EMTP-RV

Research and development

Jean Mahseredjian
Professor
jeanm@polymtl.ca
École Polytechnique de Montréal
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History: R&D project

- Research and development organization: Development Coordination Group (**DCG-EMTP**)
- **EMTP**: Electromagnetic Transients Program, developed since the 70s, major versions in 90 and 96
- Completely new software and technology: **EMTP-RV**
- Large and complex project: total duration 5 years
- First commercial release version 1 in 2003
- **Large scale software with more than 1 million lines of code**
- New computational engine and New graphical user interface (GUI)
- Commercialized: www.emtp.com
- **DCG Members**: Hydro-Québec, Électricité de France, CRIEPI (Japan), Entergy, American Electric Power, Western Area Power Administration, US Bureau of Reclamation, Hydro-One, CEATI

Old EMTP software and technology

New Computation Methods
New EMTP-RV
(Restructured Version)

Support and development

- Level 1: Neil MacKenzie, Capilano Computing
- Level 2: Awa-Marie Ndiaye, CEATI
- Level 3: Jean Mahseredjian, École Polytechnique
- Development: Jean Mahseredjian, Chris Dewhurst (Capilano)
  - Team at École Polytechnique
    - Luis Daniel Bellomo, research associate
    - Many Ph.D. students
    - Many M. A. Sc. students
- Special developments:
  - Several funded projects with Hydro-Québec
  - Several funded projects with EDF
- Major contributors:
  - Hydro-Québec
  - EDF
  - Developments, funding, funding of research

Courses on EMTP-RV

- Courses in 2008
  - Australia (May)
  - Saudi Arabia (June)
  - Madison (University of Wisconsin)
  - Montréal (September)
  - Paris (Supélec, September)
  - Orléans (Vergnet, éoliennes, September)
- Courses in 2009
  - Special course for Hydro-Québec, March
  - Croatia, April
  - New Orleans, US, November

Other courses

- Courses on transients (not software)
  - Seoul, South Korea, Sungkyunkwan University, April 2009
  - Special long course, every year, École Polytechnique de Montréal (web page)
  - Seoul, South Korea, Sungkyunkwan University, August 2009

New version 2.2

- What is new in 2.2
  - Full compatibility with Vista
  - New documentation system with new navigation features
  - Various improvements and additions to models. The data handling features for several models are now simplified to allow easier loading when separately calculated data.
  - New capability to store complete circuits in libraries. A circuit appearing in a library folder now becomes listed in the library Parts Palette and can be dragged and dropped into a design just like standard parts. This is a very powerful feature that provides easy access to user circuits and allows maintaining more complex models through libraries.
  - Subcircuits are now given the Model or Physical attribute in the Subcircuit Info menu. A model subcircuit is primarily intended to define the operation of the device represented by its parent symbol. A physical subcircuit is primarily used to contain some of the system. The devices inside the subcircuit represent actual physical elements of the system. The physical subcircuit may contain Model subcircuits. This distinction allows propagating computed data into Physical subcircuits for visualization purposes.

New version 2.2

- Several new scripting methods, including: dynamic modification of device symbol using a separately stored symbol drawing.
- Several improvements

- New ScopeView
  - Vista compatible
  - Several improvements
- A new HVDC model benchmark (for 50 Hz and 60 Hz networks) originally developed by professor Vijay Sood (University of Ontario Institute of Technology) is now available upon request. This work resulted from a collaboration with Sébastien Dennetière (Électricité de France) and École Polytechnique de Montréal.

Scenario attribute

- Allows changing scenarios in one easy step
- Each device is given a Scenario attribute and a Scenario.Script attribute
  - Built-in
- Simple user-defined scenarios

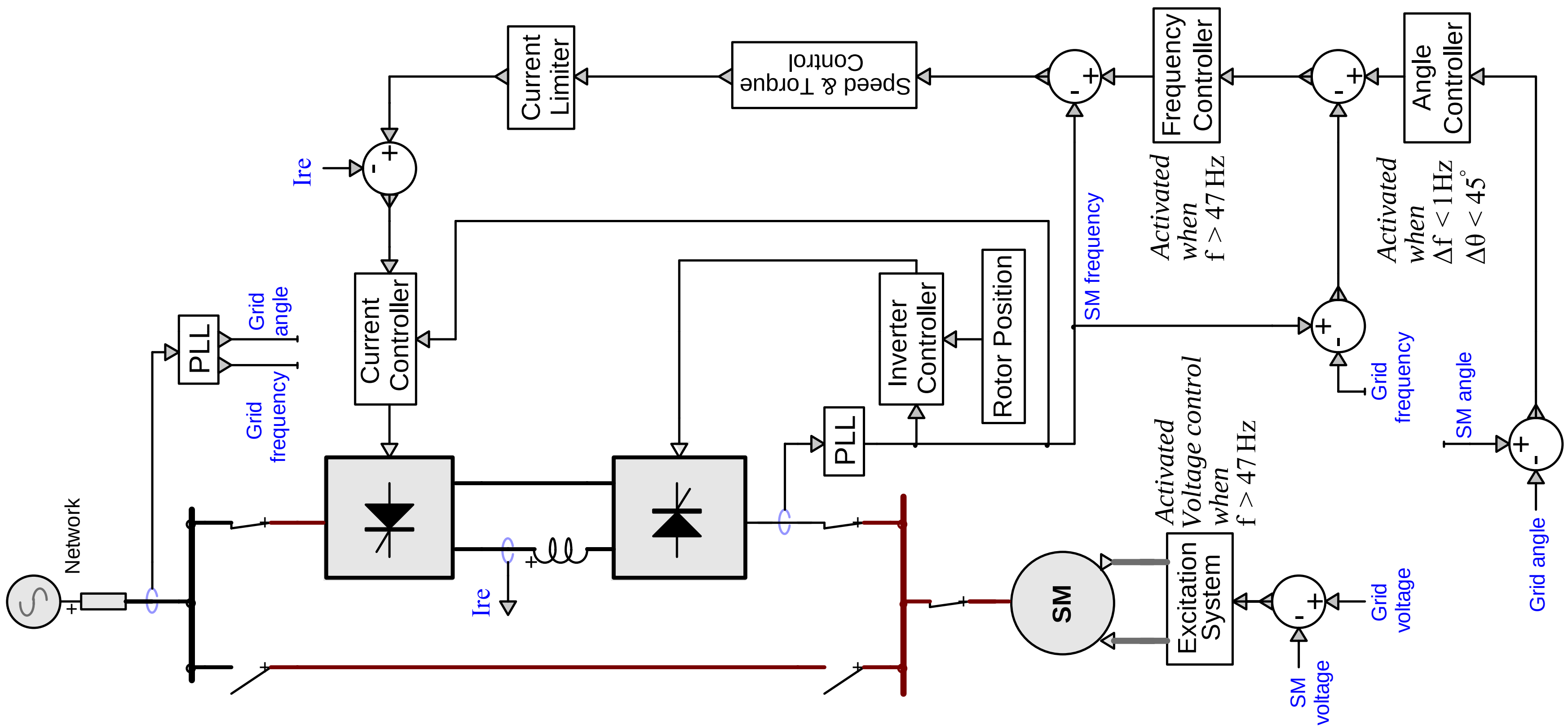
```
dev=defaultObject()
Scenario=dev.getAttribute('Scenario');
switch (Scenario){
    case '1' :
      dev.setAttribute('Exclude','Ex')
    break;

    case '2' :
      dev.setAttribute('Exclude','')
    break;
}
```

Recently completed R&D projects

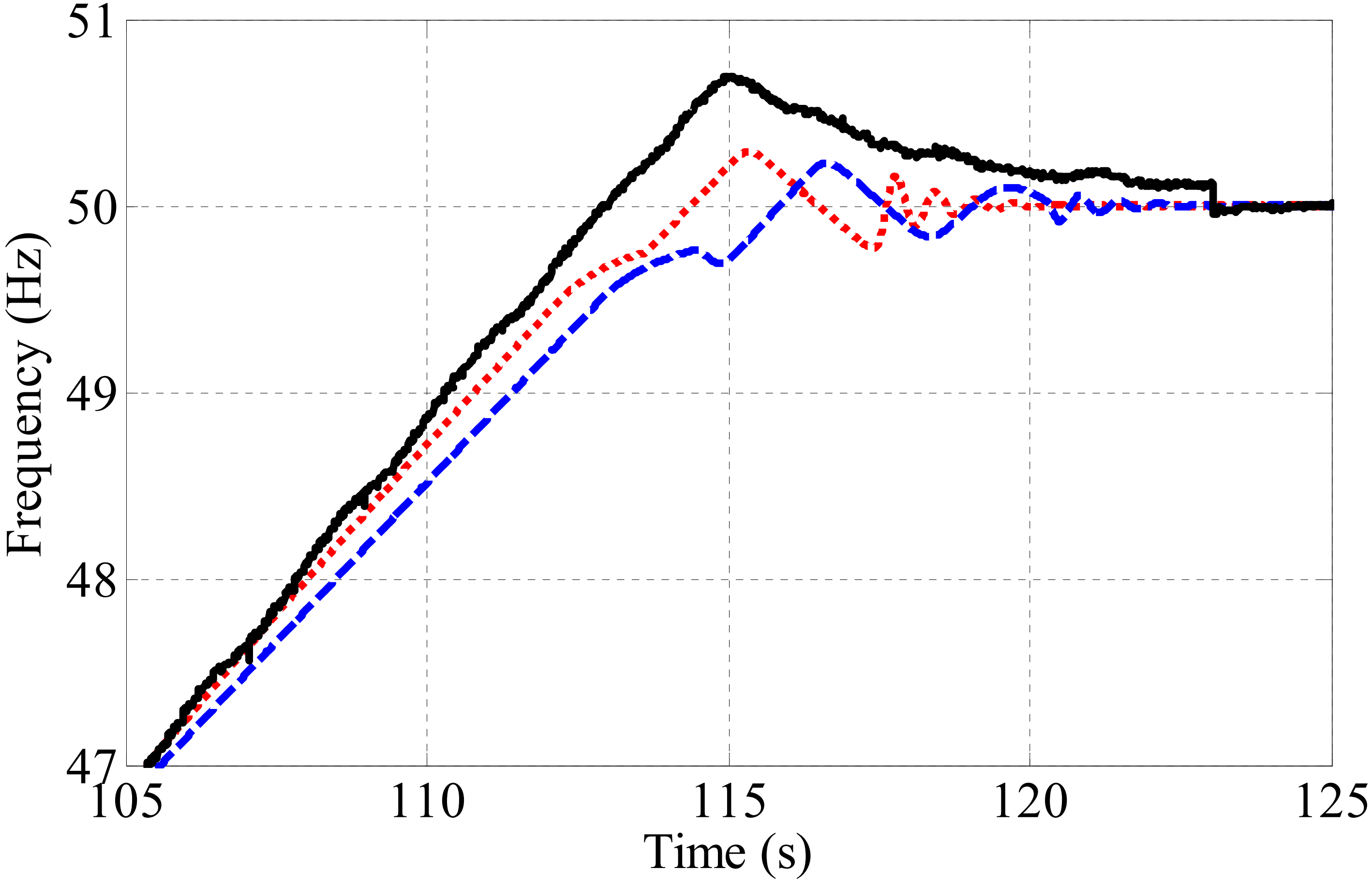
- 0-Hz startup of Synchronous machine
  - Project EDF R&D, Clamart
  - Allows using the synchronous machine model without 60 Hz or 50 Hz initialisation
  - Starts from 0 Hz.
  - Allows studying the machine startup and synchronization onto the network
  - For pumped storage studies
  - For black-start studies
- Improved wind generator models

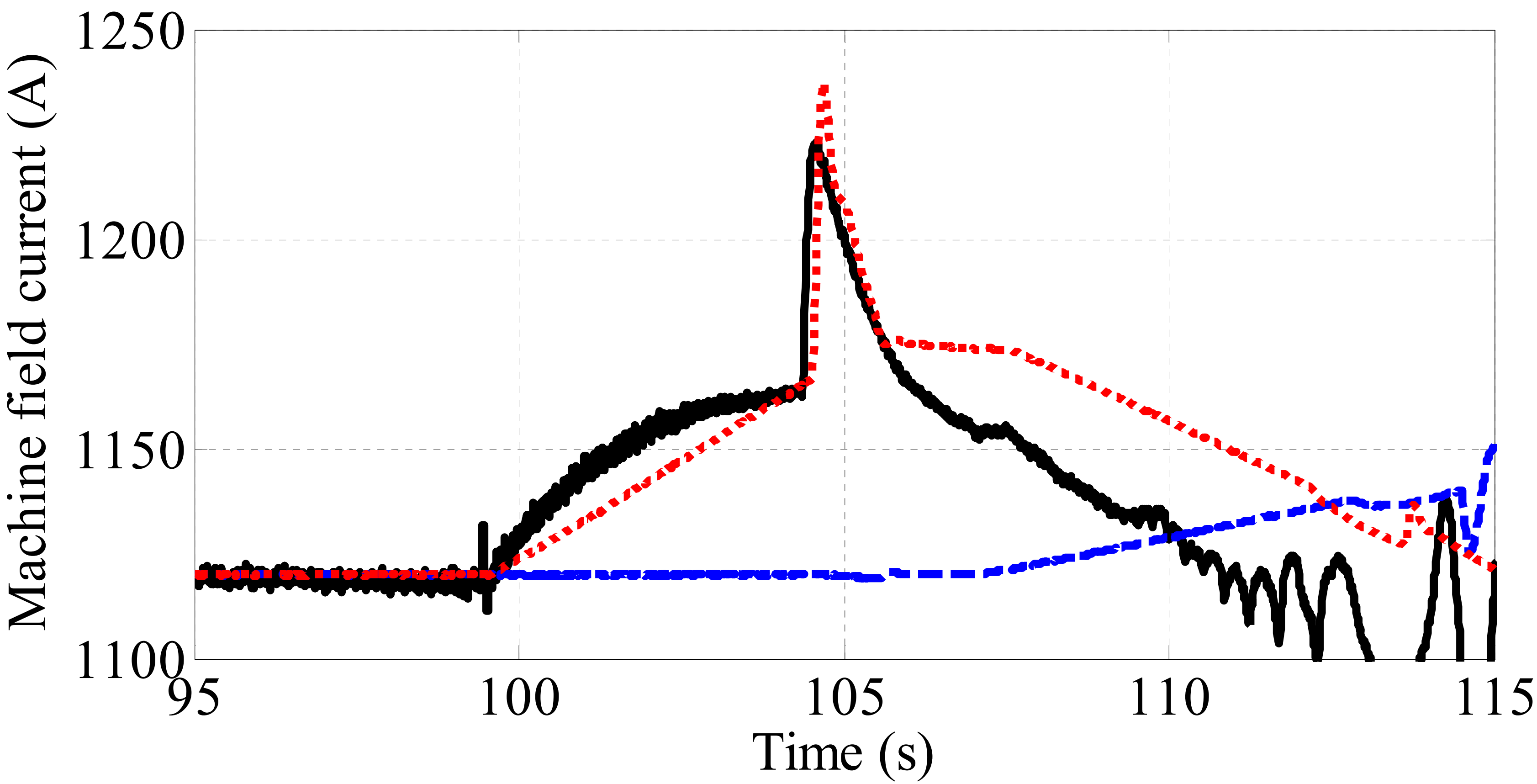
Modeling and Simulation of the Startup of a Pumped Storage Power Plant Unit

- IPST-2009 paper, U. Karaagac, J. Mahseredjian, S. Dennetière

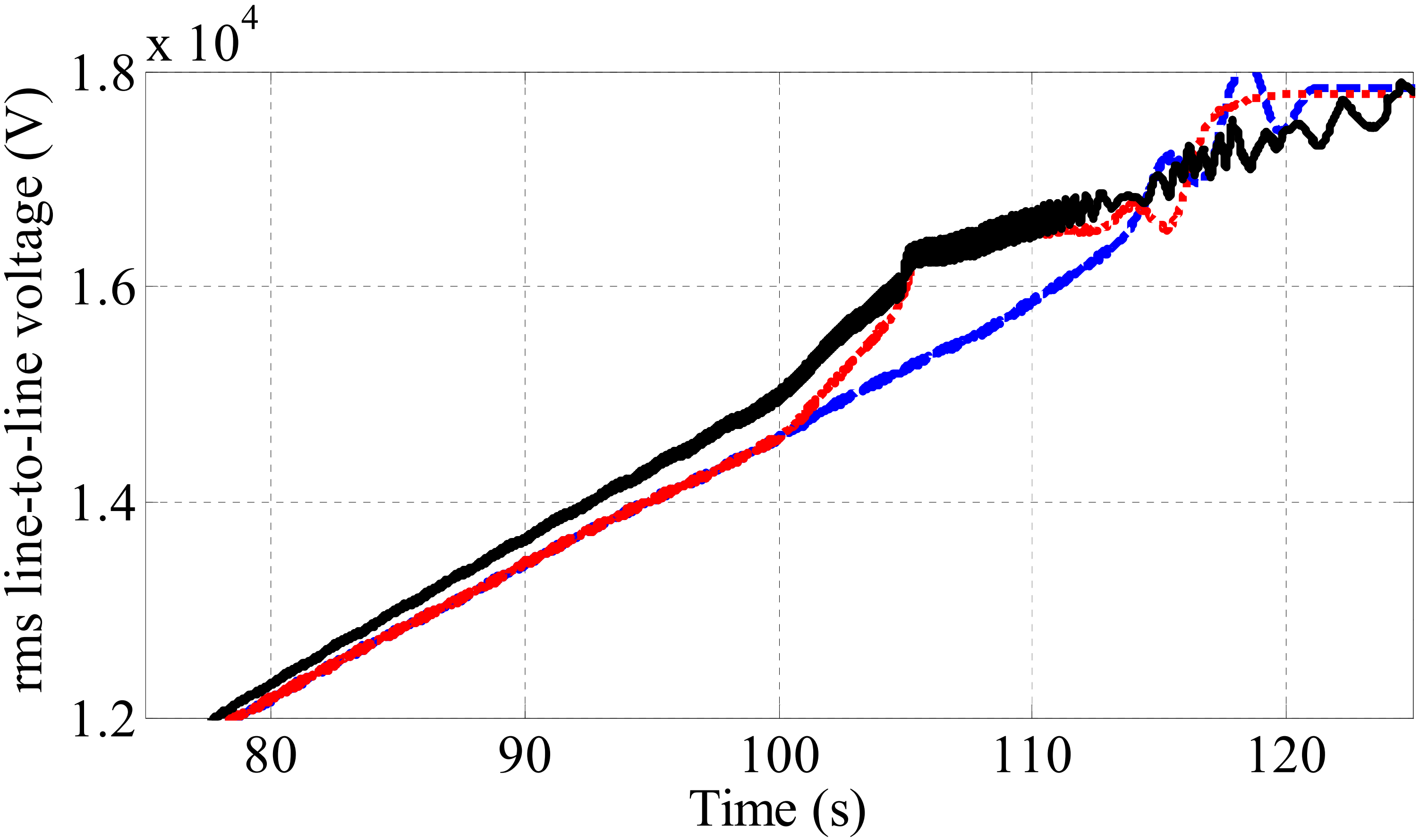


- Measured and simulated frequencies

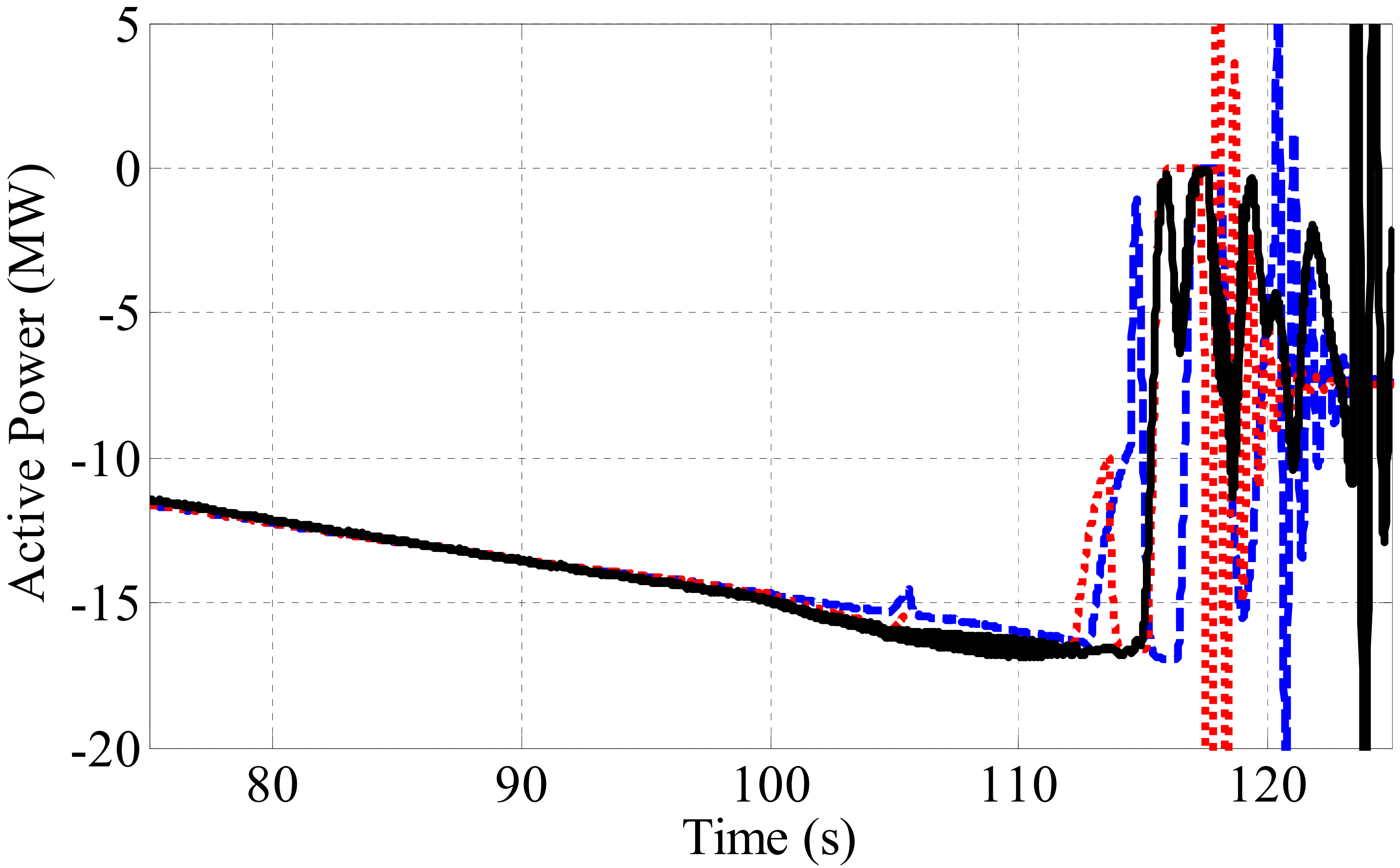




Machine field currents



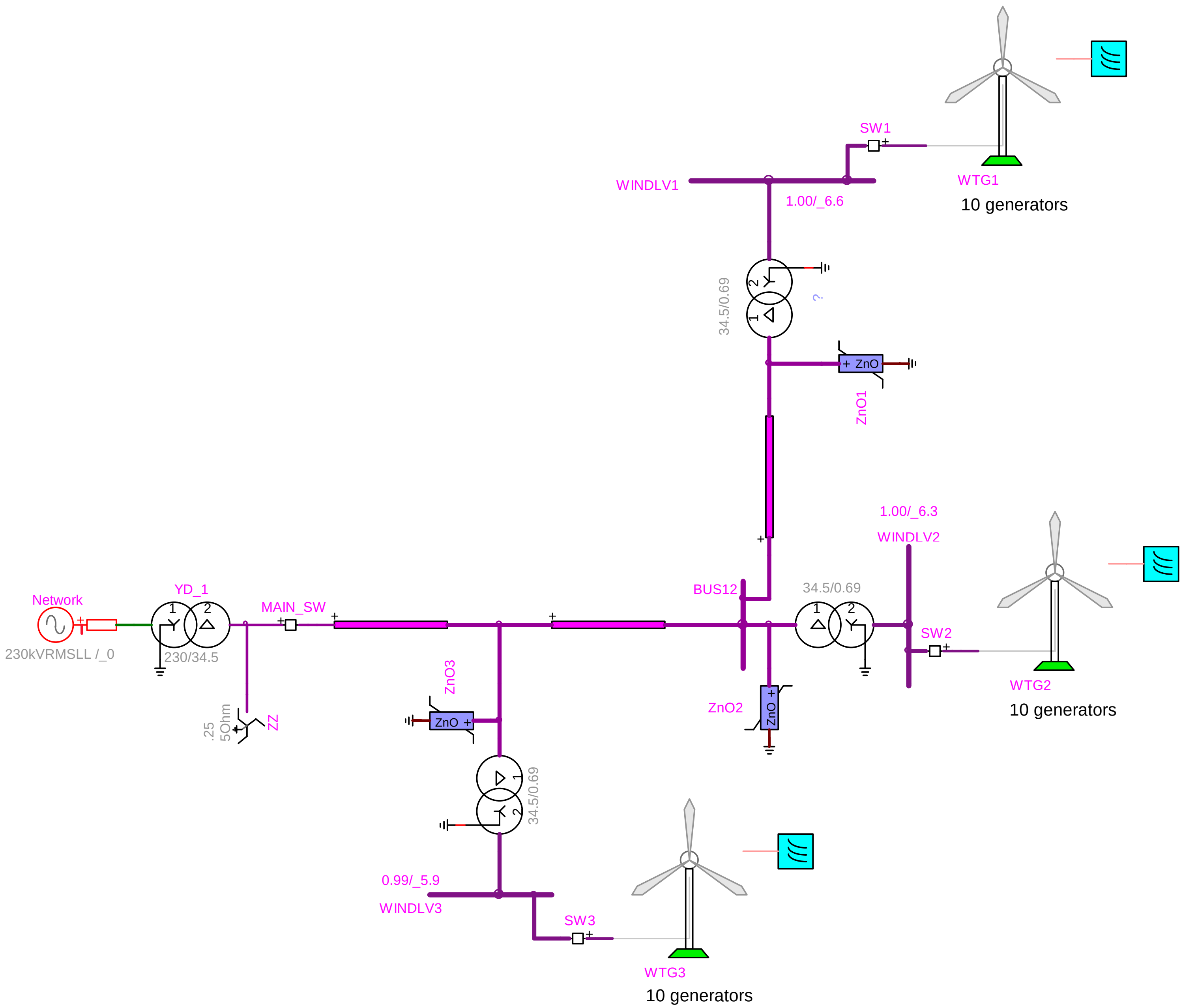
Machine terminal rms line-to-line voltage



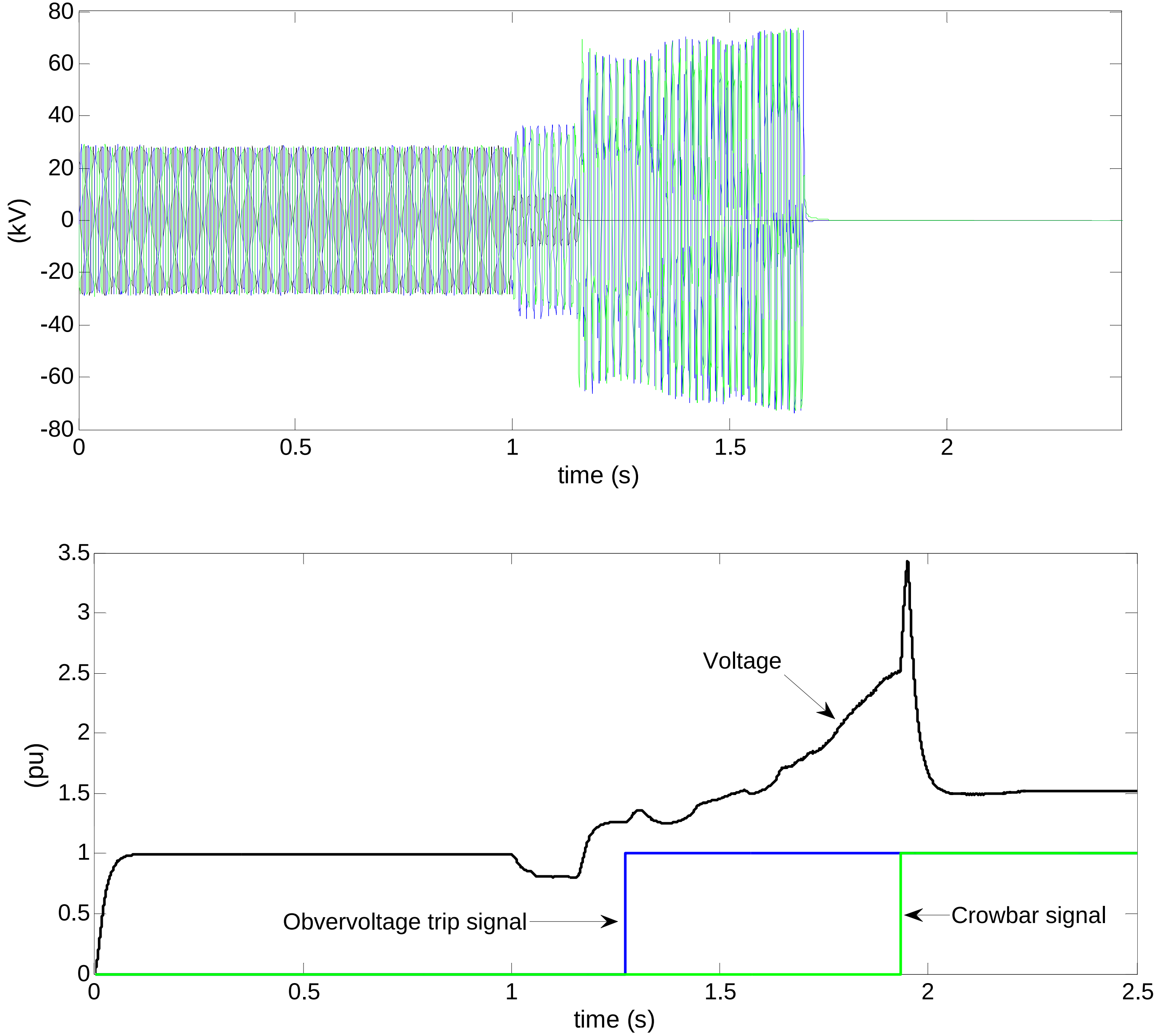
Active power delivered by the machine

Improved Wind generator models

- Generic models
  - Detailed
  - Mean-value models
- Matching of PSS/E results for slow transients
- Initialization scripts
- Flicker meters
- Work completed by L. D. Bellomo and J. Mahseredjian (École Polytechnique)



SW1
WINDLV1
1.00/_6.6
WTG1
10 generators
34.5/0.69
ZnO
ZnO1
1.00/_6.3
WINDLV2
Network
YD_1
MAIN_SW
BUS12
34.5/0.69
SW2
230kVRMSLL /_0
230/34.5
WTG2
10 generators
ZnO3
ZnO2
ZnO
ZnO
.25
5Ohm
ZZ
34.5/0.69
0.99/_5.9
WINDLV3
SW3
WTG3
10 generators



80
60
40
20
0
-20
-40
-60
-80
(kV)
0
0.5
1
1.5
2
time (s)
3.5
3
2.5
2
1.5
1
0.5
0
(pu)
Voltage
Obvervoltage trip signal
Crowbar signal
0
0.5
1
1.5
2
2.5
time (s)

Improvements to the load-flow module (next versions)

- Presentation and location of worst mismatch locations
- Presentation and location of reactive power violations
- Presentation of PQ power on transmission lines (on the design symbols)
- Automatic calculation of tap positions
  - Automatic initialization for tap control signals
- Automatic calculation of asynchronous machine slip from mechanical power or electrical power
- The area control notion
- Attribute scripting for device data based on LF solution

Toolboxes

- CRINOLINE: electromagnetic compatibility
- EGERIE
  - Short-circuit analysis package
  - Automates short-circuit studies
- Harmonic analysis
  - Harmonic source models
  - Analysis tools
  - Compensator models
- Parametric studies
  - Advanced functions, high level scripting
  - Scenario studies
- LIPS: Lightning impact on power systems
  - Automation level for lightning analysis

Other works

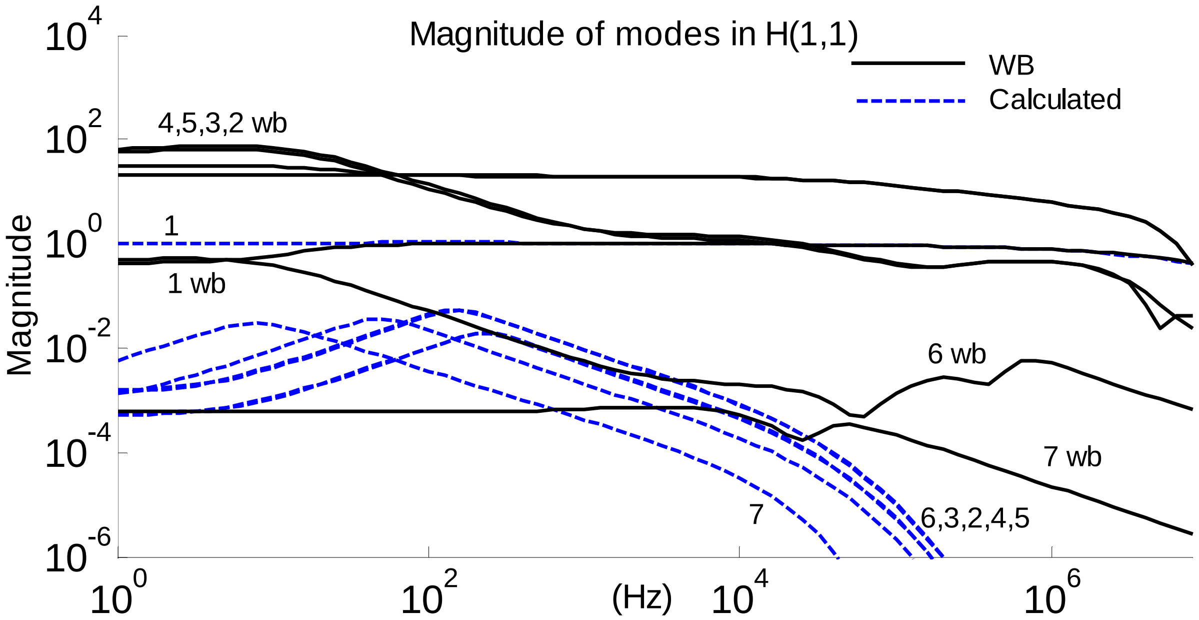
- Conversion of remaining device scripts to the object-oriented version
- Scripts for automatic layout of signals, automatic connections for building entire networks
- Simplified SVC model: controlled inductance (currently available)
- Switching to the Intel compiler
  - Compatibility of DLLs
- New C/C++ DLL (prebuilt) for direct interfacing through DLL (IREQ)
- New DLL specific to control systems, based on perturbation theory

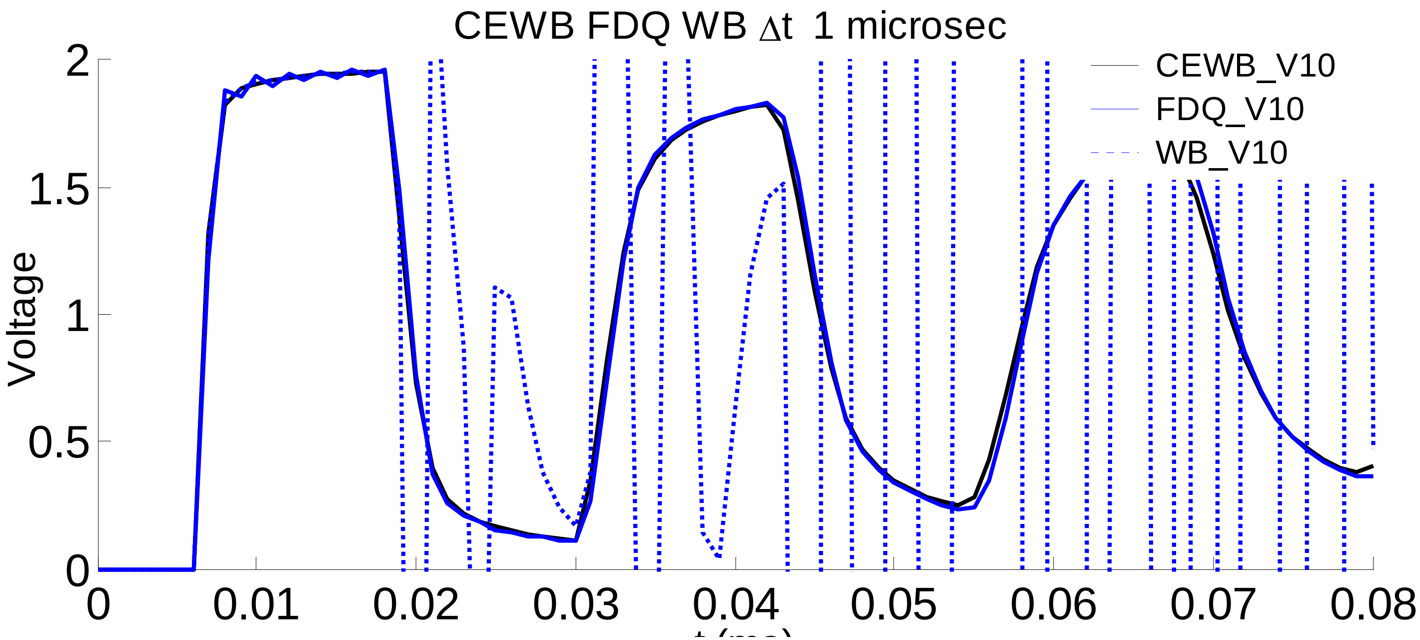
Modeling of transmission lines and cables

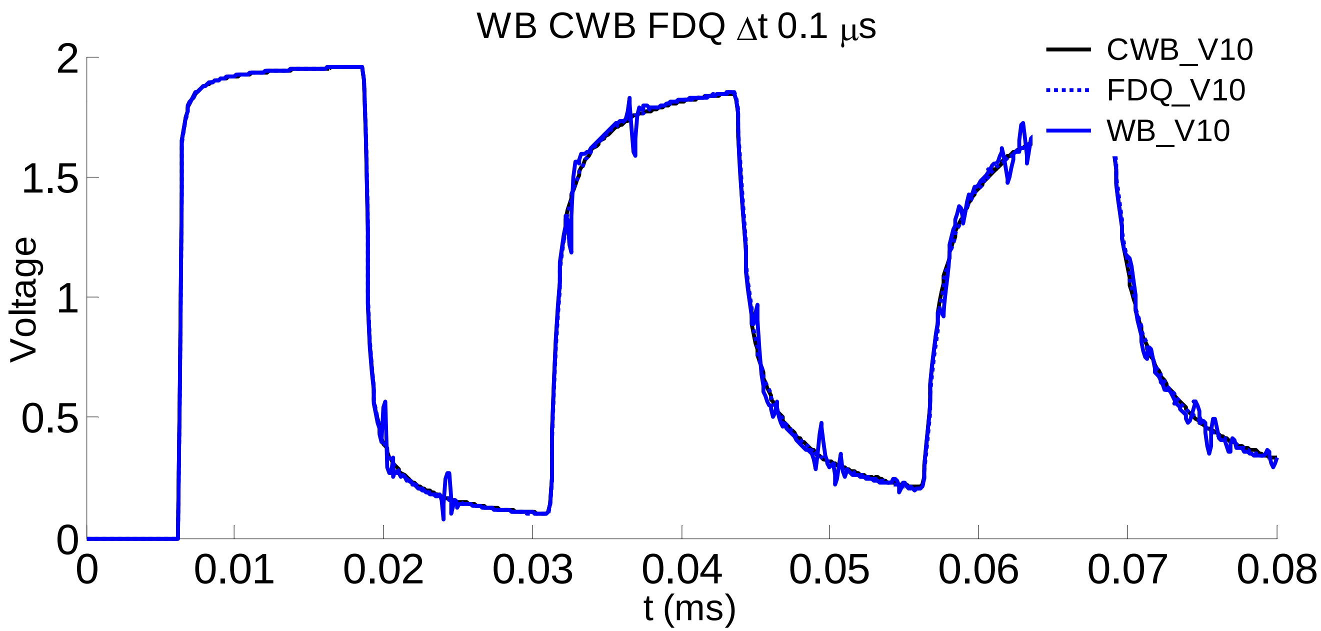
- Current limitations
  - The Wideband model may encounter numerical problems
    - Can be fixed by user manipulations of the fitting function, not simple
    - Complex research problem in the literature, many papers
    - Prominent problem for short cable
- Development of a new fitting method: WVF
- Contribution of an error control technique in time-domain
  - More robust, stable model
- Results presented in IEEE papers

$$\mathbf{H} = \mathbf{exp}\left(-\sqrt{\mathbf{YZ}l}\right) \qquad \mathbf{H} = e^{\left(\mathbf{T}\boldsymbol{\Lambda}\mathbf{T}^{-1}\right)} = \mathbf{T}\,e^{\boldsymbol{\Lambda}}\,\mathbf{T}^{-1}$$

$$H_{mode} \cong e^{-s\tau} \sum_{n=1}^{N} \frac{\underline{c}_n}{s + \underline{p}_n} \qquad H_{ij}(s) \cong \sum_{m=1}^{M} \left[\sum_{n=1}^{N_m} \frac{c_{ij\,mn}}{s + p_{mn}} \right] e^{(-s \cdot \tau_m)}$$




CEWB FDQ WB Δt 1 microsec
CEWB_V10
FDQ_V10
WB_V10
Voltage
2
1.5
1
0.5
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08


WB CWB FDQ Δt 0.1 μs
CWB_V10
FDQ_V10
WB_V10
Voltage
2
1.5
1
0.5
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
t (ms)

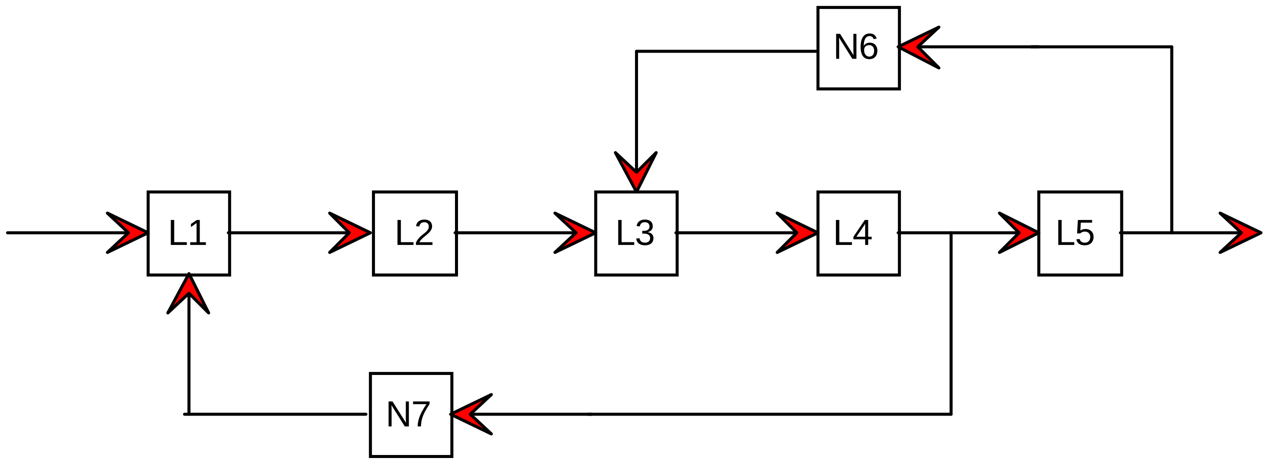
Other R&D based on EMTP-RV

- New hysteretic reactor model, completed M. A. Sc. project
  - Better fitting method
- Other hysteretic reactor models:
  - Preisach based model (University of Toronto), completed
  - Programming of the old EMTP type 96, started
- Vacuum breaker model, currently available
- Fast to superfast computations
  - The dynamic phasor approach for slow transients (stability analysis needs)
  - Relaxation techniques
  - Automatic adjustment of synchronous machine solutions for slower transients
  - Parallel computations
    - Using the Multi-Core processors
    - One simulation to many simulations
  - New solution methods for control systems
  - FPGA programming of a sparse-matrix based solver solver

New solution methods for control systems (research)

- Improvement of speed
- Reduction of Jacobian matrix size (demonstration prototype)
- Elimination of the matrix based solver
- Estimated gains in speed: 5 to 10 times
- Research on a single system of equations: power and control-diagram based models

Control system equations



$$
\begin{bmatrix}
1 & & & & & & & \\
 & 1 & & & & & & \\
 & & 1 & -k_{L5} & & & & \\
 & & & 1 & -k_{L4} & & & \\
 & 1 & & & 1 & -1 & & \\
 & & & & & 1 & -k_{L2} & \\
1 & & & & & & 1 & -1 \\
 & & & & & & & 1
\end{bmatrix}
\begin{bmatrix}
x_{N7} \\ x_{N6} \\ x_{L5} \\ x_{L4} \\ x_{L3} \\ x_{L2} \\ x_{L1} \\ u
\end{bmatrix}
=
\begin{bmatrix}
f_{N7}(x_{L4}) \\ f_{N6}(x_{L5}) \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ s
\end{bmatrix}
$$

Iterative solver

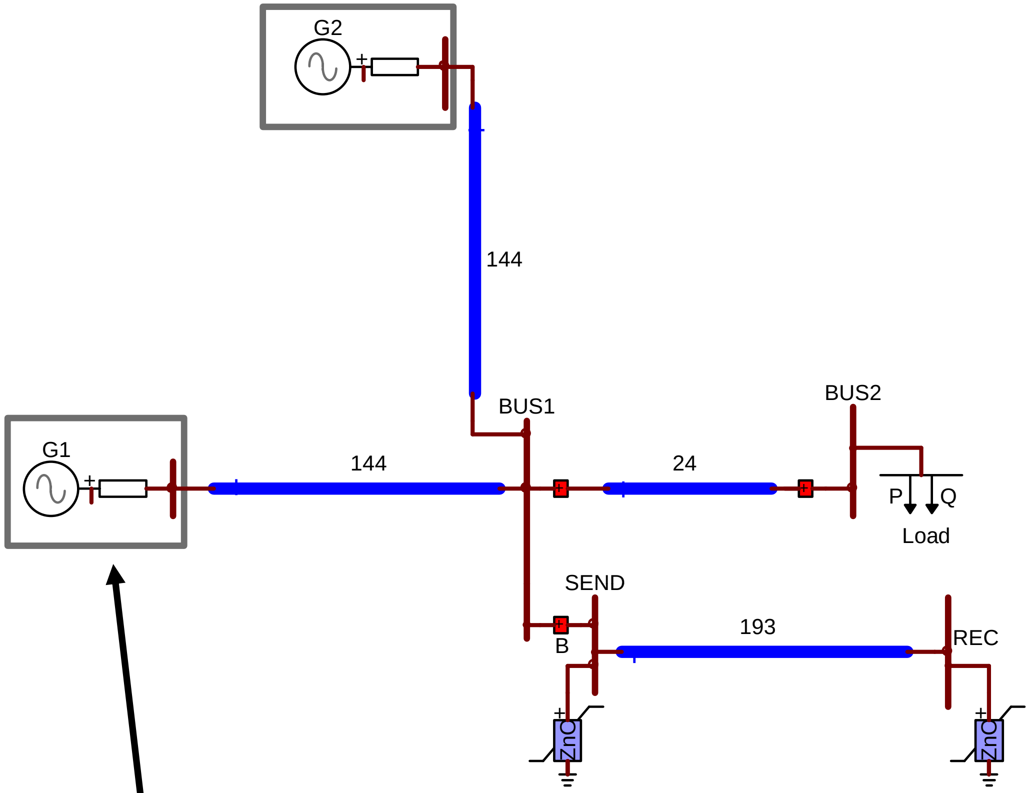
Computation of Jacobian matrix by perturbation

$$\mathbf{Jx} = \mathbf{b}$$

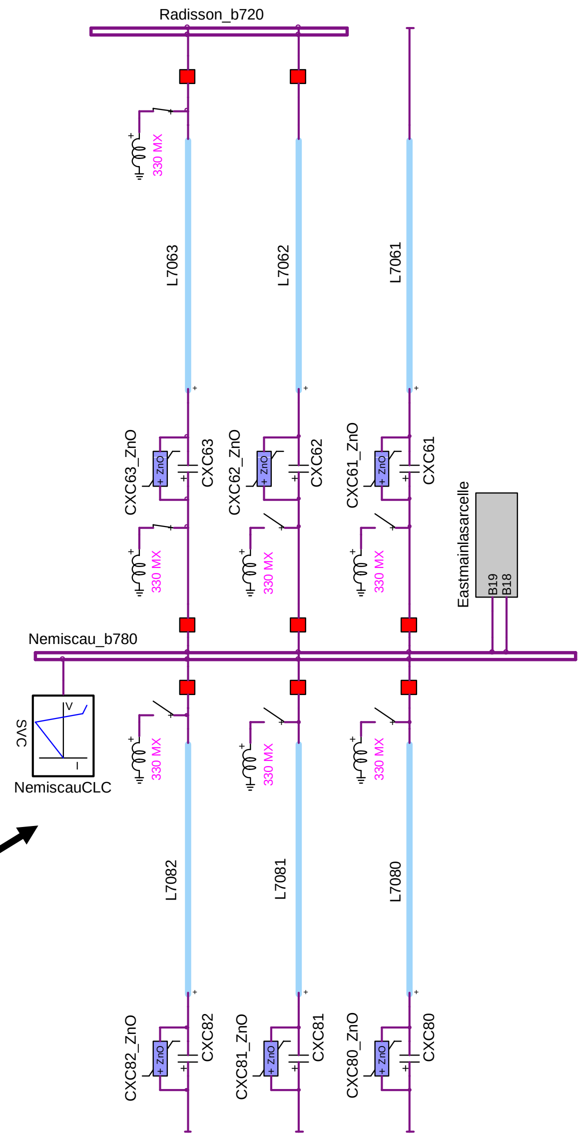
Other R&D based on EMTP-RV

- Database!
- Development of portable data modeling methods
  - Portability standards: CIM, Verilog-VHDL?
  - Data
  - Portable modeling between applications
- New IEEE Task Force

Very large networks



Equivalent



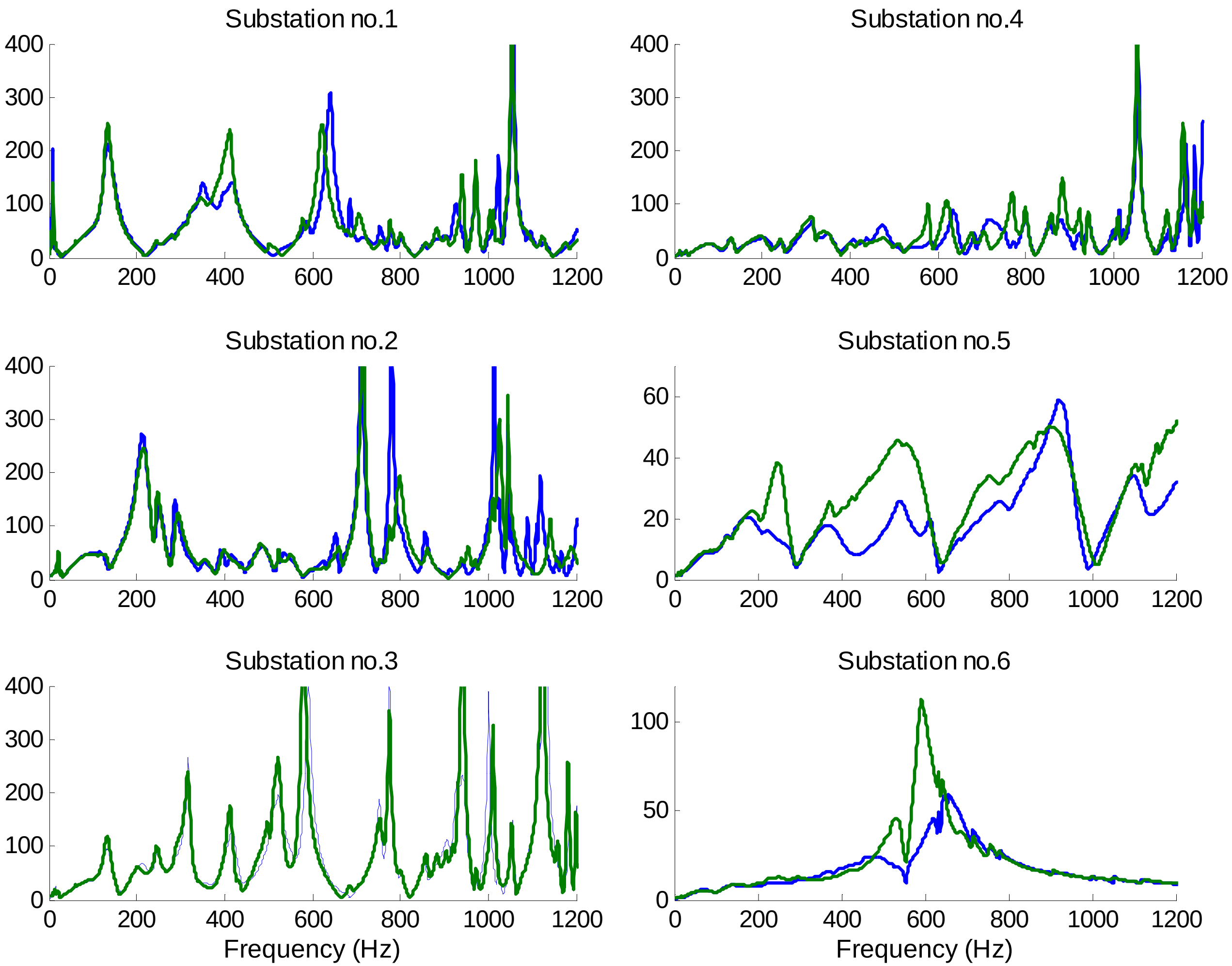
Details

Hydro-Québec Network

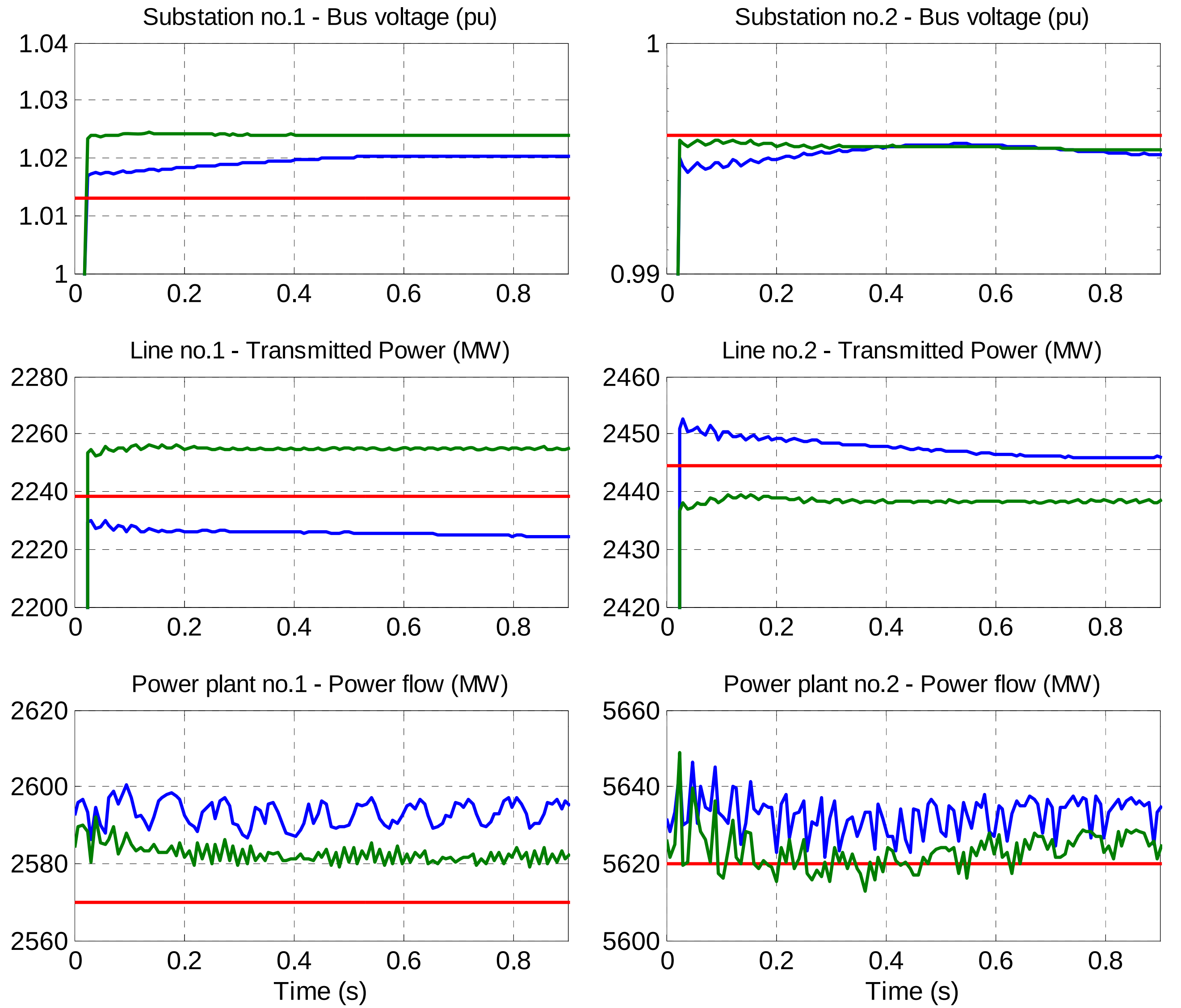
- IPST-2009 paper, L. Gérin-Lajoie, J. Mahseredjian
- Complete network (L)
  - The complete Hydro-Québec network is organized using a multilevel hierarchical design structured on 6 pages in the GUI. There are a total of 30000 physical devices and 28000 signals. The list of physical devices includes 19000 control devices and coupled 3, 6 or 9-phase devices are counted once. The signal count adds 8000 power nodes to 20000 control system signals.

- Complete network (L)
  - The top level listing (subnetwork contents are not counted) of main devices is:
  - 1100 transmission lines representing the existing 1560 lines and derivations
  - 296 three-phase transformers representing the existing 1500 three-phase units connected in Ynyn, DD, Dyn, Ynd, Ynynd, Yndd and ZigZag grounding banks
  - 532 load models representing a total of 36000 MW. All medium and high voltage shunt capacitors and inductors were modeled separately. Some loads were modeled with the transformer and shunt capacitor at the lower voltage level.
  - 7 SVC (Static Var Compensator) models of 300 Mvars and 600 Mvars. The SVCs have been combined on some buses by creating 600 Mvar models.
  - 32 series capacitor MOVs and 303 nonlinear inductances used for high voltage power transformer saturation representation.
  - 99 synchronous machines (SM) with associated controls representing more than 49 power stations and four synchronous compensators. All synchronous machine devices are matched to corresponding load-flow type devices for specifying the PV constraints used for initializing machine phasors at load-flow solution convergence. All machines are given a single-mass model except one nuclear power plant generator modeled using 10 masses.

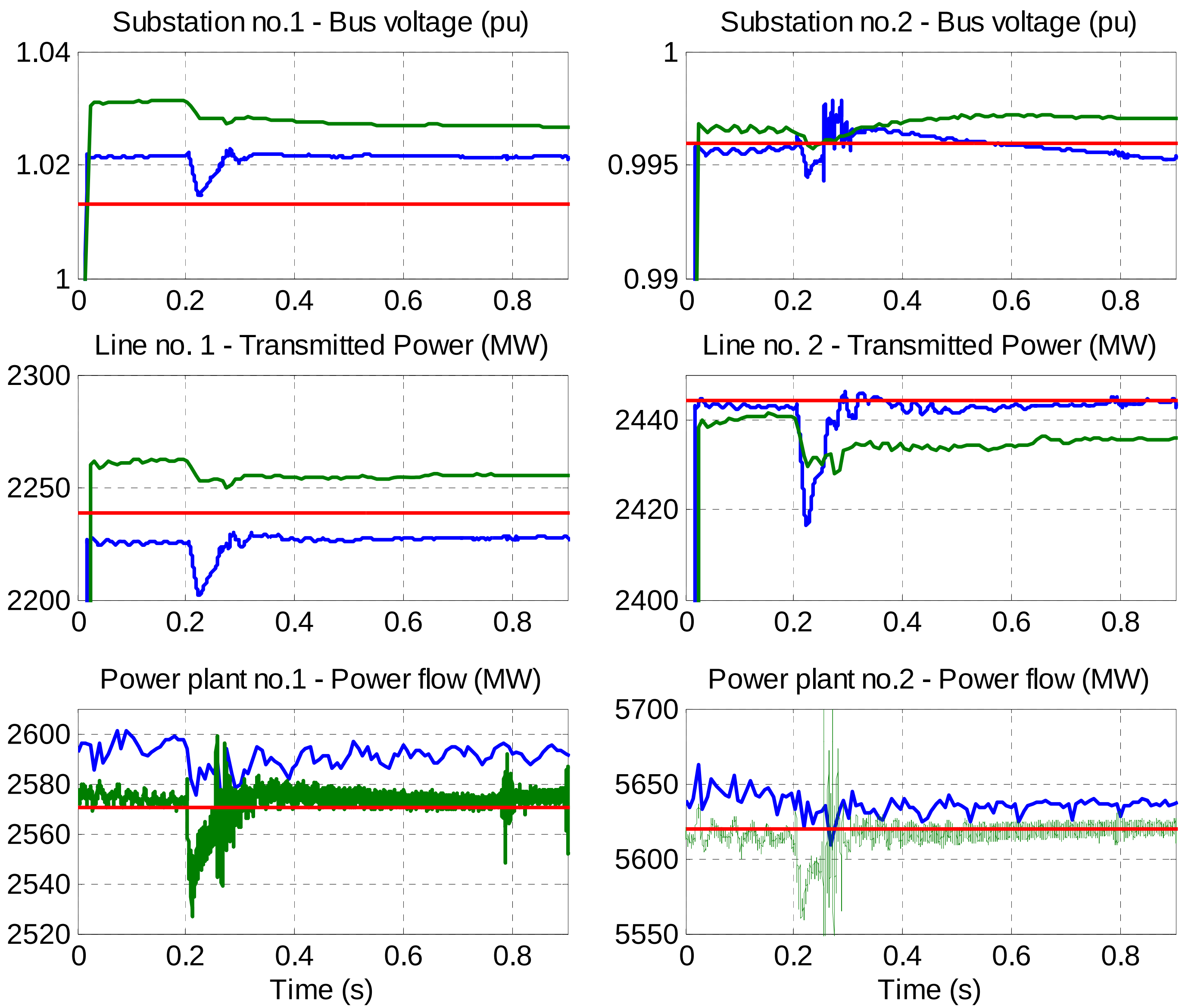
- Reduced network
  - The reduced network has a total of 24000 physical devices and around 24000 signals. There are 4000 power devices and 2500 power nodes. The listing of top level devices is:
  - 170 lines, with 75 lines at the 735 kV level, 53 at 315 kV, 23 at 230 kV and 19 at 120 kV
  - 90 three-phase transformers
  - 27 load models, 7 at 315 kV, 6 at 230 kV, 4 at 161 kV, 6 at 120 kV and 4 at 13.8 kV for a total of 33800 MW
  - 7 SVC models
  - 39 synchronous machines with AVRs for representing 31 power stations and 3 synchronous compensators for a total of 35600 MW of generation.



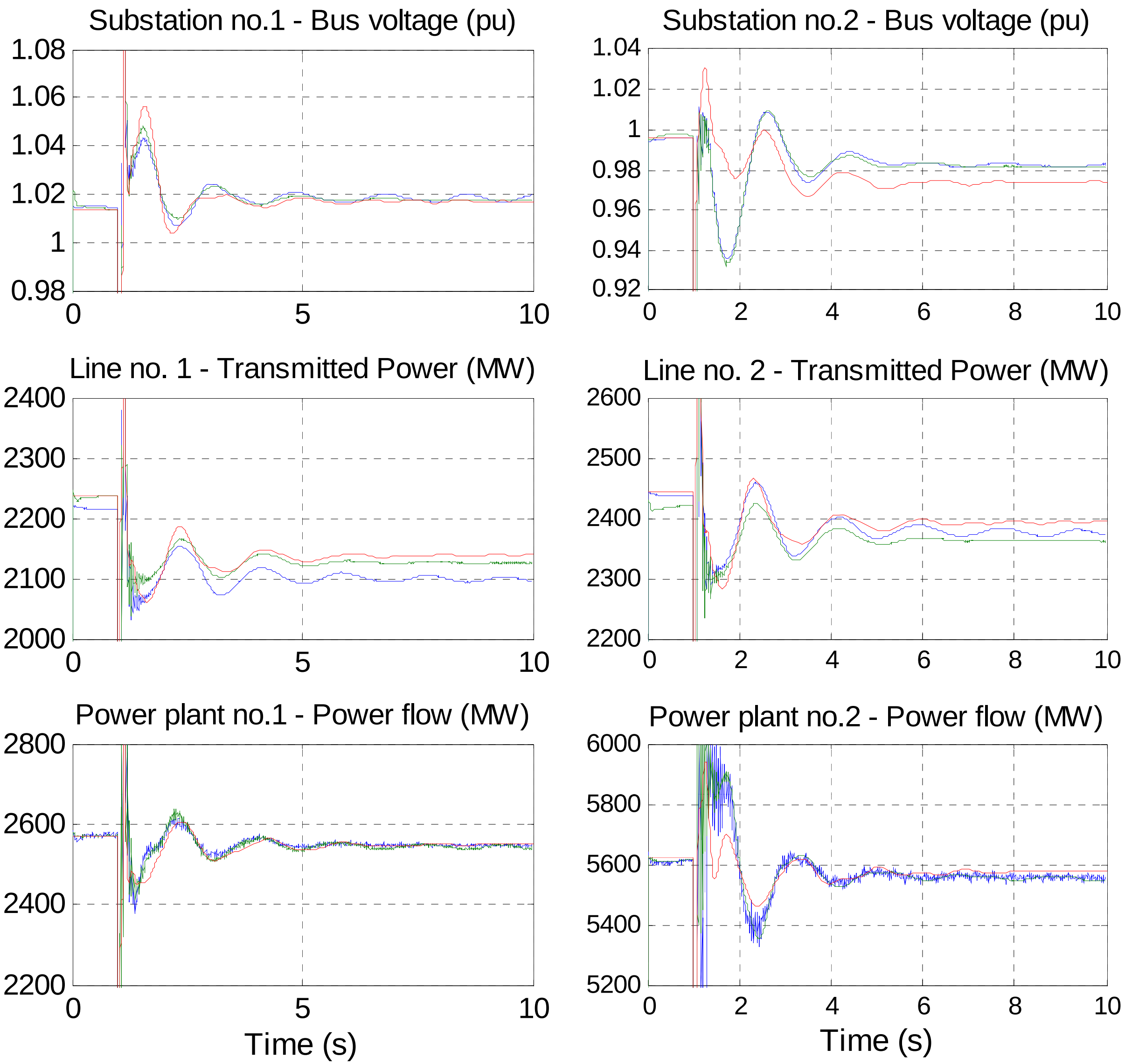
Frequency response (positive sequence impedance) plots for the complete (blue) and reduced (green) networks. Left column plots show three 735 kV substations and right column plots show three 315 kV substations.



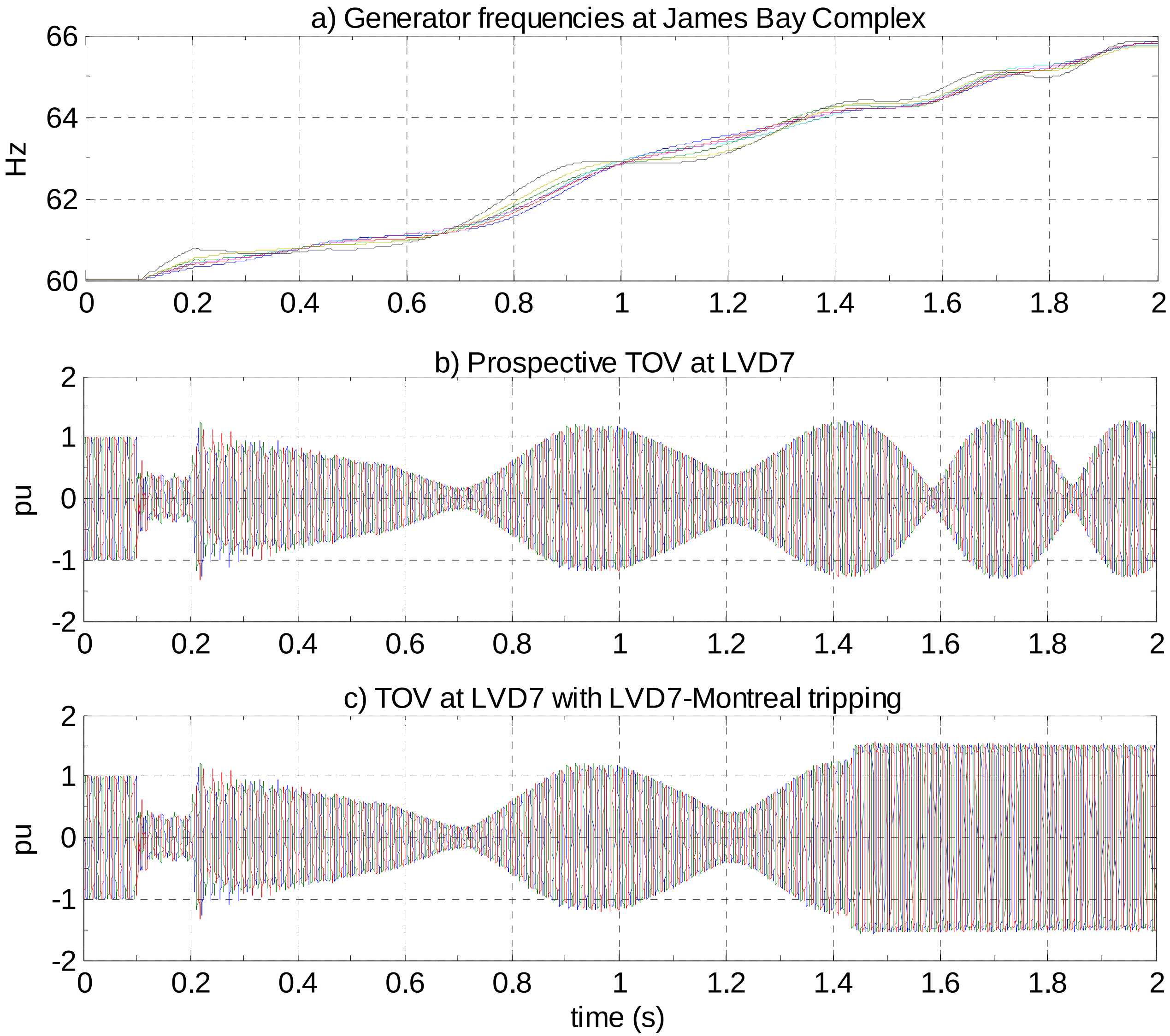
Network initialization test without SVCs, L-Network (blue), R-Network (green) and PSS/E (red)



Network initialization test with SVCs, L-Network (blue), R-Network (green) and PSS/E (red)

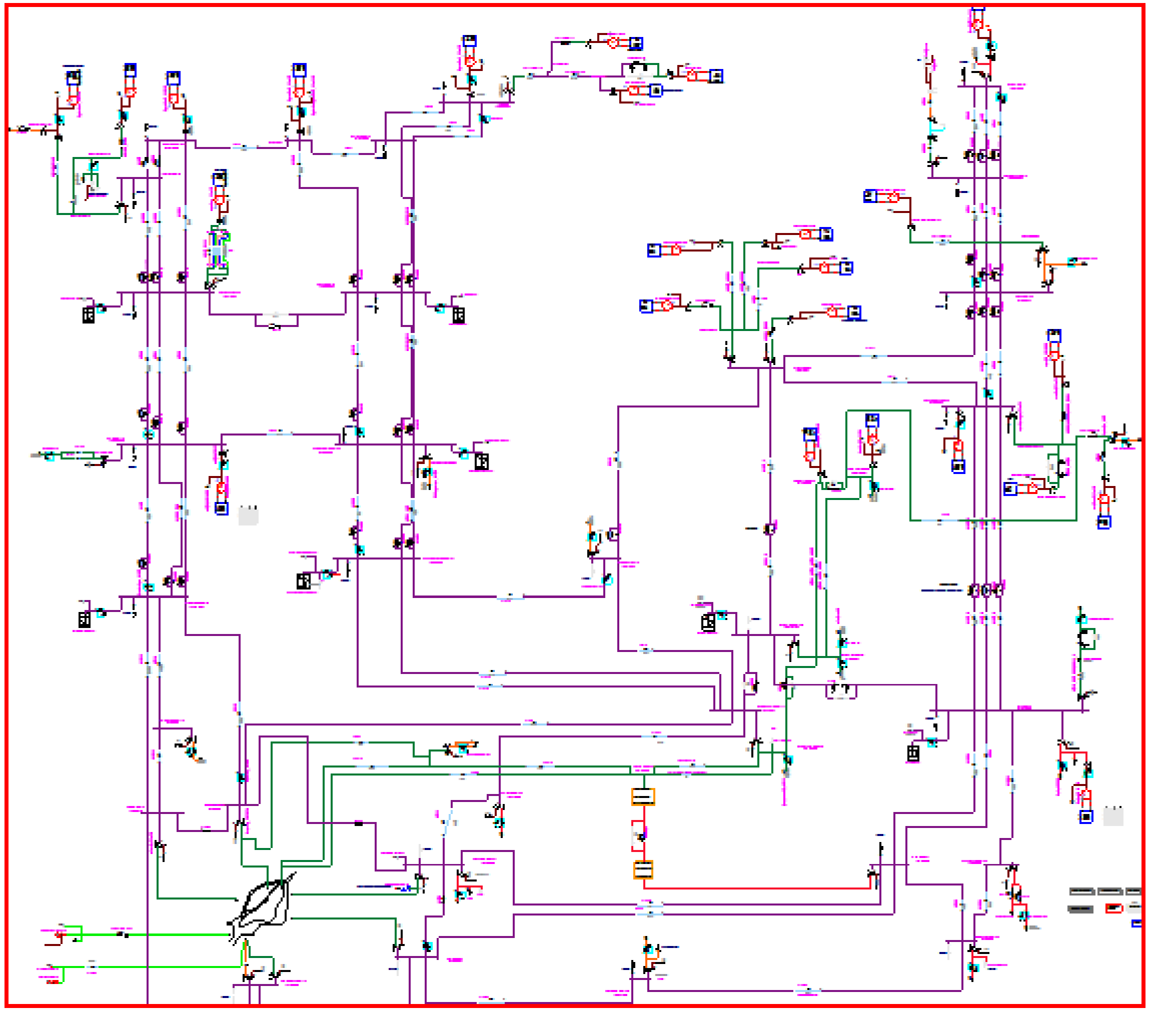


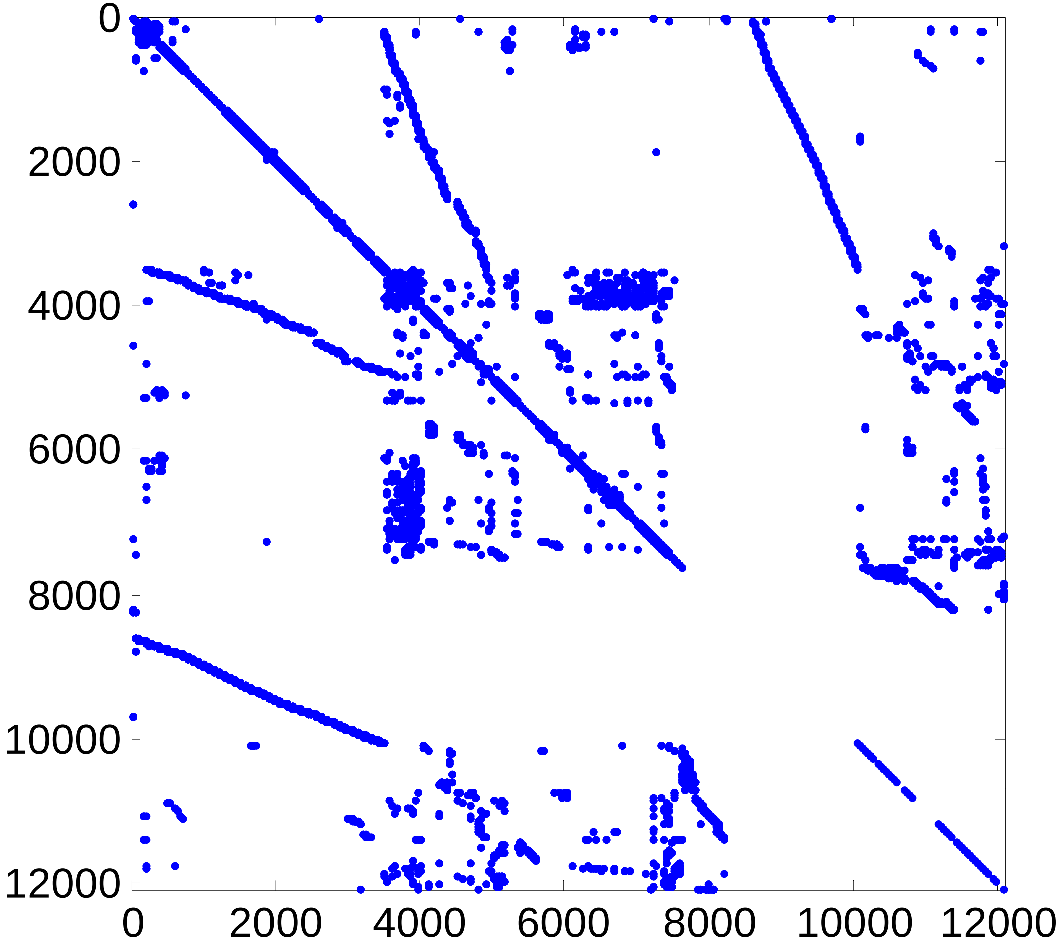
Simulation of a 3-phase fault and loss of a 735 kV transmission line, L-Network (blue), R-Network (green) and PSS/E (red)



James Bay system voltage oscillations due to an extreme disturbance

30000 devices
28000 signals





Solved time-domain sparse matrix for the L-Network,
50269 non-zeros

CPU timings (s) for a 10 s simulation interval

CPU Timers	L-Network		R-Network	
GUI File (design) load	9		4	
Data generation	10		3	
Load-flow solution	181 (6 iterations)		21 (7 iterations)	
Steady-state solution	0.48		0.12	
Time-step	100 μs	200 μs	100 μs	200 μs
Time-domain network equations	4710	2548	538	276
Time-domain control equations	846	435	715	389
Time-domain updating	409	210	75	36
Time-domain solution total	5965 99 min	3103 52 min	1328 22 min	701 12 min