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Simulation Technologies for the Emerging Grid

1st International Symposium on Smart Grid Methods, Tools and Technologies, Shandong University, Jinan, China, May 2015

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Electrical and Computer Engineering Department
University of Manitoba

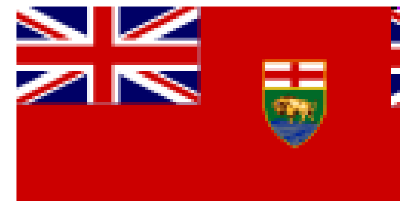
Canada:

10 provinces + 3 Territories

Population: 35 Million

Manitoba:

Population 1.1 Million



University of Manitoba:

- Major Provincial University (29,000 students)

- Oldest University in Western Canada (est. 1877)

- Power Eng. Program : 6 Faculty+6 Adjunct Faculty, 35 M.Sc.+25 Ph.D. students

-Simulation tools a major research area

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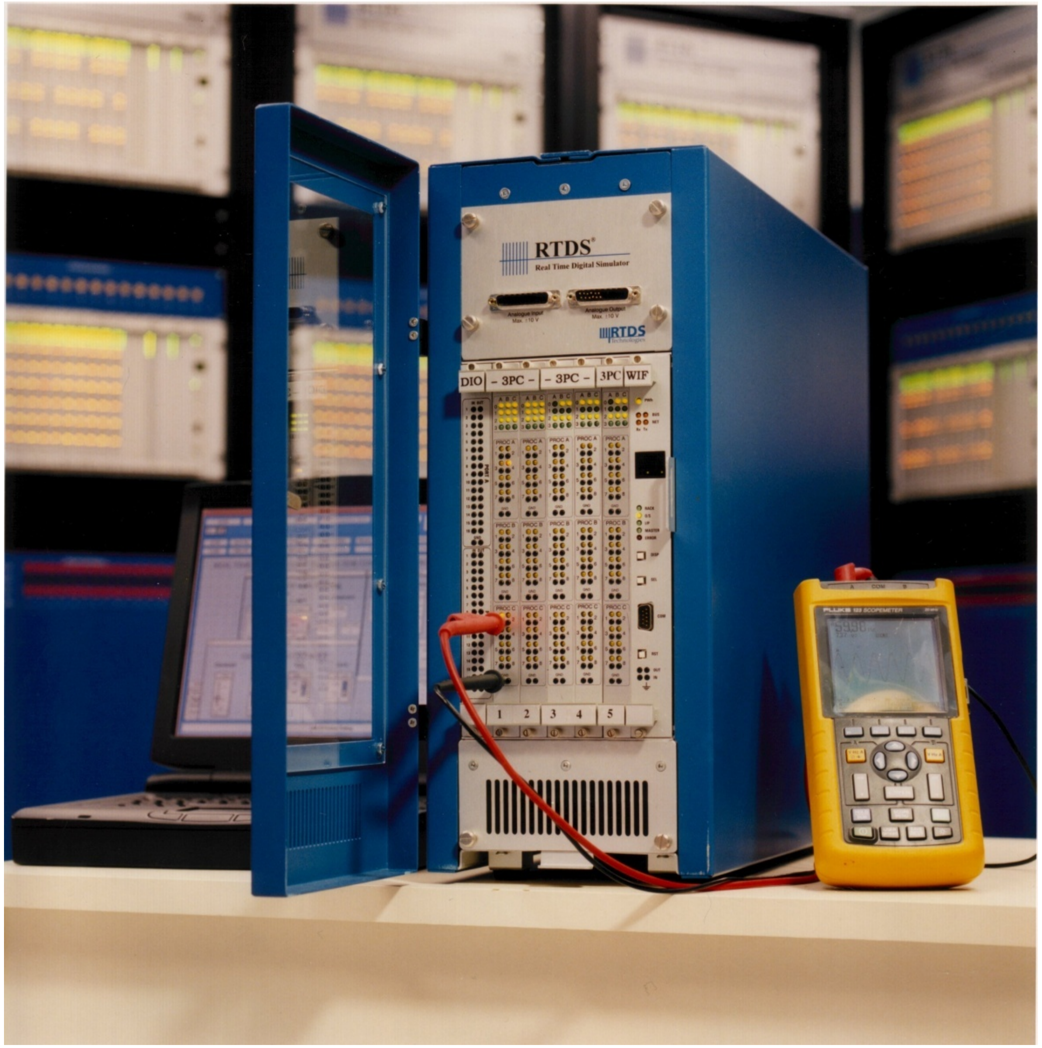
PSCAD/EMTDC: Electromagnetic Simulation Platform

Real Time Simulator (RTDS Technologies, Winnipeg)



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Outline

- The traditional and the Emerging Grid
- Why is Transient Simulation important in Todays Systems ?
- What can be done with RT Simulation
- How can very Large Systems be modelled?
- How can Simulation help in design and Decision Making?

The Traditional Power Grid versus the Emerging Power Grid

Traditional Power Network

- 3-phase Ac Generators
- Transmission Lines and Cables
- Induction motors and other loads
- Protection Equipment (non-electronic)
- Integrated and Regulated

Evolution of the Energy Supply System

- More deregulated
- Require Advance Protection and Control Methods
- Increasing inclusion of renewable energy sources (wind)
- Require More Precise control of Power Flow- a move towards the pipeline model *through the use of Power Electronics*
  - HVDC and FACTS Controllers
- Incorporation of Grid Intelligence at the Distribution Level - Smartgrids

Evolution of the Energy Supply System

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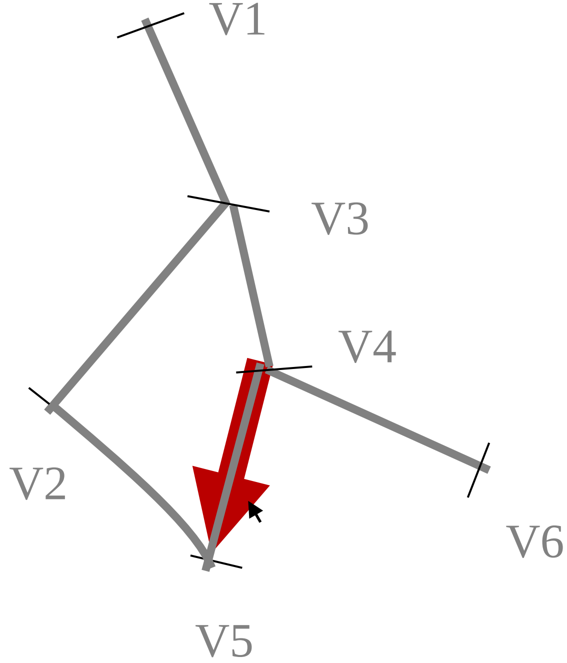
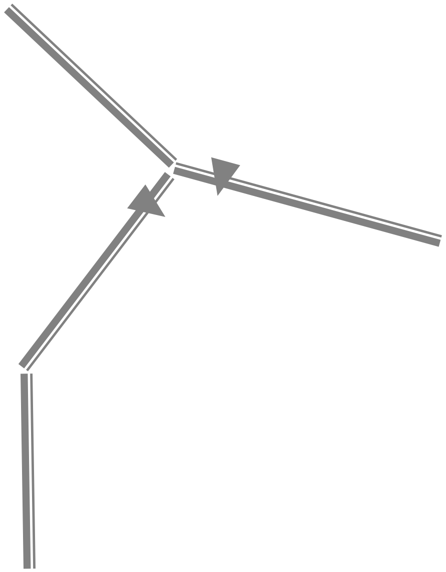
Traditional Power Network

- Power Flow dictated by voltage profile



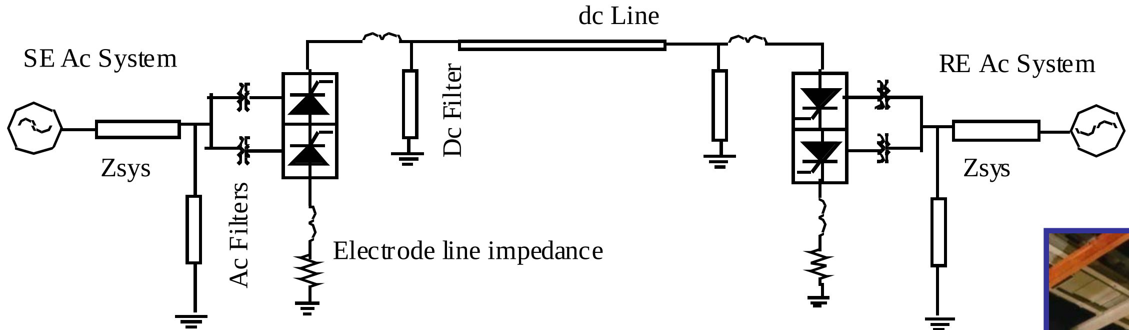
Emerging Power Network

- Pipeline: Flow is locally controllable



Emerging Power Networks
Use of Power Electronics: HVDC Systems

- Large Power Electronic Systems: Gigawatt range HVDC Transmission



<u>Completely decoupled. Any desired level of power flow can be established</u>

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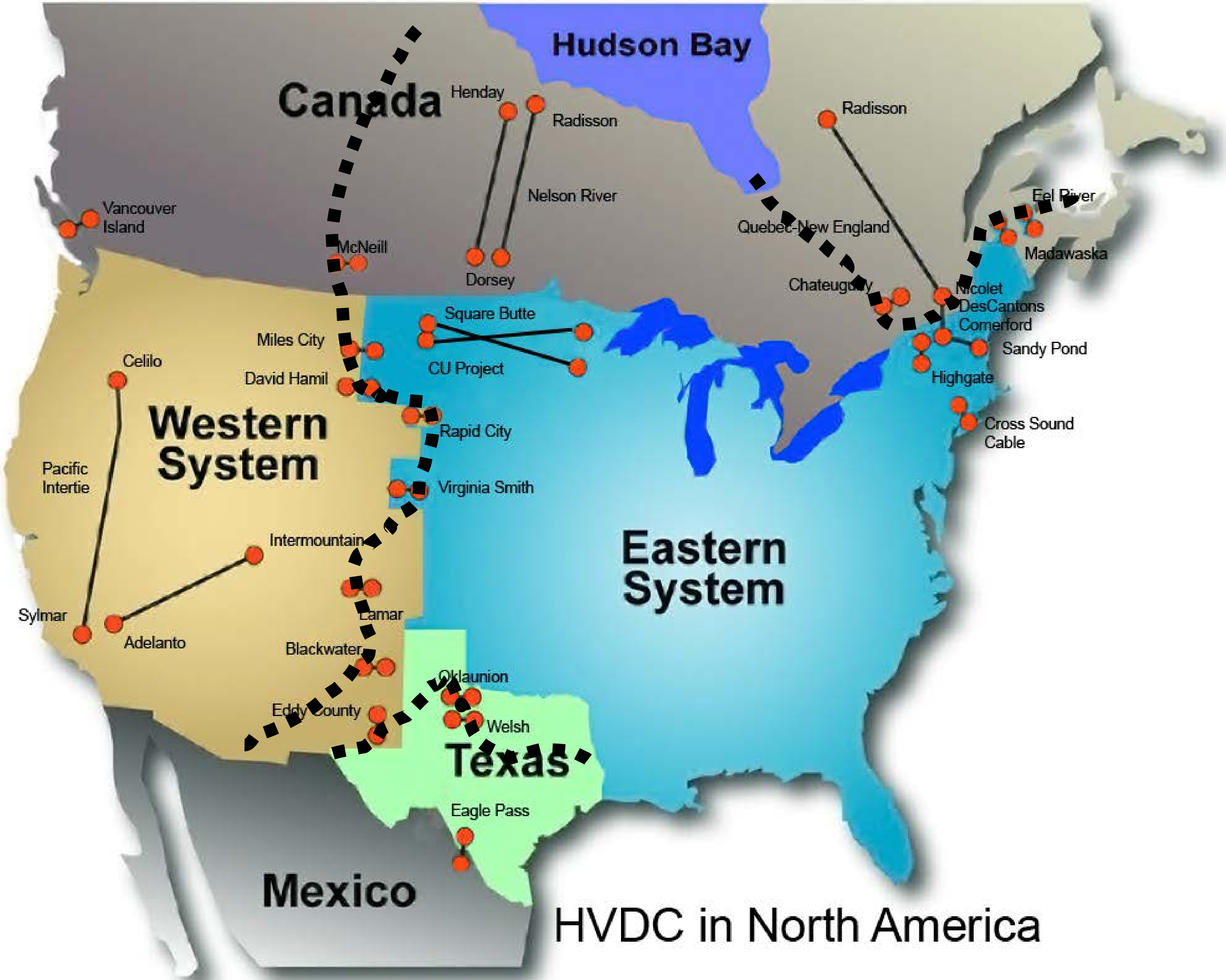
HVDC in North America

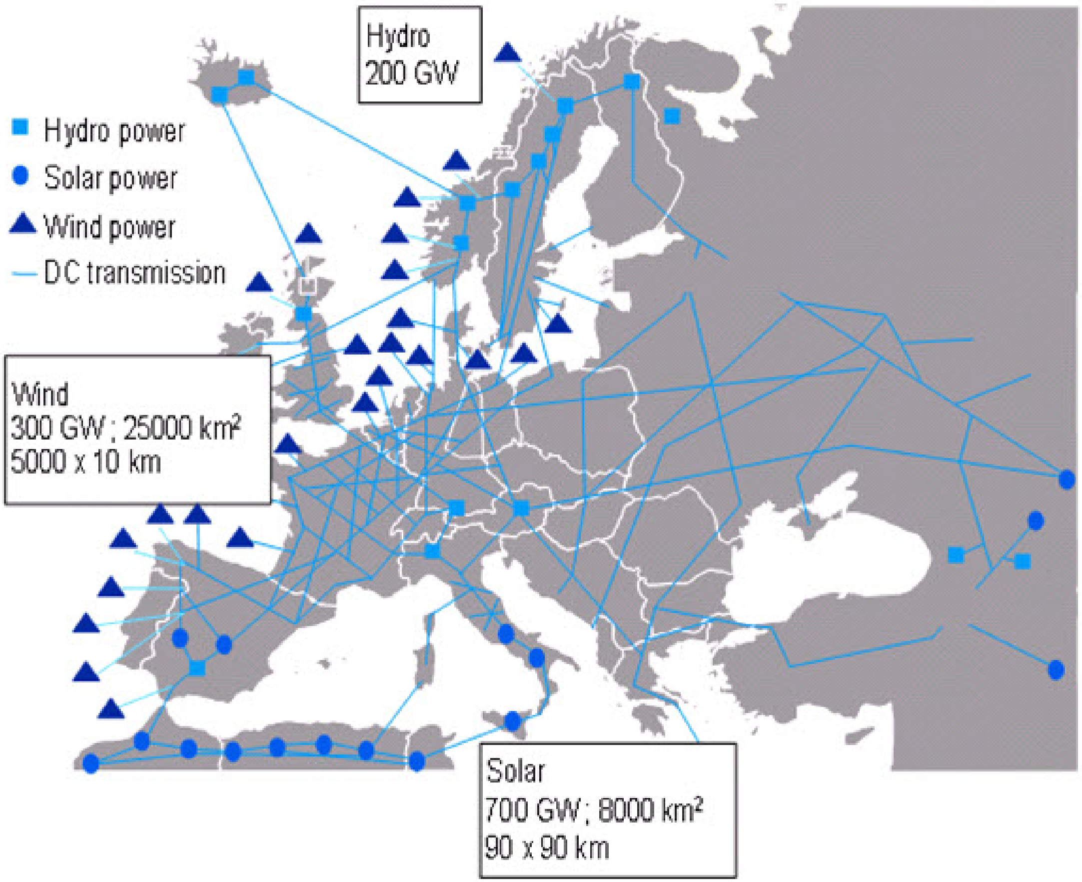


DC Grid for Atlantic Wind Project

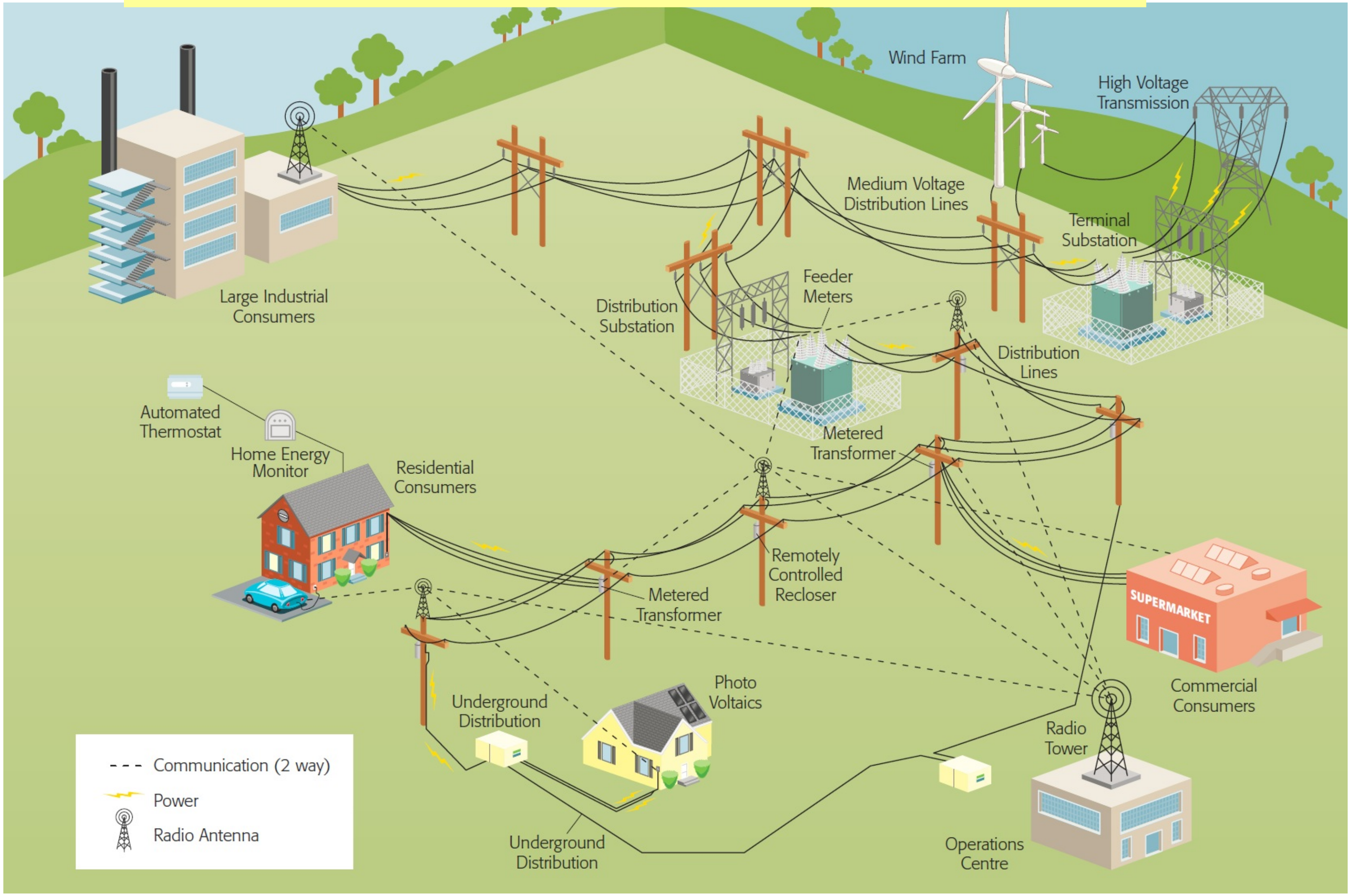
(http://offshorewind.biz)

DC Grid Vision for Europe

(http://offshorewind.biz)



Microgrids



Microgrid (Environmental Commissioner of Ontario : http://www.eco.on.ca/blog/tag/smart-grid/)

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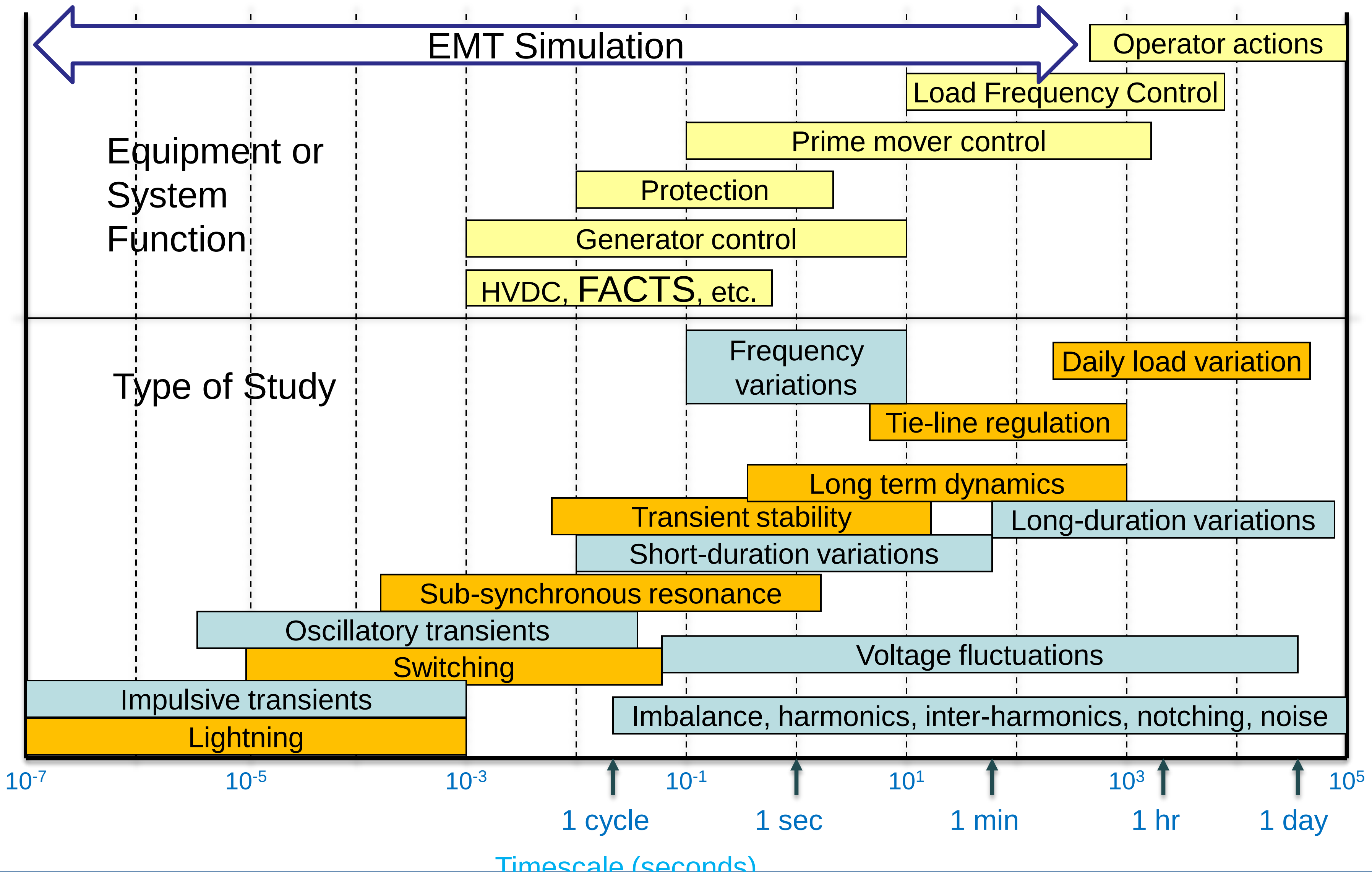
Simulation Tools

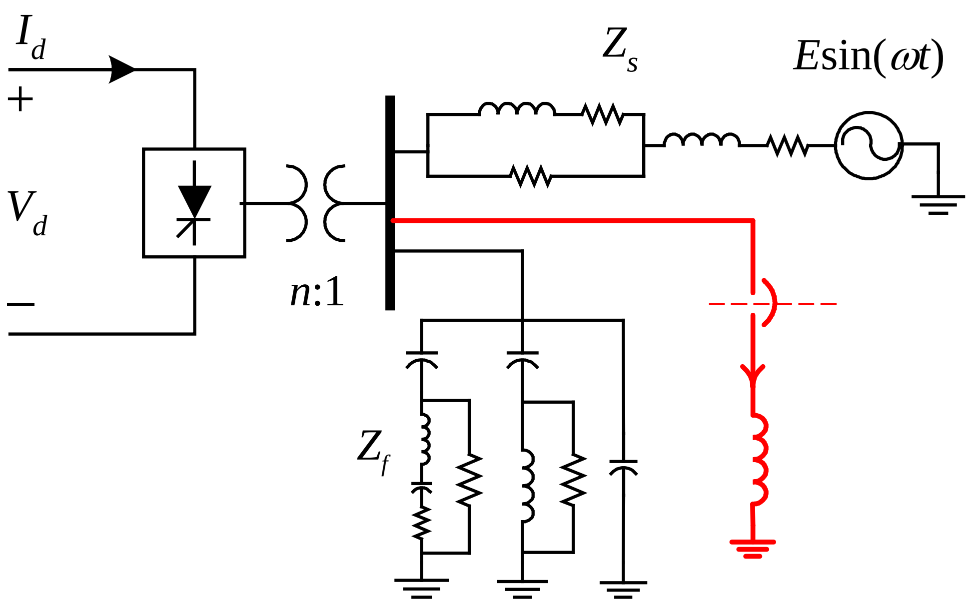
Simulation Tools Used in Power System Studies

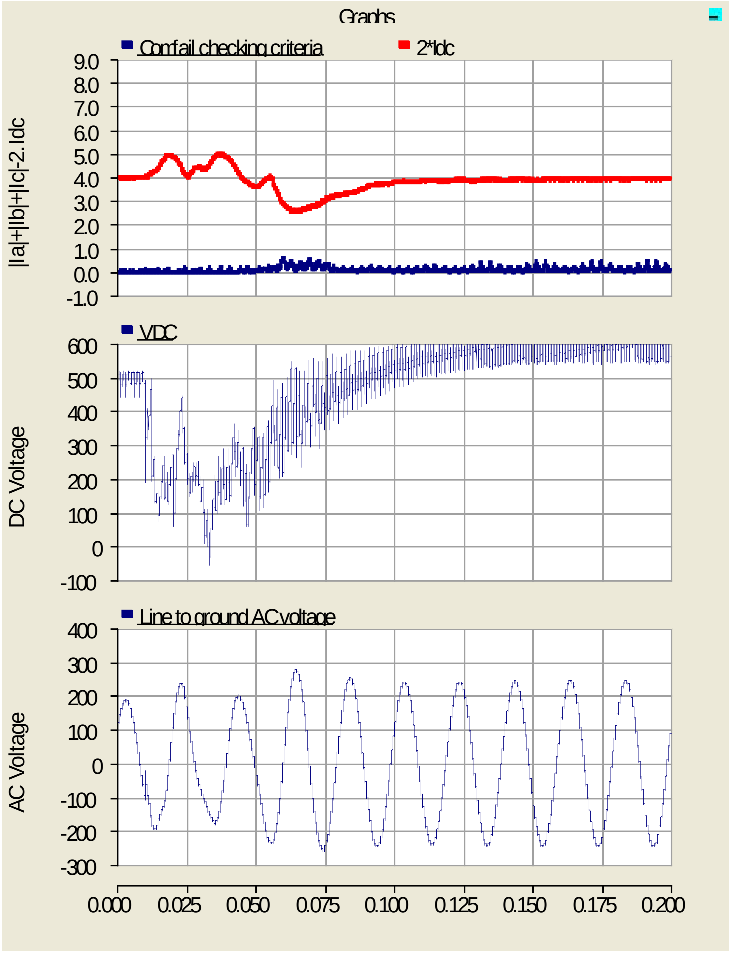
- Small Signal Analysis Tools
  - simplified model, eigenvalues show general behaviours
- Transient Stabilty Analysis
  - Only electric machines and slower controls are modelled using differential equations. Ac network is modelled using phasors
  - Can model very large networks to assess global stabilty
- Electromagnetic Transients Simulation
  - Most detailed simulation. Seeing increasing use as computers become faster
  - Can be slow if run on sequential machines

Electromagnetic Transients Simulations:



Typical Waveforms from EMT simulation





- Waveforms show the entire transient
  - (not frequency domain phasor values)

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How does the future Grid Structure impact simulation technology?

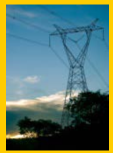
How does the future Grid Structure impact simulation technology?

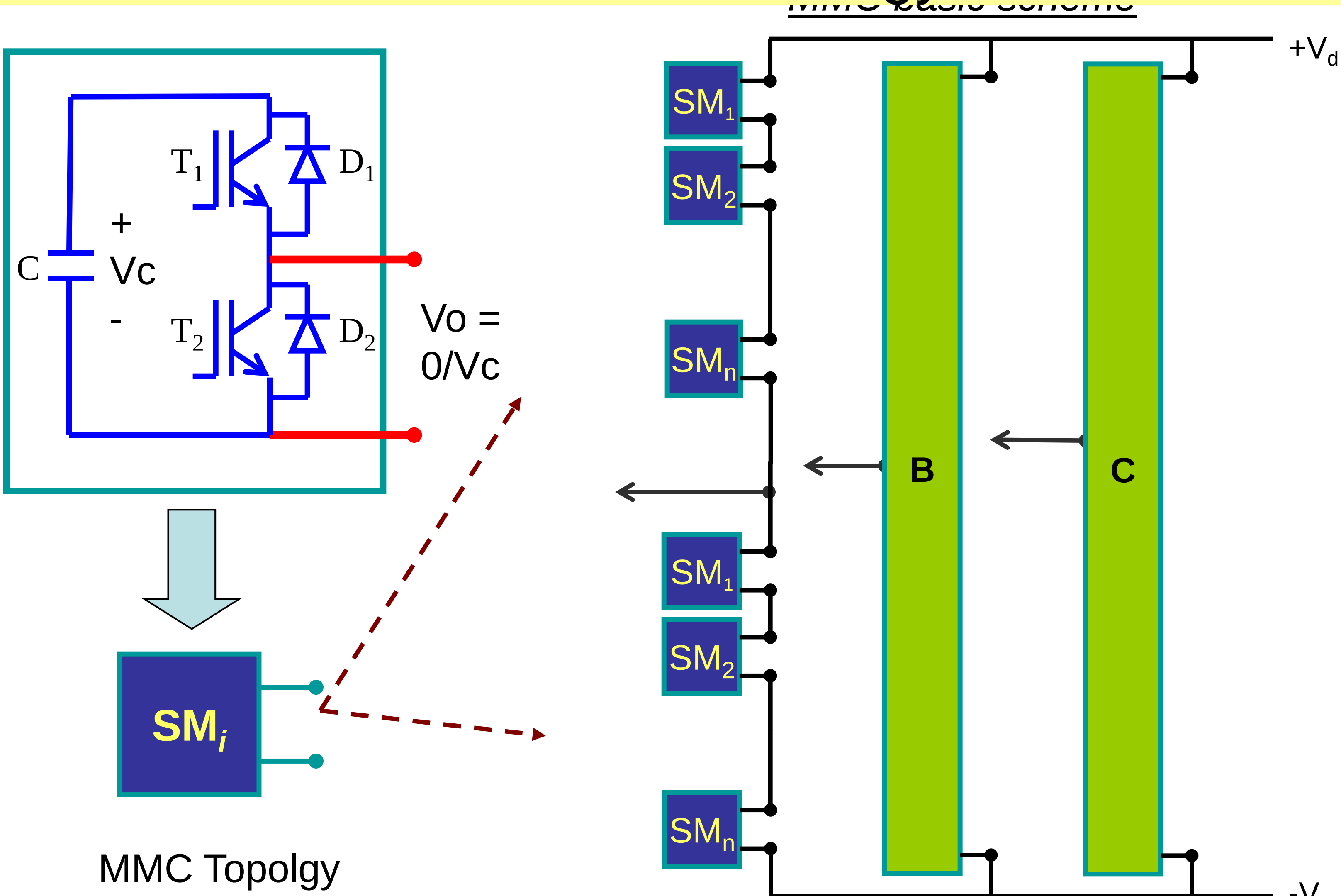
New Components in the grid such as:

- Wind Turbines
- Solar Energy harvesters
- Power Electronic Controllers
- Voltage Sourced Converters (VSC) with new topologies
  - Multilevel Modular Converters
- Smartgrids – distribution systems with close tie between the power grid and a communication overlay

Models have to be developed for these components.

Example: MMC Converter- Testing the limits of conventional simulation technology

MMC Topolgy

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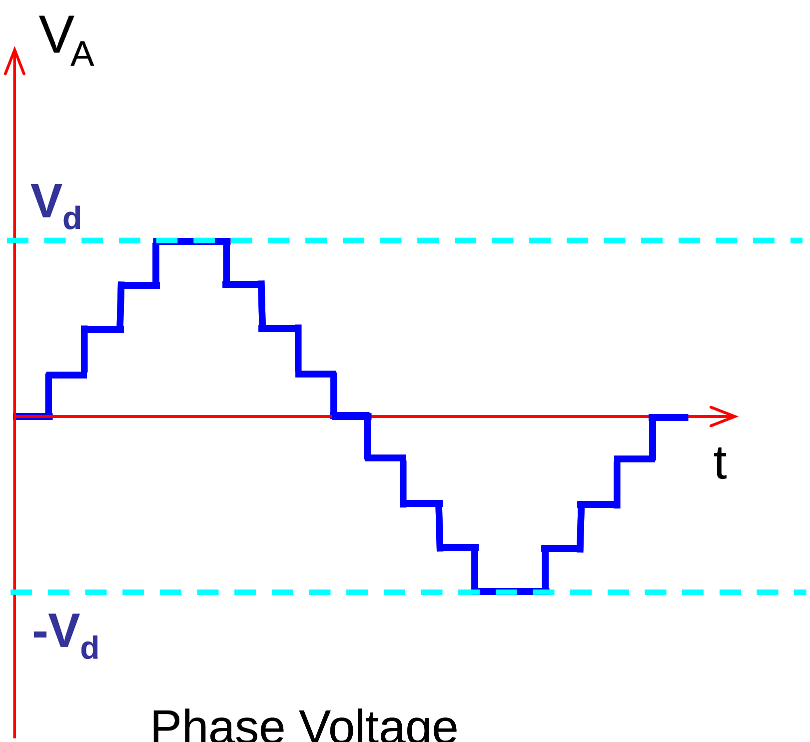
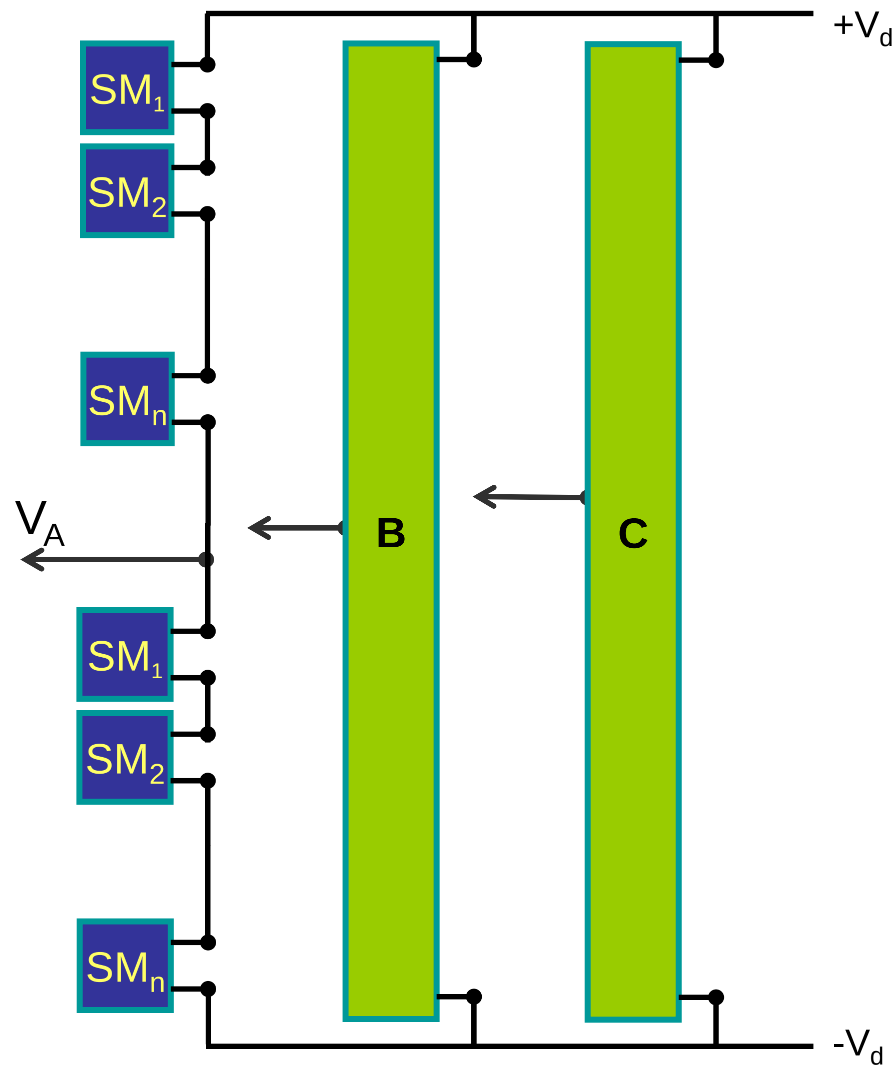
Multi-level Modular Converter Topology



Phase Voltage
(n = 10)

MMC Topolgy

MMC basic scheme



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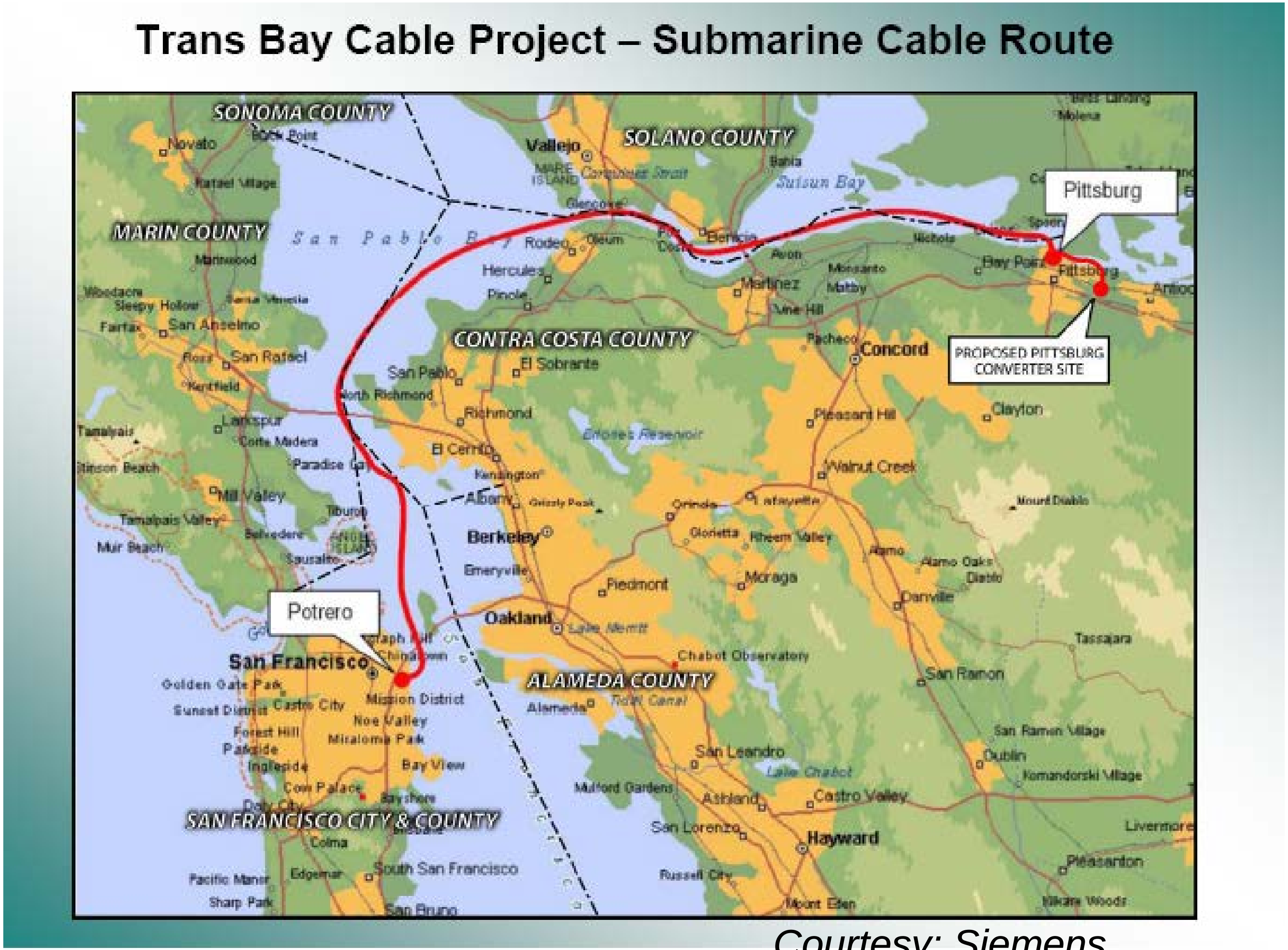
Transbay Cable (San Francisco-Oakland)



Courtesy: Siemens

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Trans-Bay HVDC Project

- **Purpose**:
  - Congestion Relief
  - Improvement of security of supply
  - Retirement of Generation in San Francisco Area
- **Customer** Trans Bay Cable, LLC
- **Location** Pittsburg, California, and San Francisco, California
- **Power Rating** 400 MW
- **Voltage levels** ± 200 kV DC, 230 kV /138 kV, 60 Hz
- **Type of plant** 85 km HVDC PLUS submarine cable
- **Type of Thyristor** IGBT

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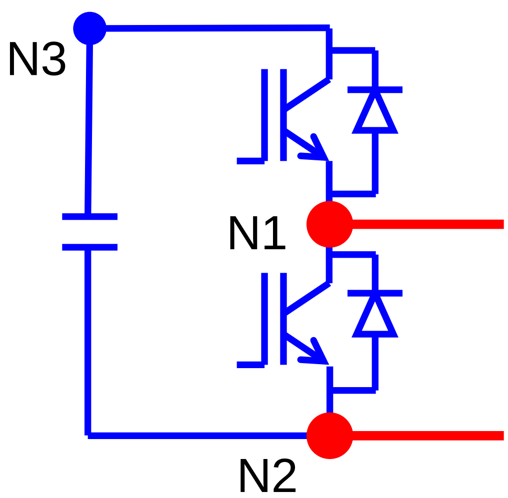
Limitations & Objectives

- Modelling the converter for EMT-based programs is very consuming of resources and computer time due to unprecedented component count



Sub-module → 3 Nodes

240 - Sub-modules (1 Phase Arm) → 720 Nodes

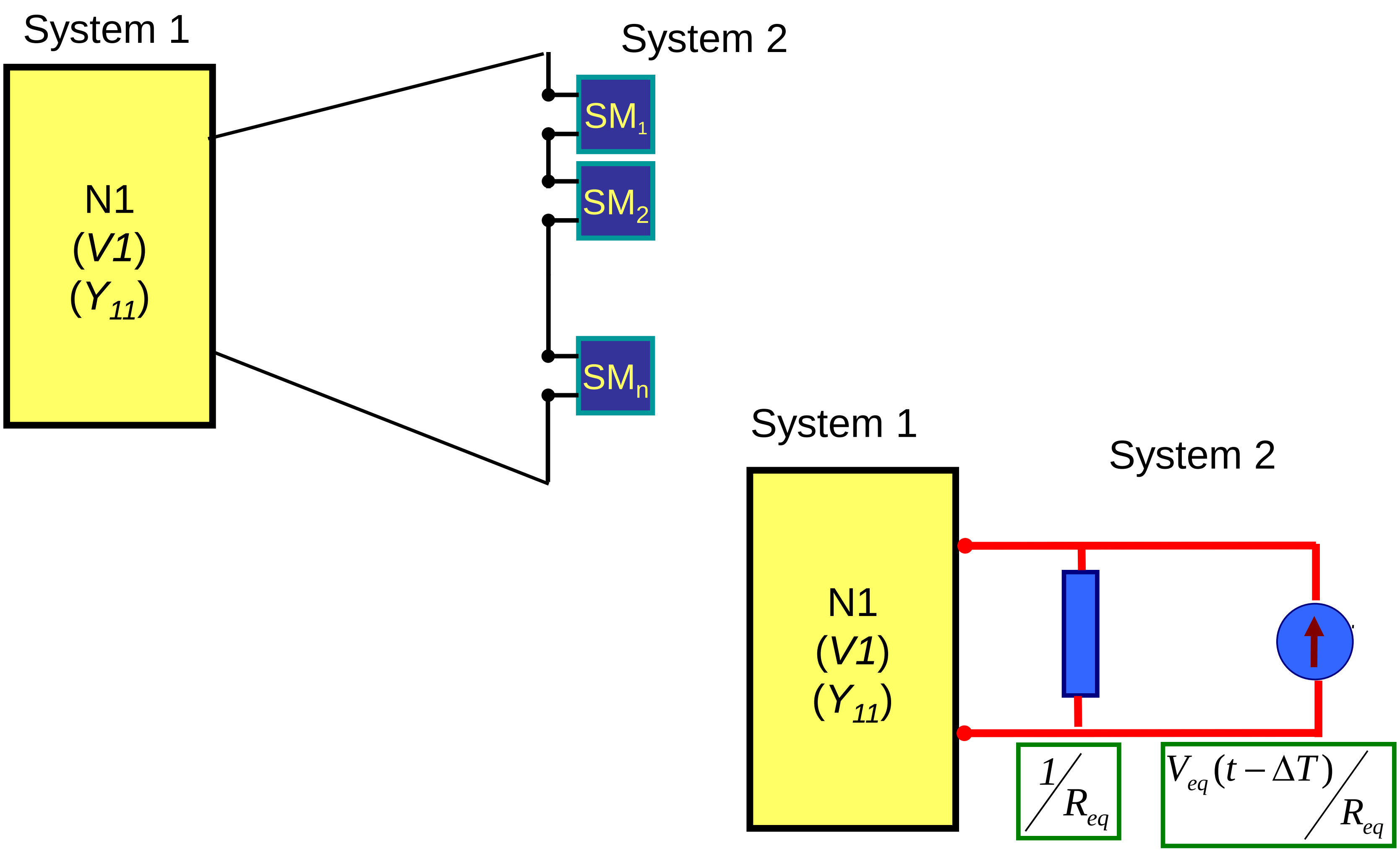
3 Phases → 2160 Nodes

Uni-polar HVDC system → 4320 Nodes

Uni-polar HVDC system → 2880 PE switches

- Can we speed this up?

Modeling the converter for EMT-based programs



Results – Time Comparison

# of Sub-Modules	Run Time (s)		Ratio (%)
	PSCAD Converter	Modelled Converter	
2	5	2	250
6	11	2	550
12	22	3	733
24	72	4	1800
48	335	7	4786
72	1337	11	12155
96	3447	19	18142
120	9021	29	31107

Time taken for a single phase converter

Total Simulation Time = 5 s
Simulation Time Step = 20 μs

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How does the future Grid Structure impact simulation technology?

- Increased Use of Real-time Simulation for testing and parameter selection
- Increased use of Hybrid Simulation (e.g. TSA+EMT)

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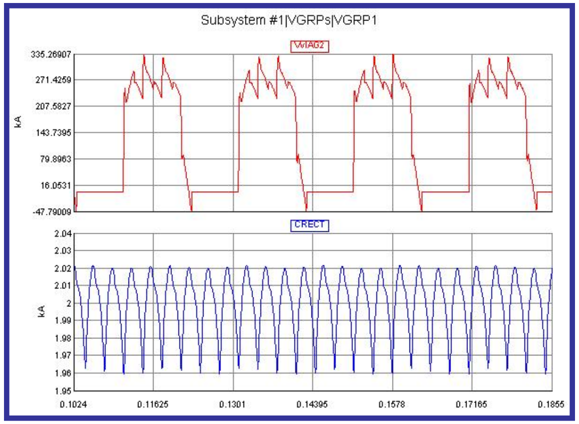
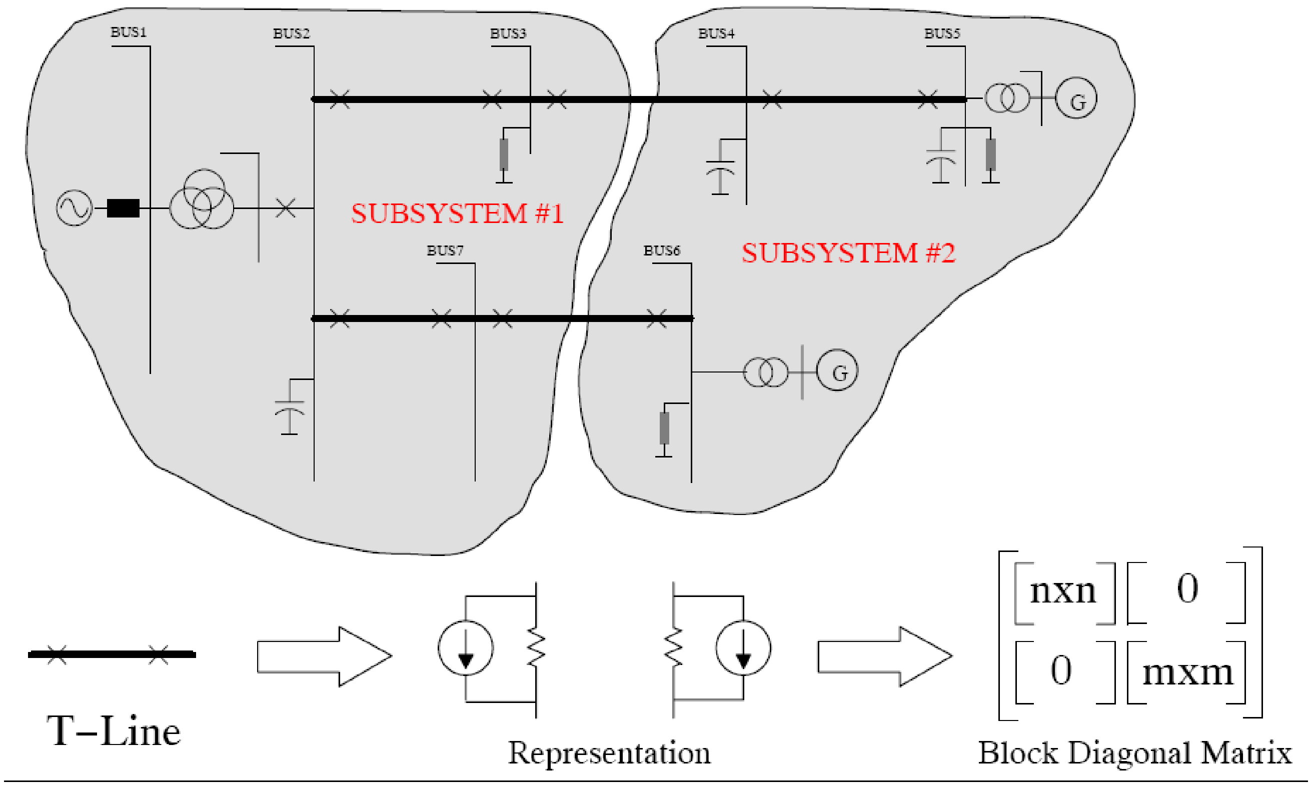
Real Time Digital Simulation

- Continuous *hard real-time* response must be achieved and sustained if physical control and protection equipment is to be included in the simulation study
- The RTDS Simulator
    - A combination of specially designed parallel processing hardware and detailed, efficient solution algorithms

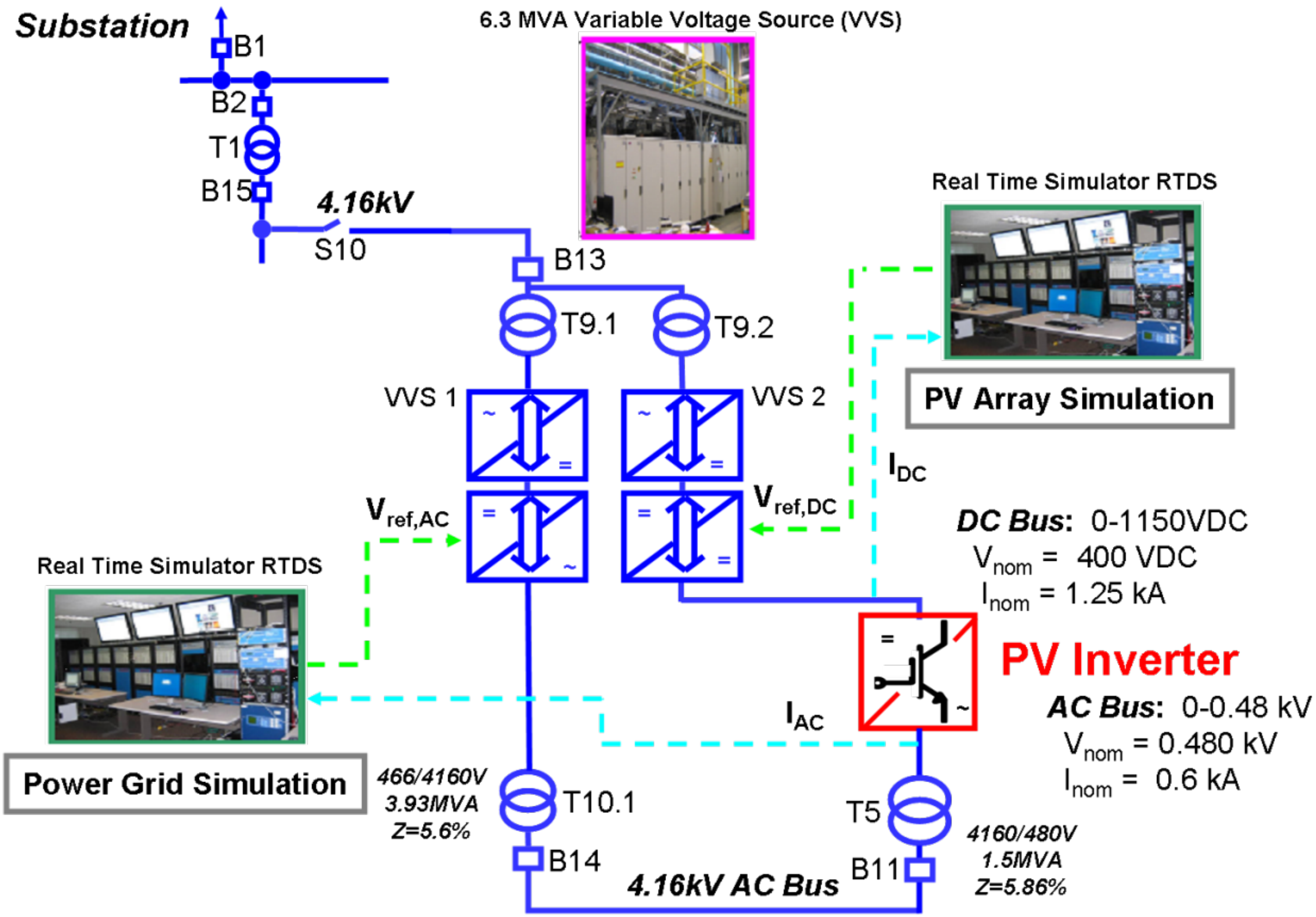


How is RT Simulation Achieved?

- -Exploitation of natural delays due to relativistic speed limits
- -Matrix size related to sub-network size
- -Subnetworks can be simulated in parallel)



Power Hardware in Loop Simulation (PHIL)



PHIL arrangement for an inverter testing at a testing facility

(courtesy M. Steurer, CAPS/FSU)

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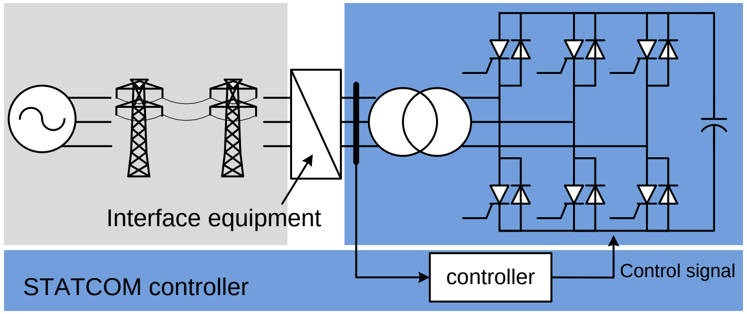
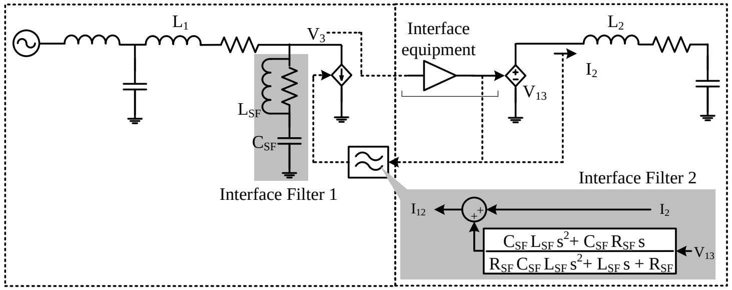
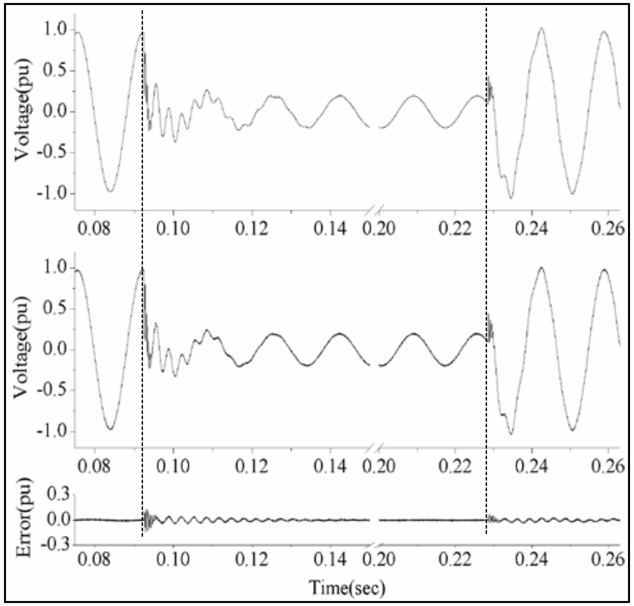
Simulation Accuracy Improvement in Power Hardware In Loop Simulation

- PHIL interface can be unstable/inaccurate
- Interface algorithms and hardware for improving stability and accuracy of PHIL has to be developed







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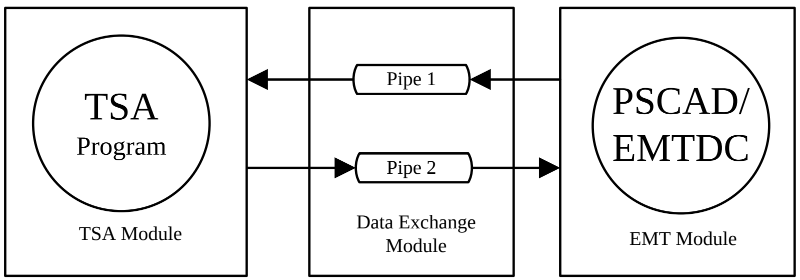
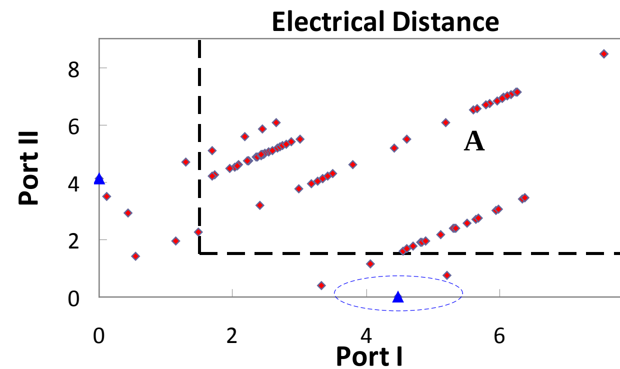
Hybrid Simulations:

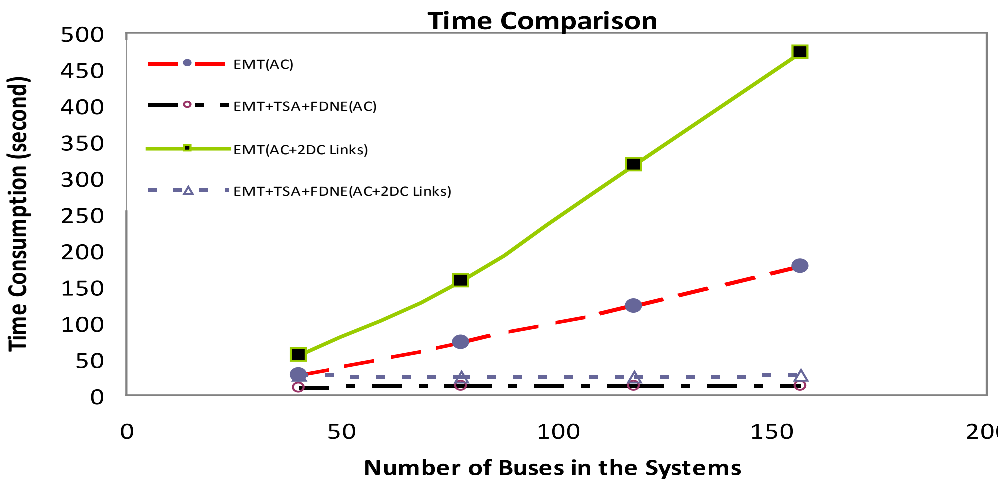
- It is often impractical to model the entire system in detail for analysis
- The larger system is divided into an several subsystems which are simulated using different simulation tools
- Where detail is important, components are represented in full **electromagnetic transient detail**
- Other subsystems can be reduced order models, e.g., **transient stability models**

Development and Analysis of Applicability of a Hybrid Transient Simulation Platform Combining TSA and EMT Elements

- Very large Networks can be studied in reasonable time by combining EMTP and Transient type Programs
- Can faults in TSA part be modelled to accurately affect transients in EMT part - yes!

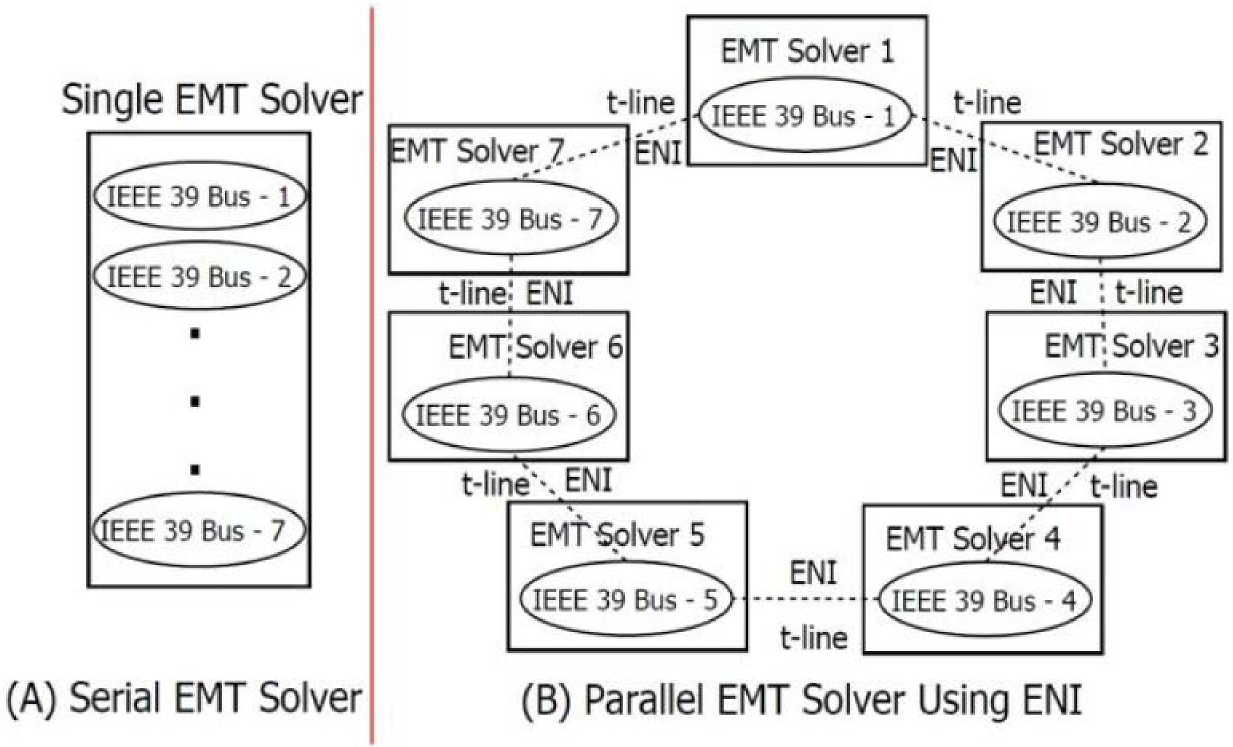




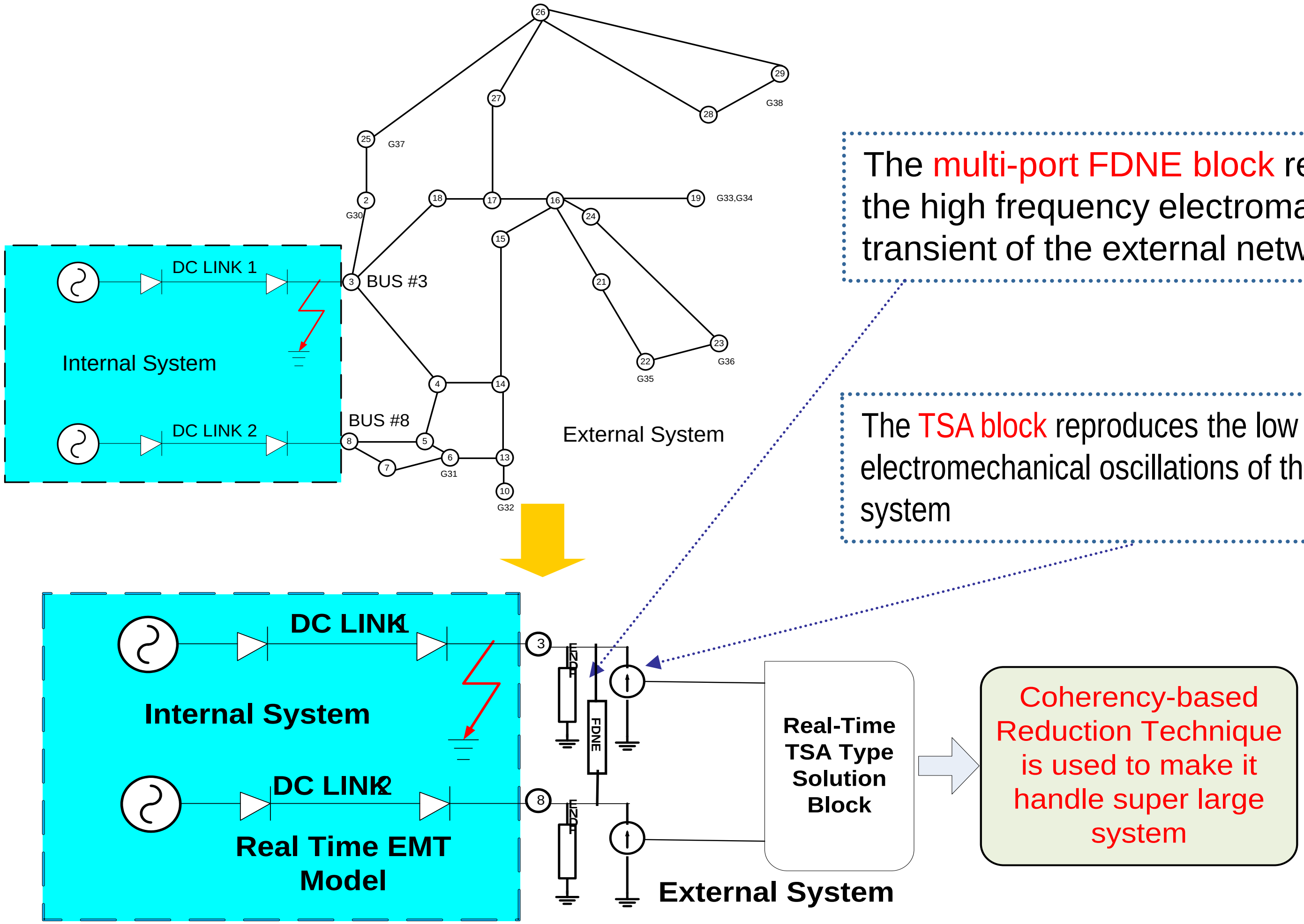


Development and Analysis of Applicability of a Hybrid Transient Simulation Platform Combining TSA and EMT Elements

- Hybrid Simultions can greatly be speeded up with multi-core/multi-CPU computing platforms



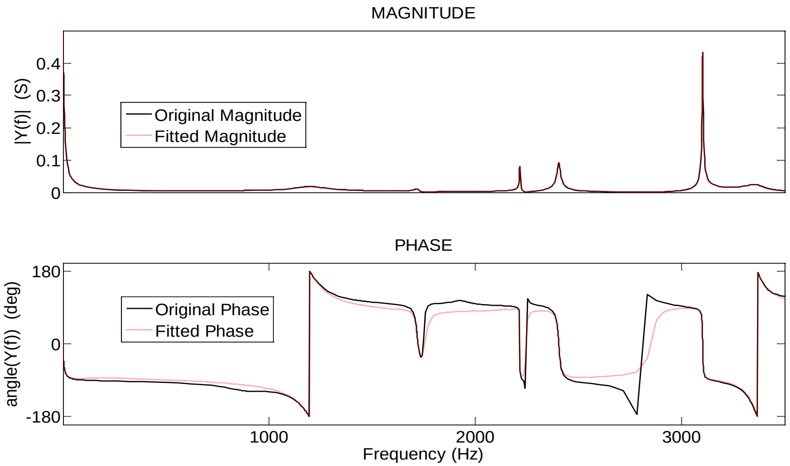
Freq. Dependent Network Equivalents for interfacing TSA with EMT

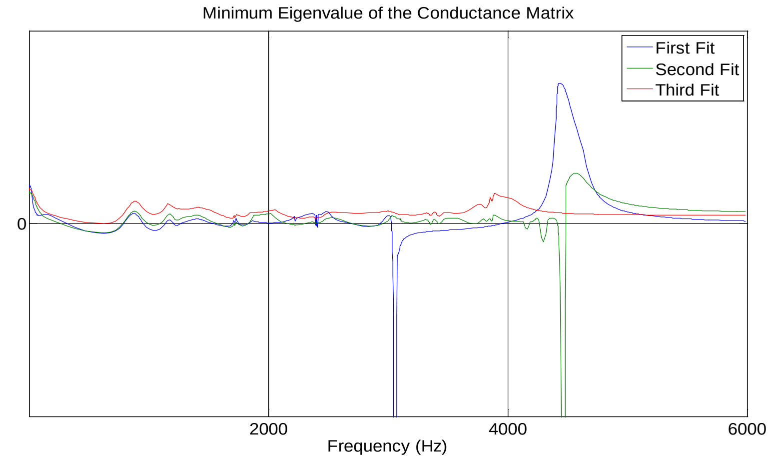




Frequency Dependent Network Equivalent (FDNE)

1. Develop the frequency domain response of the external system from detailed component values or measurement
2. The FDNE is realized as a multi-port admittance matrix with rational function elements using vector fitting.
3. The s-domain rational function admittance is directly included in the EMT time-domain simulation (while ensuring passivity)





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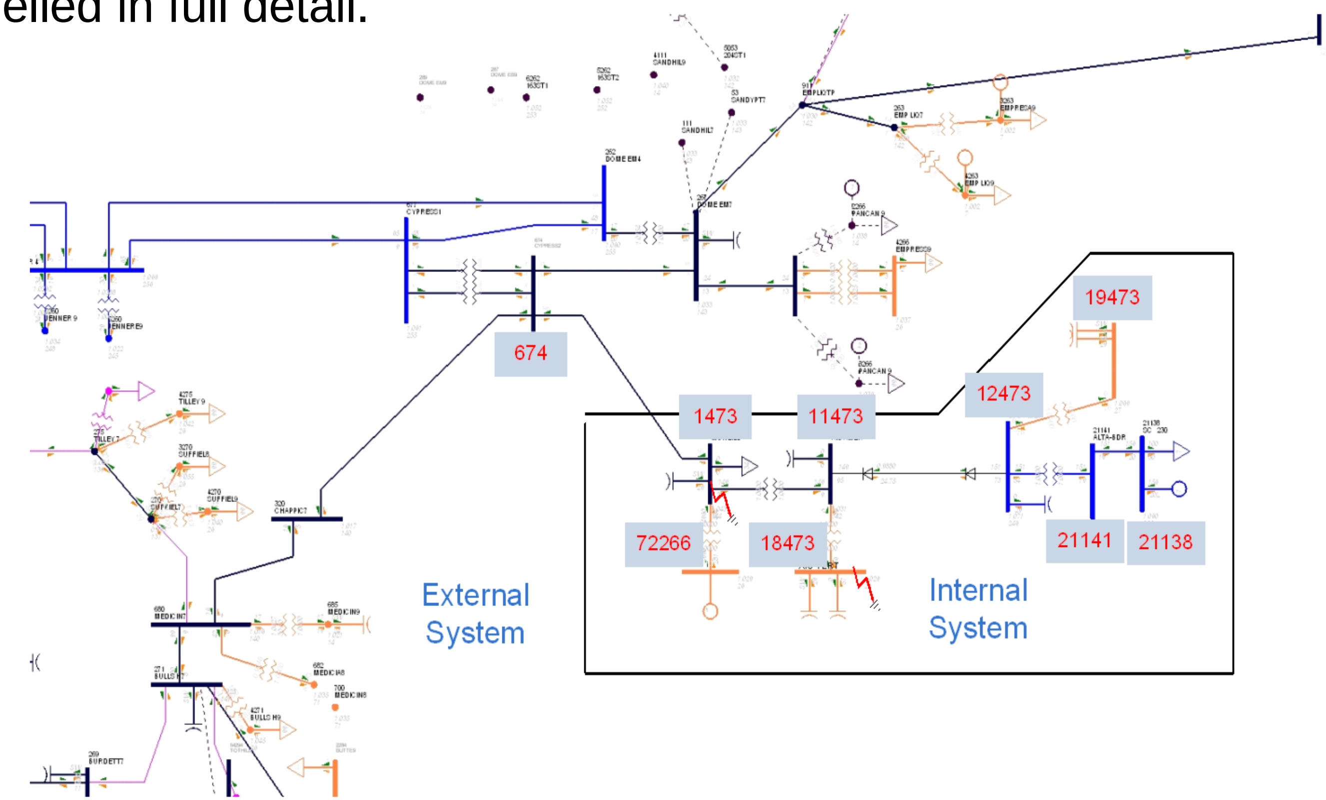
Modelling a very large Network in Real-time

- 2292 bus Southern Alberta Network
    - 802 loads, 137 generators, 142 shunts, 1006 transmission lines and 1338 transformers
- simulated in real time on 2 RTDS racks (64 processors) and connected to two HVDC infeeds modelled in full detail.



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How does the future Grid Structure impact simulation technology?

• Design of Grids requires repetitive simulations:

- Traditionally, Approach: Monte-Carlo simulation with random or sequential parameter variations (e.g. overvoltage studies)

- Today's planners demand more automation- inclusion of optimization tools and sensitivity analysis tools. These are commonly referred to as Decision Support Tools

Simulation Based Decision Support Tools, e.g.,:

- Simulation Based Optimization (OE-EMT or optimization enabled EMT simulation)
- Sensitivity Analysis using Simulation
- Simulation for obtaining Surrogate Models

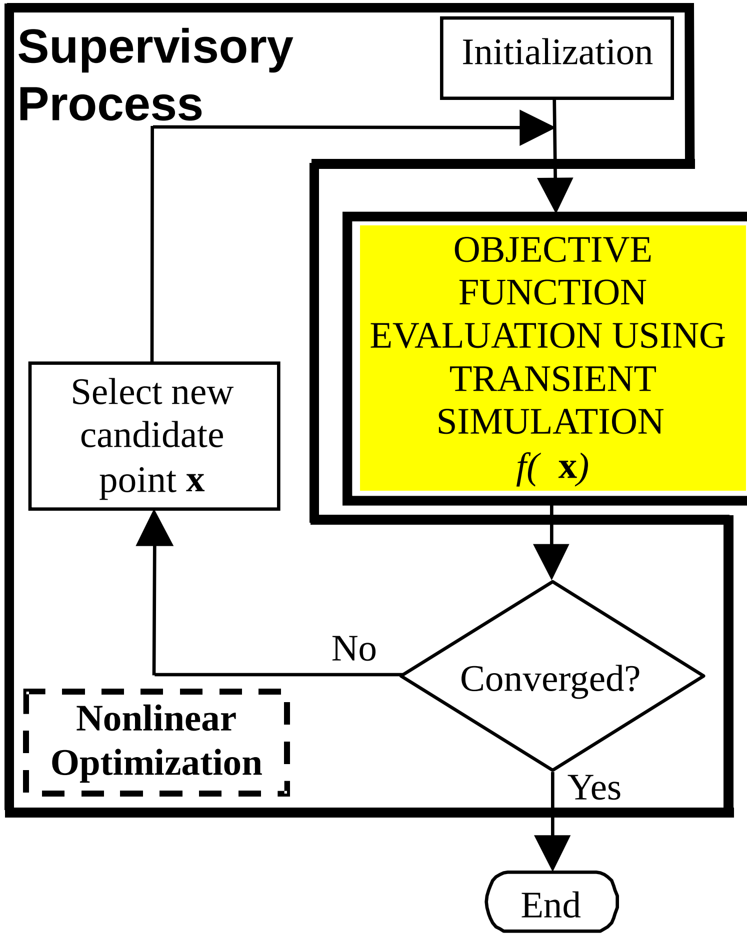
The Optimization Tool

Optimization-Enabled Transient Simulation

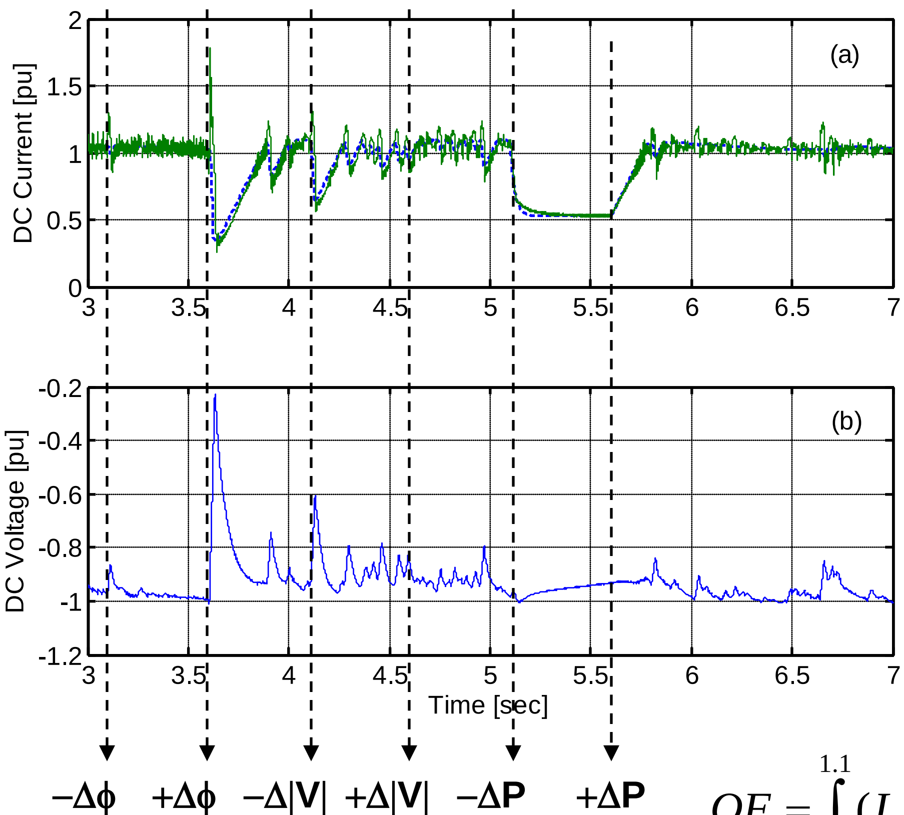
- A mathematical optimization algorithm strategically selects the trial points
- Result- orders of magnitude less runs than with brute force approach

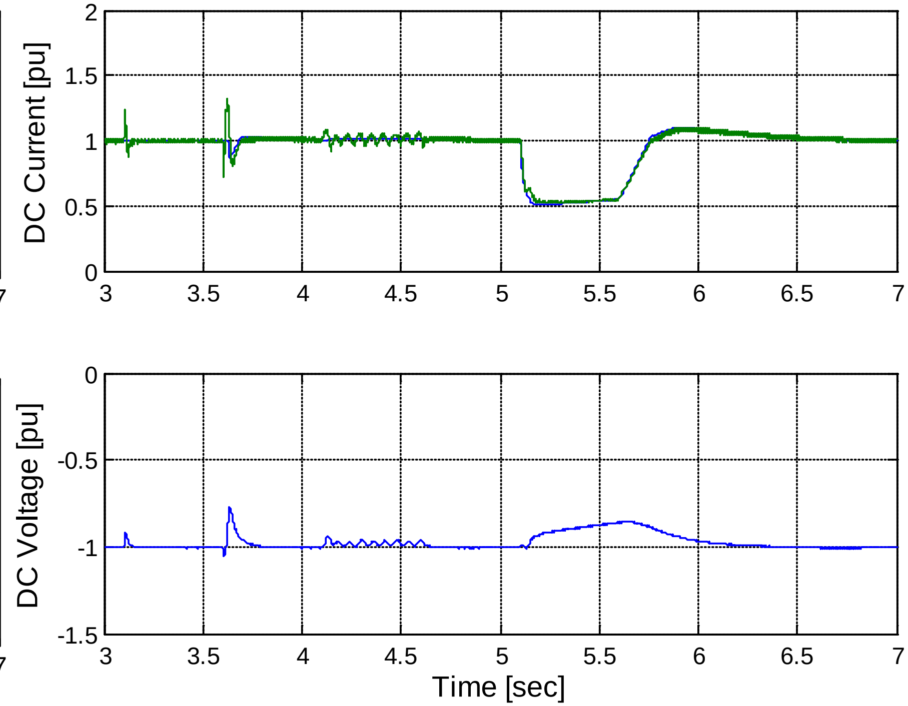
$$\text{minimize } f(\mathbf{x})$$

$$\mathbf{x} = [x_1, \cdots, x_n]^T$$



Pre- and post- optimization HVDC Response (strong system)





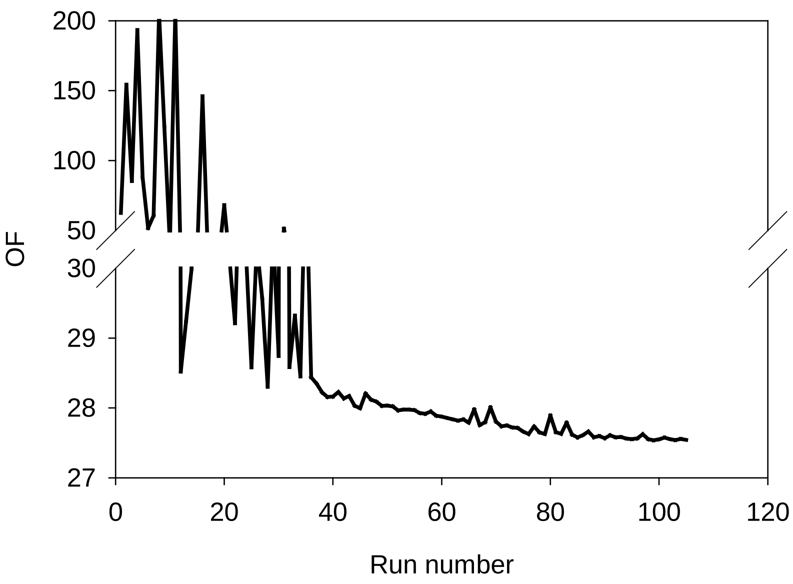
$$OF = \int_{0}^{1.1} (I_{dref} - I_d)^2\, dt + \int_{1.1}^{1.65} 2(I_{dref} - I_d)^2\, dt + \int_{1.65}^{4.0} (I_{dref} - I_d)^2\, dt$$

Optimization Performance)

Table 1. Initial and Optimized Parameters

	Initial Parameters	Optimized Parameters
Gain (rectifier)	1	1.04
Time constant (rectifier)	0.3	0.007
Gain (inverter)	1.44	0.3
Time constant (inverter)	0.0083	0.033

- •OF reduced from 62.5 to 27.5 in 108 runs.
- •With 10 steps in each of 4 variables, traditional multiple-run techniques would require 104=10,000 simulation runs.
- •2 Orders of Magnitude time savings!



Example: Optimization of Converter Gains in a Dc Grid

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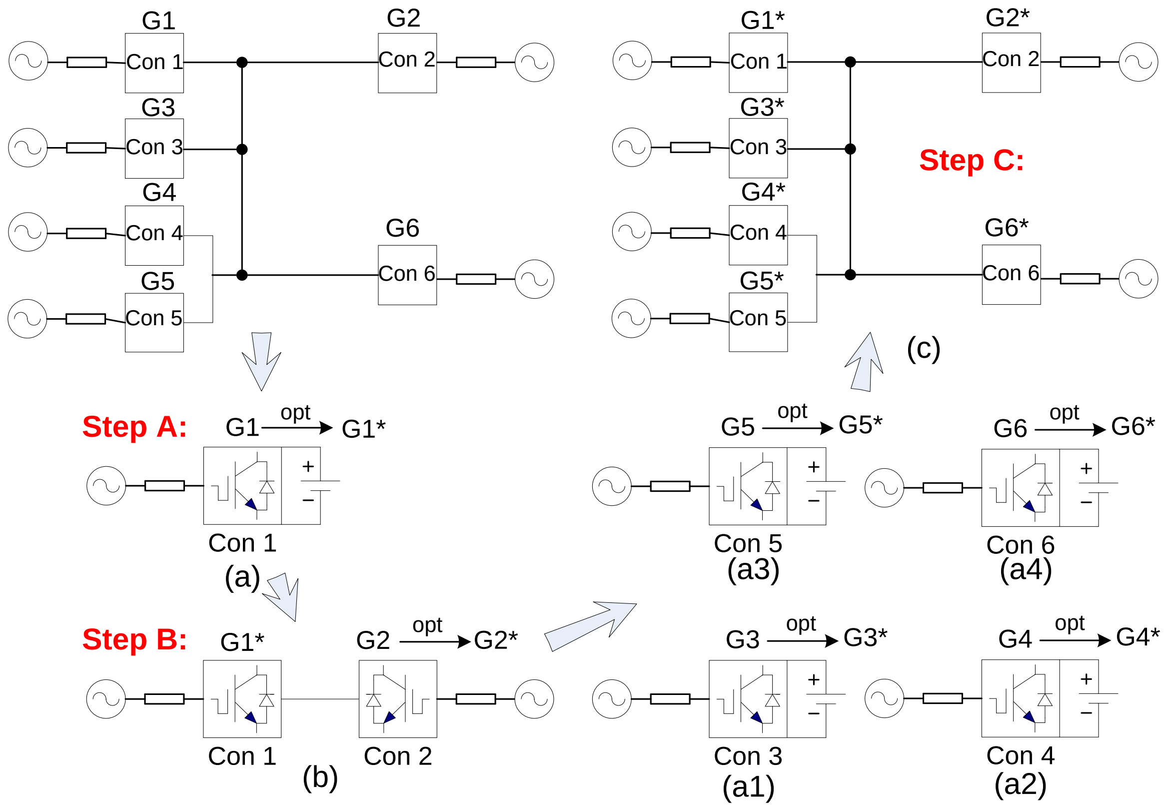
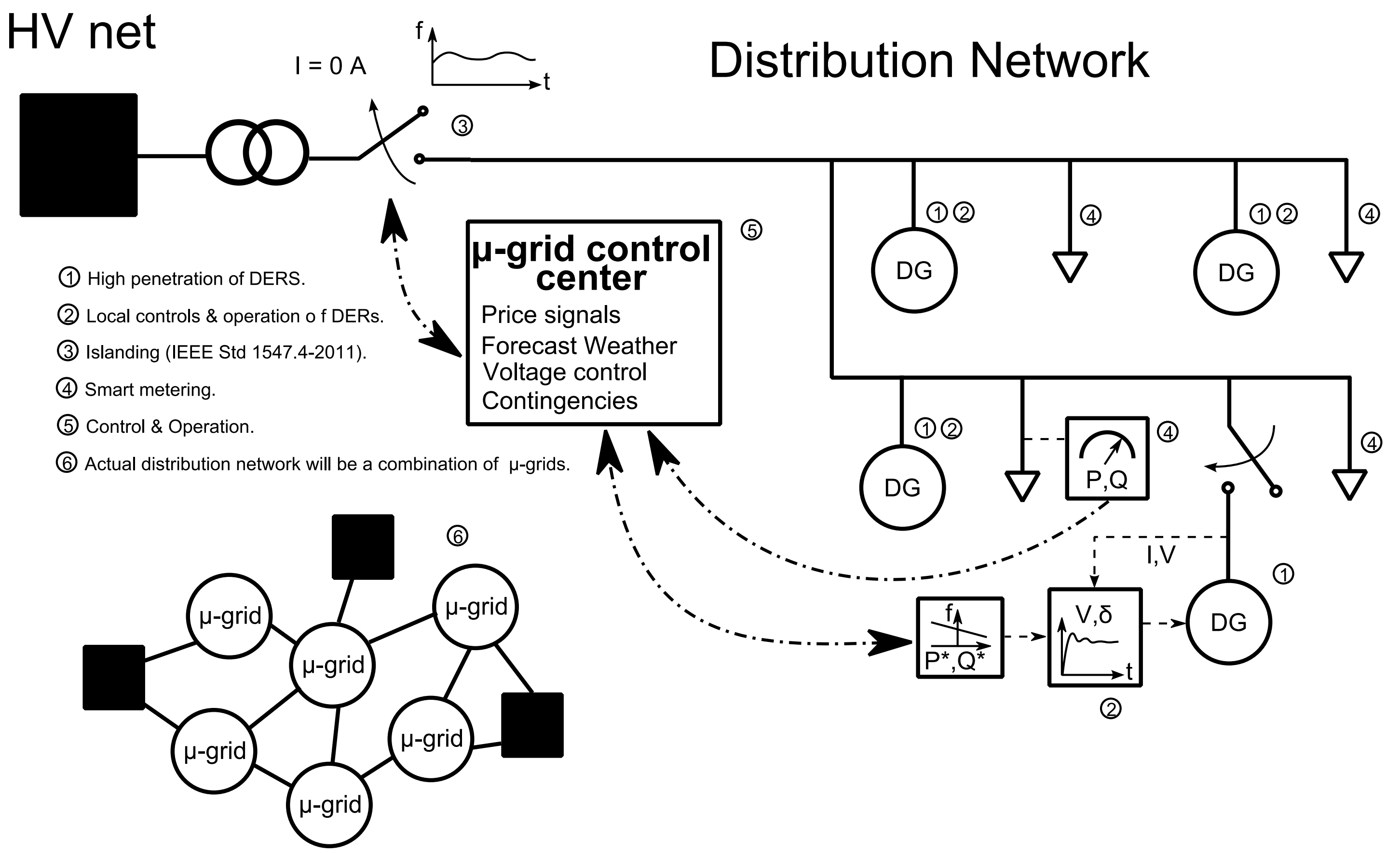


Fig. 4: Optimization Usingof the single converter relaxation method

Optimum Gains must be selected for several converter controllers considering several operating scenarios

VSC2 (V_{dc}, V_{ac})						VSC1 (P, V_{ac})	
SCR	K_{p_Vdc}	T_{i_Vdc}	K_{p_Vac}	T_{i_Vac}	OFs	**SCR**	***OFs***
1.8	6.181	0.008	1.233	0.018	4.391	2	2.805
2	23.83	0.007	0.952	0.049	4.054		2.809
3	8.310	0.006	1.443	0.047	1.926		2.819
4	9.416	0.013	0.273	0.009	1.899		2.818

Stability and reliability of a Microgrid



Use of grid-computing to speed up Decision Support Simulations

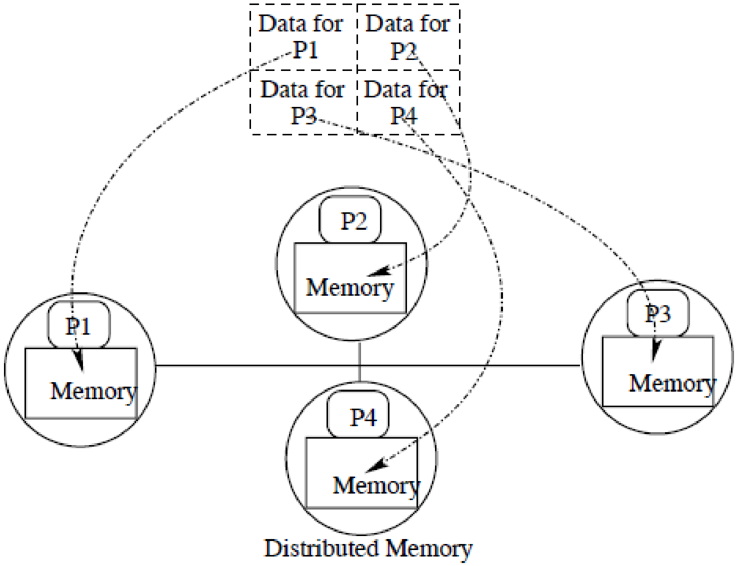


Fig. 1. Distributed Memory Architecture

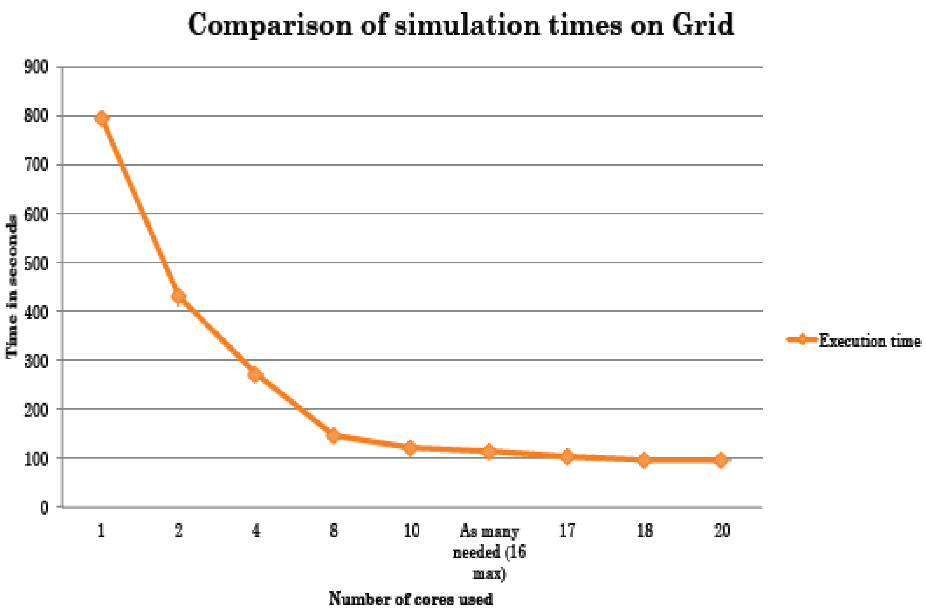


Fig. 6. Simulation Times for Various Execution Environment Sizes on the Grid

The Model as a Specification

The Approach of Model Based Specification

- Suppliers are provided with a model platform of the system into which the proposed equipment is to be installed

- The specification is stated in terms of a desired performance requirement for the overall power network

- This is an emerging trend in procurement of large Power Electronic Applications in Power Transmission Systems

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Advantages of MBS

- Manufacturers can experiment with different design alternatives on the platform provided
- The model can be made available on established simulation platforms (e.g. PSCAD/EMTDC
- For the utility, keeping the system model updated provides an excellent knowledge base and training tool for future engineers.

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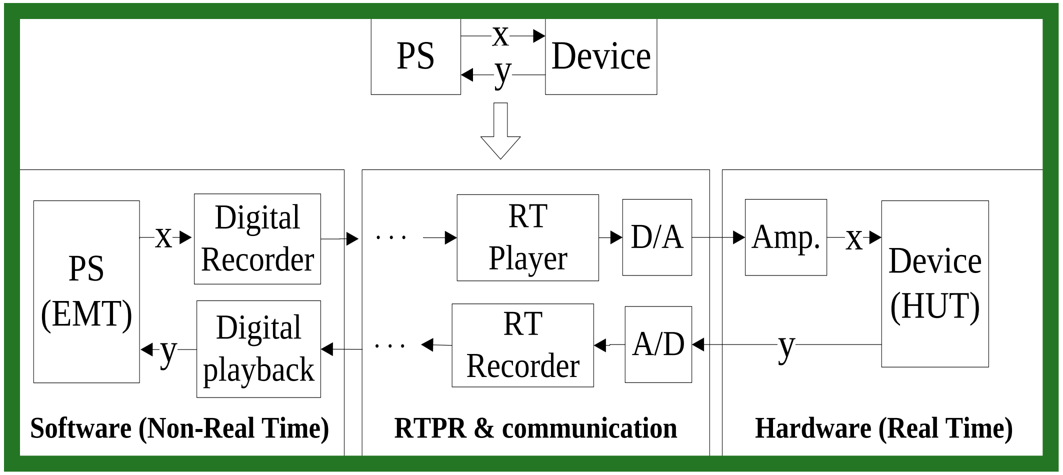
Waveform Relaxation Based Real-time HIL Simulation (WR-HIL)

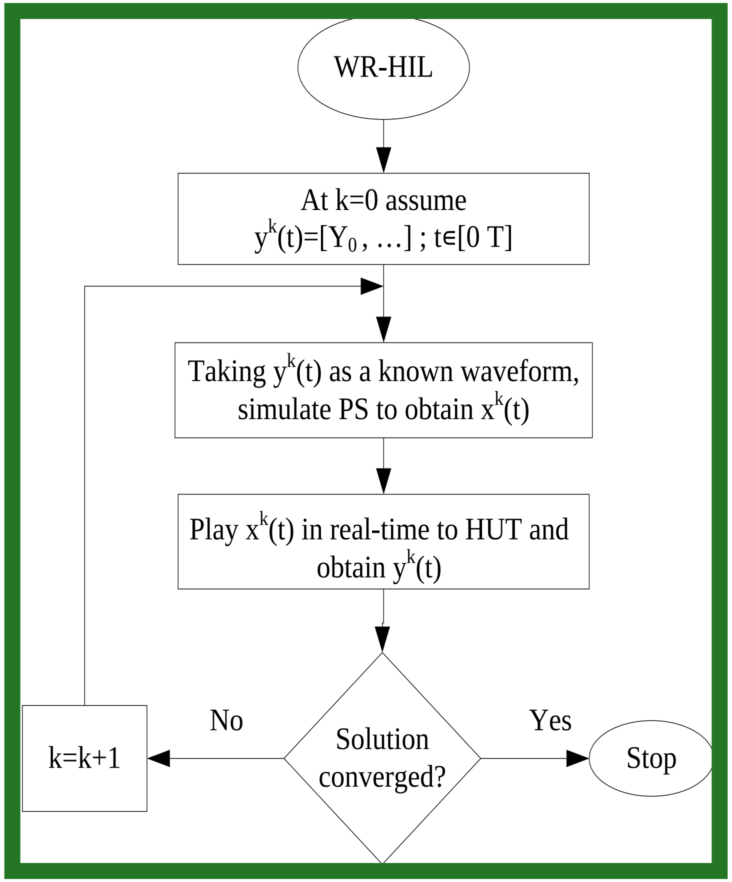
Block Diagram:



PS: Power System

RTPR: Real Time Player / Recorder

Algorithm:



WR-PHIL Example

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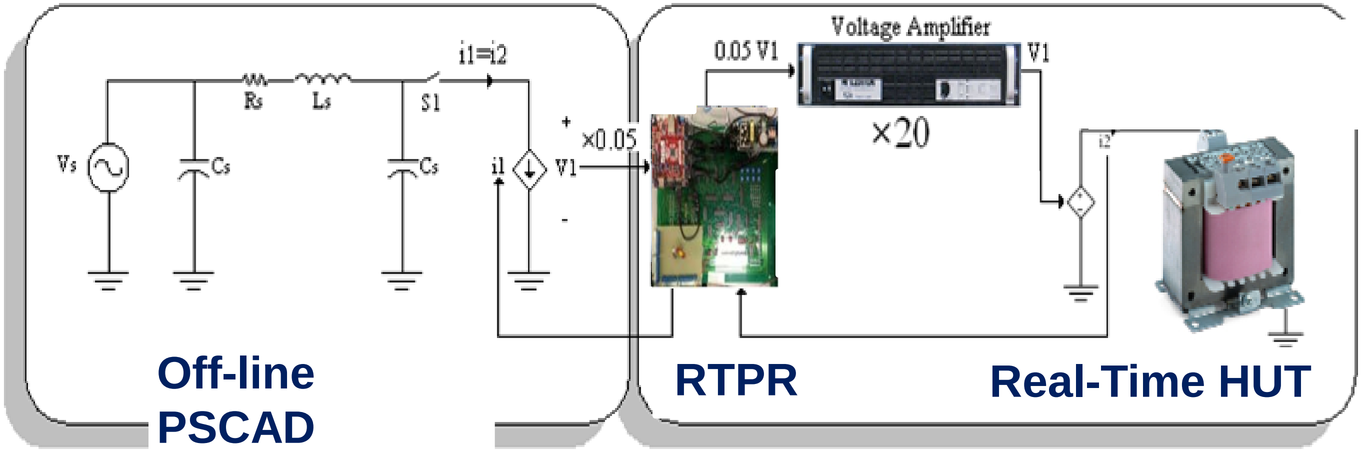
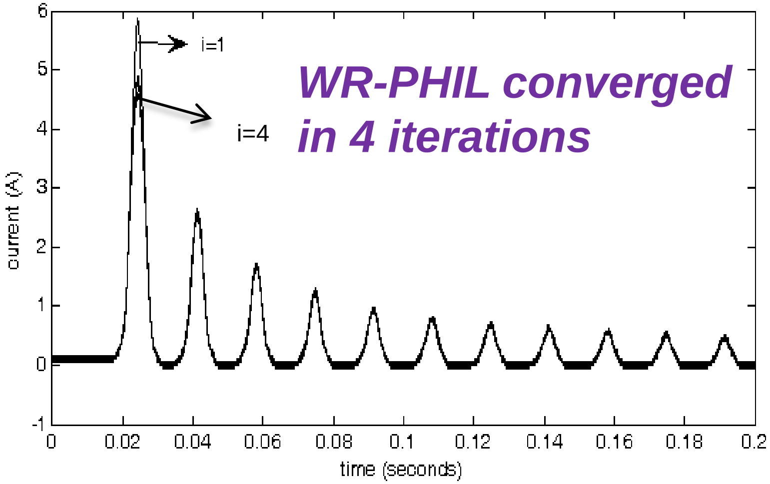
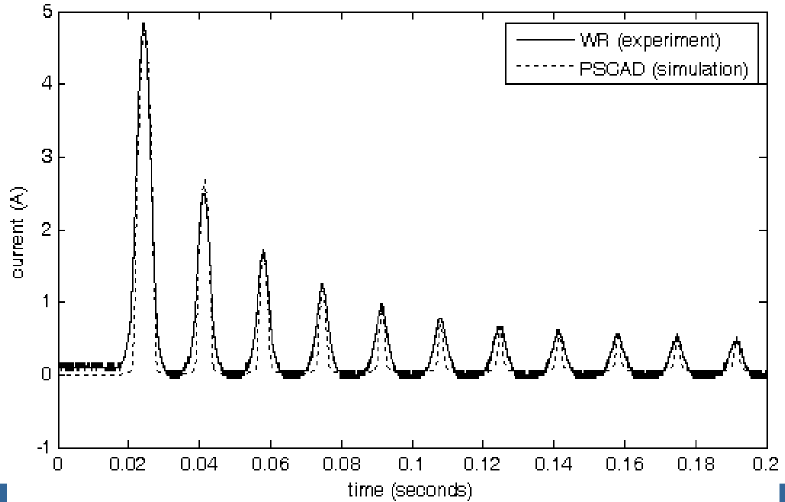
inrush current of an unloaded transformer







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Concluding Remarks

- The emerging grid is creating new demands and challenges for simulation tools
- Simulation tools are evolving:
  - ✓ Improved methods for Real-time and HIL Simulation
  - ✓ Innovative models for new components
  - ✓ Hybrid Simulations
  - ✓ Decision Support Layers
  - ✓ Introduction of new computing platforms

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- Dharshana Muthumuni, MHVDCRC
- Rohitha Jayasinghe, MHVDCRC
- Craig Muller, MHVDCRC
- Shaahin Filizadeh , U of M
- Yuefeng Liang, RTDS Technologies
- Yi Zhang, RTDS Technologies,
- Jianzhong Xu, NCEPU, Beijing/U of M
- Yi Zhang, Tsinghua University/U of M
- Mischa Steurer, CAPS/FSU

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Questions?