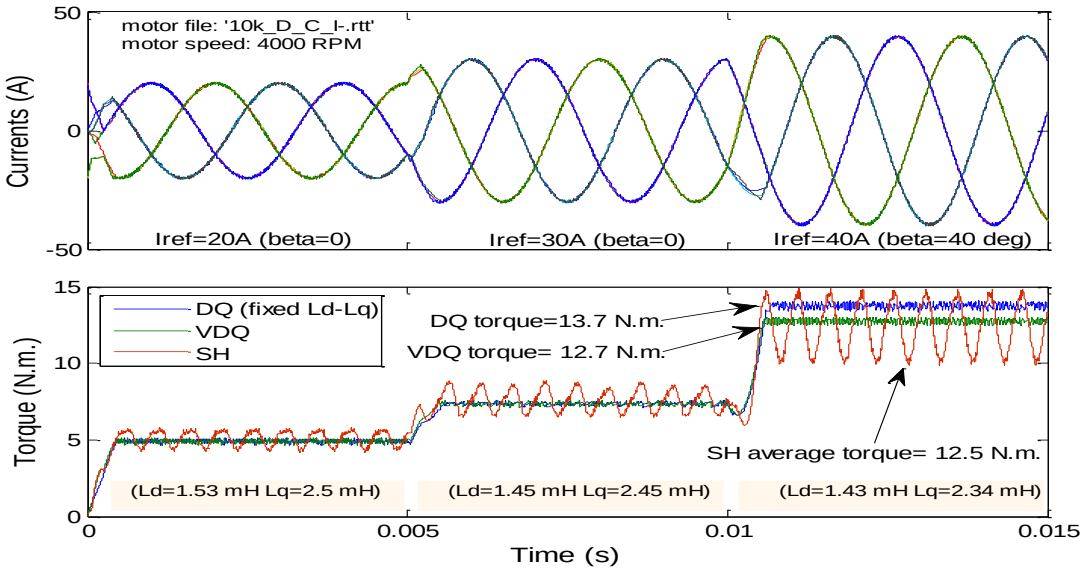


Motor Parameter File



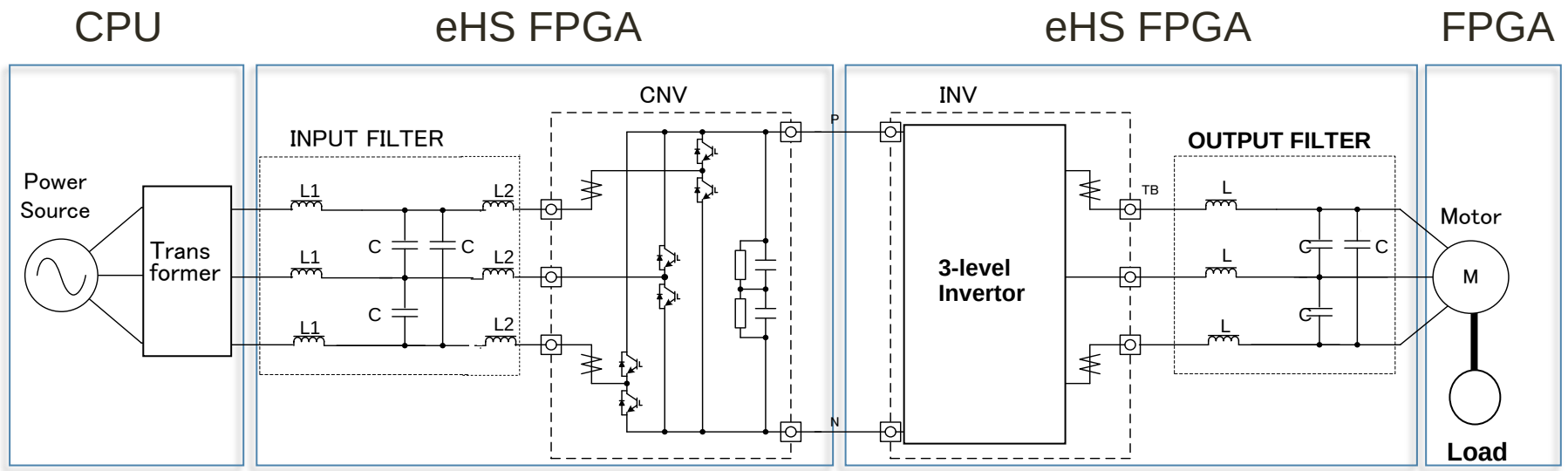
Specialized models

- **Comparative results :**



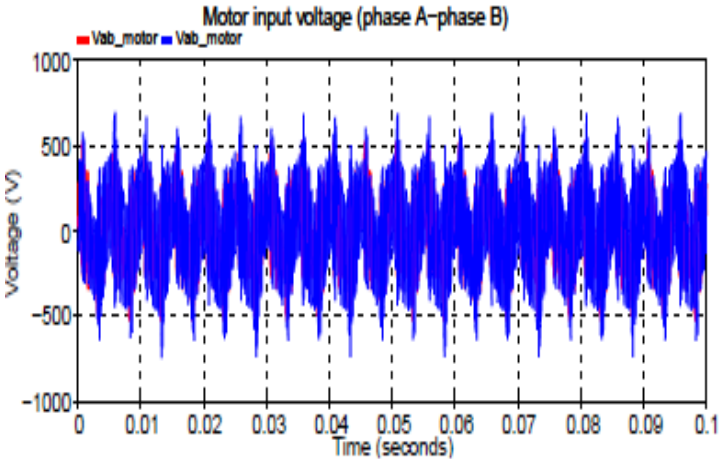
✓ Torque control results at high currents (saturation)

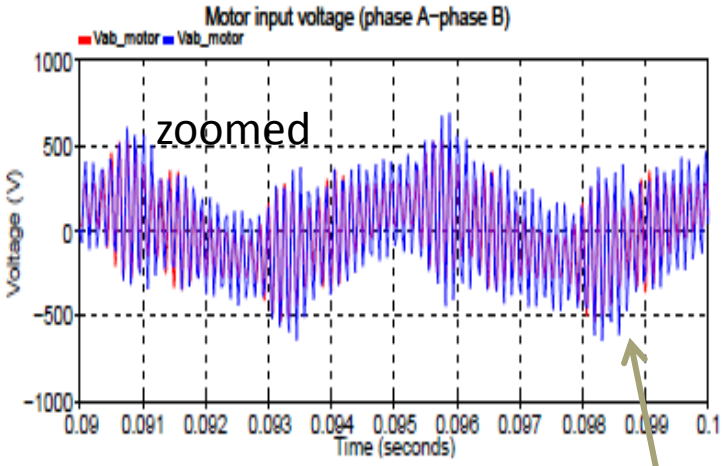
Real-Time FPGA-based Simulation Example



- **eHS Real-Time (eFPGAsim, Virtex 6)**
  - Ac side & Converter: 400 ns
  - Inverter & Filter: 690 ns
  - FPGA PMSM motor: 100ns
  - Inverter switching frequency = 8 kHz
  - Converter switching frequency = 4 kHz

Real-Time FPGA-based Simulation Example

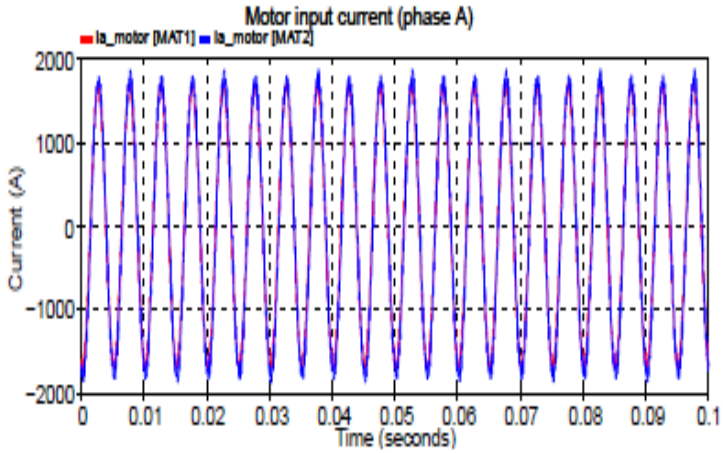


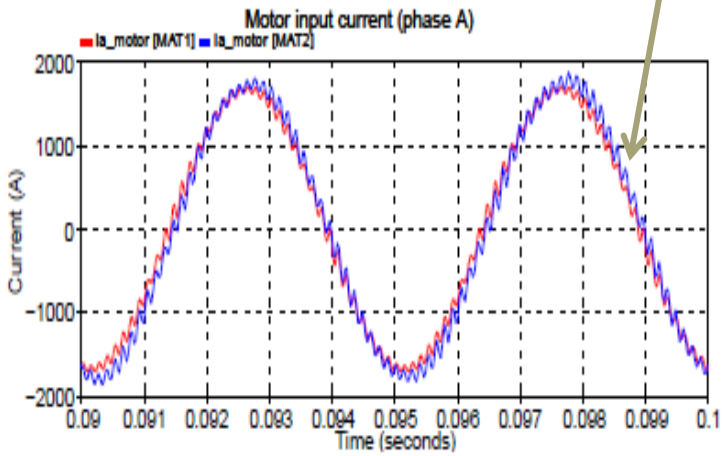


Motor voltage (Phase-to-phase)

eHS and SPS superimposed

8-kHz components due to the 8-kHz PWM carrier



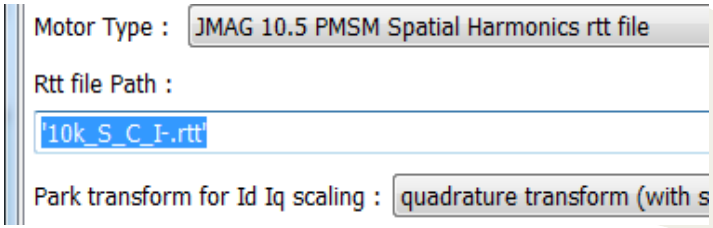


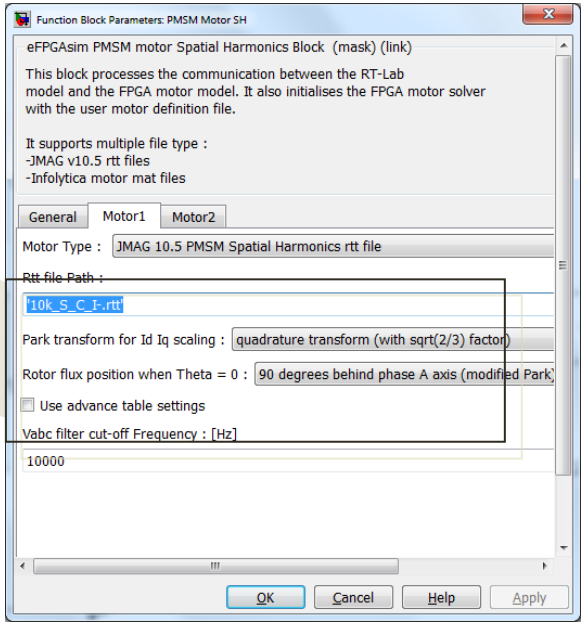
Motor current

eHS and SPS superimposed

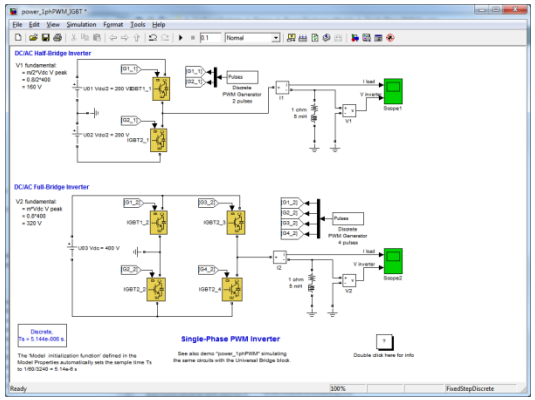
OPAL-RT FPGA-based Simulation

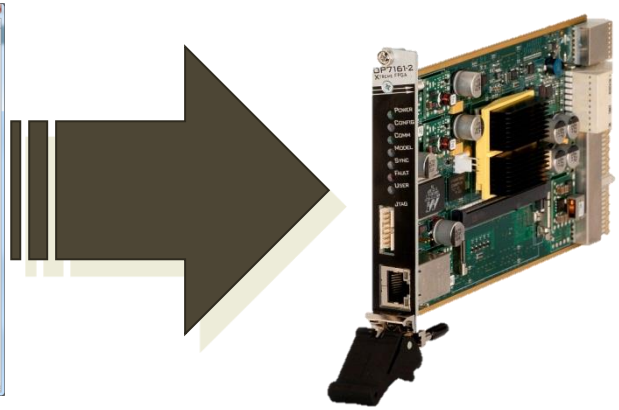
- **Non-Flashing technology:**
  - 1 firmware by application which handle a large number of configuration





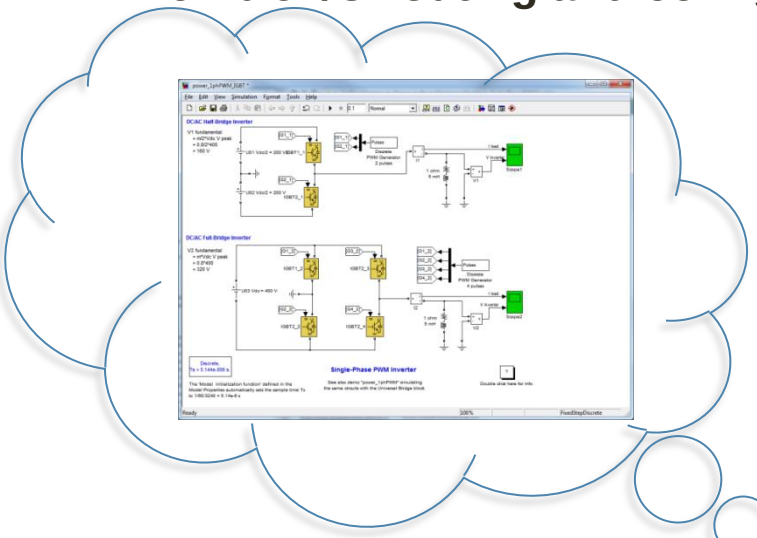
- **Multiple configurations:**
  - Generic Power Systems solver
  - Modification in a model editor
  - Reconfigurable from the host PC

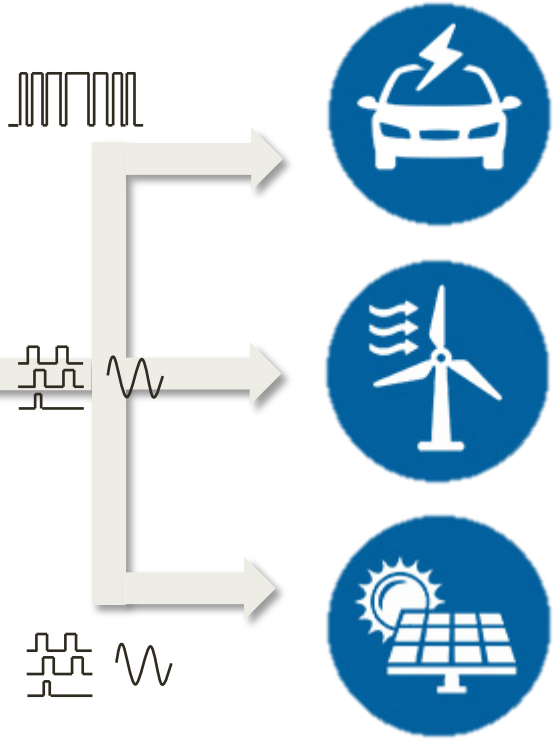




OPAL-RT Real-Time Simulation

- **Flexible I/O routing and configuration**





OPAL-RT Real-Time Simulation

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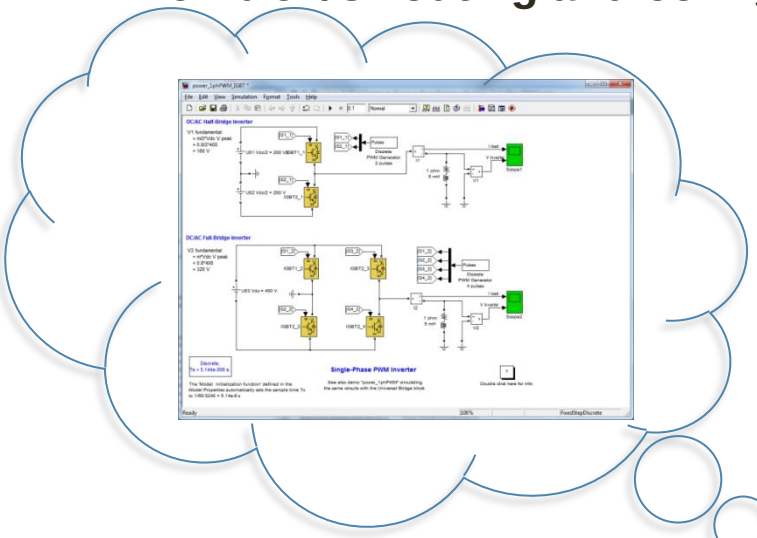
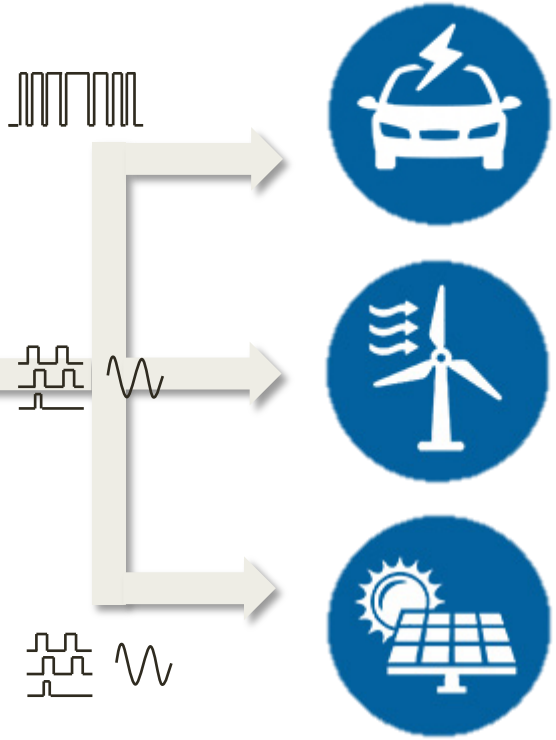
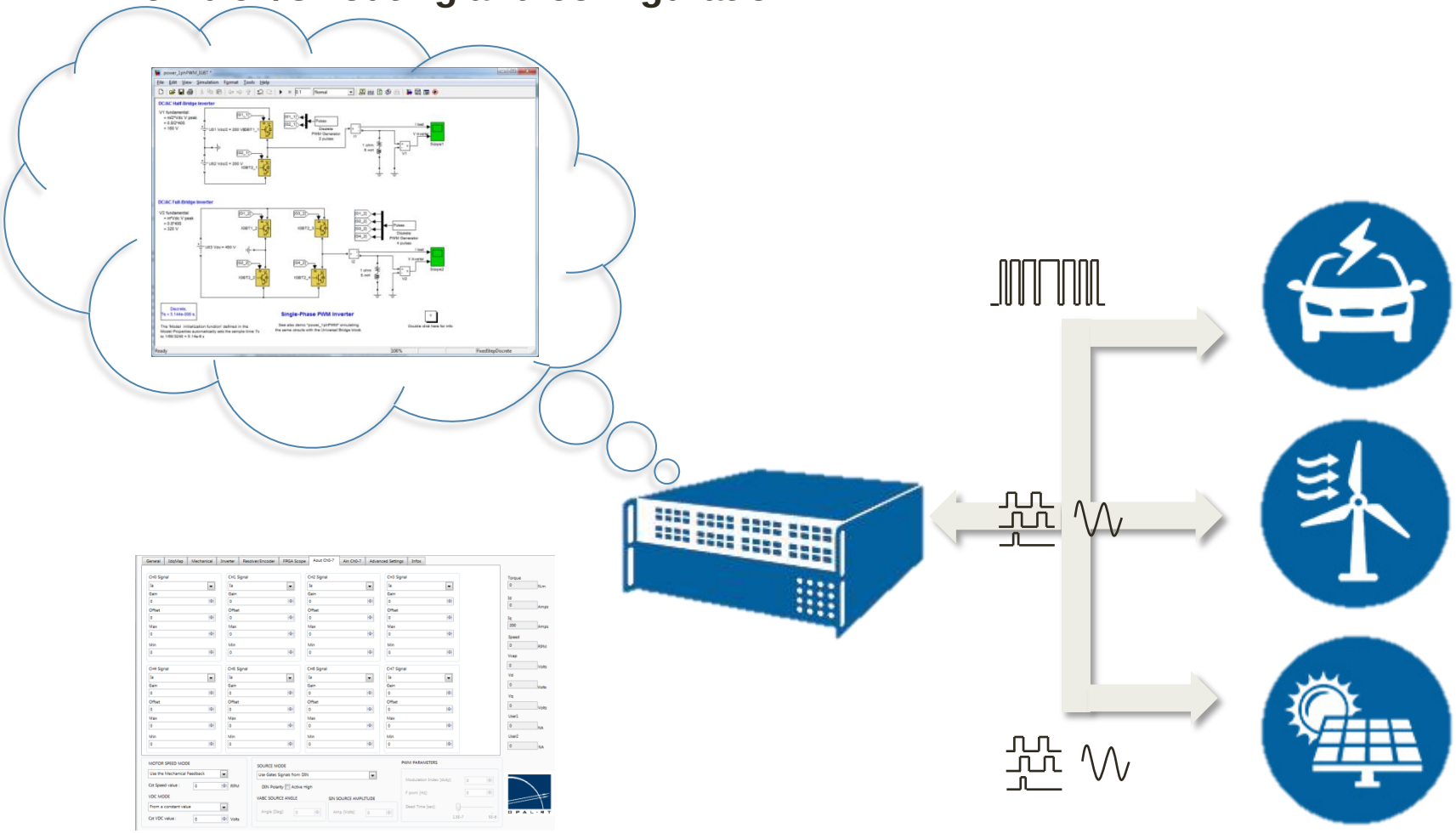




OPAL-RT Real-Time Simulation

- **Flexible I/O routing and configuration**



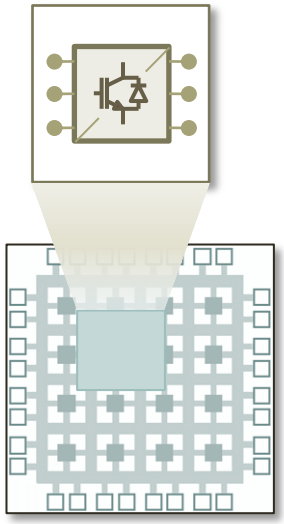
Summary

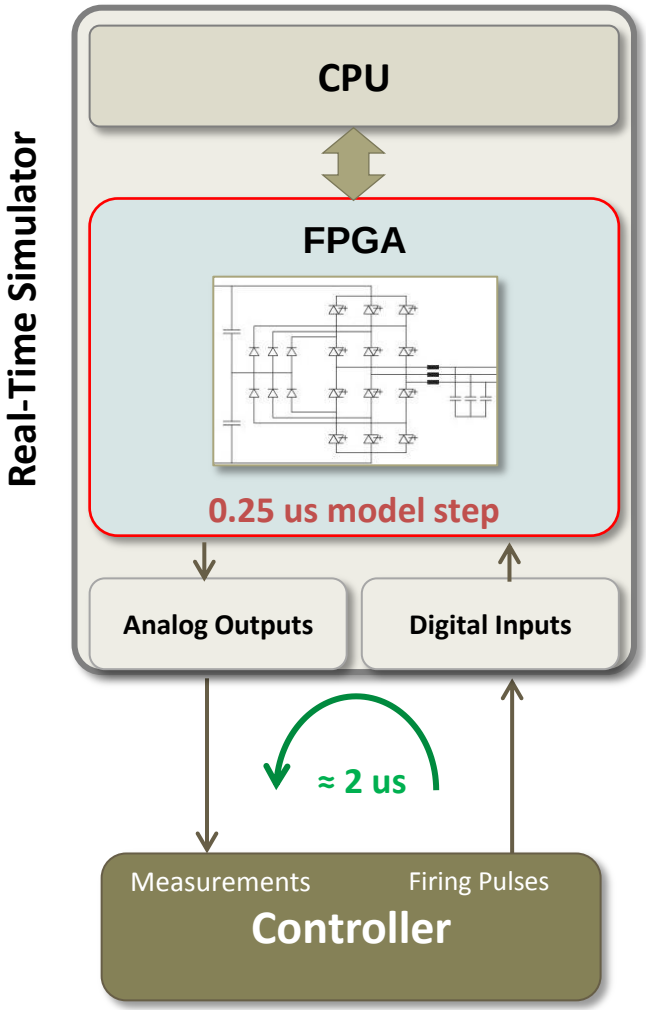
FPGA-based Simulation has many advantages over regular CPU-based simulation

- High Resolution Simulation
- Low Latency

With OPAL-RT's eFPGAsim, modelling is :

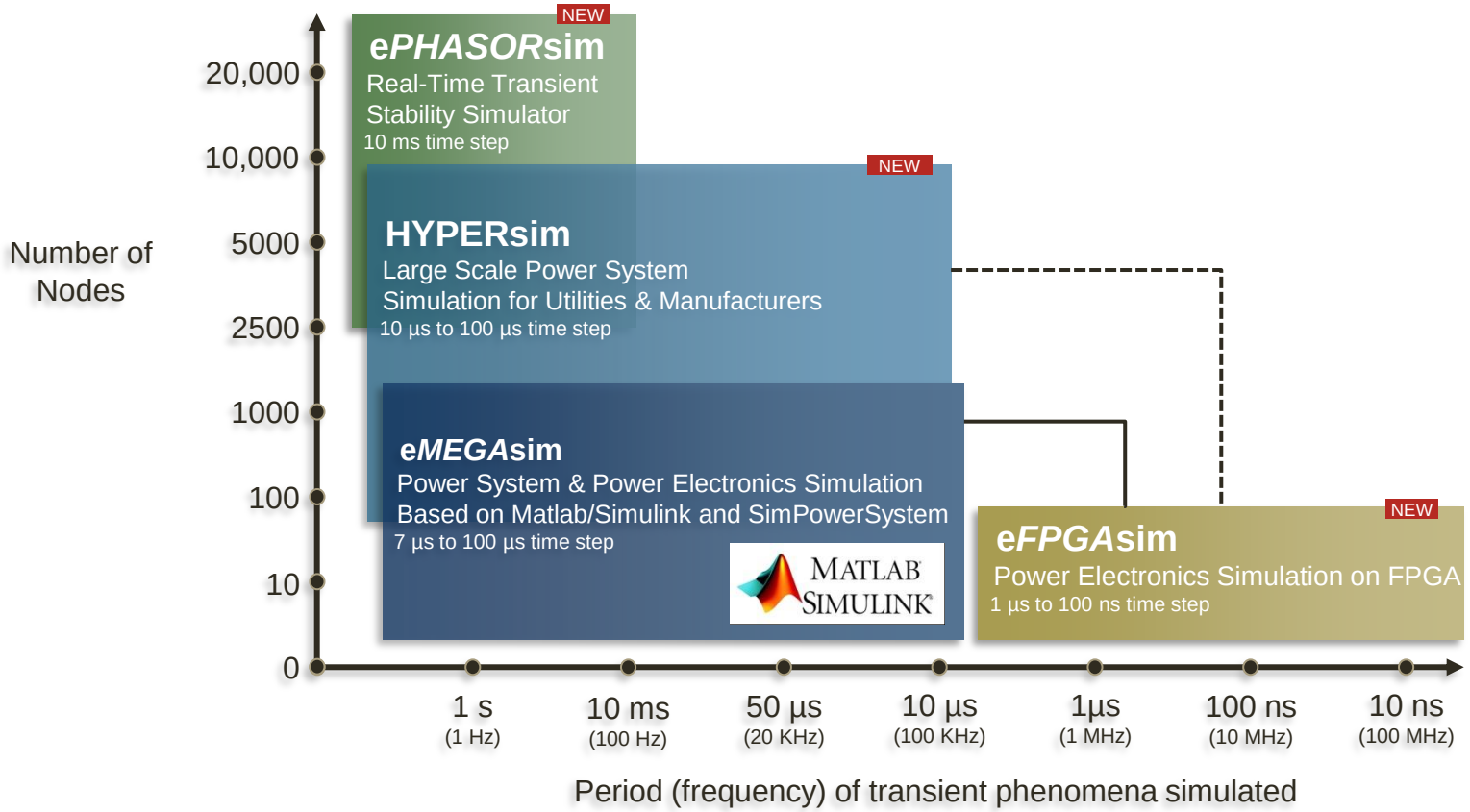
- Easy
- Reliable
- Flexible
- Customizable



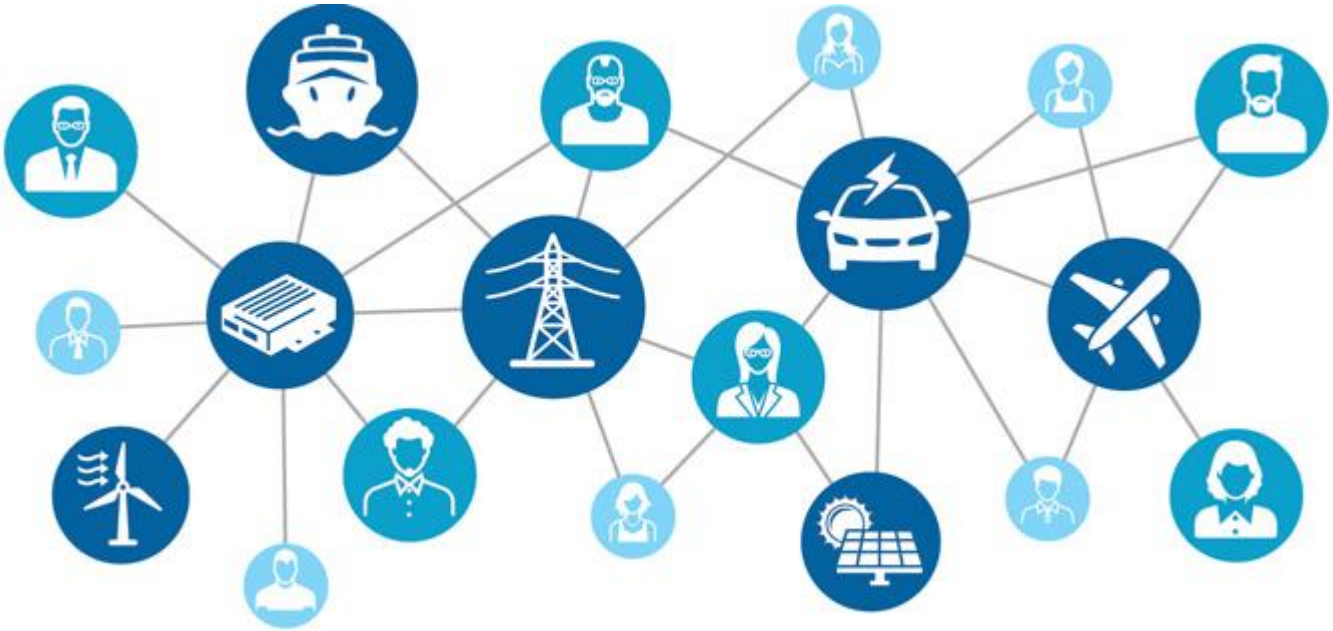


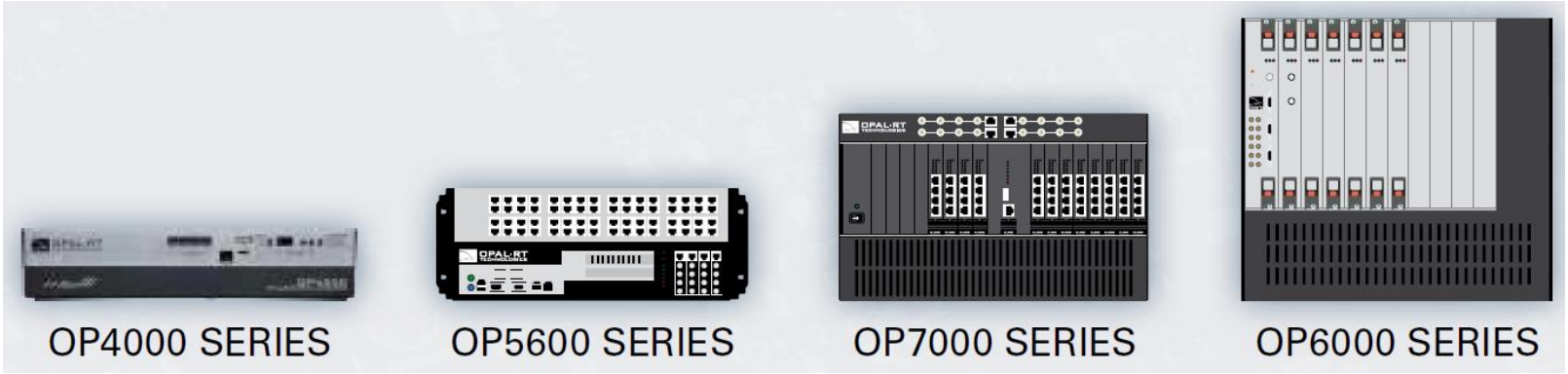
e*POWER*grid Product Family

- **Cover the complete spectrum of power system analysis & studies**



OPAL-RT Democratize Real-Time Simulation





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IEEE Advancing Technology for Humanity

OPAL-RT

From Imagination to Real-Time

Real-Time Simulation of Renewable Energy Systems Using RT-LAB

Thank you !

Presented by Andy Yen

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 - June 24th, 2013