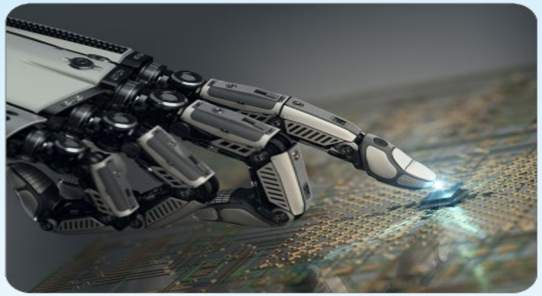
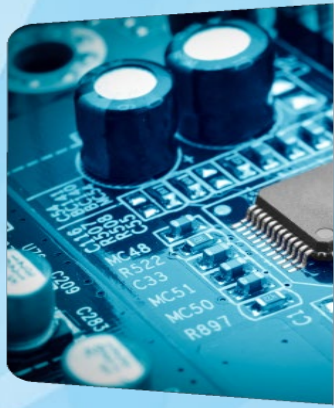






Challenges in Real-time Simulation of Power Electronics Enabled Power Systems

Adrien Genic, Typhoon HIL

IEEE

Outline

- Introduction
- What real-time simulation is
- Why do we need real-time simulation
- Technical challenges in RT simulation of PE enabled PS
- Application examples

Typhoon HIL, Inc.

- Founded in 2008
- Stata Ventures backed
- Headquarters in Cambridge, MA, USA
- Two fully owned subsidiaries:
  - Typhoon HIL GmBH, Baden, Switzerland
  - Tajfun HIL doo Novi Sad, Serbia

Typhoon HIL, Inc. Leadership

Ray Stata, Chairman of the Board
Co-founder of Analog Devices, Inc. (ADI), in 1965. and CEO from 1971 - 1996
Awards
1990 Elected to the American Academy of Arts and Sciences
1992 Elected to the National Academy of Engineering
2003 Recipient of the IEEE Founder's Medal

John D. Joannopoulos, Board Member and Founder
MIT Professor of Physics 1974-

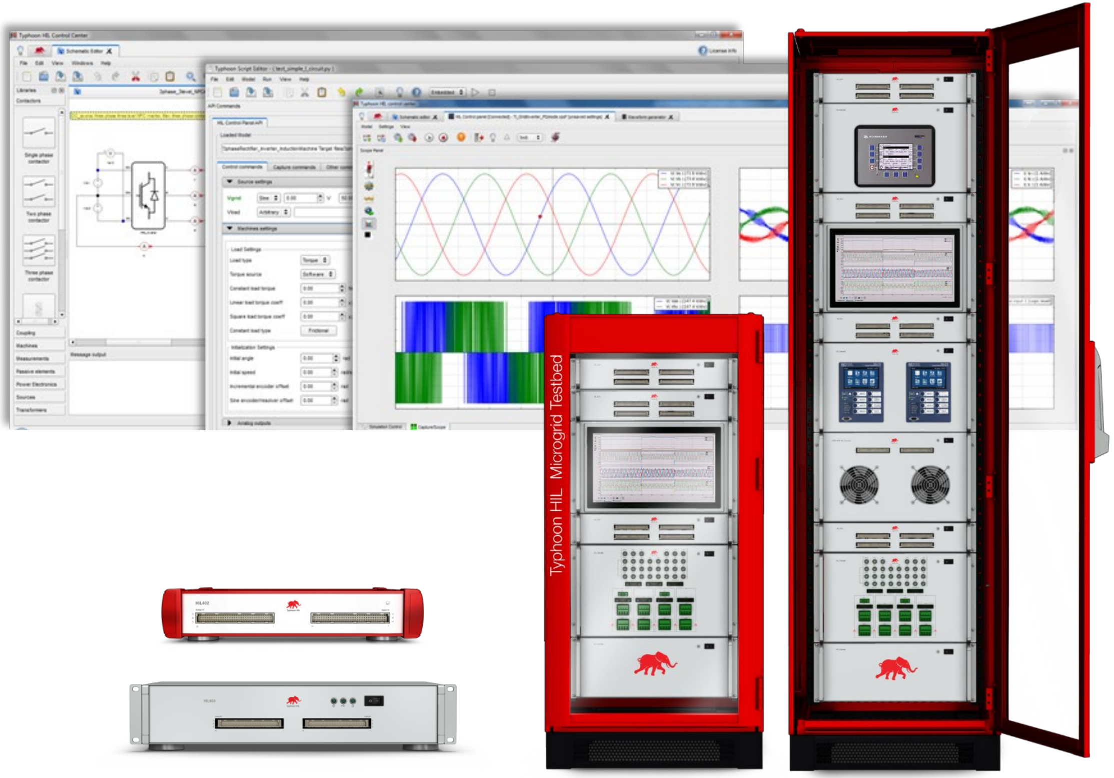
Director of the MIT Institute for Soldier Nanotechnologies 2006- Co-founder of OmniGuide, Luminus Devices, WiTricity, Typhoon HIL. National Academy of Sciences Member, and a Fellow of the American Association for the Advancement of Science (2002); Author and co-author of 500 refereed scientific journal articles From 2003 on the Thompson ISI most Highly Cited Researchers list

Nikola Fischer Celanovic, Chief Executive Officer / Founder / Board Member
Lead the team that developed both the theoretical algorithms and experimental validation of the world's first 1us ultra-low latency Hardware-in-the Loop (HIL) real-time emulator platform for power electronics. Prior to founding Typhoon HIL he was with the ABB Drives Development Department, Turgi, Switzerland. Previously he was with the ABB Research Center, Baden-Dättwil, Switzerland. He holds a Ph.D. degree from Virginia Polytechnic Institute and State University, Blacksburg in 1995, an M.S. degree in mechanical engineering from the Vanderbilt University, Nashville, TN, and a B.S. degree in electrical engineering from the University of Novi Sad, Serbia.

Ivan Celanovic, Chief Business Development Officer / Founder / Board Member
Member of the team that developed both the theoretical algorithms and experimental validation of the world's first 1us ultra-low latency Hardware-in-the Loop (HIL) real-time emulator platform for power electronics. He is responsible for business development, technology and product development vectors, and innovation. He holds an Sc.D. degree from the Massachusetts Institute of Technology (MIT), Cambridge, an M.Sc. degree from Virginia Polytechnic Institute and State University, and a Diploma Engineer degree from the University of Novi Sad, Republic of Serbia, all in electrical engineering and computer science.

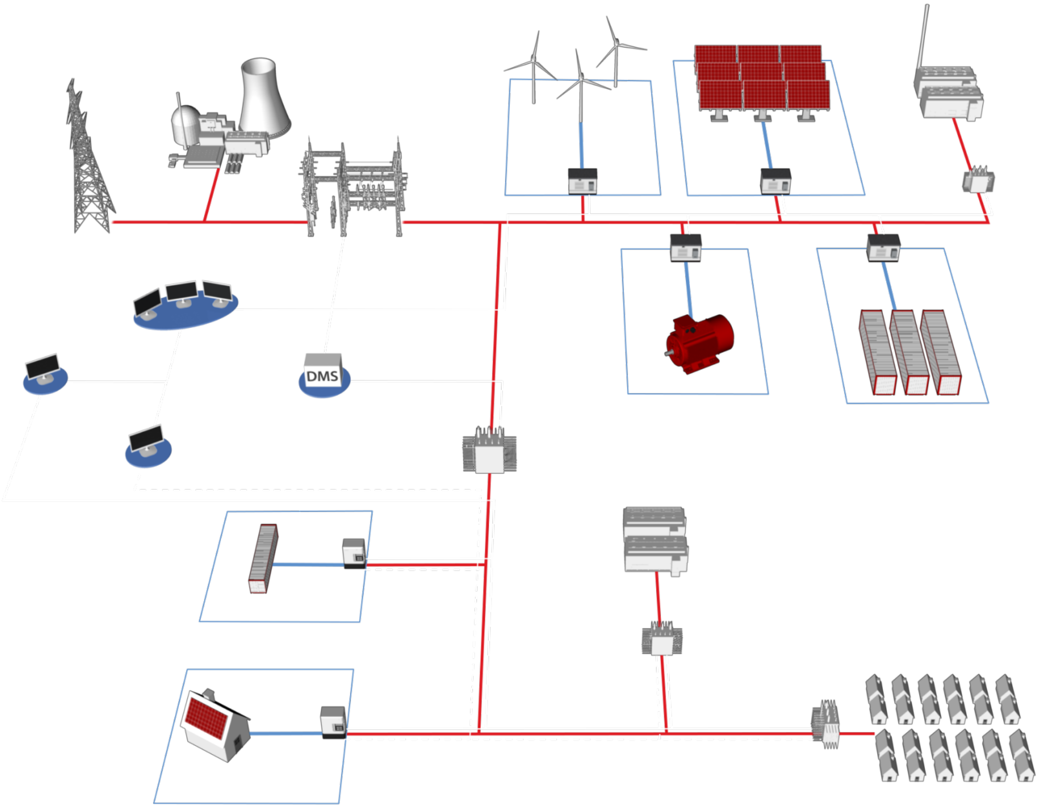
Real-time simulation and HIL infrastructure

- Software
- Hardware
- Services



D3 - the reason

- Digitalization
- Decentralization
- Decarbonization



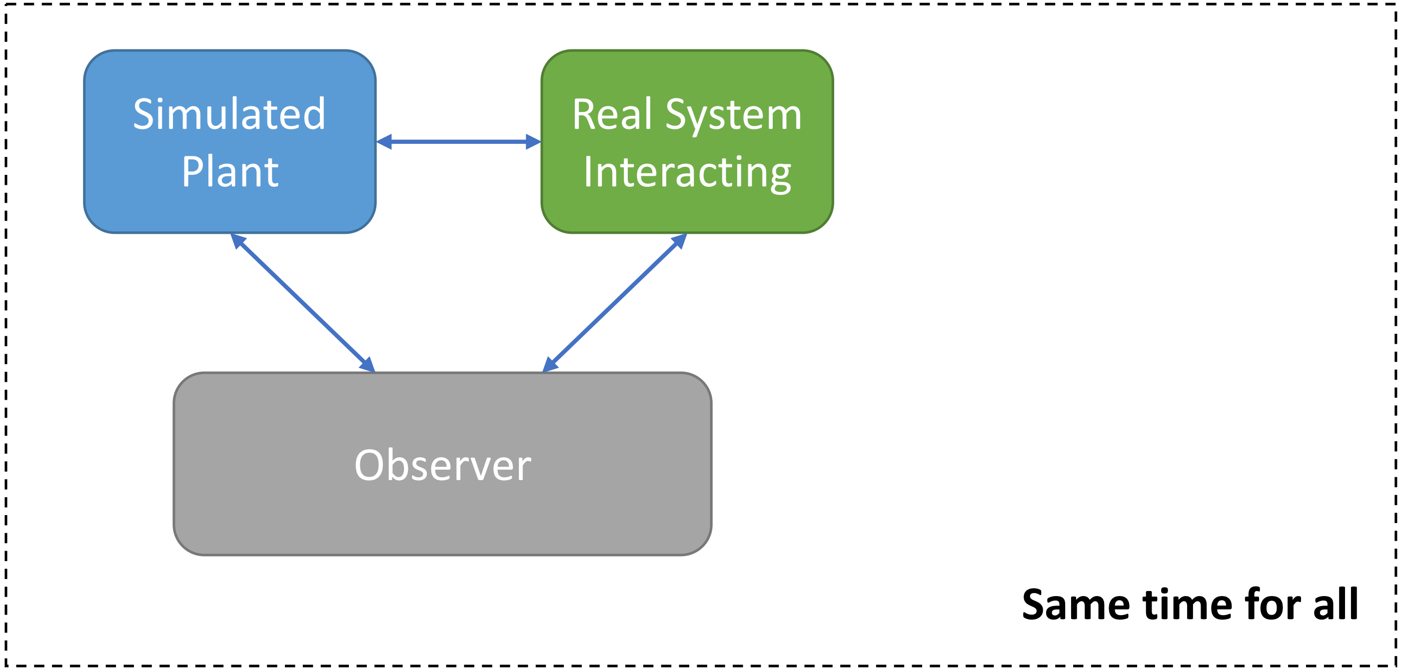
D3 - the reason

- Todays simulation tools are made to model/simulate physical systems.
- The new grid is a Cyber-Physical system ”thanks” too A LOT of software.
- There are no tools that are able to do model cyber-physical systems
- Temporary solution - real systems combined with real time simulation:
  - Model the physics
  - Use the real software from the real system

What is real-time simulation

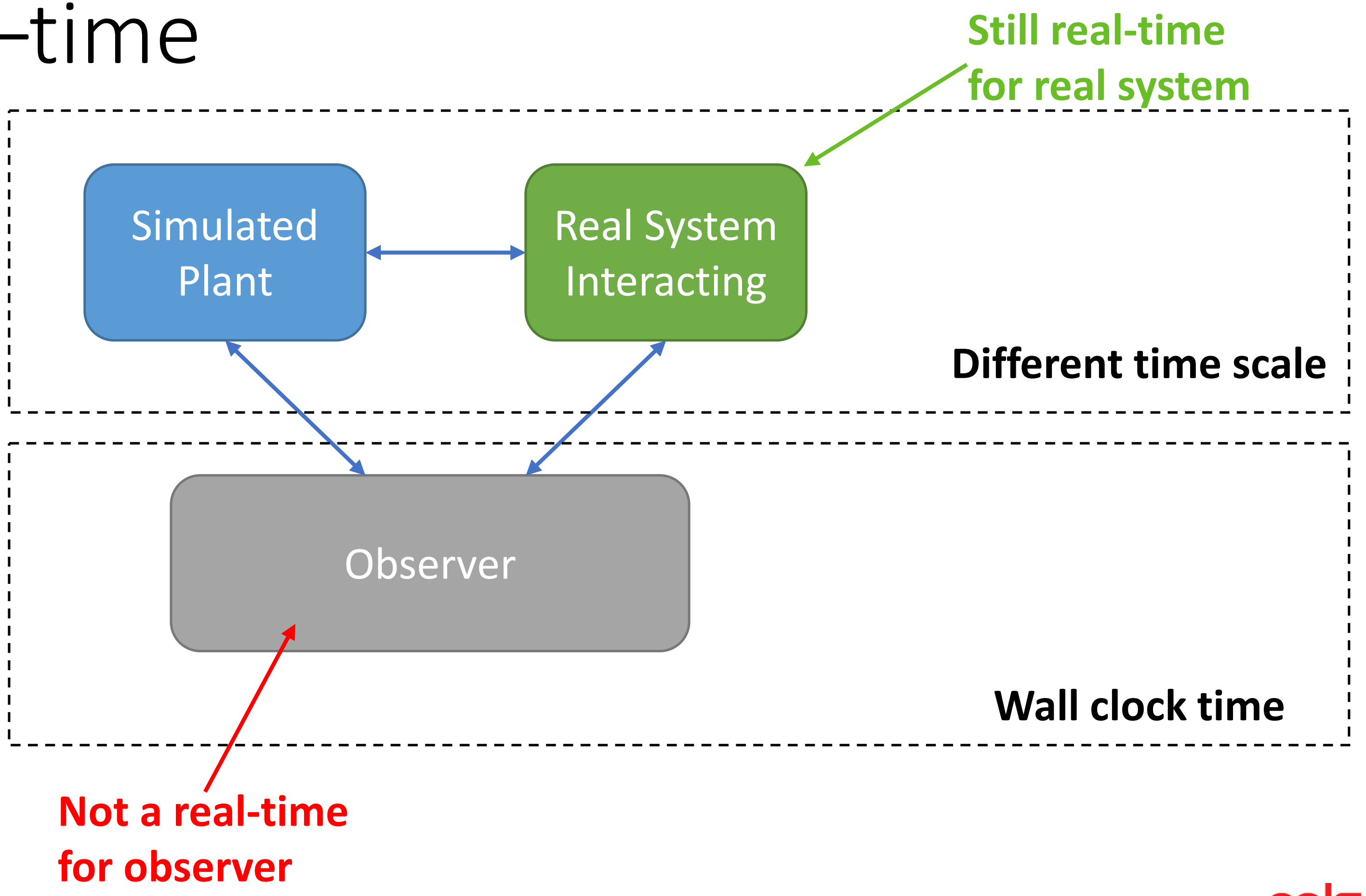
- **Real-time simulation** refers to a computer model of a physical system that can execute at the same rate as actual "wall clock" time. In other words, the computer model runs at the same rate as the actual physical system. For example, if a tank takes 10 minutes to fill in the real-world, the simulation would take 10 minutes as well. *taken from Wikipedia*

Real–time



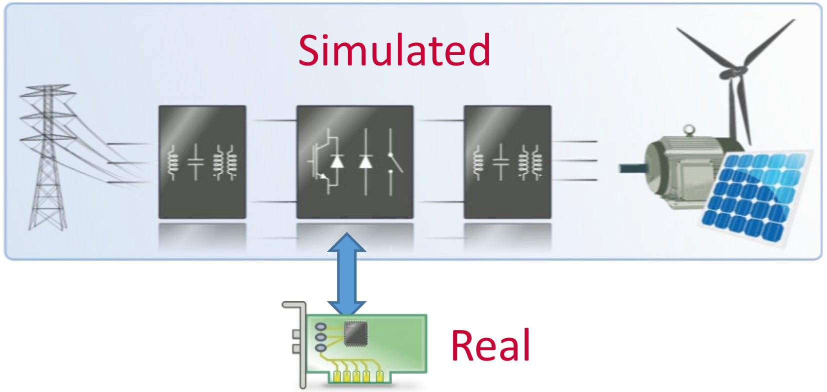
Simulated Plant
Real System Interacting
Observer
Same time for all

Real–time

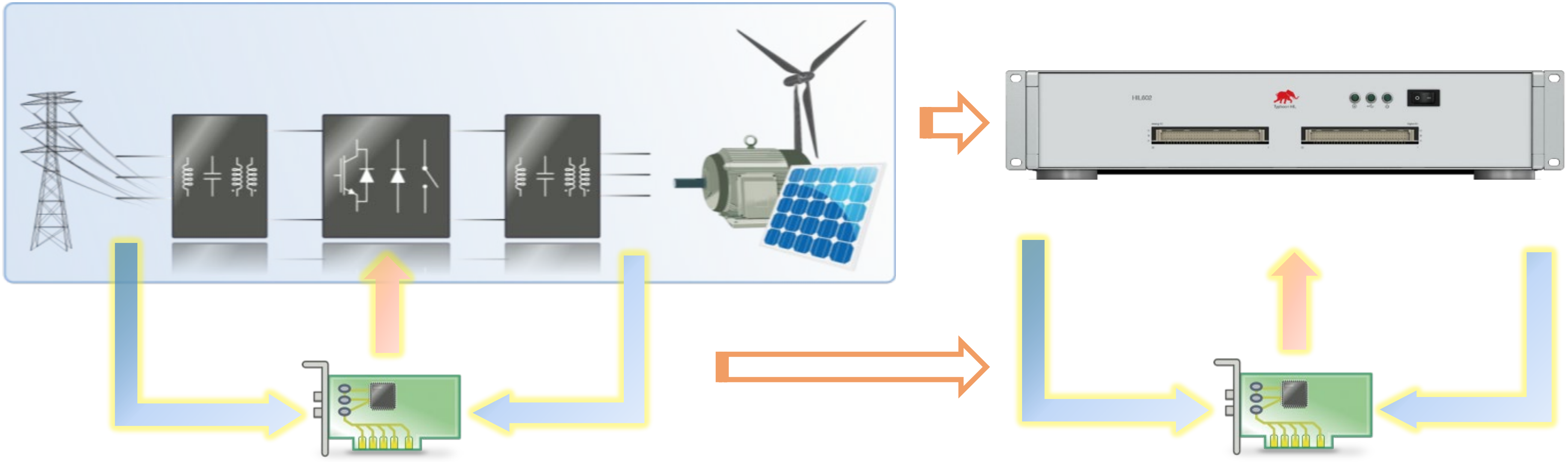

Still real-time
for real system
Simulated
Plant
Real System
Interacting
Different time scale
Observer
Wall clock time
Not a real-time
for observer

In-the-Loop with RT simulation

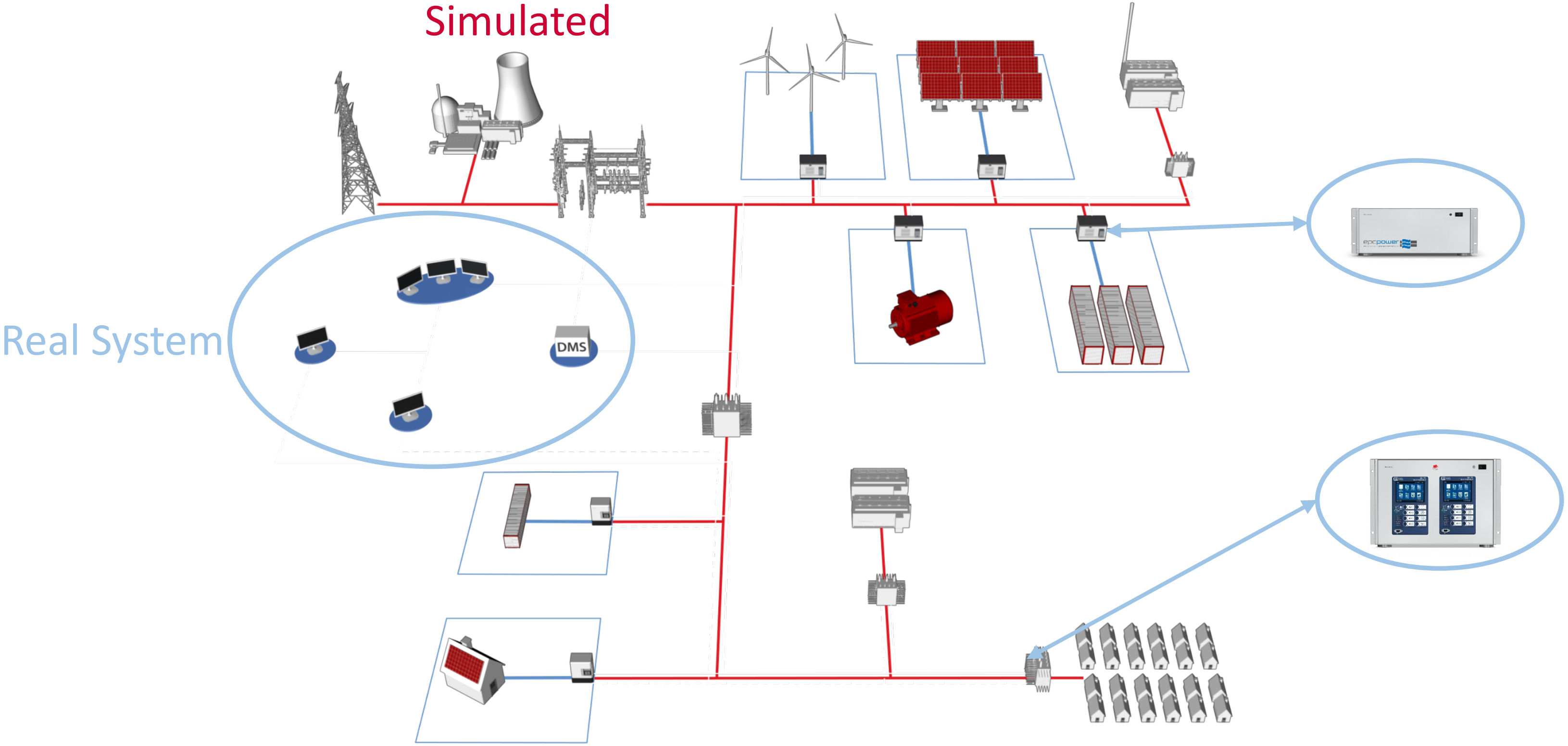
- *Software-In-the-Loop*
- Hardware-In-the-Loop
- Human-In-the-Loop



HIL in Power Electronics



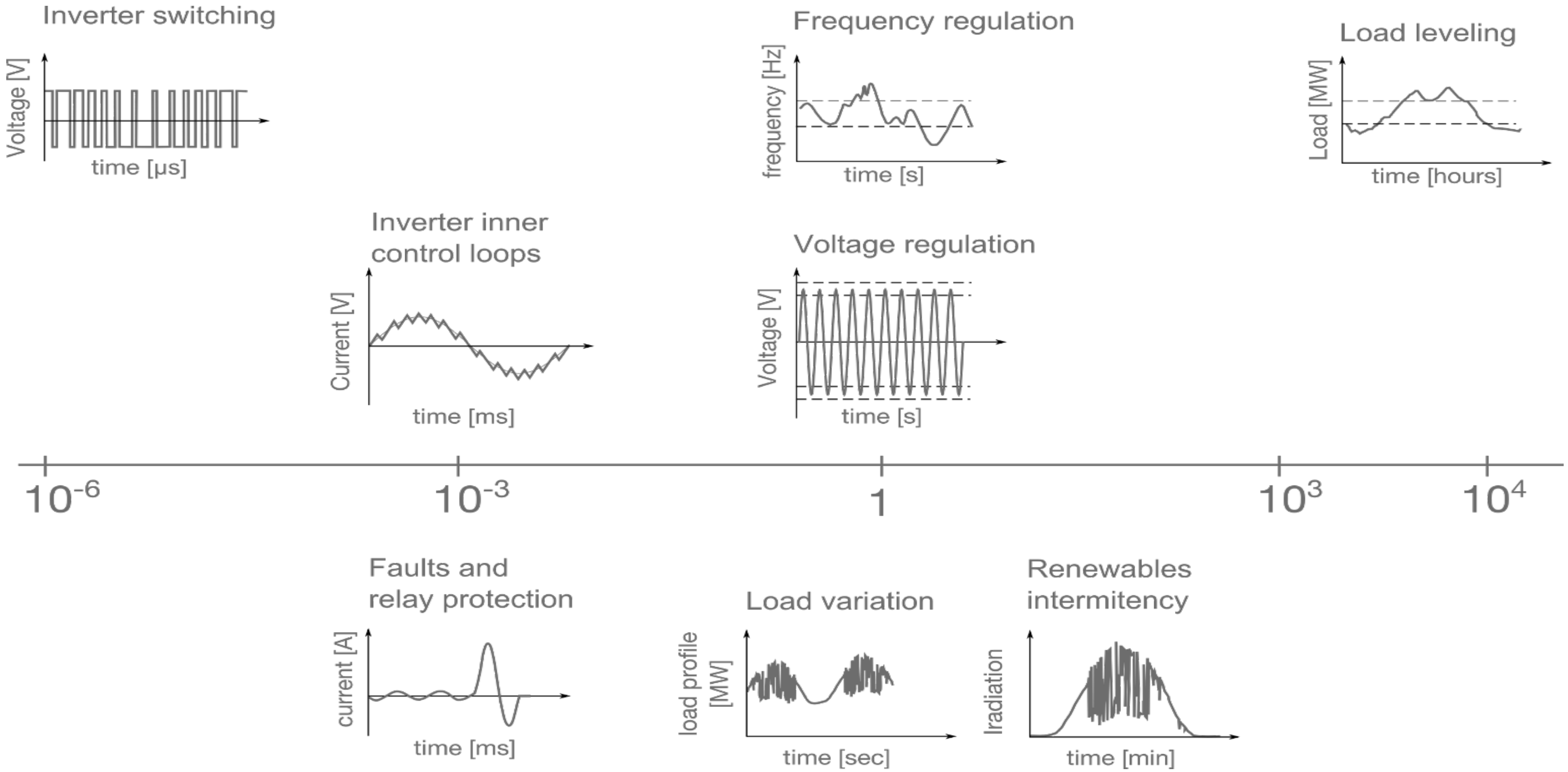
HIL in power system



Challenges for RT simulation

- Time constants from ns to hours
- Large and complex systems
- Model depth
- Model parametrization
- Model validation
- Interfaces
- Software tools
- Dedicated hardware and processors

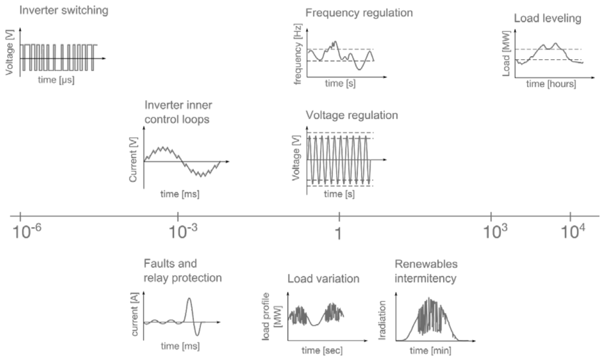
Time scales of interest



Time scales of interest

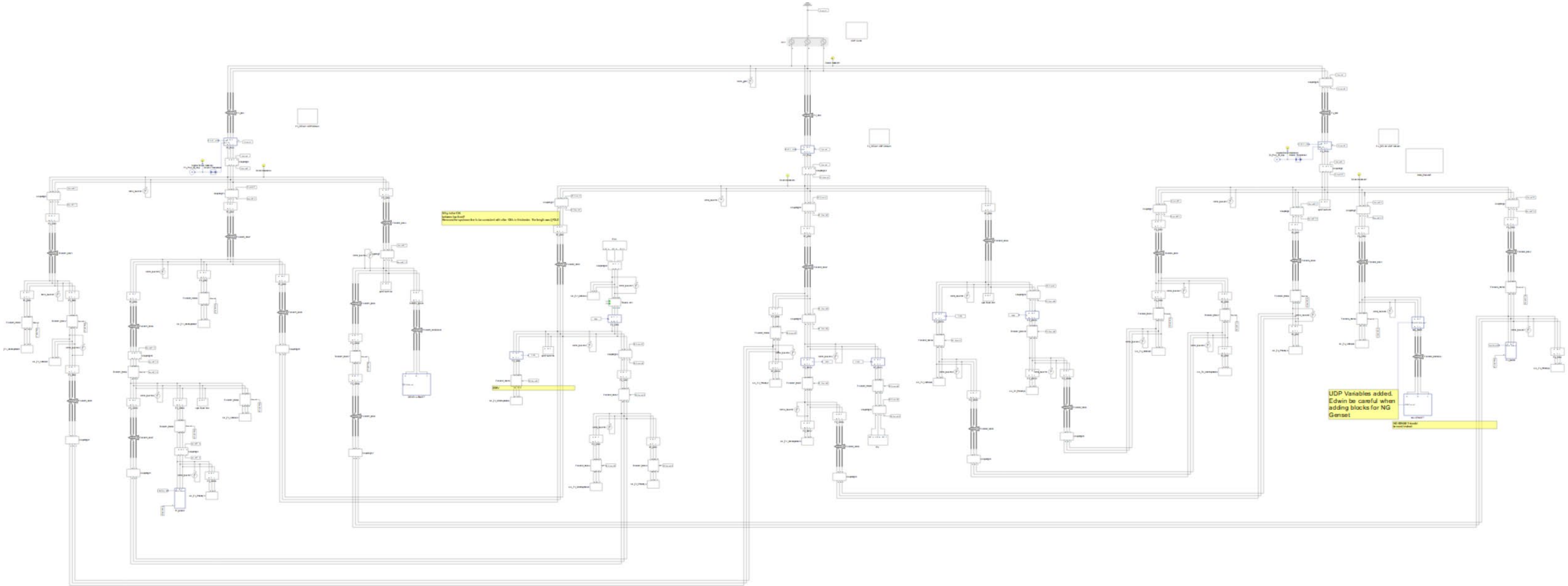
- Events oversampling and compensation – 20ns
- Small simulation time steps – 0.5us
- Long simulation run times – days/weeks

- Ensuring long term stability
  - no “slightly” unstable poles in the system (due to numerics and arithmetics)



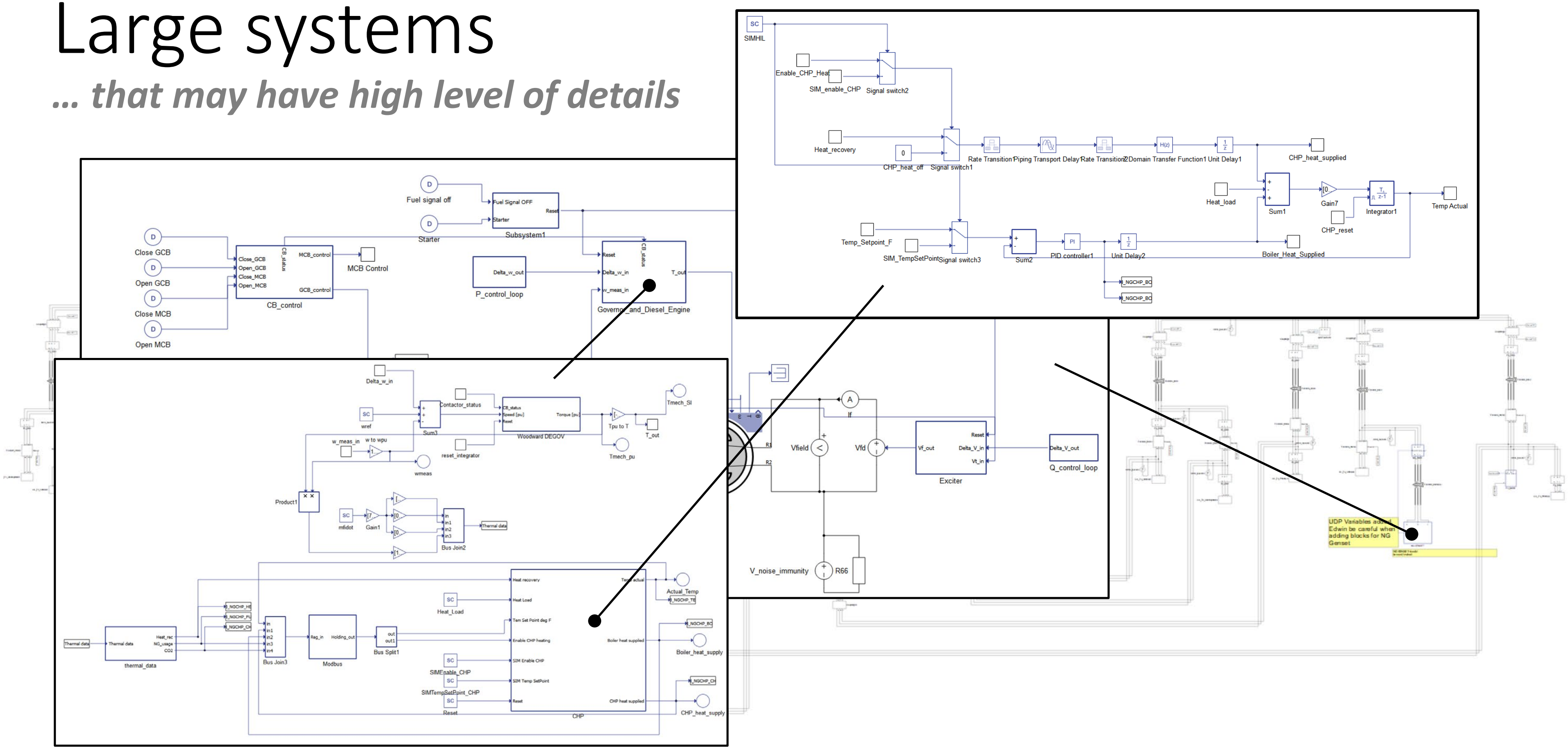
Large systems

… that may have high level of details



Large systems

… that may have high level of details



Large systems

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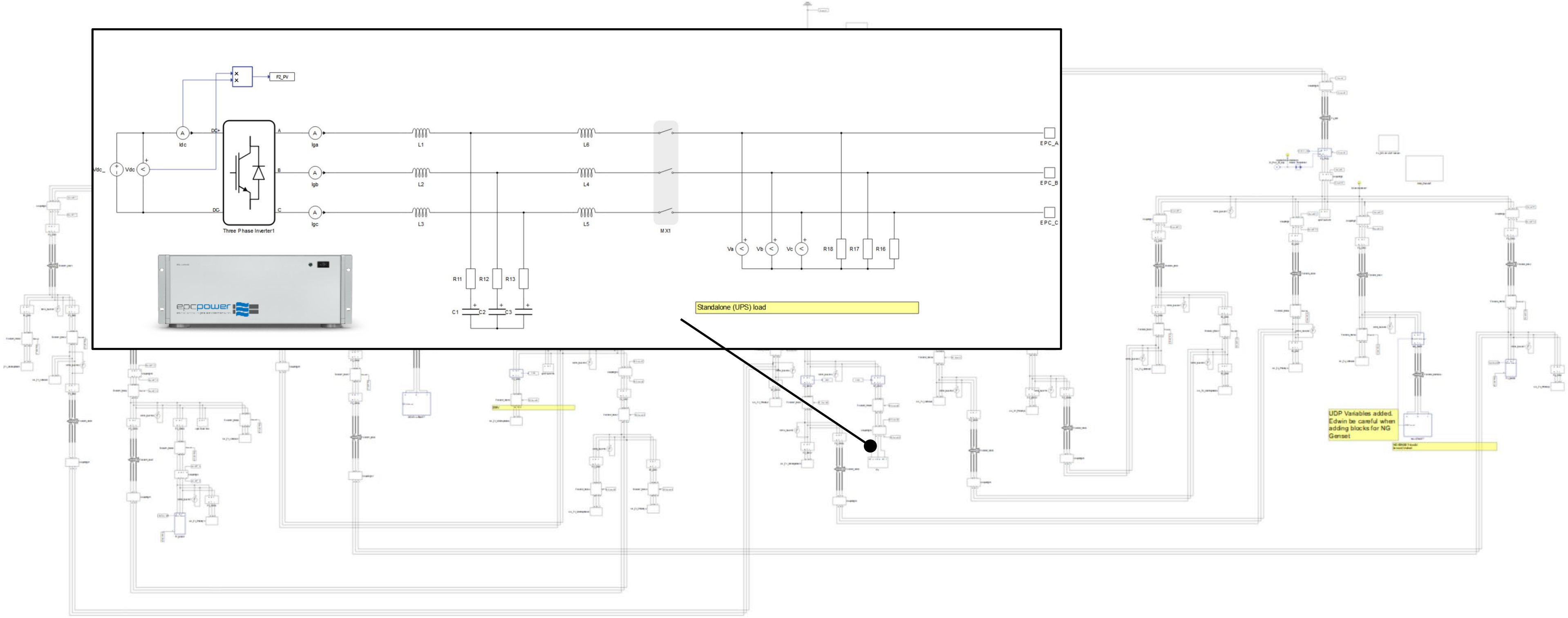
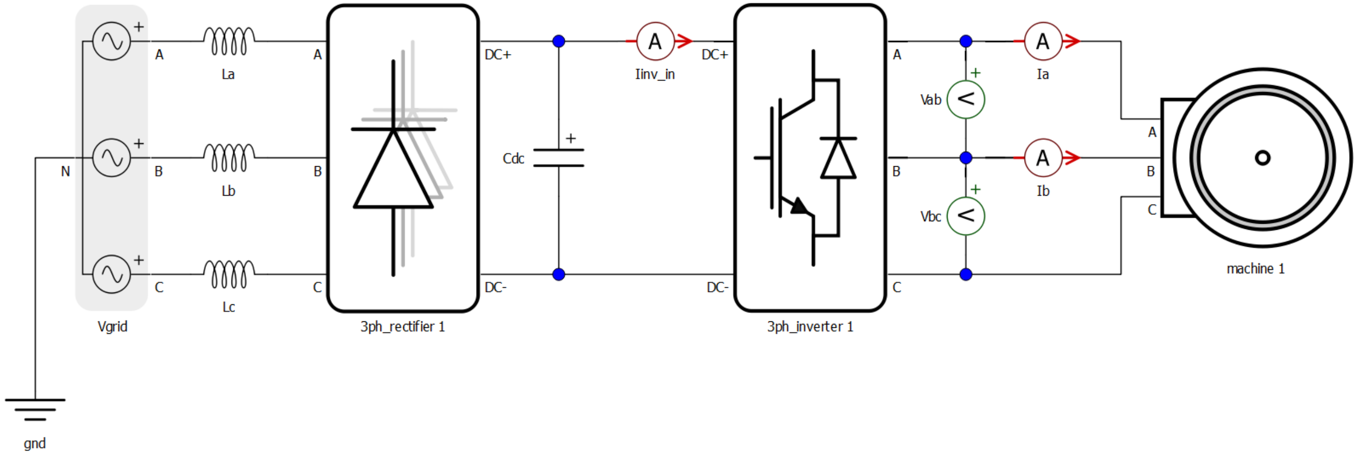


Large systems

… that may have high level of details

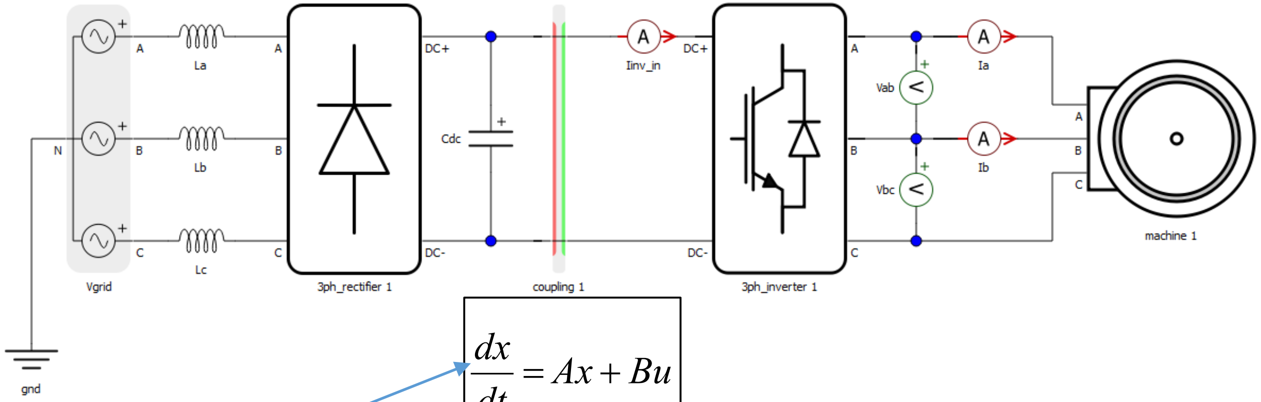
- Model partitioning and parallel computing



Large systems

… that may have high level of details

- Model partitioning and parallel computing



$$\frac{dx}{dt} = Ax + Bu$$
$$y = Cx + Du$$

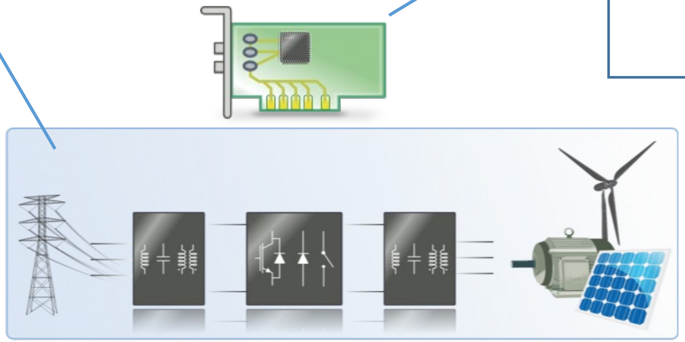
$$\boxed{\begin{aligned} \frac{dx}{dt} &= Ax + Bu \\ y &= Cx + Du \end{aligned}}$$

$$\boxed{\begin{aligned} \frac{dx}{dt} &= Ax + Bu \\ y &= Cx + Du \end{aligned}}$$

Model depth and details

What is the suitable level of depth and details

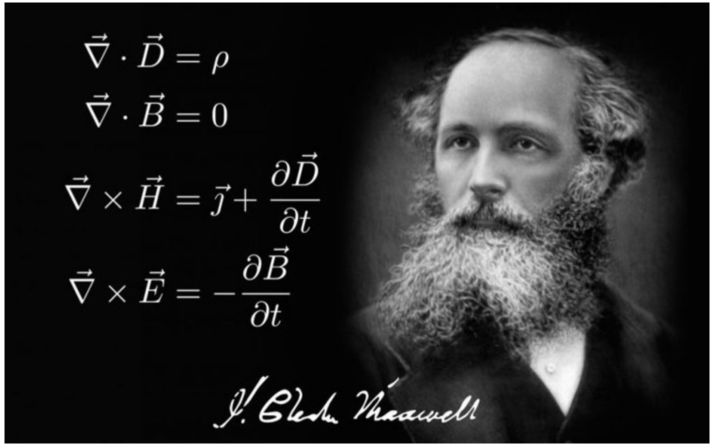
- Non-linearities
- Average Models
- Switching devices
- Parasitics



- Communication
- State Machine
- Protection
- U/I control loops

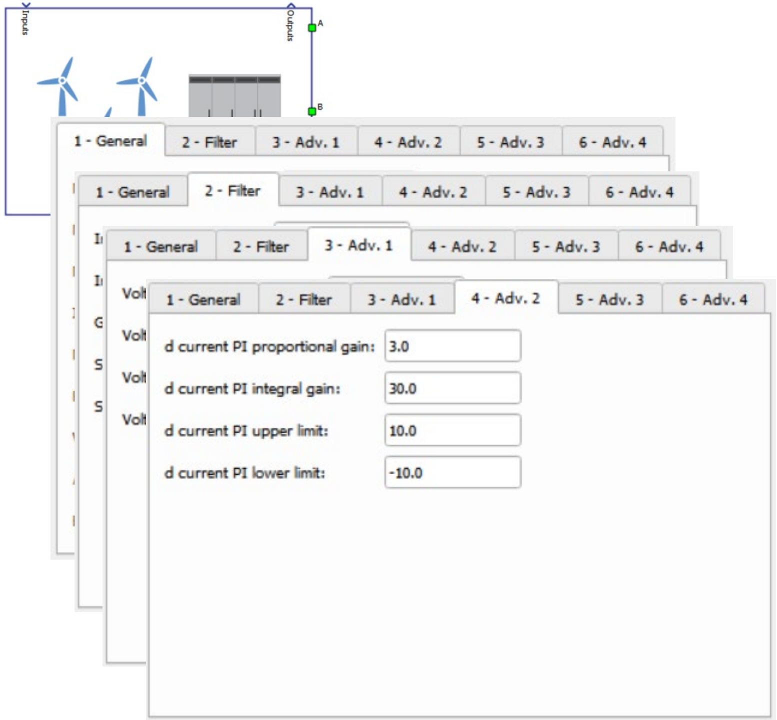
Model parametrization

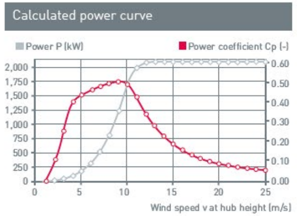
- Let’s say there is an ultimate model of our system, with all possible parameters.
- Can we parametrize it???



Model parametrization

An example – ENERCON E-82





Wind (m/s)	Power P (kW)	Power-coefficient Cp (-)
1	0.0	0.00
2	3.0	0.12
3	25.0	0.29
4	82.0	0.40
5	174.0	0.43
6	321.0	0.46
7	532.0	0.48
8	815.0	0.49
9	1,180.0	0.50
10	1,580.0	0.49
11	1,810.0	0.42
12	1,980.0	0.35
13	2,050.0	0.29
14	2,050.0	0.23
15	2,050.0	0.19
16	2,050.0	0.15
17	2,050.0	0.13
18	2,050.0	0.11
19	2,050.0	0.09
20	2,050.0	0.08
25	2,050.0	0.04

Cut-out wind speed: 28 - 34 m/s (with ENERCON storm control*)

Model validation

Can we trust the simulation results?

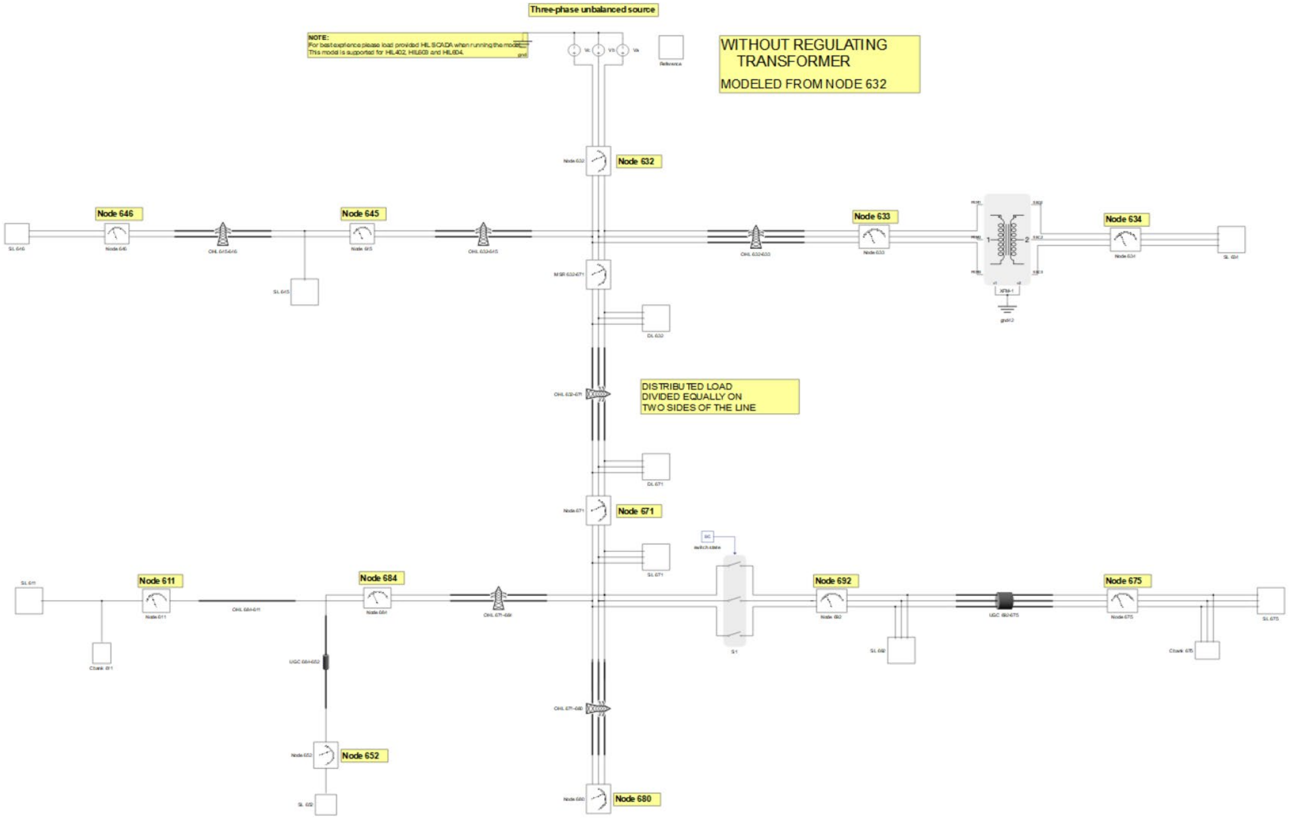
- Models need validation

- It can be done:
  - By comparison to steady state analysis results and/or load flow solvers
  - By comparison to real system measurements

- Model can be trained to match the real world system!

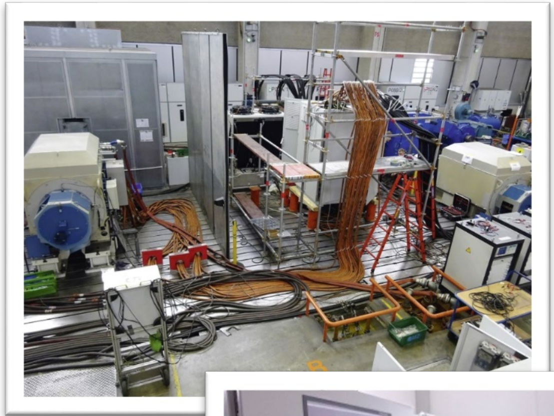
Model validation

IEEE Test Feeders



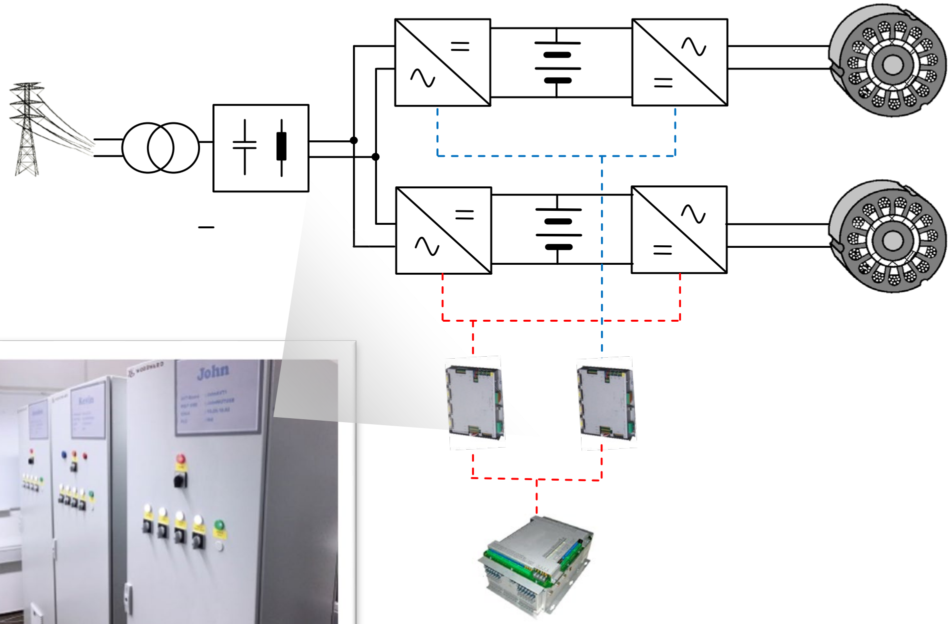
Model validation

HIL vs Real System measurements: 4.5MW Full Size Converter



Full power LAB

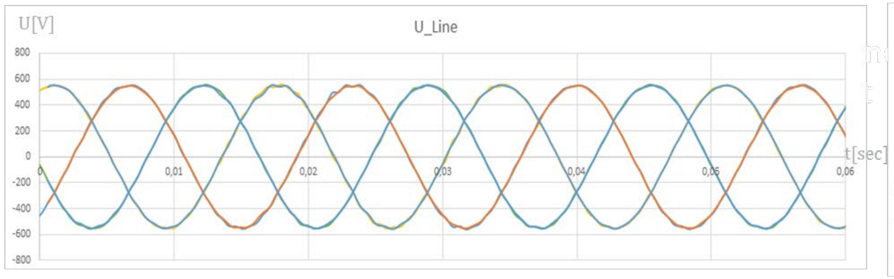
HIL LAB

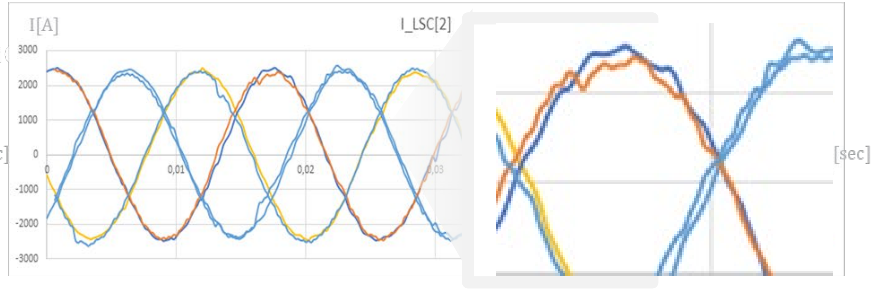


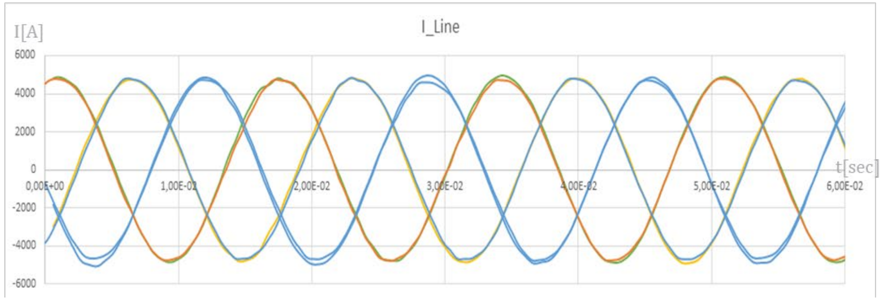
Model validation

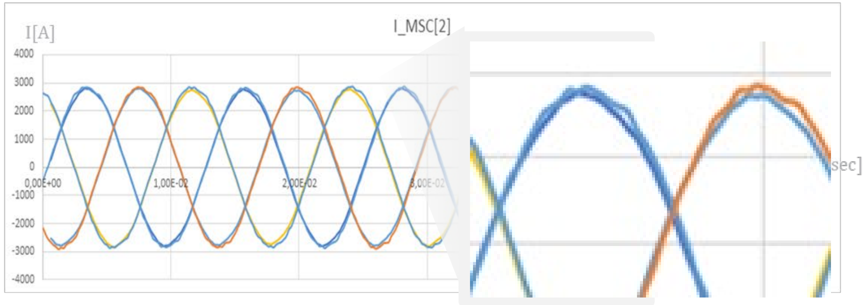
HIL vs Real System measurements: 4.5MW Full Size Converter

Steady state operation field measurements vs. HIL emulation results





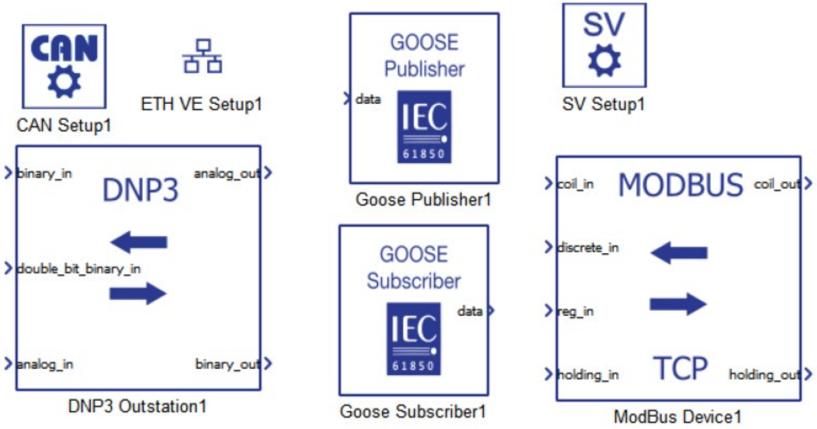




Interfaces

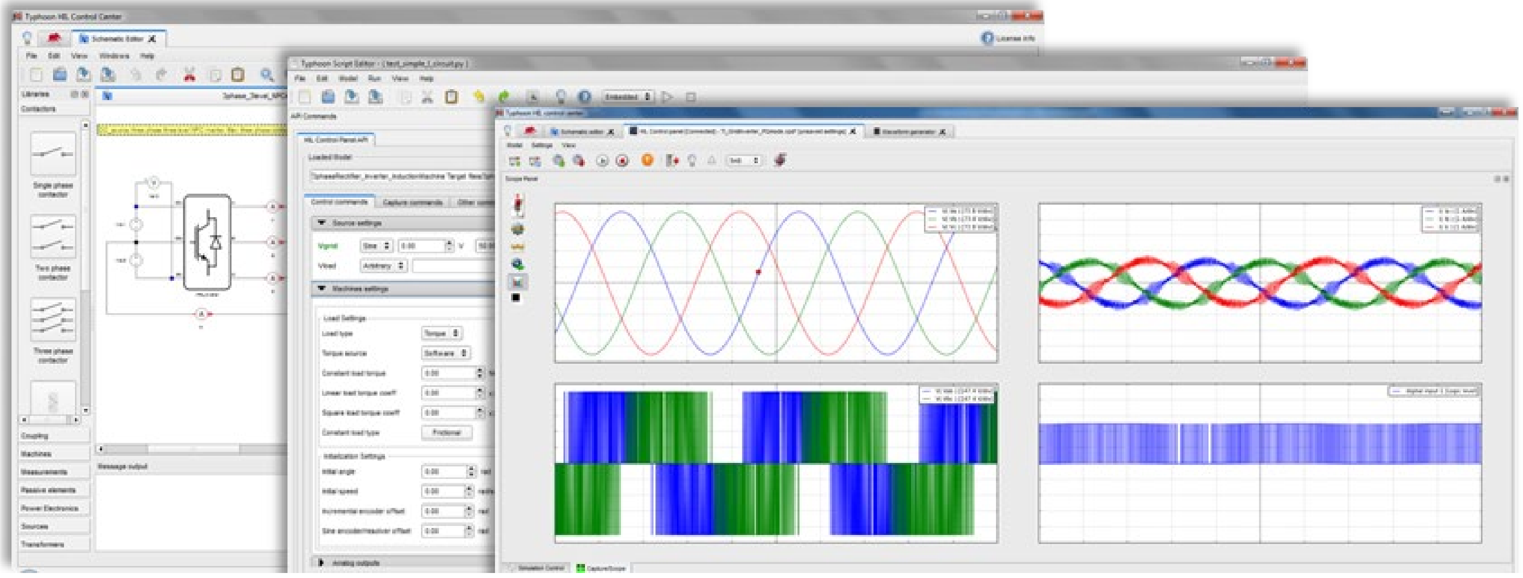
… with real world

- Power Electronics – simple
  - Digital input/outputs
  - Analog inputs/outputs
- Power systems, smart grids, microgrids – complex communication protocols:
  - Modbus
  - IEC61850
  - DNP3
  - …



Software Tools

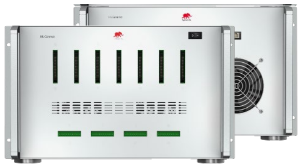
That enable ease of use



Hi precision hardware

- Hi speed digital I/O
  - 6.6 ns resolution
- Hi accuracy analog IO
  - 16 bit AD/DA
- Low latency

- ❑ HIL Simulators

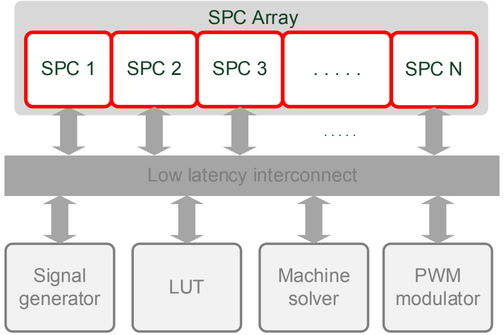


- ❑ Interfaces

- ❑ Network devices

Dedicated processor

- Modular design
- FPGA based + GP processors
- Dedicated processor architecture
  - Designed for PE and PS model solving
  - Designed for parallel computing
  - Designed for scalability



CAN

Modbus

IEC 61850

pels IEEE

Examples

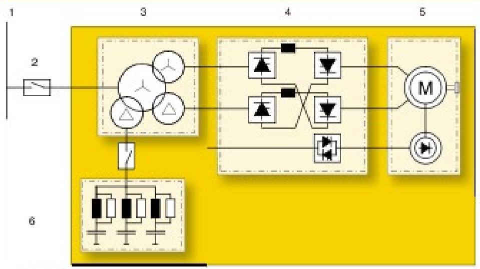
ABB-Statoil 48MW compressor drive

Variable speed drive systems for Ormen Lange

ABB supplied three MEGADRIVE-LCI variable speed drive (VSD) systems for the Ormen Lange project.

One Ormen Lange VSD system consists of:

- Four-winding transformer
- Filter system of a total of 24.6 MVAr
- 12/12-pulse MEGADRIVE-LCI converter
- 48 MW synchronous motor



1 132 kV power supply
2 Main circuit breaker
3 Four-winding transformer
4 Converter (rectifier, DC reactor, inverter, excitation, controller)
5 Synchronous motor with brushless excitation
6 Filter system

Basic circuit diagram of the 48 MW drive system for the Ormen Lange project

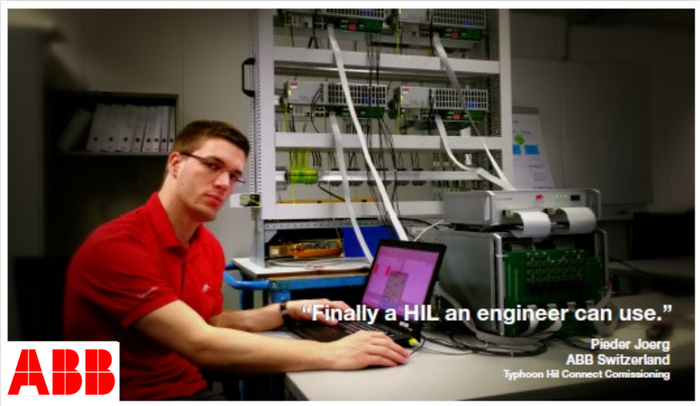
MEGADRIVE-LCI - all integrated 48 MW current source inverter, including DC reactors and water-cooling unit

Examples

ABB-Statoil 48MW compressor drive

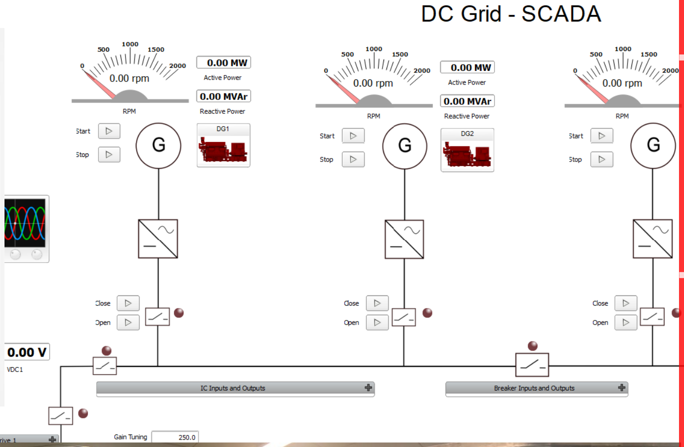
Before HIL

After HIL



Examples

ABB Marine



Distribution	AC and DC
Modeled	▪ 4 diesel gensets ▪ 4 active rectifiers ▪ 2 propulsion units ▪ >10 protective relays
In the loop	▪ PMS unit ▪ 4 Active rectifier controllers ▪ 4 AVR controllers ▪ 2 Propulsion unit controllers ▪ 4 protective relays (ABB)
Sim step	2us
HIL setup	3xHIL603 (each)
Protocols	IEC61850 GOOSE

Examples

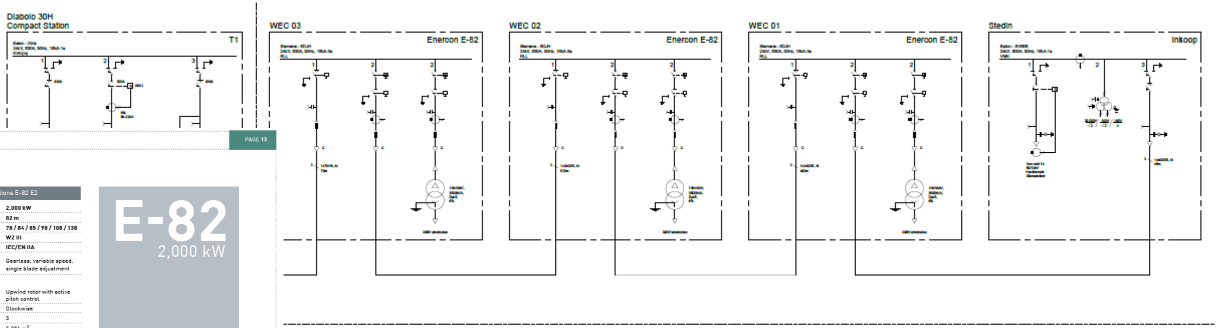
Giessenwind site – part of DRIvE project

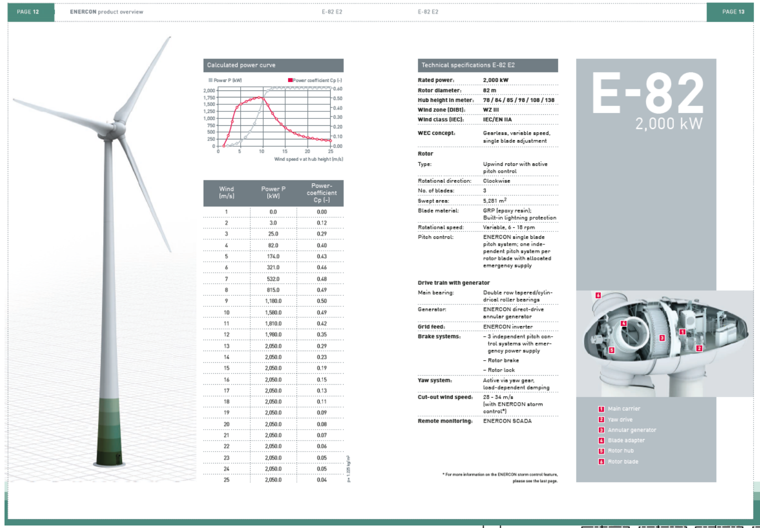
- Demand Response Integration tEchnologies
  - Enervalis, Airbus, Comsa, CEA, Typhoon

Examples

Giessenwind site – part of DRIvE project

- The Spec





PAGE 12 ENERCON product overview E-82 E2

E-82 E2 PAGE 13

Calculated power curve

Power P (kW) / Power coefficient Cp (-)

Wind speed v at hub height (m/s)

Wind (m/s)	Power P (kW)	Power-coefficient Cp (-)
1	0.0	0.00
2	3.0	0.12
3	25.0	0.29
4	82.0	0.40
5	174.0	0.43
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21	2,050.0	0.07
22	2,050.0	0.06
23	2,050.0	0.05
24	2,050.0	0.05
25	2,050.0	0.04

$\rho = 1.225\ kg/m^3$

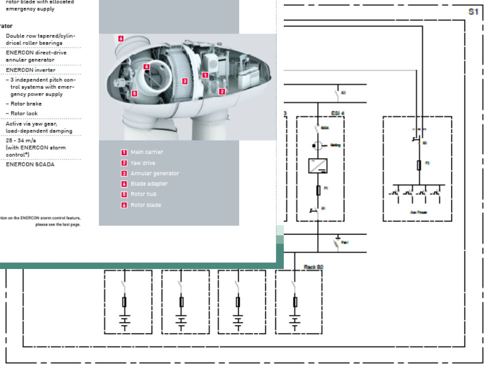
Technical specifications E-82 E2	
Rated power:	**2,000 kW**
Rotor diameter:	**82 m**
Hub height in meter:	**78 / 84 / 85 / 98 / 108 / 138**
Wind zone (DIBt):	**WZ III**
Wind class (IEC):	**IEC/EN IIA**
WEC concept:	Gearless, variable speed, single blade adjustment
Rotor	
Type:	Upwind rotor with active pitch control
Rotational direction:	Clockwise
No. of blades:	3
Swept area:	5,281 m^2
Blade material:	GRP (epoxy resin); Built-in lightning protection
Rotational speed:	Variable, 6 - 18 rpm
Pitch control:	ENERCON single blade pitch system; one independent pitch system per rotor blade with allocated emergency supply
Drive train with generator	
Main bearing:	Double row tapered/cylindrical roller bearings
Generator:	ENERCON direct-drive annular generator
Grid feed:	ENERCON inverter
Brake systems:	– 3 independent pitch control systems with emergency power supply – Rotor brake – Rotor lock
Yaw system:	Active via yaw gear, load-dependent damping
Cut-out wind speed:	28 - 34 m/s (with ENERCON storm control*)
Remote monitoring:	ENERCON SCADA

* For more information on the ENERCON storm control feature, please see the last page.

E-82

2,000 kW

1 Main carrier
2 Yaw drive
3 Annular generator
4 Blade adapter
5 Rotor hub
6 Rotor blade

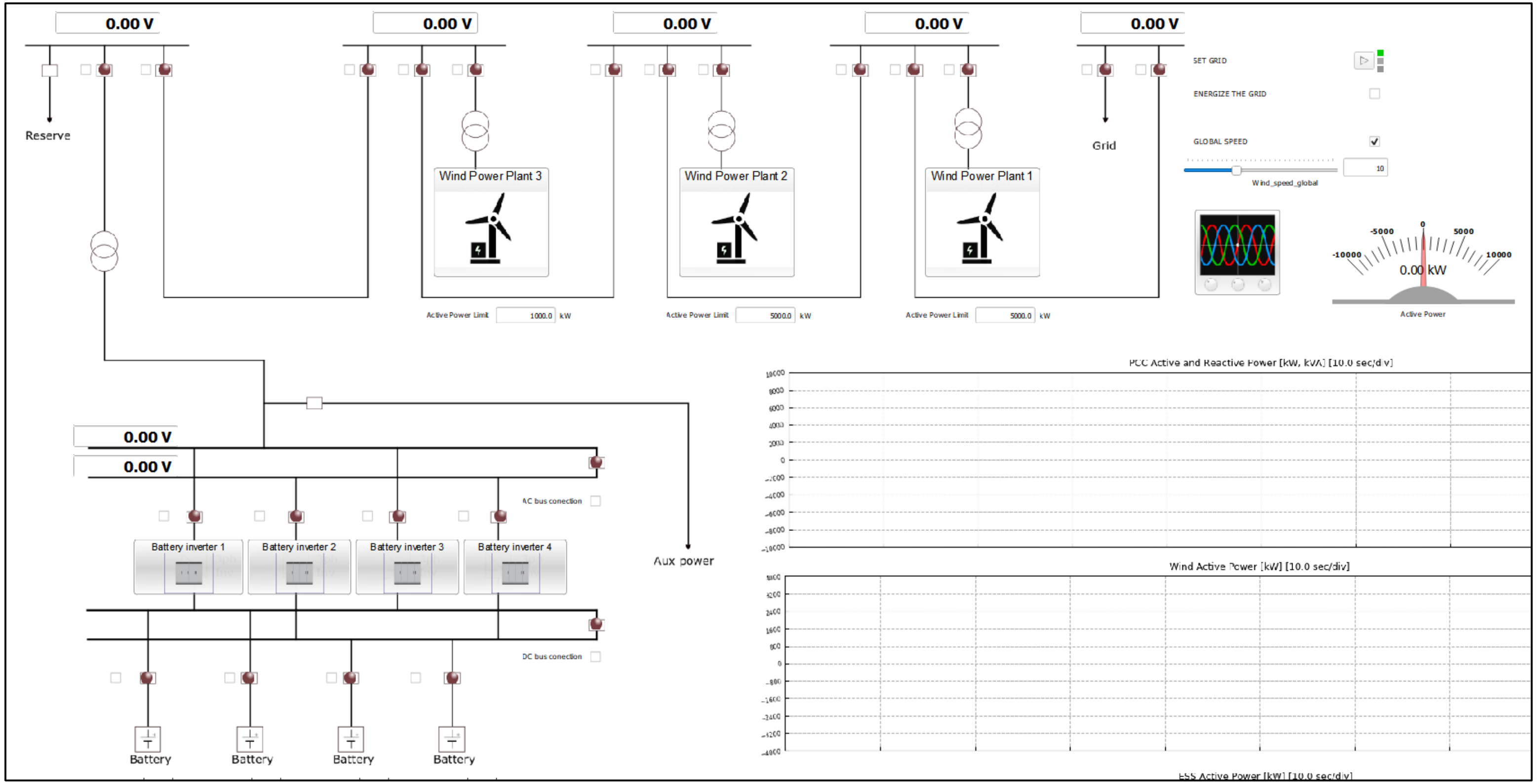


Modbus

Register map for the Battery Inverters

Examples

Giessenwind site – part of DRIvE project



Summary

- Challenges are in various aspects:
  - Numerical and circuit analysis algorithms suitable for both PE and PS
  - Wright amount of modeling depth and details
  - Model parametrization and validation
  - Supporting software tools
  - Dedicated solvers-processors

- Power Electronics enabled Power System is a cyber-physical system
  - Modeling the physics is not enough

Thank You!