IEEE Workshop on Representations of PEGD Studies

FPGA-based simulations for power electronics and power systems applications

5th December 2019

IEEE

pels IEEE POWER ELECTRONICS SOCIETY Powering a Sustainable Future

Imperial College London

OPAL-RT TECHNOLOGIES

AGENDA

1. **OPAL-RT TECHNOLOGIES**
2. CONTEXT & CHALLENGES
3. FPGA-BASED SOLUTIONS
4. APPLICATION CASES
   - MOTOR DRIVES
   - DISTRIBUTION GRIDS
   - TRANSMISSION GRIDS (HVDC)

OPAL-RT TECHNOLOGIES

OPAL-RT manufactures high-end **real-time simulators**, scaling from compact portable devices to integrated HIL test benches. OPAL-RT systems are deployed for *design*, *validation* and *optimization* of complex control systems through **Control Prototyping** and **Hardware in-the-loop** approaches.

FIGURES

OPAL-RT Technologies Inc.

- Created in 1997
- 230 employees (25 nationalities)
- Headquarters in Montreal, Canada
- 5 local subsidiaries
- A network of 20+ distributors

900 customers worldwide

OPAL-RT TECHNOLOGIES

OFFICES & SECTORS

OPAL-RT TECHNOLOGIES

AGENDA

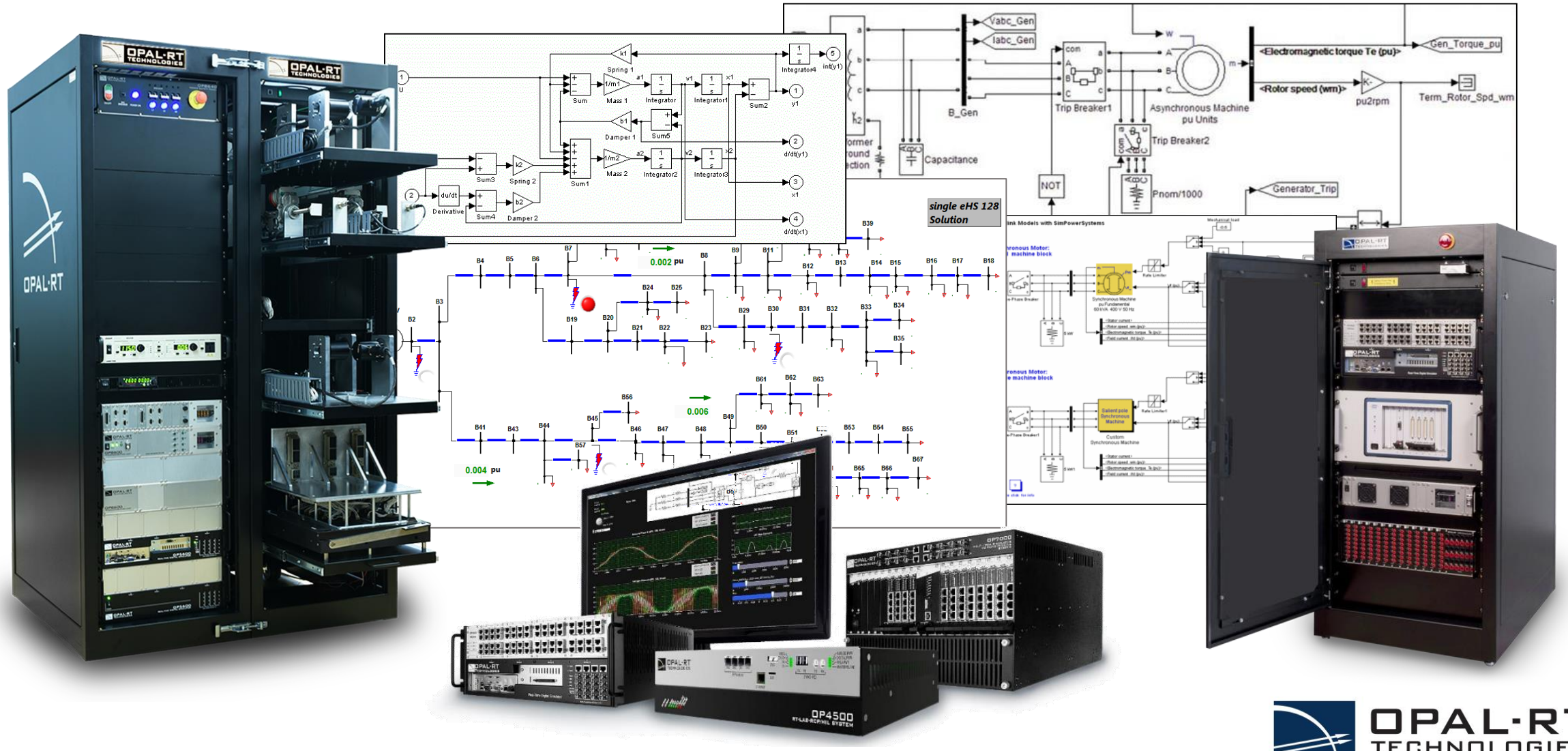
1. OPAL-RT TECHNOLOGIES
2. **CHALLENGES**
3. FPGA-BASED SOLUTIONS
4. APPLICATION CASES
   - MOTOR DRIVES
   - DISTRIBUTION GRIDS
   - TRANSMISSION GRIDS (HVDC)

COMPLEX SYSTEMS – CHALLENGES

- Very complex and sophisticated systems
- New technologies for electrical systems
- More complex control and protection strategies
- New IT approaches
- On-field tests hard to conduct

OPAL-RT TECHNOLOGIES

COMPLEX SYSTEMS – CHALLENGES



OPAL-RT TECHNOLOGIES

COMPLEX SYSTEMS – CHALLENGES

A MODEL ? WHAT FOR ?

- Facilitate the development of complex control systems
- Use less physical prototypes
- Test complex/dangerous cases is a safe way
- Replace missing hardware by software models

COMPLEX SYSTEMS – CHALLENGES

TO TEST A CONTROL OR PROTECTION DEVICE IN A GRID… WITHOUT A GRID !

Voltage & Current measurements

Commands to switch breakers

Real protection relay

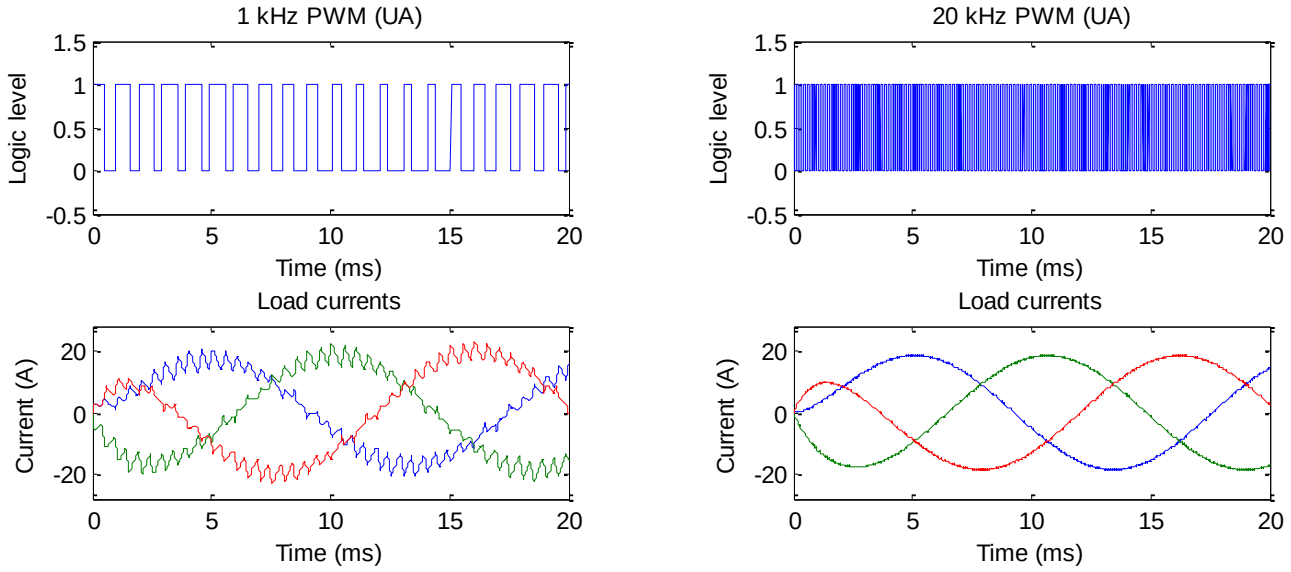
OPAL-RT TECHNOLOGIES

COMPLEX SYSTEMS – CHALLENGES

- Simulation of more **complex** electrical circuits
- Need for more **representative/accurate** models
- Need to sample signals very **precisely**
- **Higher switching** frequencies for power electronics (SiC, GaN)

COMPLEX SYSTEMS – CHALLENGES - FOCUS ON ACCURACY

- Higher switching frequencies (>100 kHz) – *SiC, GaN*
- Higher power density, lower THD
- Requires higher sampling rates (< 1 µs)



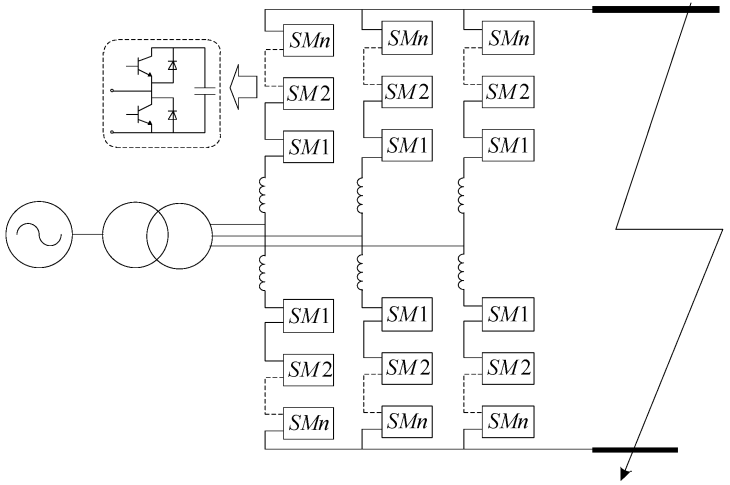
OPAL-RT TECHNOLOGIES

COMPLEX SYSTEMS – CHALLENGES FOCUS ON COMPLEXITY

Modular Multilevel Converters for HVDC

- N submodules (SM) per arm (N -> 500)
- Up to 5 switches per SM

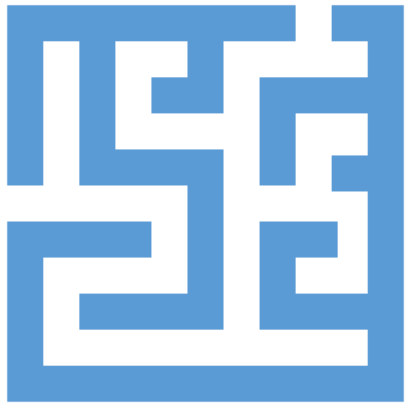
➔ Up to **15 000 switches** per converter



Credit: ABB, Siemens, MDPI

OPAL-RT TECHNOLOGIES

COMPLEX SYSTEMS – CHALLENGES



Complexity

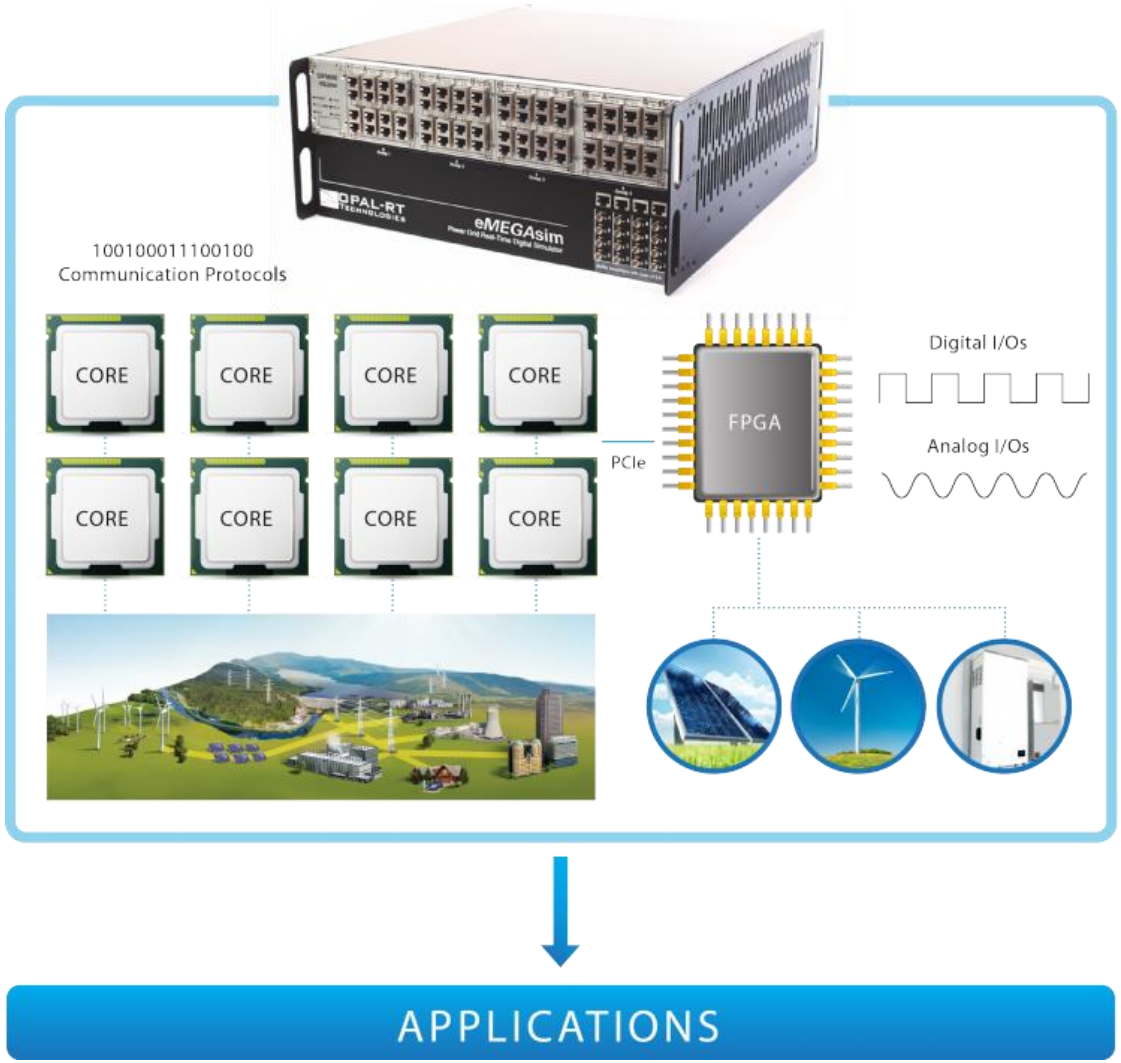
Accuracy

Speed

AGENDA

1. OPAL-RT TECHNOLOGIES
2. CHALLENGES
3. **FPGA-BASED SOLUTIONS**
4. APPLICATION CASES
   - MOTOR DRIVES
   - DISTRIBUTION GRIDS
   - TRANSMISSION GRIDS (HVDC)

CPU & FPGA CO-SIMULATION



All OPAL-RT systems take advantage of both CPU and FPGA resources.

- **CPU**: massive computation power

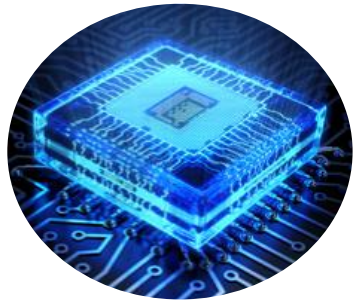
  Ts > 10 µs

- **FPGA**: great accuracy and low latency Ts < 1 µs

OPAL-RT TECHNOLOGIES

ONE SOLUTION: FPGA SIMULATION

- **ACCURATE**: Low sampling time and therefore excellent resolution for high frequency switching (up to 50-100 kHz)
- **FAST**: Excellent execution latency (typ. 1 µs)
- **PARALLEL**: Massively parallel processing unit

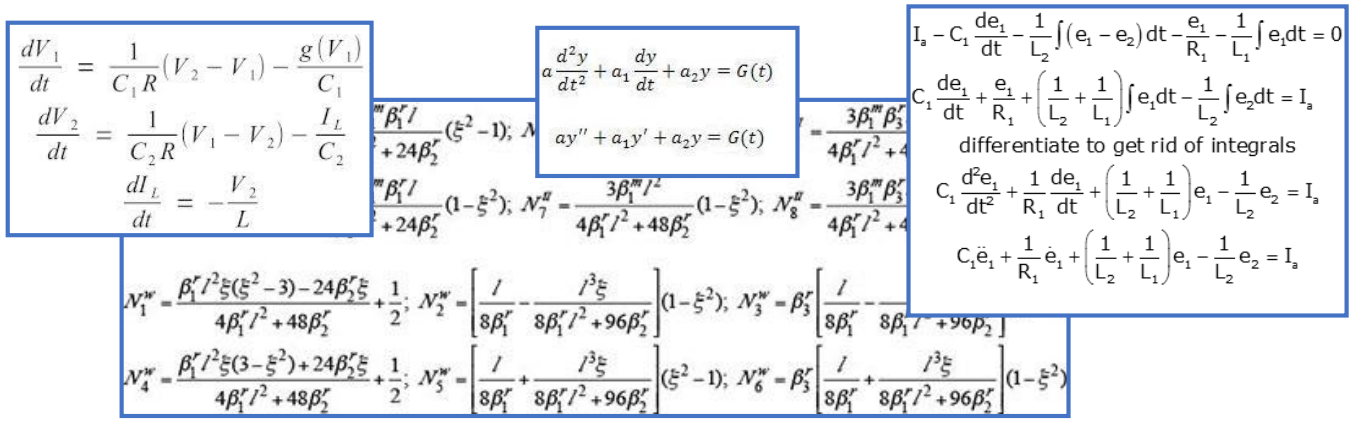


Credit: Technolution

OPAL-RT TECHNOLOGIES

FPGA DRAWBACKS

- **COMPLEX DESIGN**: Higher coding complexity (‘for’ loop, division, …)
- **TIME CONSUMING**: Very long compilation time (~hours)
- **DIFFICULT DEBUGGING**: Increased debugging difficulty

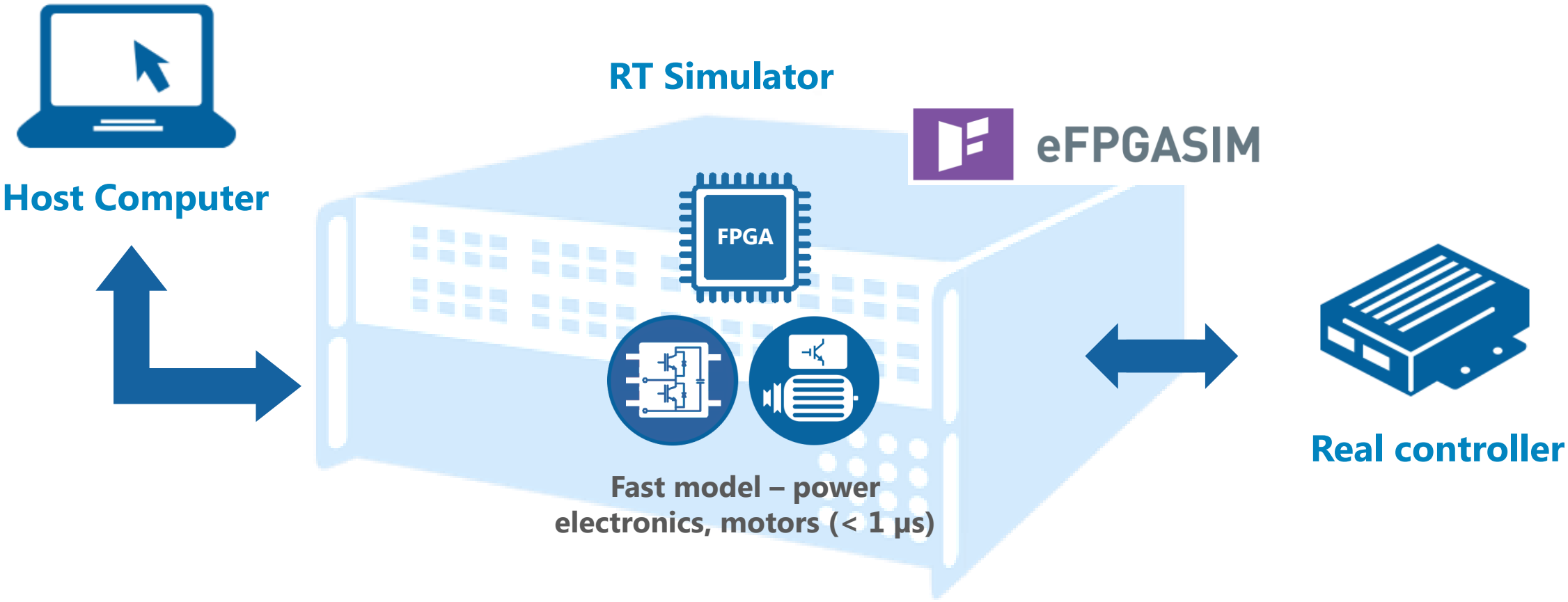


OPAL-RT TECHNOLOGIES

INTRODUCING eFPGASIM

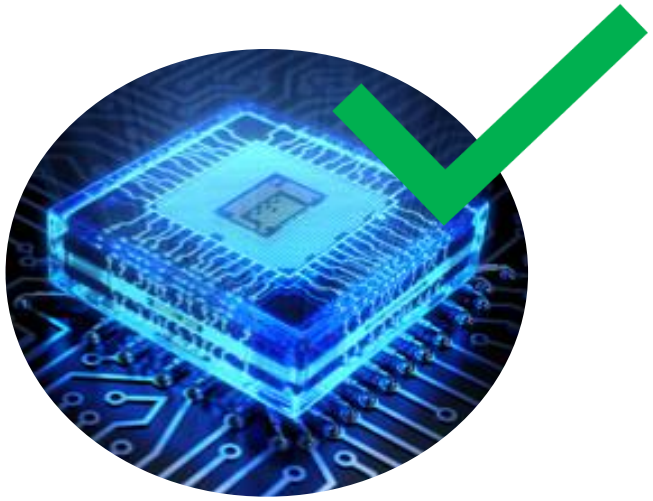
Set of **models** and **solvers** designed to facilitate the fast and accurate simulation of **electrical circuits on FPGA**, as well as associated services *(gating signals, sensor emulation, communications)*

MOTOR DRIVES – eHS CONCEPT



MOTOR DRIVES – CHALLENGES

FPGA performance

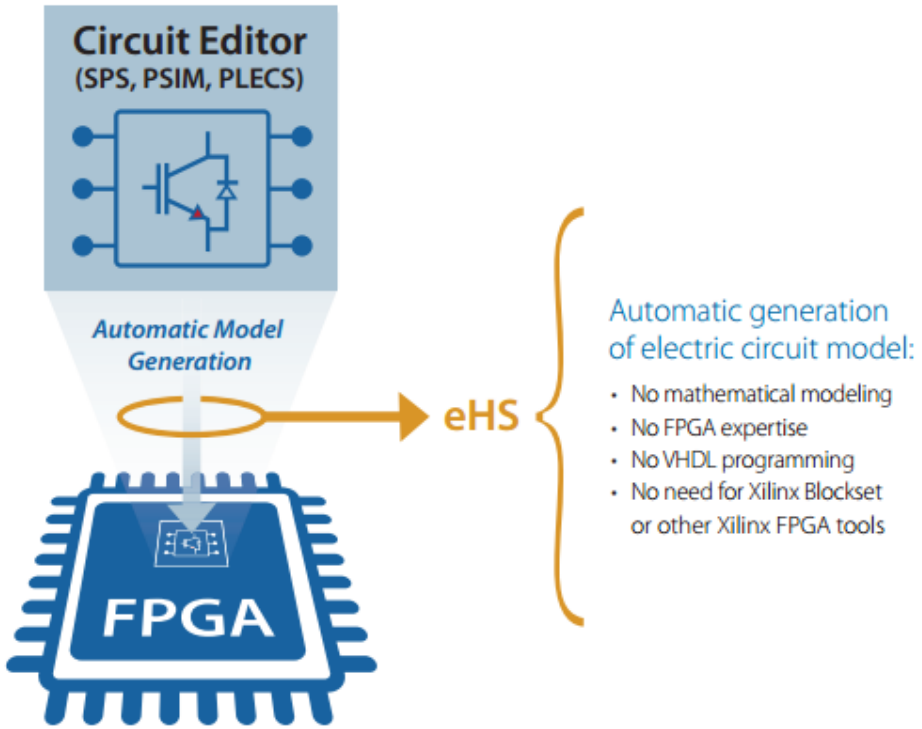


FPGA ease of use

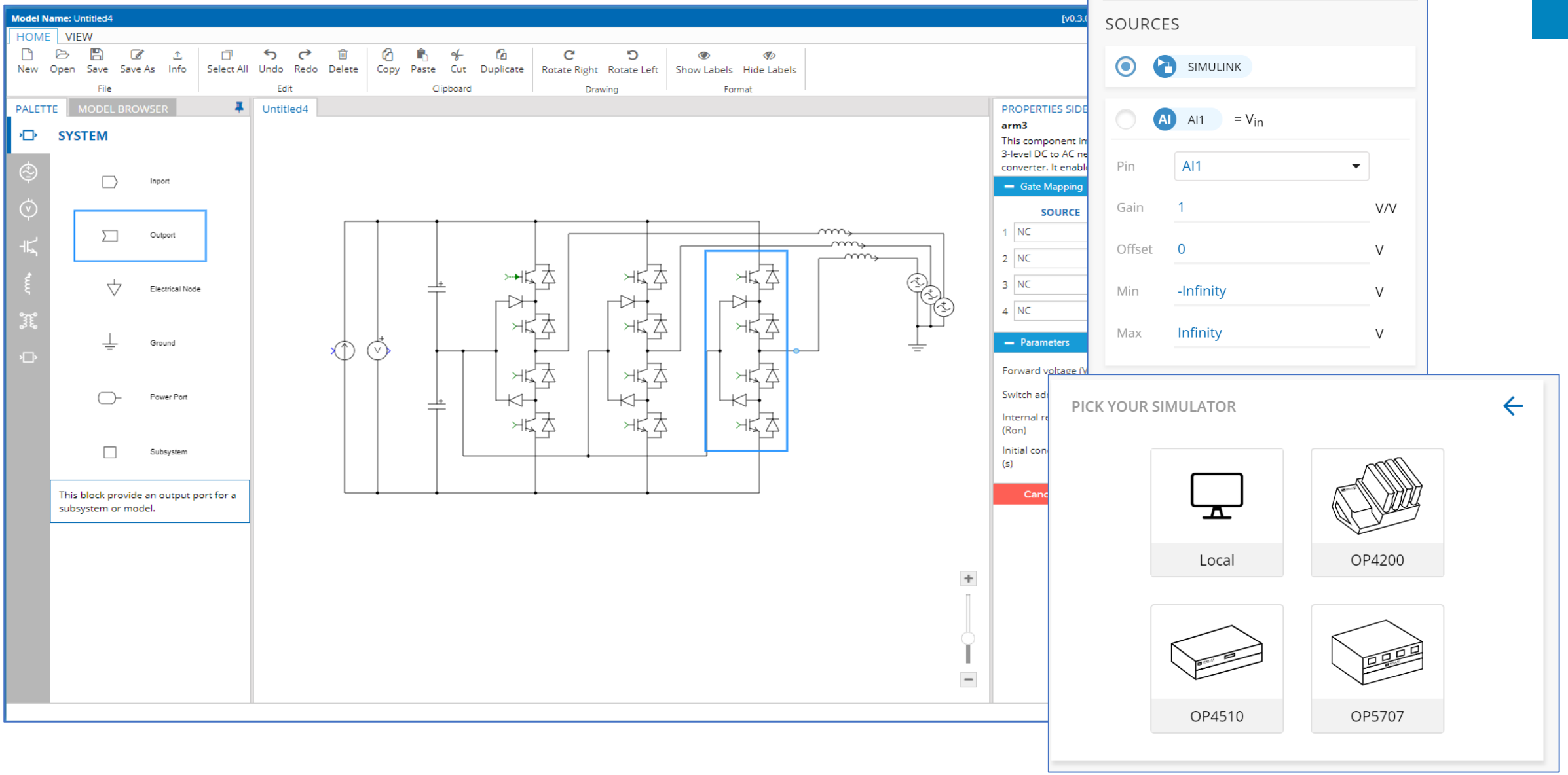
MOTOR DRIVES – eHS CONCEPT

eHS: **e**lectrical **H**ardware **S**olver

- Allows the use of a **comprehensive circuit editor** …
- … while taking advantage of the **FPGA performance** …
- … **without writing** a single line of HDL code !



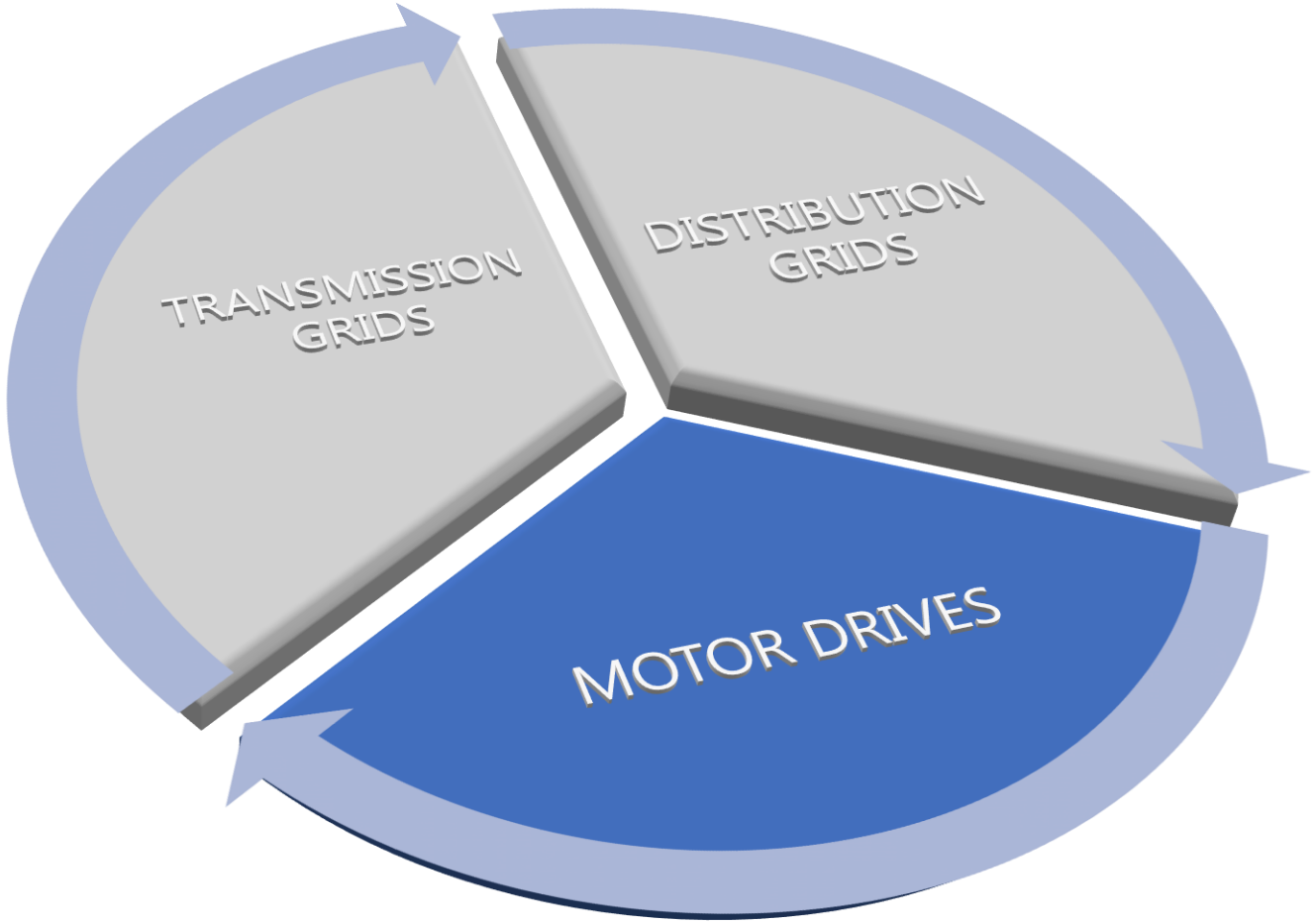
MOTOR DRIVES – eHS CONCEPT



AGENDA

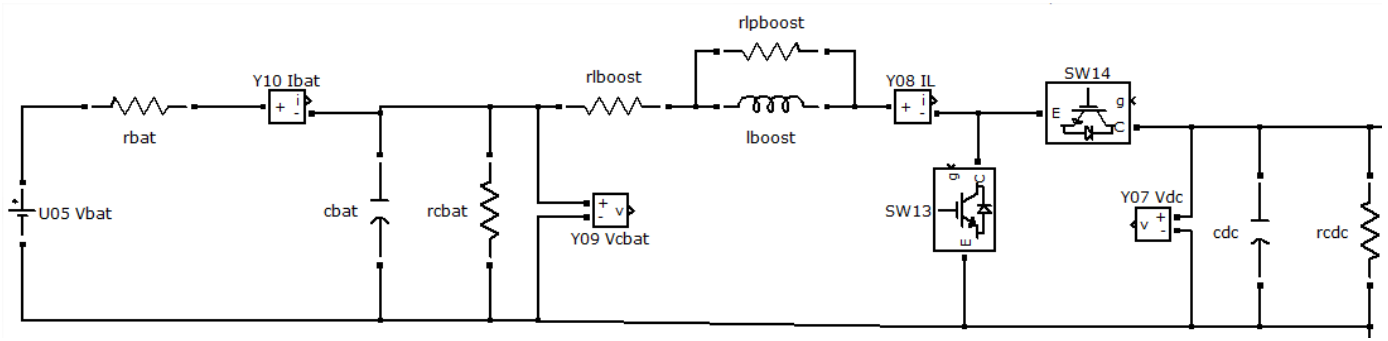
1. OPAL-RT TECHNOLOGIES
2. CHALLENGES
3. FPGA-BASED SOLUTIONS
4. **APPLICATION CASES**
   - **MOTOR DRIVES**
   - **DISTRIBUTION GRIDS**
   - **TRANSMISSION GRIDS (HVDC)**

APPLICATION CASES



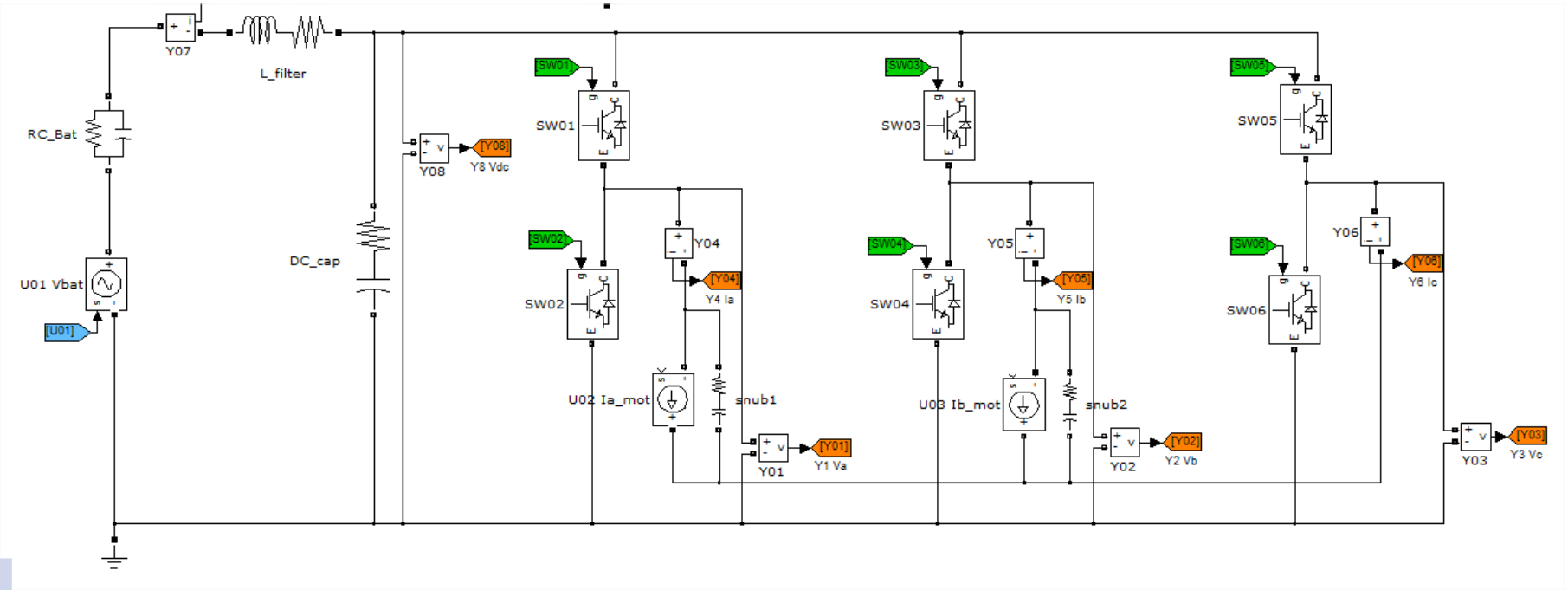
OPAL-RT TECHNOLOGIES

INITIALLY…



Boost
Model Time Step = **150 ns**
10 kHz PWM

MOTOR DRIVES

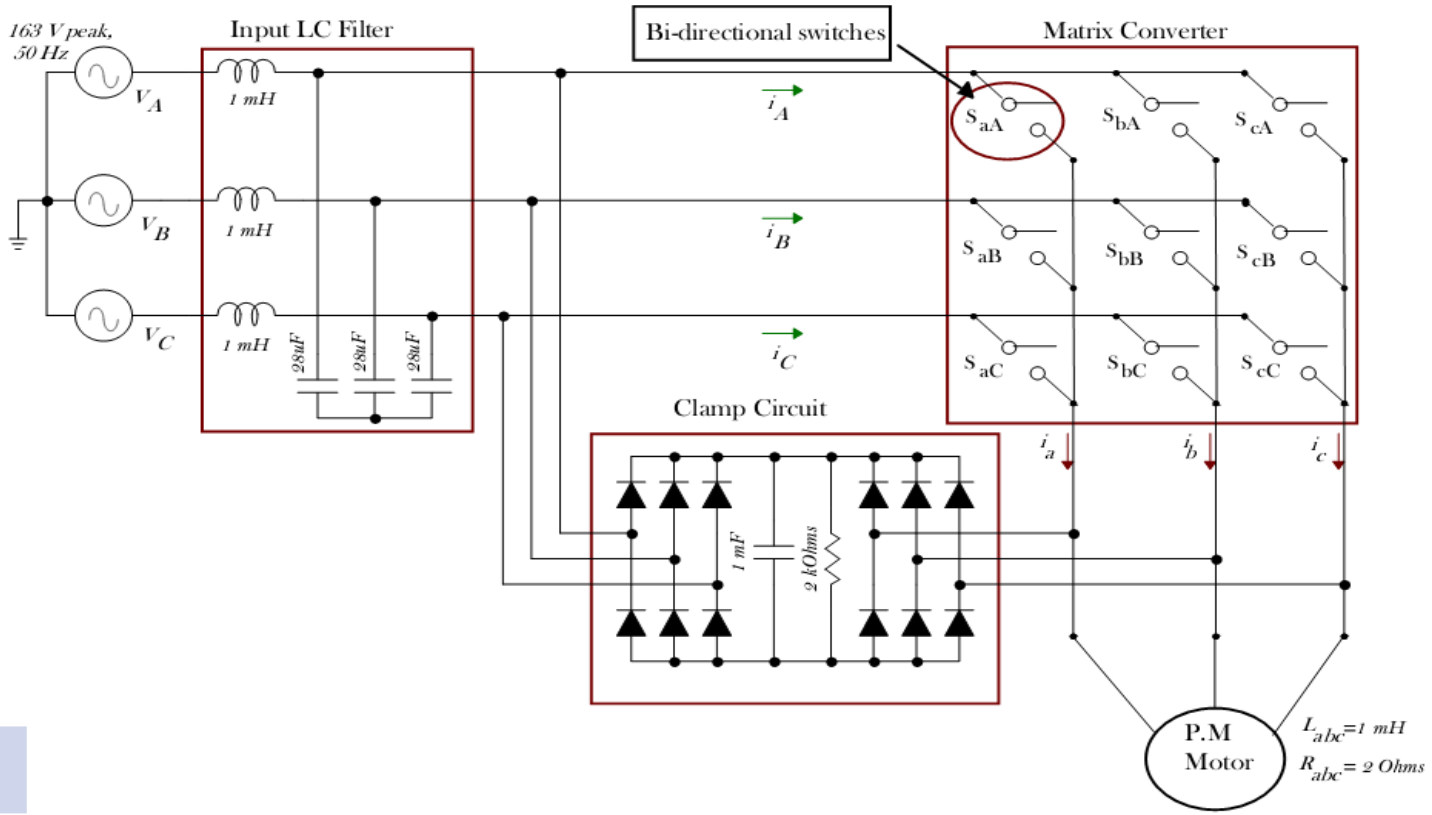


States	5
Switches	6
Inputs	4
Outputs	8

3-phase 2-level Inverter
Model Time Step = **200ns**
50 kHz PWM

OPAL-RT TECHNOLOGIES

MOTOR DRIVES



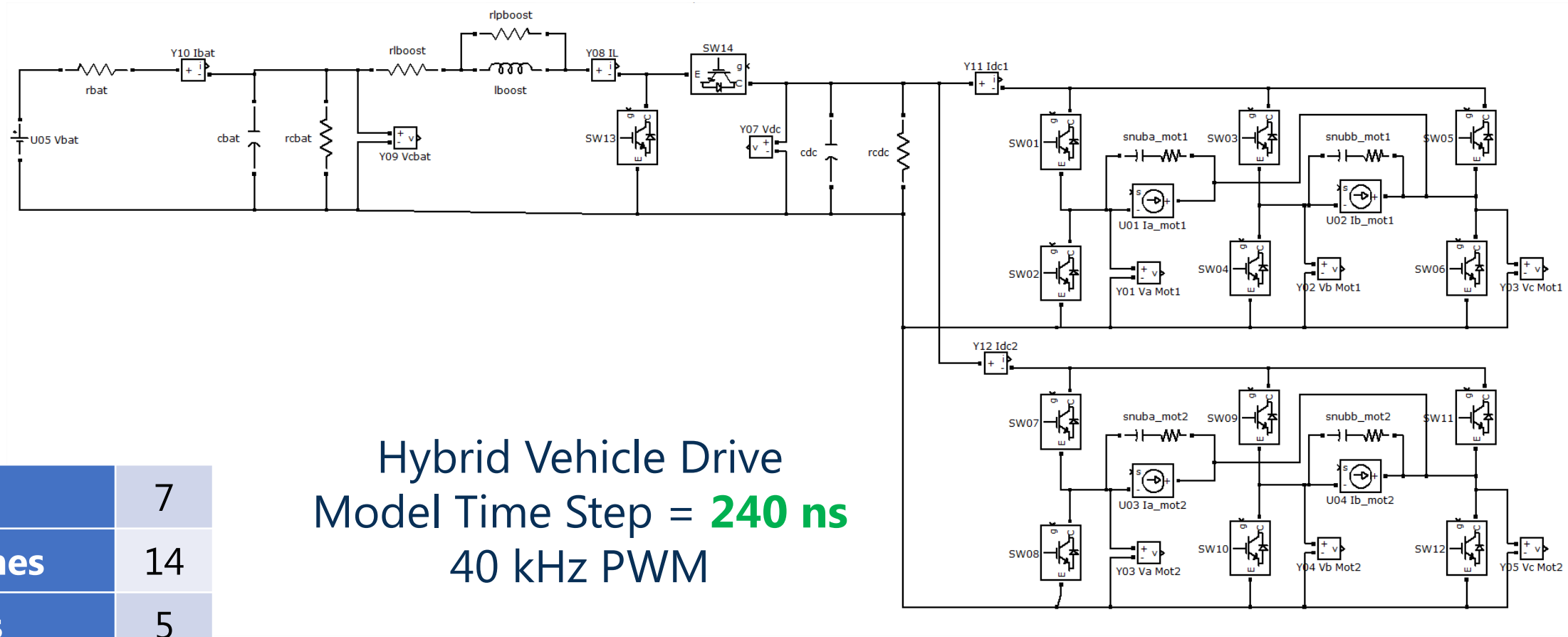
States	7
Switches	22
Inputs	3
Outputs	8

Matrix converter drive

Model Time Step = **350 ns**

OPAL-RT TECHNOLOGIES

MOTOR DRIVES

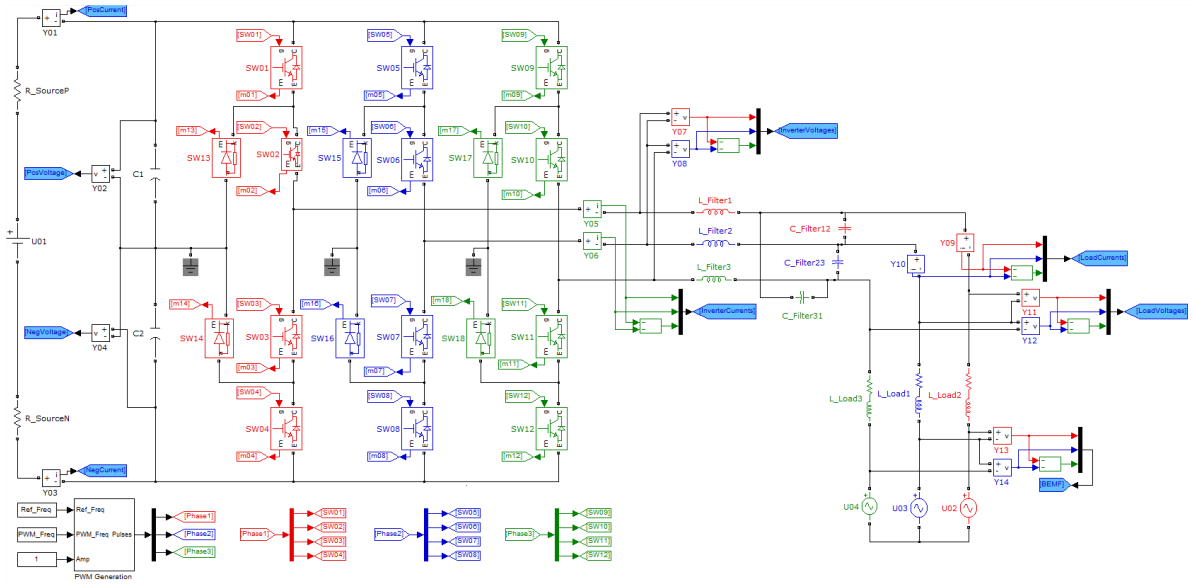


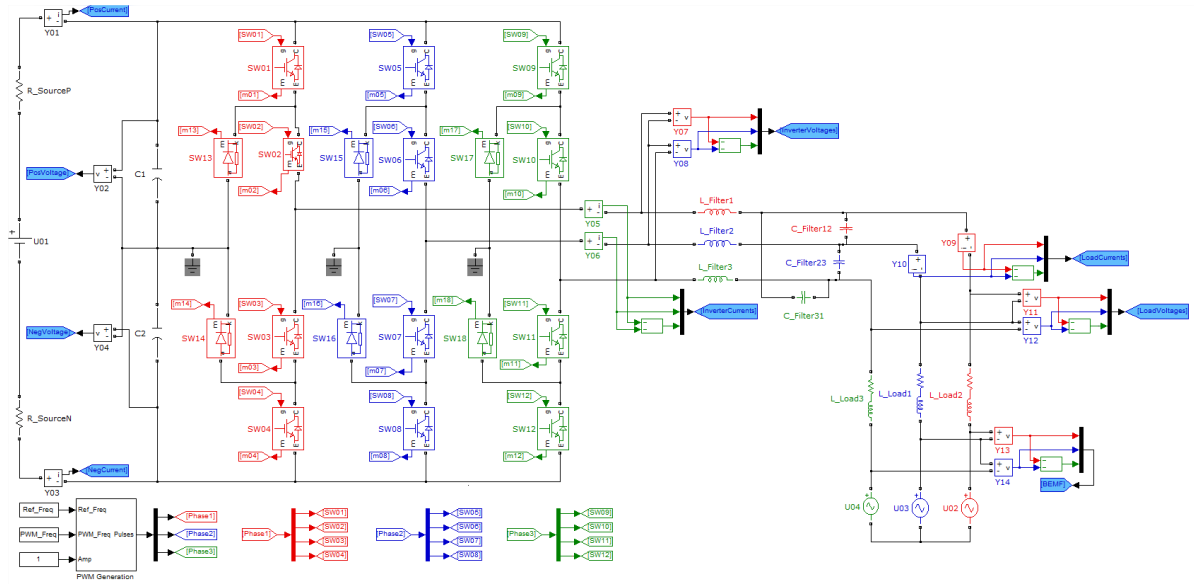
States	7
Switches	14
Inputs	5
Outputs	12

Hybrid Vehicle Drive
Model Time Step = **240 ns**
40 kHz PWM

OPAL-RT TECHNOLOGIES

MOTOR DRIVES



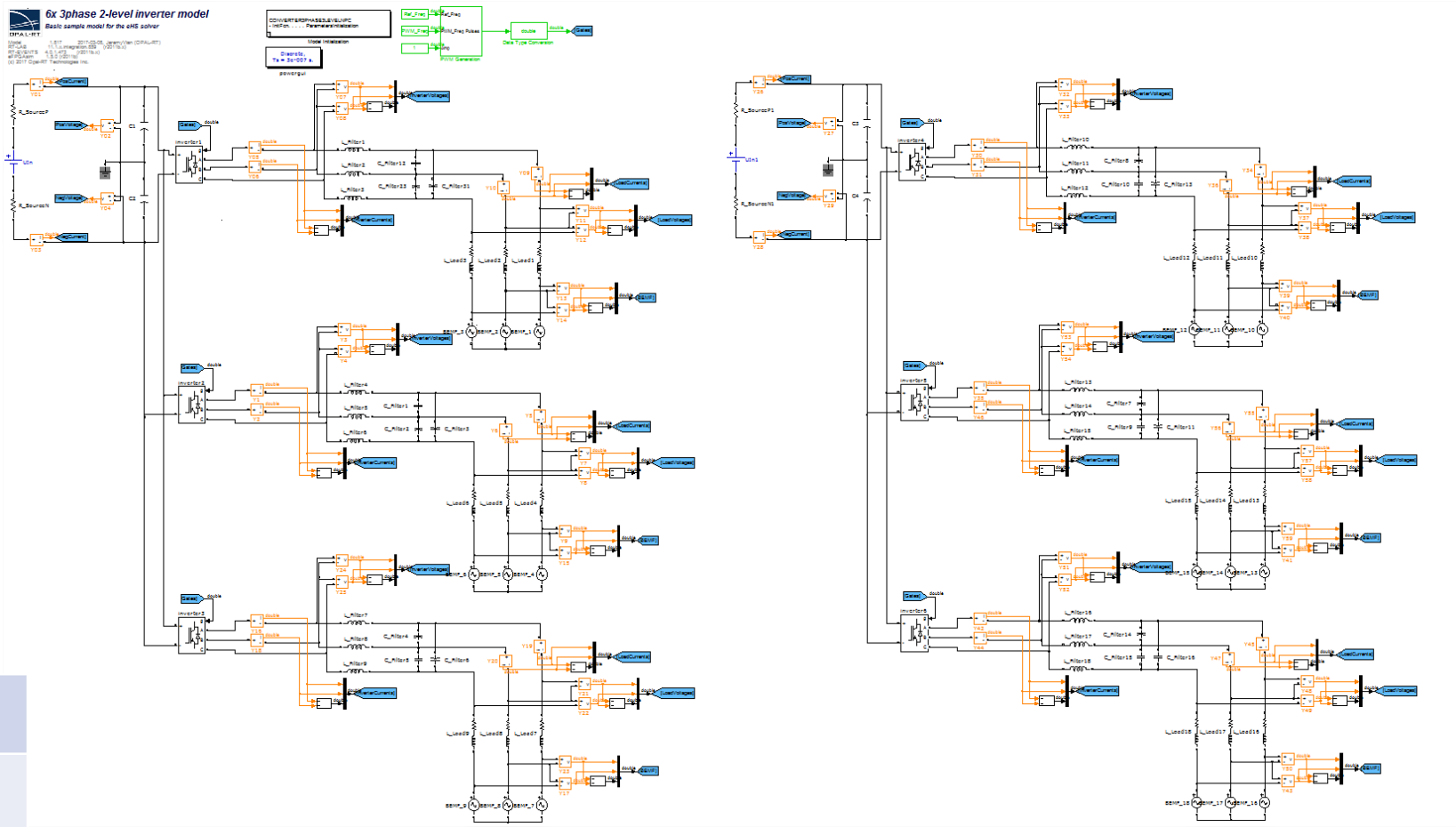


States	22
Switches	36
Inputs	8
Outputs	28

2 x NPC 3-phase 3-level converters
Model Time Step = **580 ns**
17 kHz PWM

OPAL-RT TECHNOLOGIES

MOTOR DRIVES



States	58
Switches	36
Inputs	20
Outputs	68

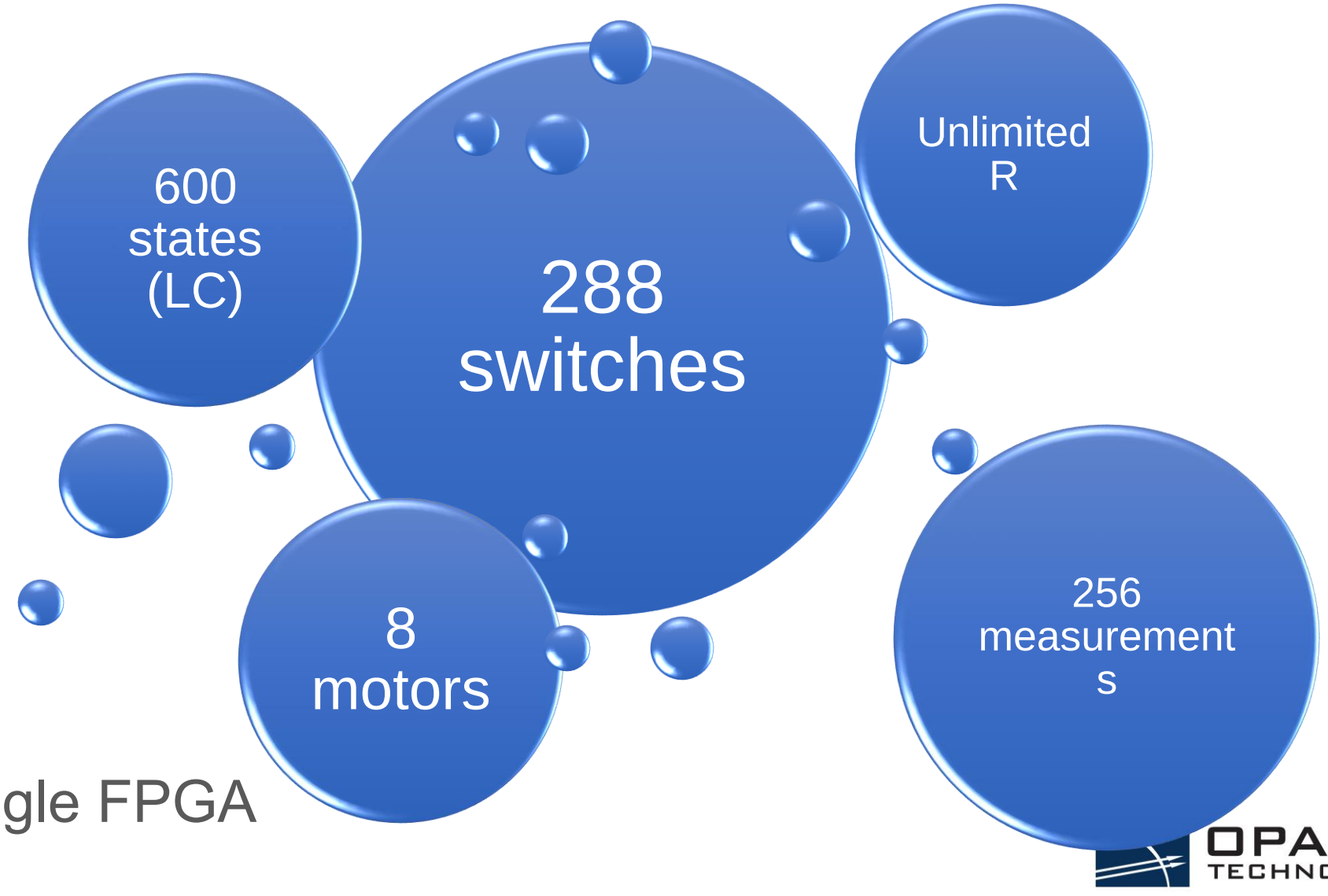
6 x 3-phase 2-level converters with filters and loads

Model Time Step = **880 ns**

OPAL-RT TECHNOLOGIES

MOTOR DRIVES – eHS CAPABILITIES

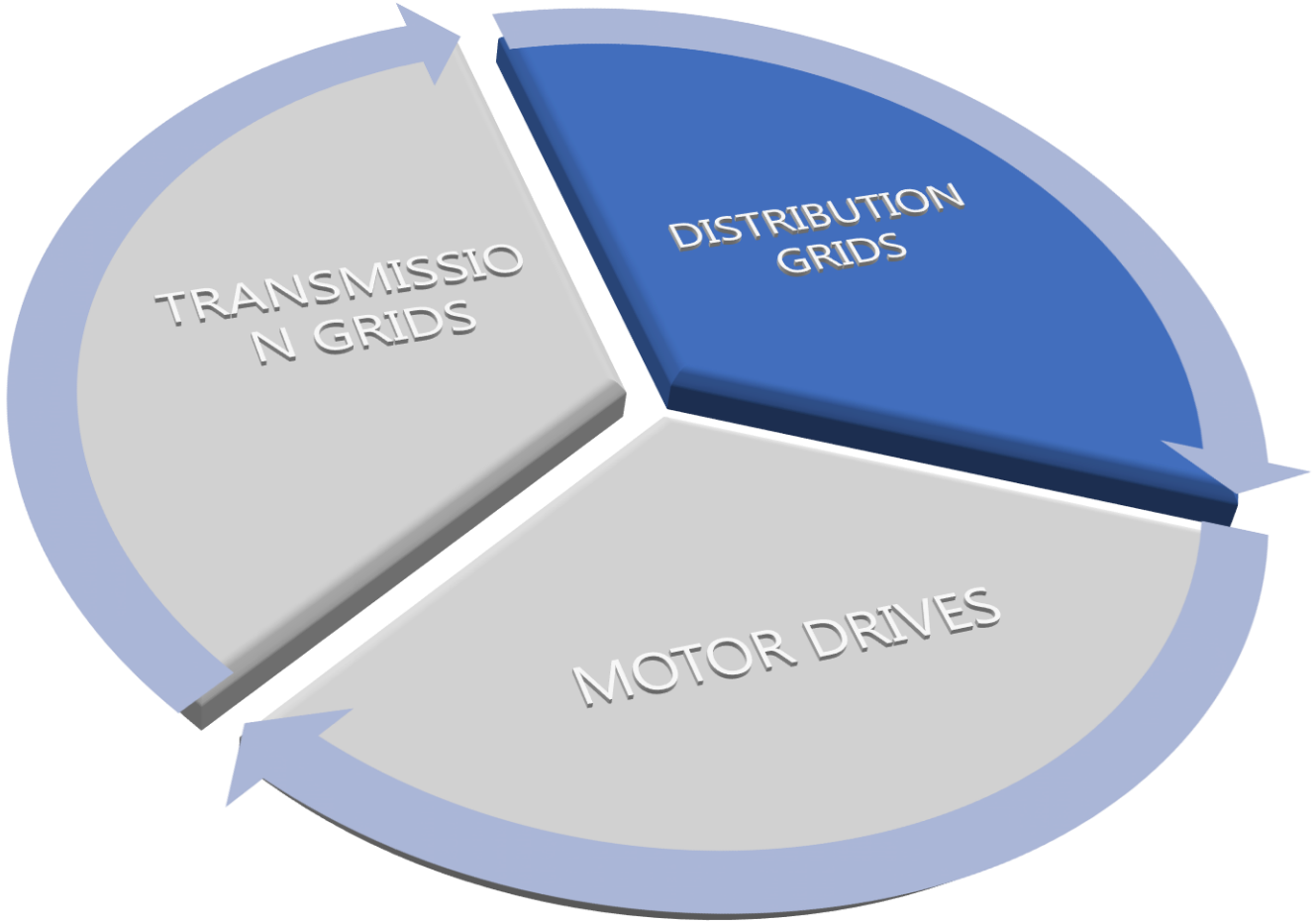
NOW…



… On one single FPGA

OPAL-RT TECHNOLOGIES

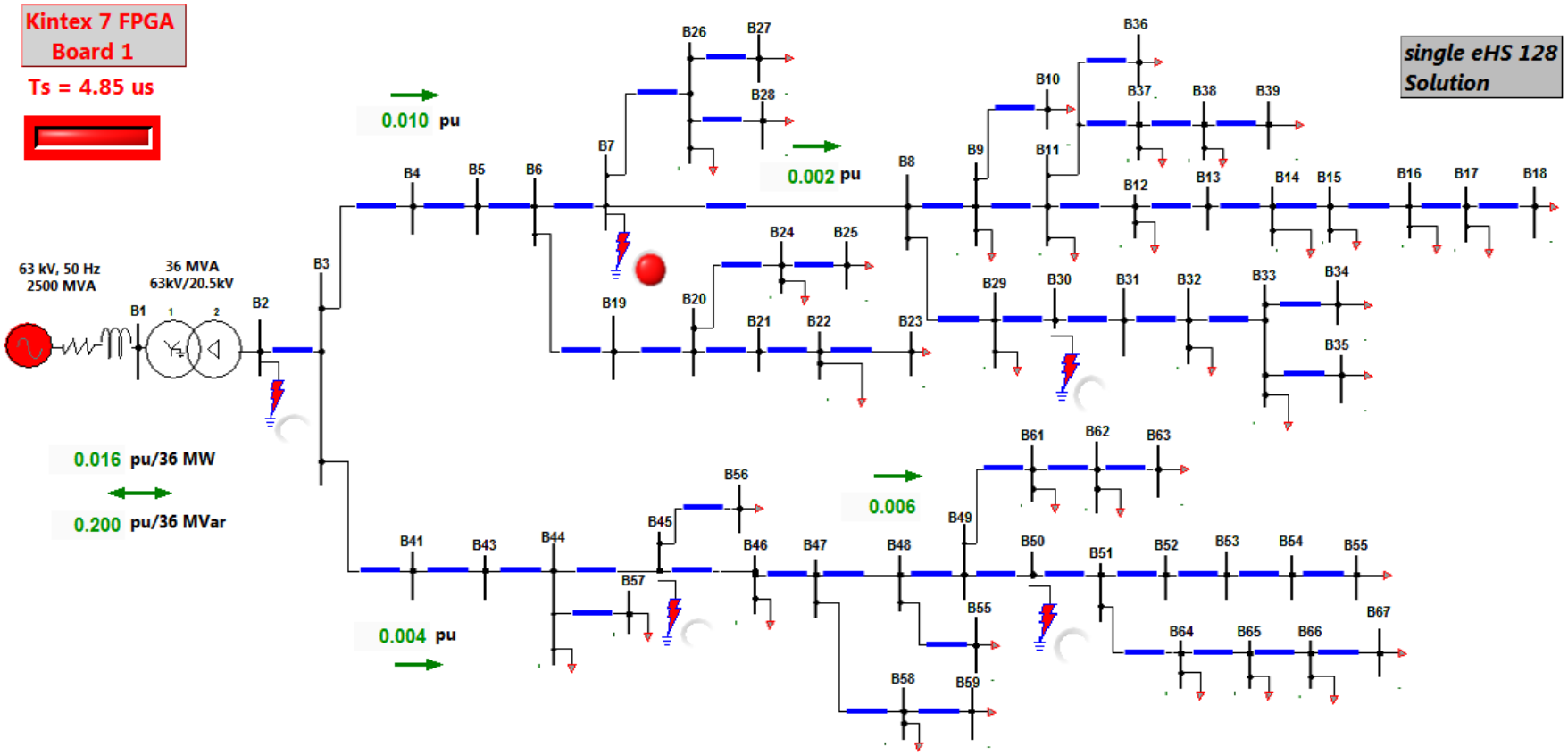
APPLICATION CASES



OPAL-RT TECHNOLOGIES

DISTRIBUTION GRIDS

1 FPGA



: 62 3-Ph RL connections

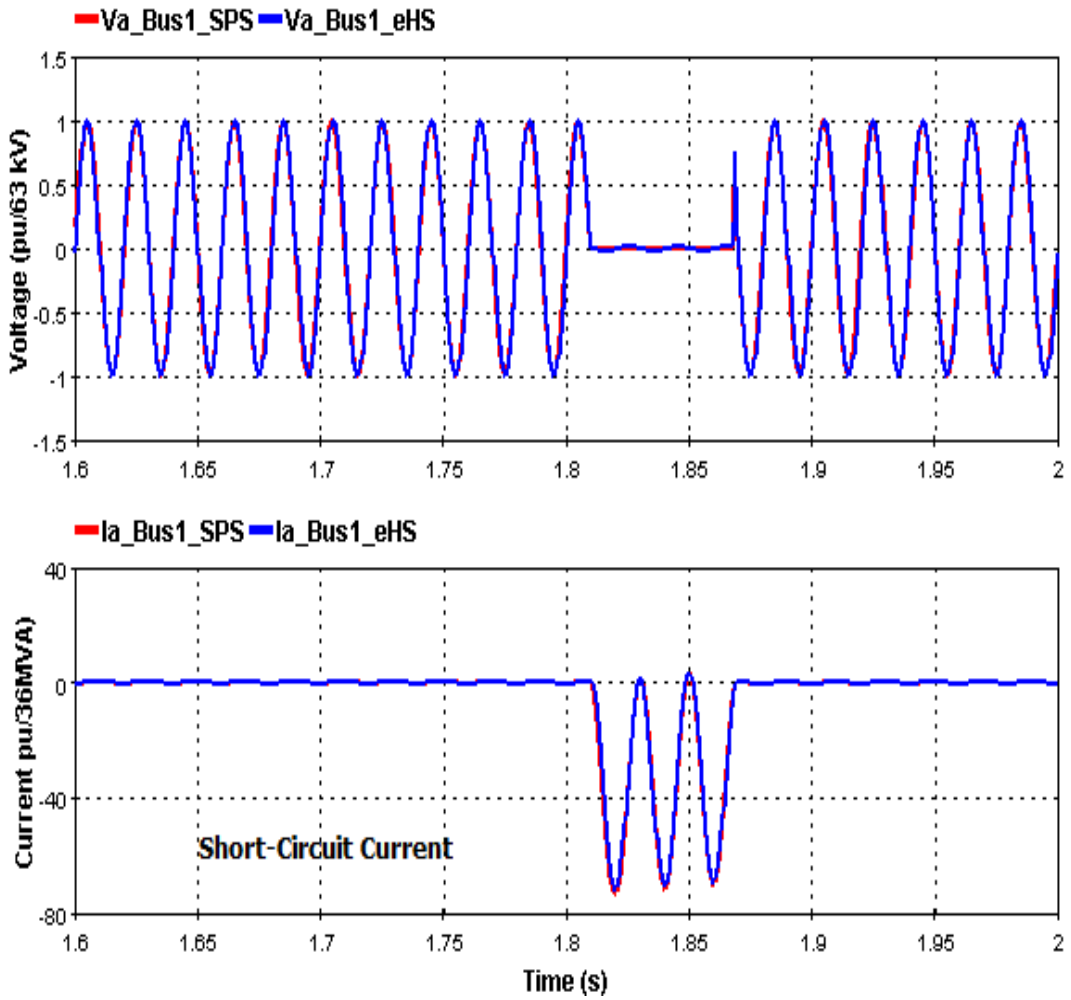
: 41 3-Ph RL Loads

: 64 3-Ph Bus Bar

: 5 3-Ph Breaker Circuit

OPAL-RT TECHNOLOGIES

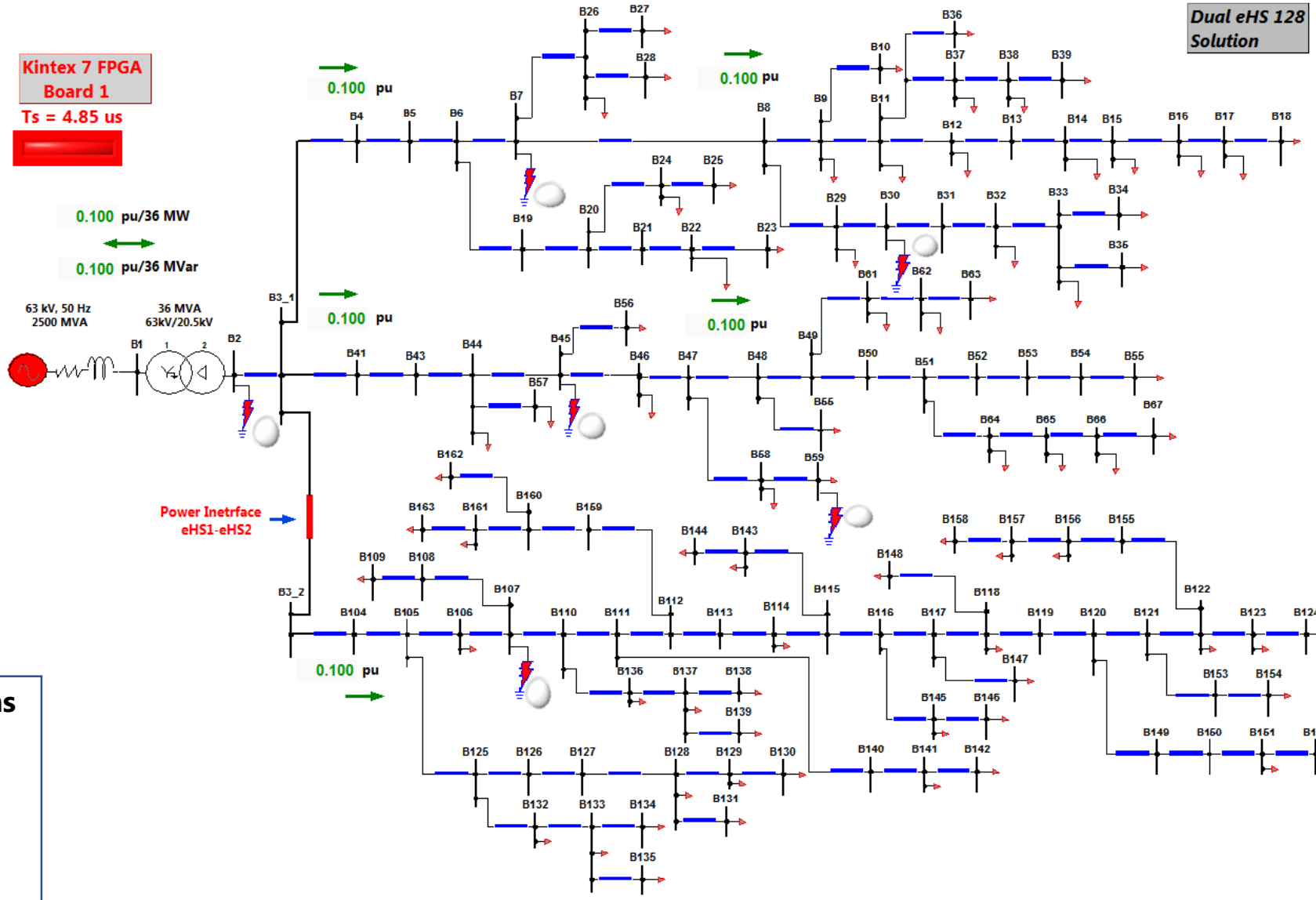
SPS offline vs eHS



OPAL-RT TECHNOLOGIES

DISTRIBUTION GRIDS

1 FPGA



: 125 3-Ph RL connections

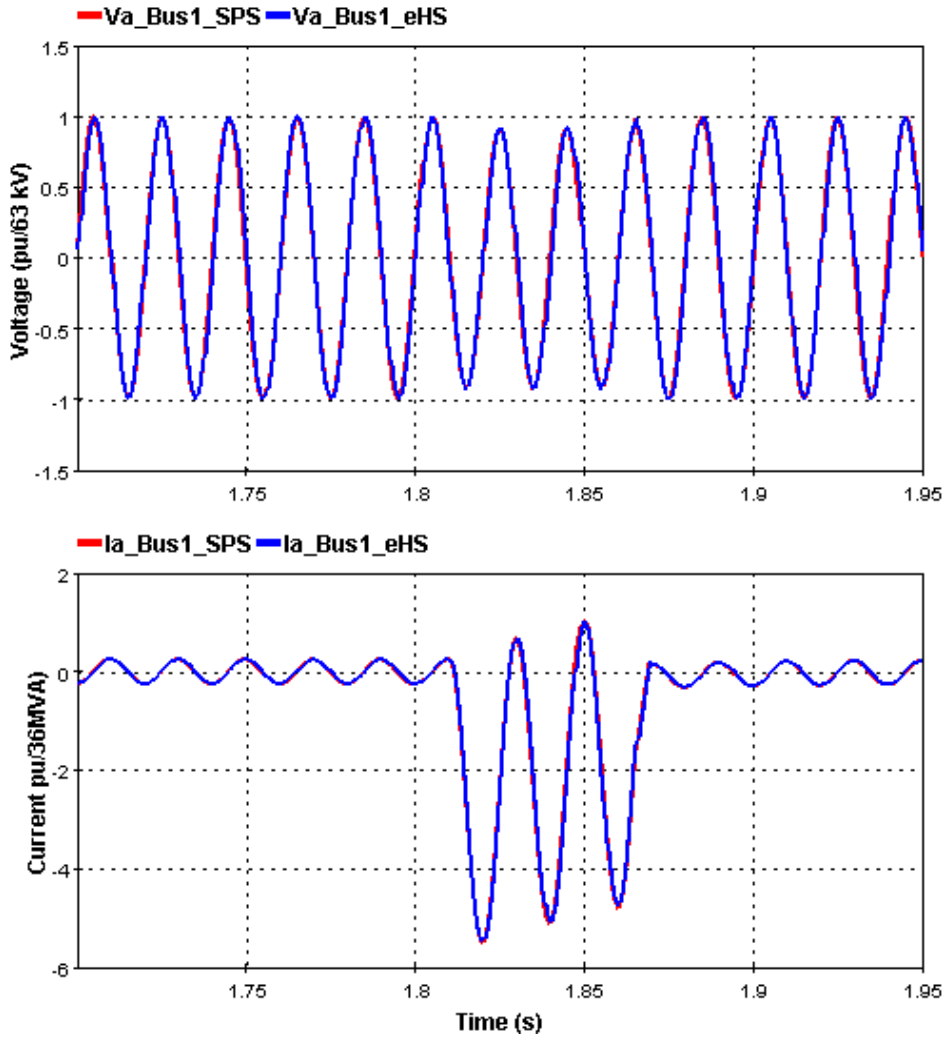
: 80 3-Ph RL Loads

: 129 3-Ph Bus Bar

: 5 3-Ph Breaker Circuit

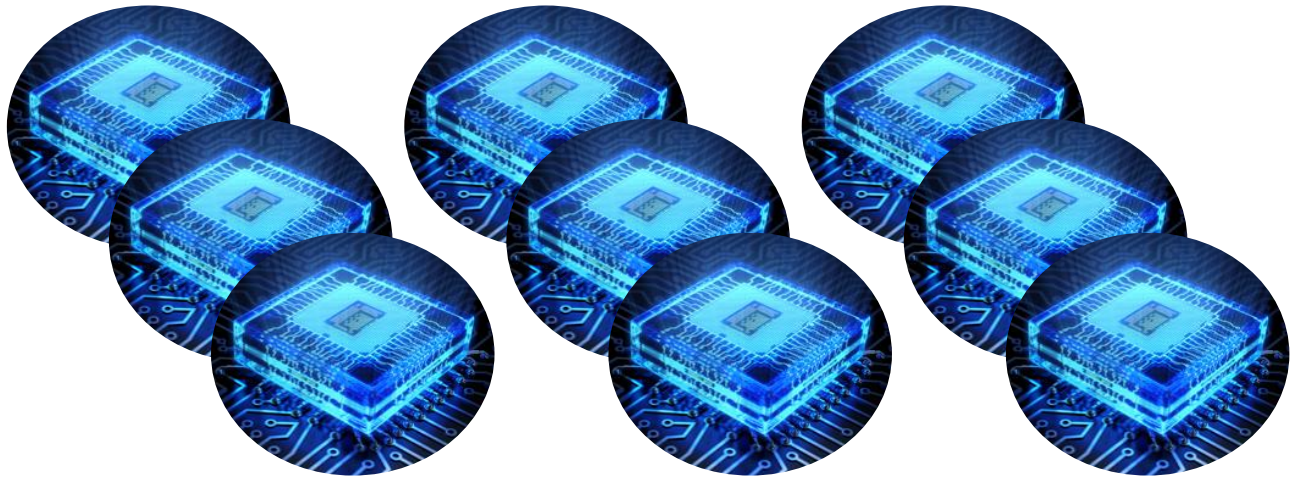
DISTRIBUTION GRIDS

SPS offline vs eHS



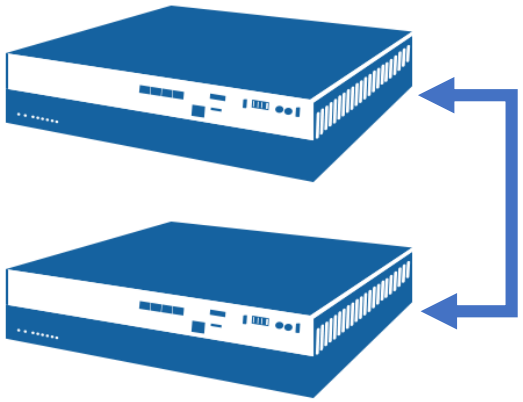
DISTRIBUTION GRIDS

- Reaching FPGA limits
- Future : **multi-FPGA** setups

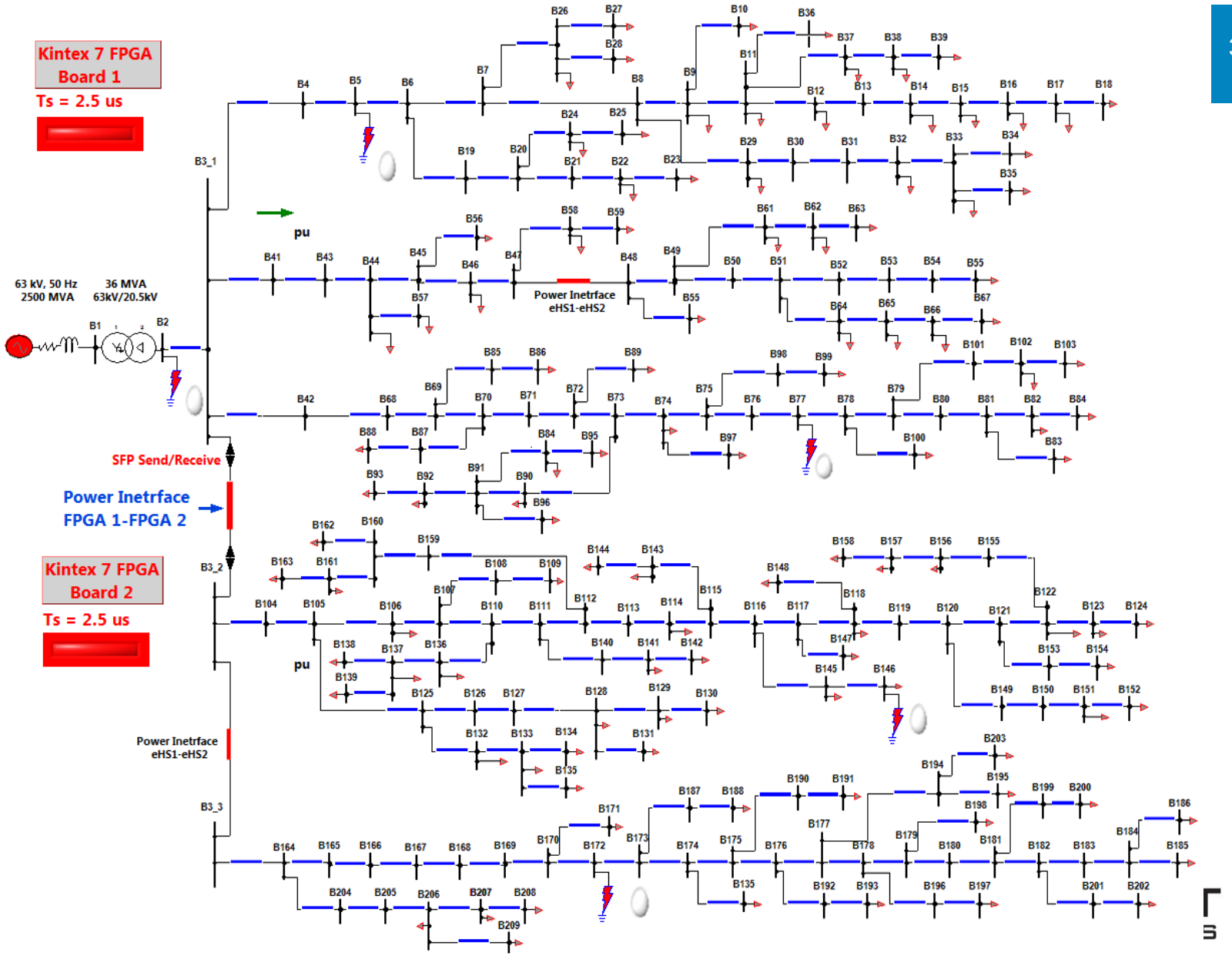


OPAL-RT TECHNOLOGIES

DISTRIBUTION GRIDS



2 FPGAs



: 208 3-Ph RL connections

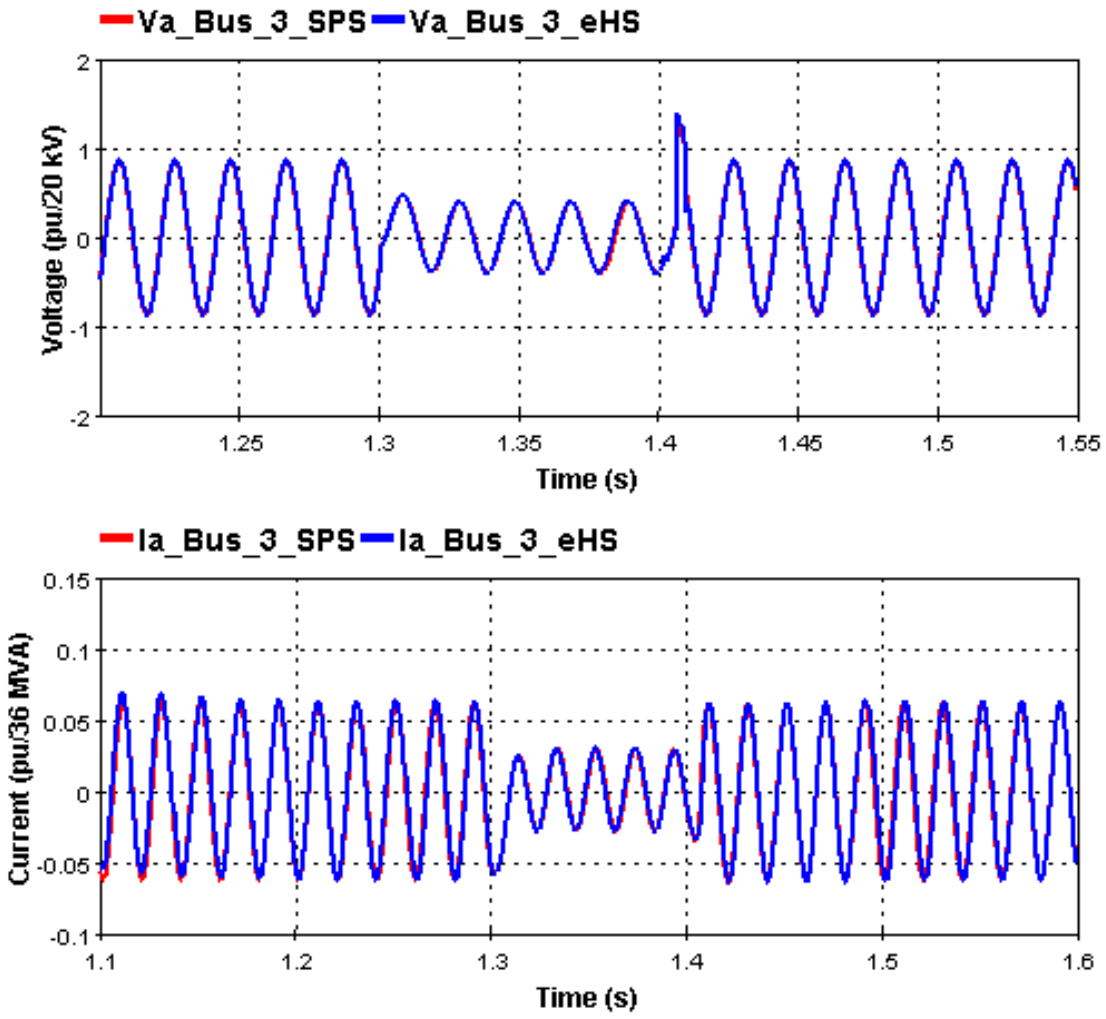
: 124 3-Ph RL Loads

: 210 3-Ph Bus Bars

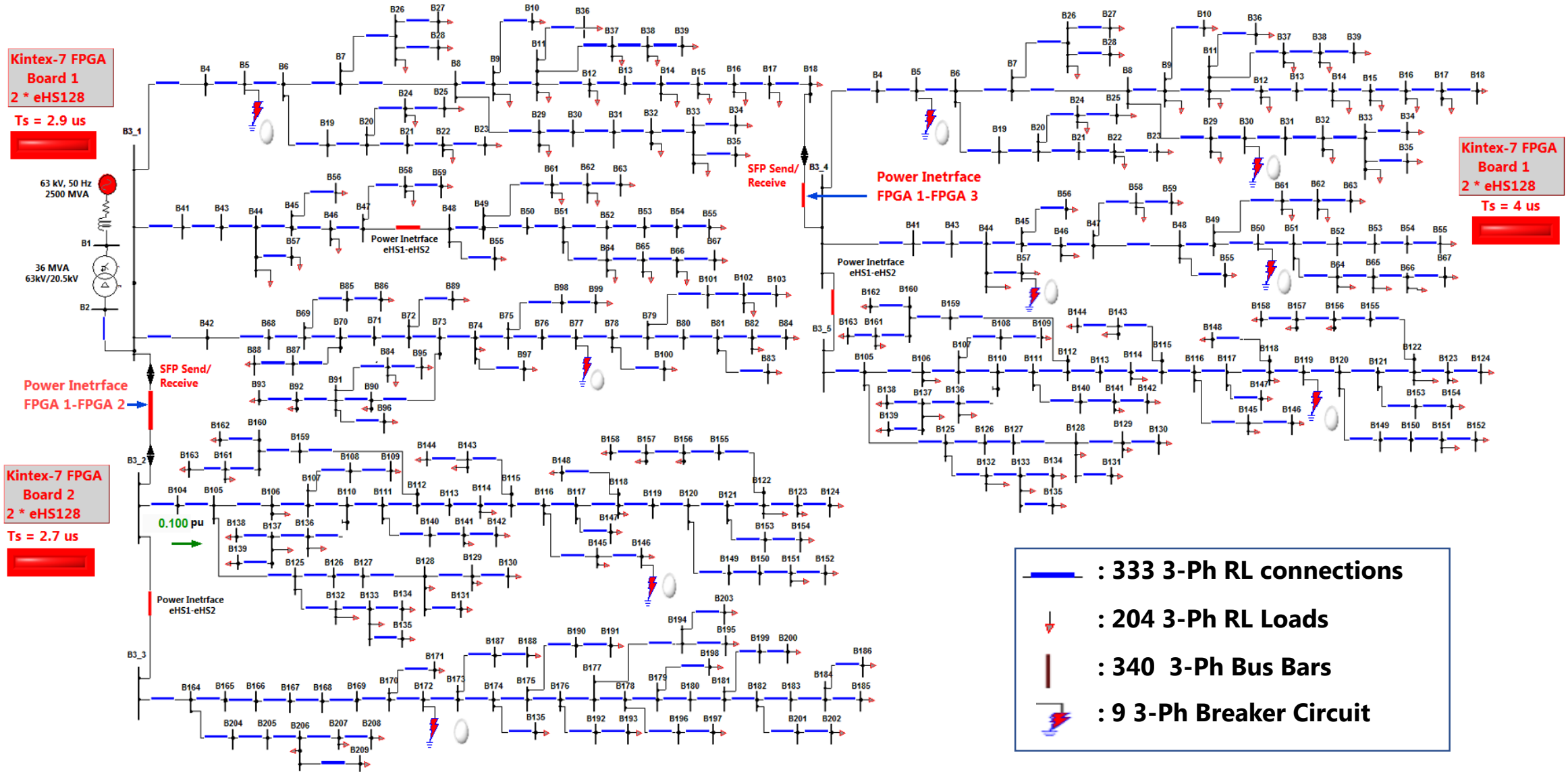
: 5 3-Ph Breaker Circuit

DISTRIBUTION GRIDS

SPS offline vs eHS

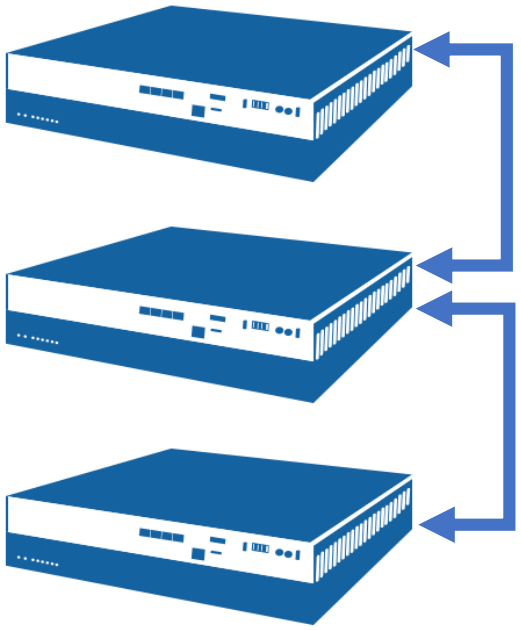


DISTRIBUTION GRIDS

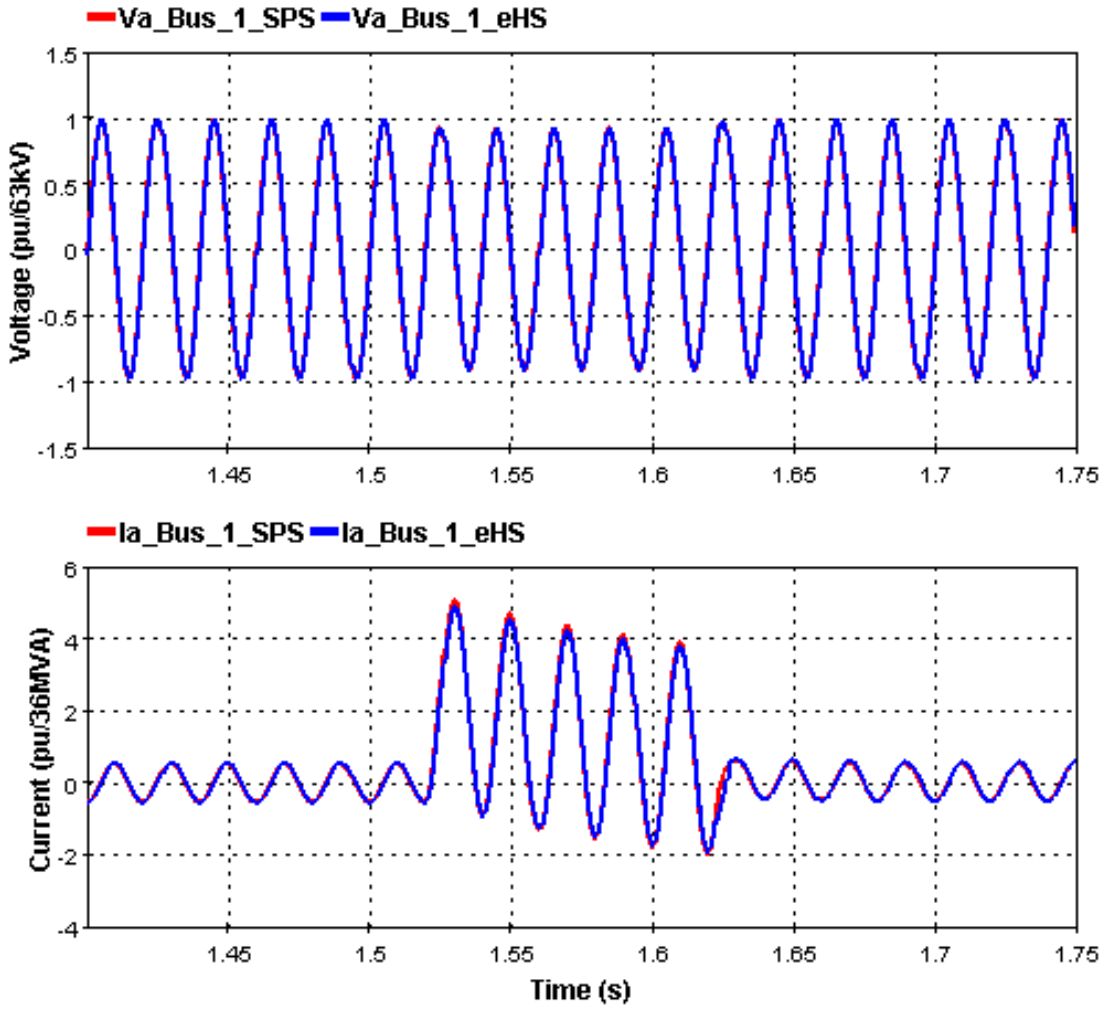


DISTRIBUTION GRIDS

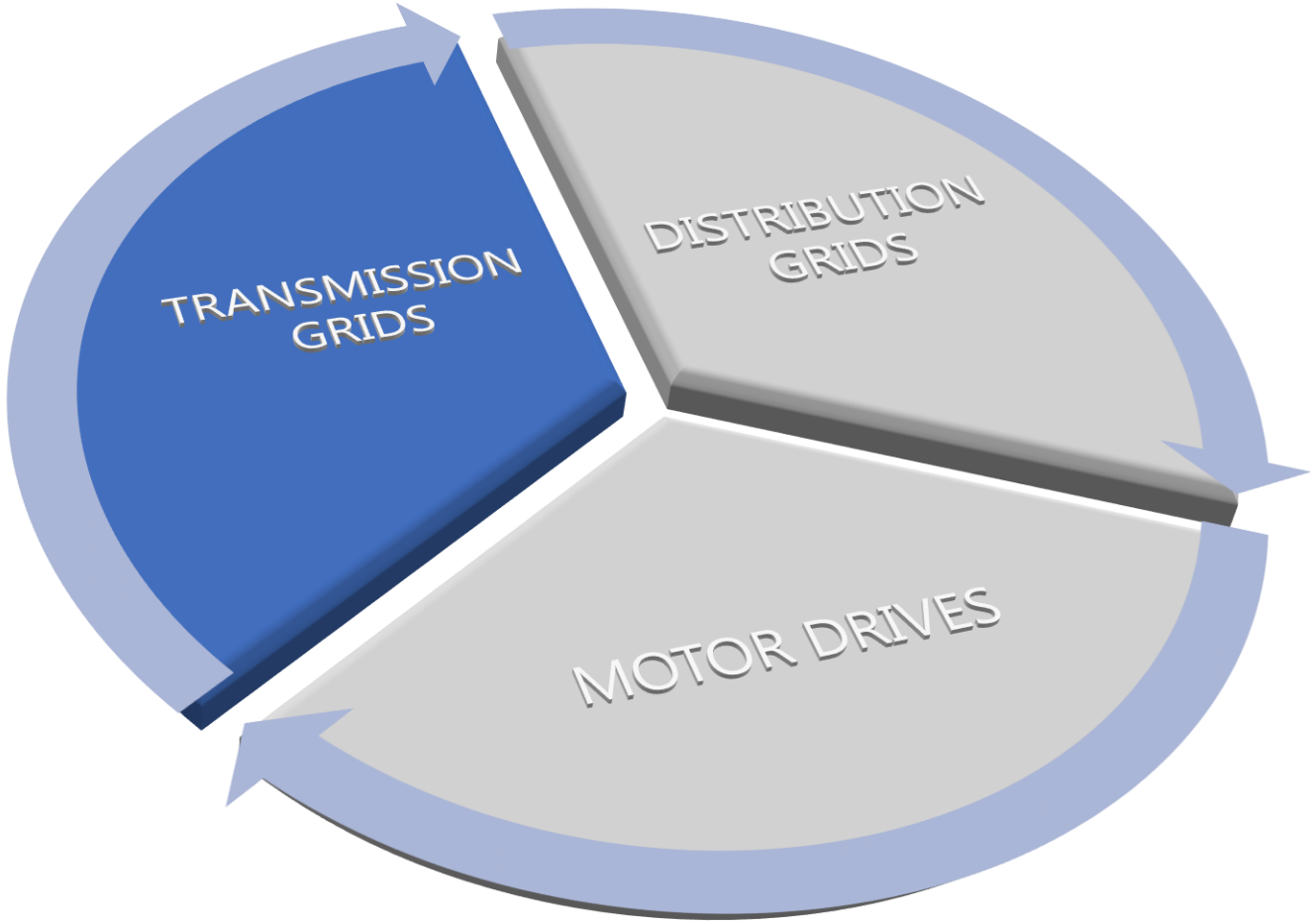
SPS offline vs eHS



3 FPGAs



APPLICATION CASES

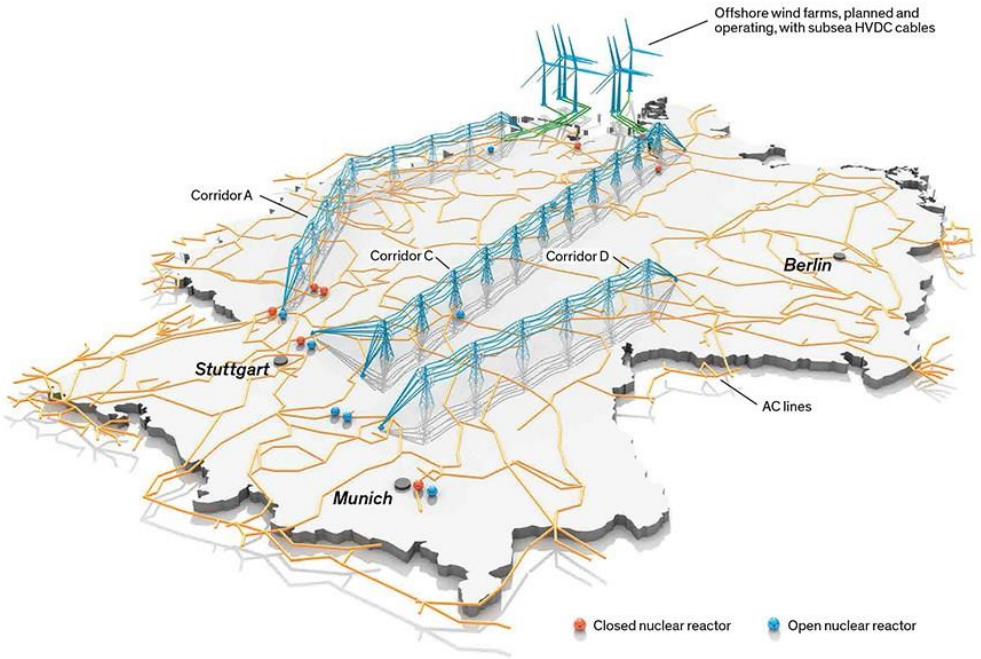


OPAL-RT TECHNOLOGIES

TRANSMISSION GRIDS

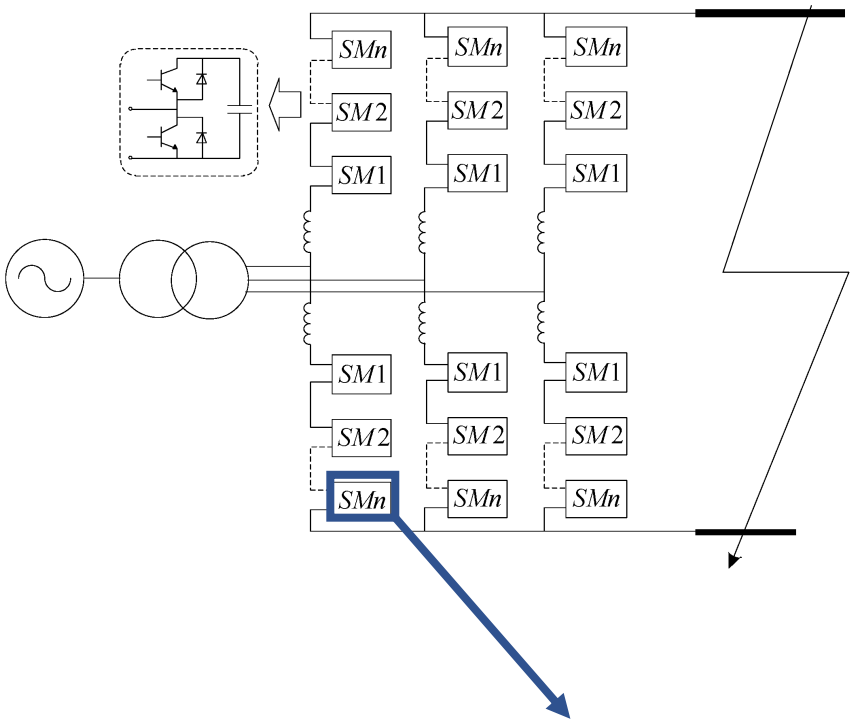
HVDC : **H**igh **V**oltage **D**irect **C**urrent

- Transmission lines
- Many advantages vs HVAC
  - Less electrical losses
  - Easy decoupling of AC grids
  - Better controllable
  - Cost affordable for longer distances
- **MMC** stations



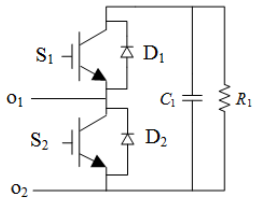
Credit: CarbonNation

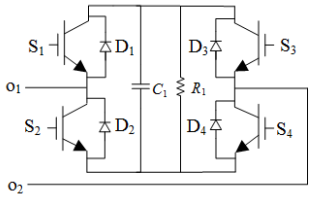
OPAL-RT TECHNOLOGIES

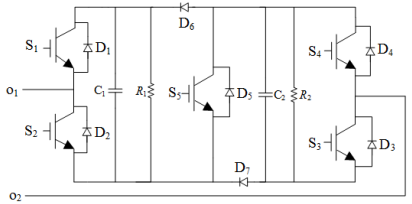


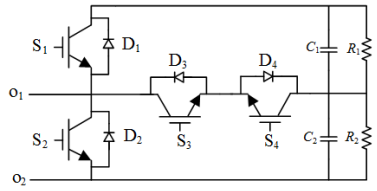
MMC: Types of submodules

- Half-Bridge
- Full-Bridge
- Clamp-Double
- T-Type









OPAL-RT TECHNOLOGIES

TRANSMISSION GRIDS

Example of MMC-HVDC link **INELFE** (Spain-France)

- 401-levels
- 4800 half-bridge submodules
- 9600 IGBTs

How to simulate such a complex system in **real-time**?

Source: www.siemens.com

OPAL-RT TECHNOLOGIES

Challenges

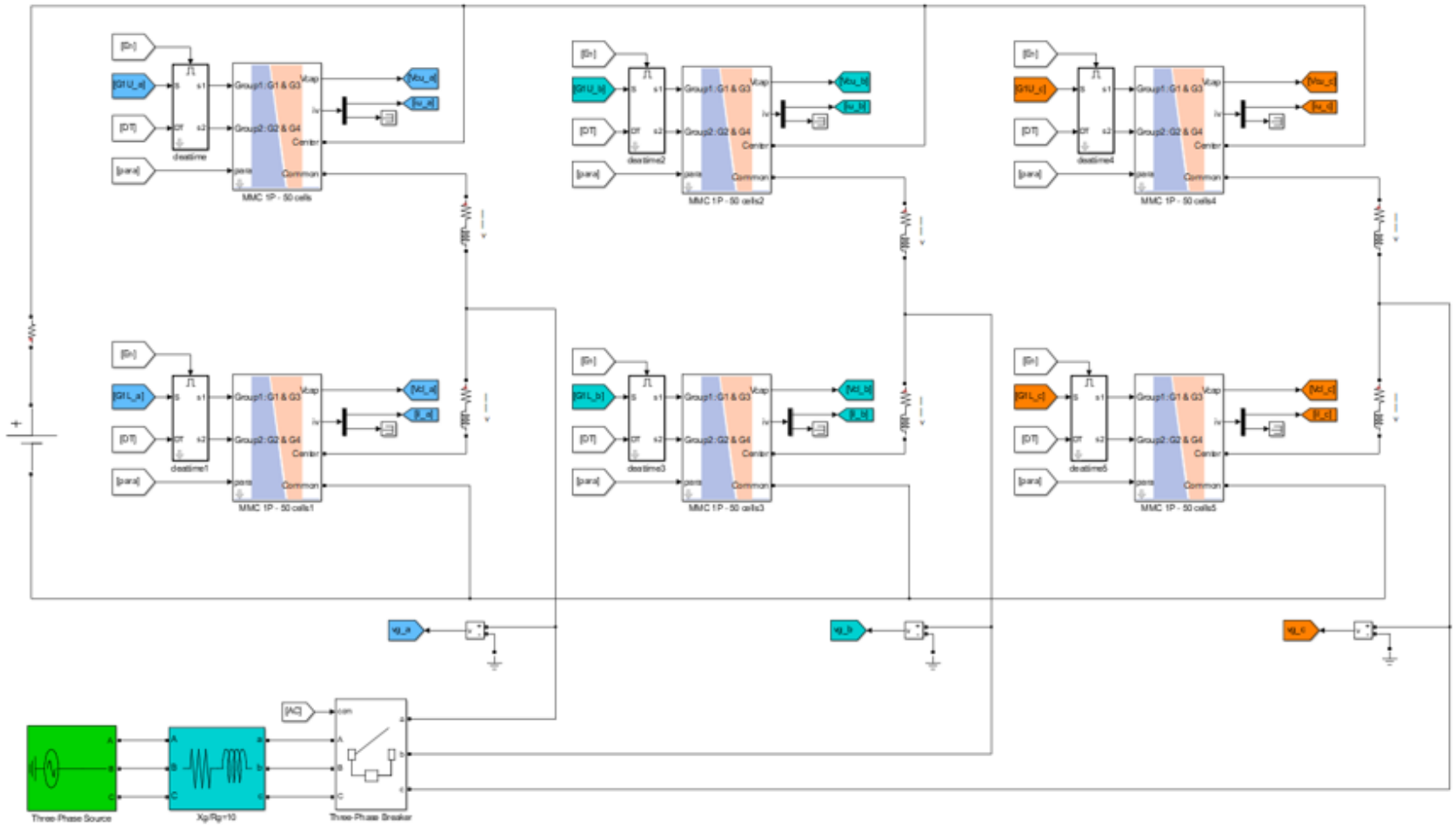
- Complexity of converter
- Complexity of control
- Complexity of signal management
- Communication between control and converters/station

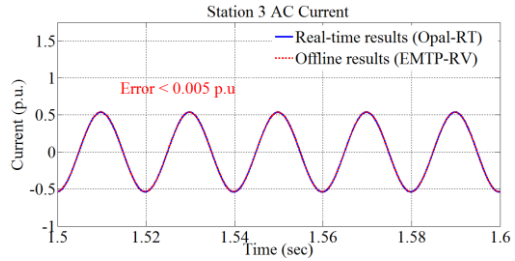
TRANSMISSION GRIDS

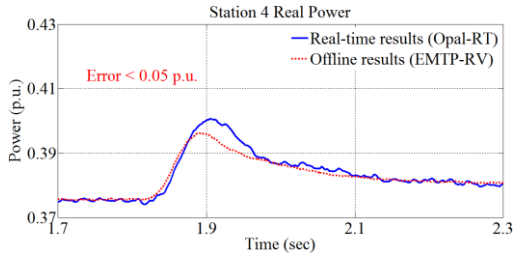
Solution

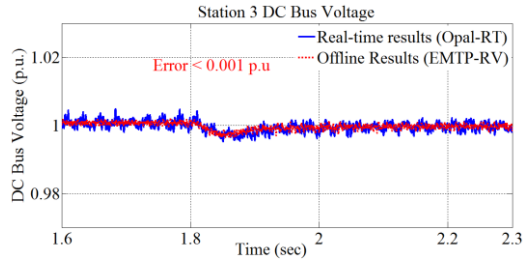
- FPGA Simulation of MMC
- Up to **6000 submodules** per FPGA
- **250 ns** time step
- Connection with controller : Aurora or Gigabit Ethernet
- Co-simulation with CPU which runs the station and grid models

TRANSMISSION GRIDS



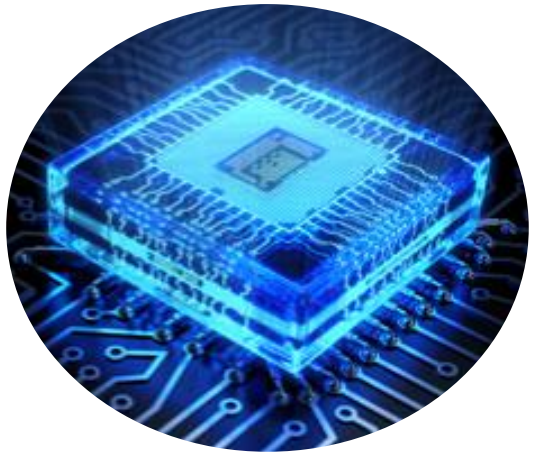




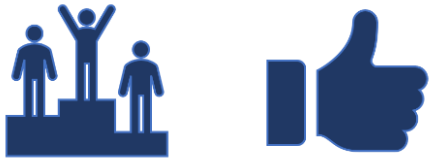


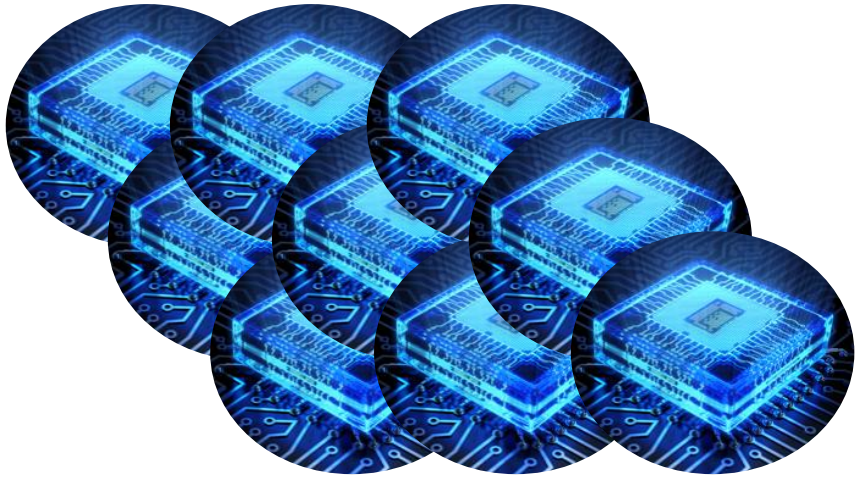
OPAL-RT TECHNOLOGIES

CONCLUSION



OPAL-RT






FROM
IMAGINATION...
TO REAL-TIME