Open Discussion on Full EMT Simulation of Large Power Systems

Yi Zhang, RTDS Technologies Inc.

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Outline

- Overview Real Time Simulation
- Challenge to Real Time Simulation for Large Power System
- Super-step approach
- Implementation of Super-Step function
- Example cases demonstration
- Limitations and Discussion

Overview

- Real time digital simulation has been widely used and accepted by power industry
- The algorithms in real time simulators are based on Electromagnetic Transient (EMT)
- The most mature application of real time digital simulators is **control hardware in loop simulation**, such as testing and verification of HVDC controls and protective relays
- Large power system simulation with 10000~30000 bus brings a big challenge for current used real time EMT simulators

EMT and TSA Hybrid Simulation

- Hybrid Simulation (partly EMT and partly TSA) has been investigated as a research and development topic in the past 20 years with limited success
- Many research and try in the power system community including RTDS ourselves
- The hybrid simulation R&D we involved:
    1. FNDE function on RTDS
    2. SMRT of Tsinghua University
    3. TRI – TSAT RTDS Interface with Powertech Labs
- Obtained some results but still way to go to reach the industry acceptance

Challenge of Hybrid Simulation

TSA focuses on fundamental frequency phenomenon therefore cannot carry the information of non-sinusoidal interactions

- Example: A transformer inrush may cause commutation failure to an HVDC converter station 1000KM away.
- So EMT is not always a local phenomenon.

Alternatively, can we do real time full EMT for large systems with today's technology?

Progress of Real Time Simulation

- Fast chips – e.g., we use IBM P8/P9 technology, which significantly boost the computation speed
- New solution methodologies – e.g., recently developed “Superstep” function, providing possibility to model larger power systems with multi-rate simulation

Large System Examples

- 14 racks with 56 x PB5 cards
- 62 us timestep

Subsystem	# of Nodes	# of NS proc	# of Clt Proc	# of Load Units	# of PB5 cards used
1	45	2	1	400	4
2	66	1	1	620	4
3	72	2	1	680	5
4	42	1	1	450	3
5	102	2	1	670	5
6	63	1	1	370	3
7	72	2	1	700	5
8	48	1	1	630	4
9	75	2	1	600	4
10	72	2	2	360	4
11	87	2	1	510	4
12	105	2	1	660	5
13	54	2	1	280	3
14	69	2	1	280	3
Total	**972**	**24**	**15**	**7210**	**56**

Large System Examples

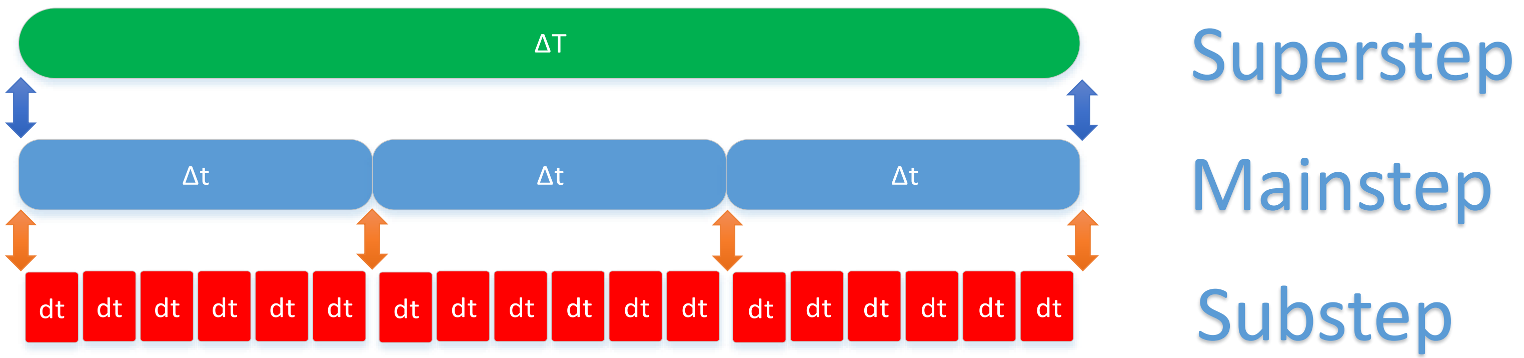


3 NovaCor™ chassis with **29 cores at 41 us!**

Subsystem	**1**	**2**	**3**
Number of Network Solution Nodes	288	297	387
Number of Load Units	2520	2290	2400
Number of Network Solution/Controls cores	1	1	2
Number of Power System Component cores	9	8	8

SUPERSTEP

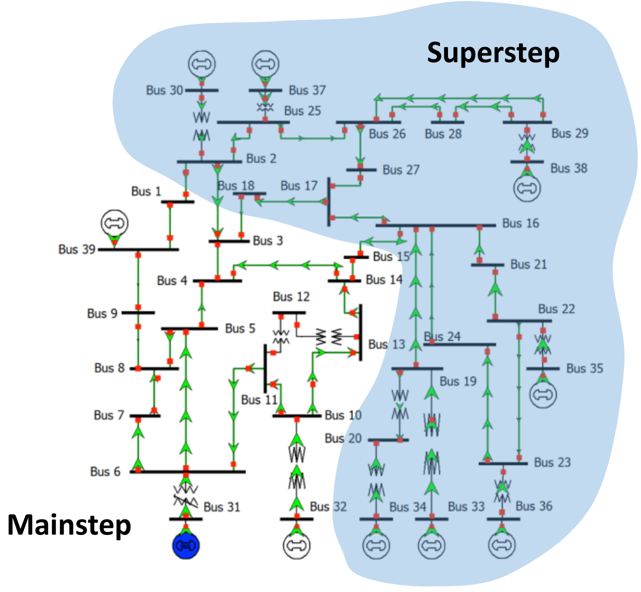
- A ***Superstep Simulation*** is a multi-rate solution approach in which a portion of simulation uses a time step larger than the main time step (~50 μs).
- The larger time step (e.g. ~150 us) allows for computation of more components and more nodes.



What is a Superstep?

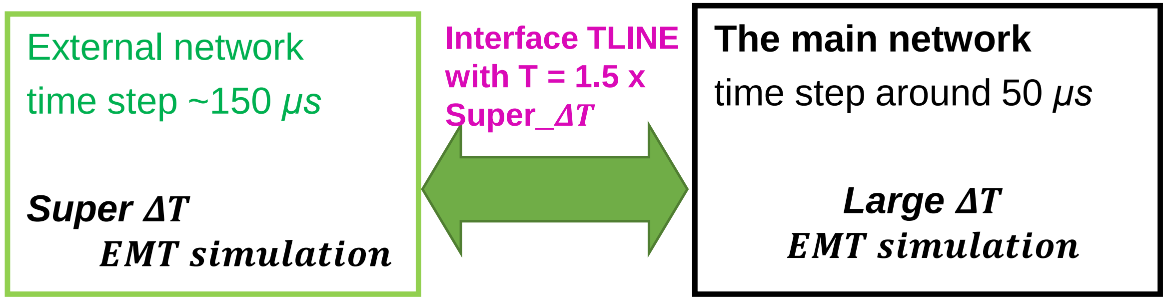
- *Superstep* is an alternative approach for system equivalence to model a large remote network. Traditionally an ideal source with an impedance has been used to model such equivalents.

- **Advantages for User:**
  1) The detail of EMT simulation is retained for the equivalent.
  2) A remote network's control elements can be modeled.
  3) Generator dynamics can be modeled so frequency deviations due to the load/generation imbalance can be observed.



Foundation of Superstep Solution

- AC networks without power electronics and nonlinear components can run stably and accurately with time step larger than 50 us, e.g., IEEE 39 bus system runs well for 24 hours on RTDS at 150 *us*.
- Traveling wave based transmission line can run with different time step on each terminal.

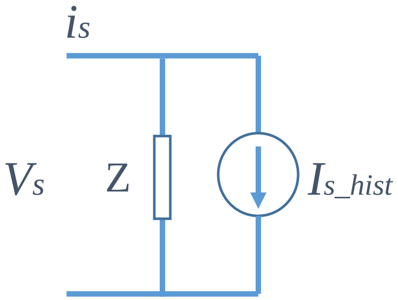


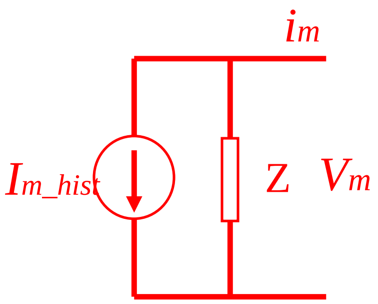
Multi-Rate T-line

- T-lines are used to connect *superstep network* to each other and to the *mainstep network* in the same way they are used to interconnect subsystems in normal real time simulation (EMT) with unified step.
- The Frequency Dependent and Bergeron T-line models have been modified so that the calculations for the two terminals are done using two separate blocks of codes that exchange information.
- The two terminals can be run using independent timesteps that are integer multiples of each other.
- The minimum signal travel time must be 1.5*(larger of terminal timesteps) when terminals operate at different rates. It must be 1.0*terminal timestep when the terminals operate at the same rate.

Multi-Rate T-line

Super Step | Main Step



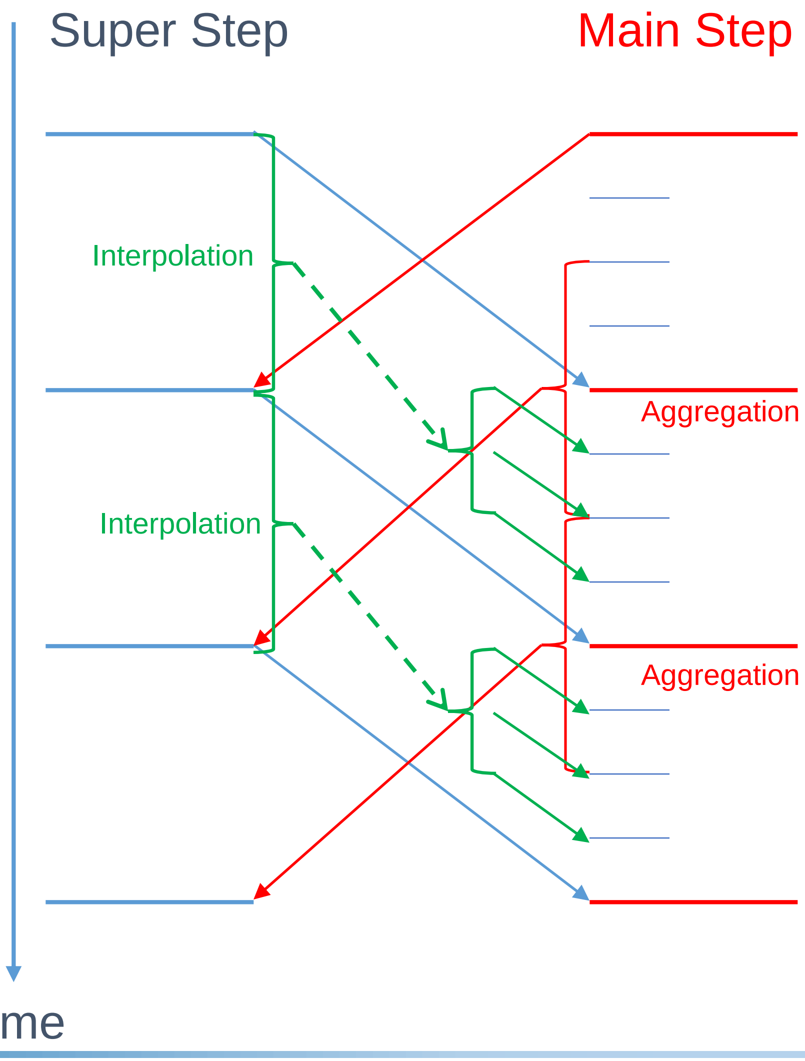


$$i_s(t)=V_s(t)/Z+I_{s\_hist}$$

I_{s_hist} --- *Aggregation from V_m and I_m*

$$i_m(t)=V_m(t)/Z+I_{m\_hist}$$

I_{m_hist} --- *Interpolation from V_s and I_s*



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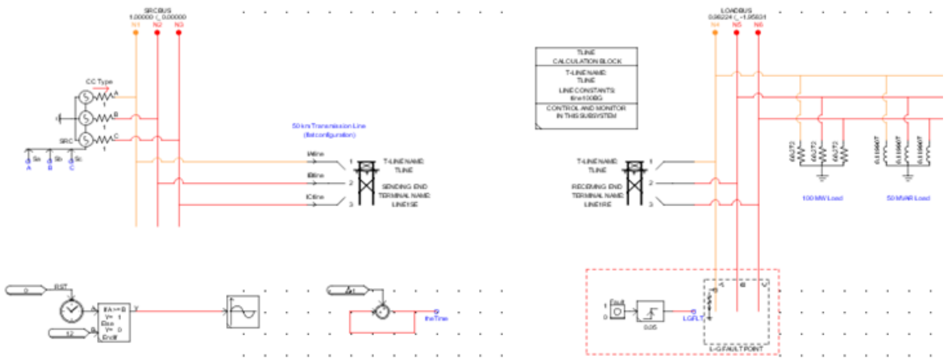
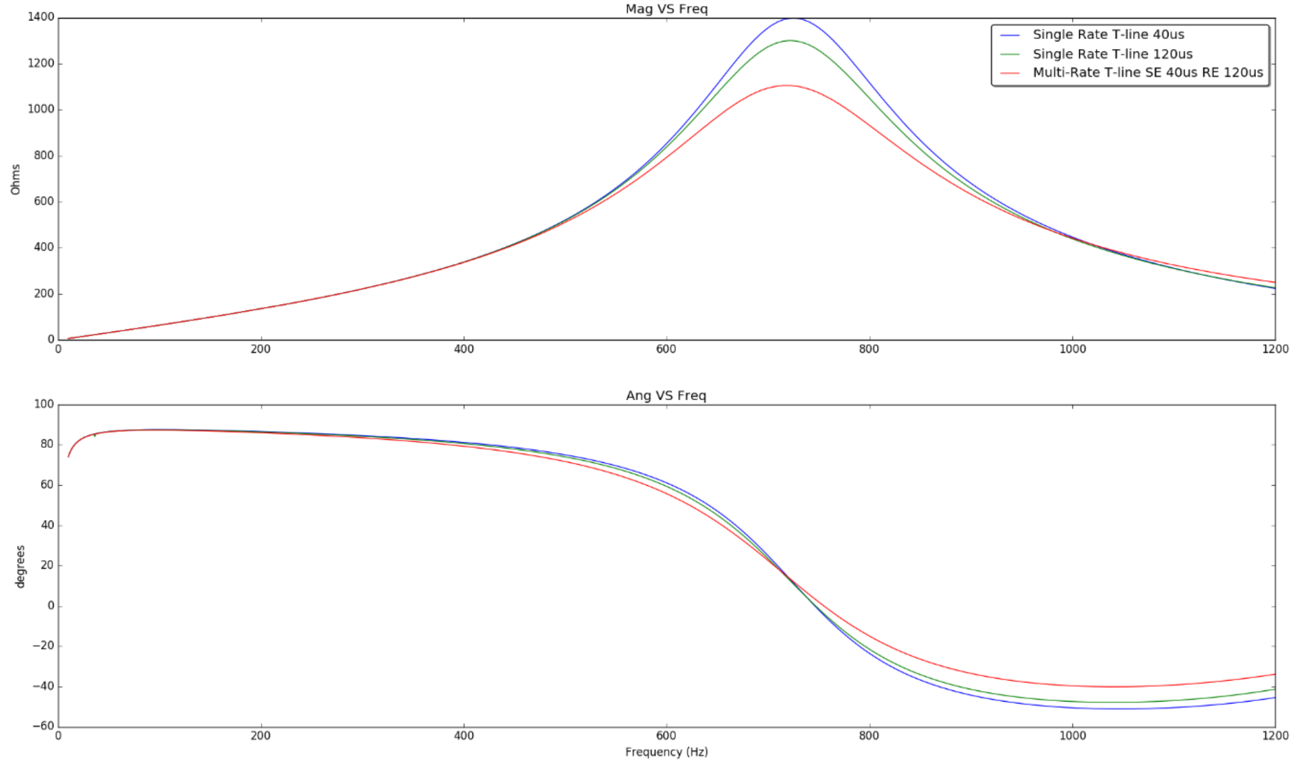
Validation of Multi-rate TLINE

Frequency response of multi-rate transmission line shows:

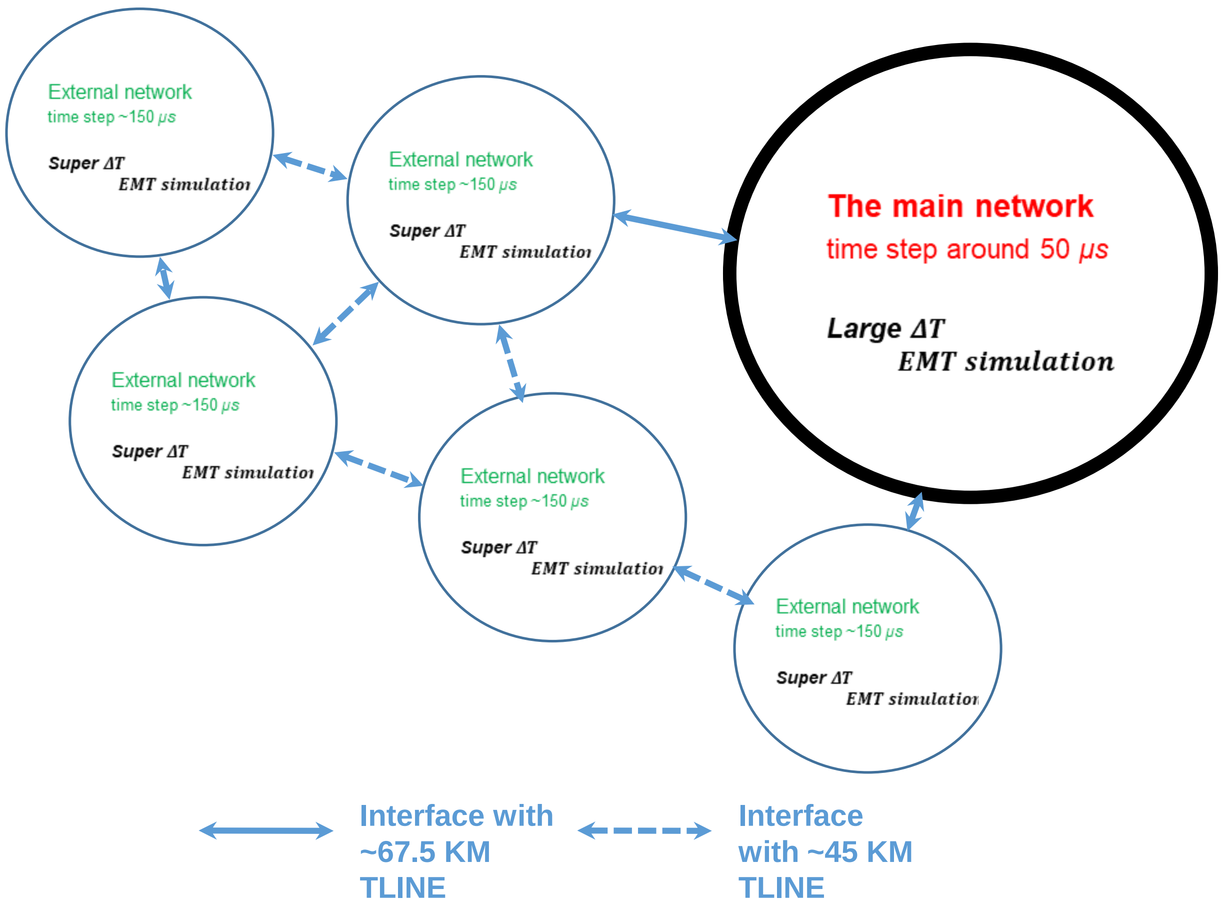
- Performance is accurate within *500Hz* for *ΔT-3ΔT* combination, up to 150 *us*



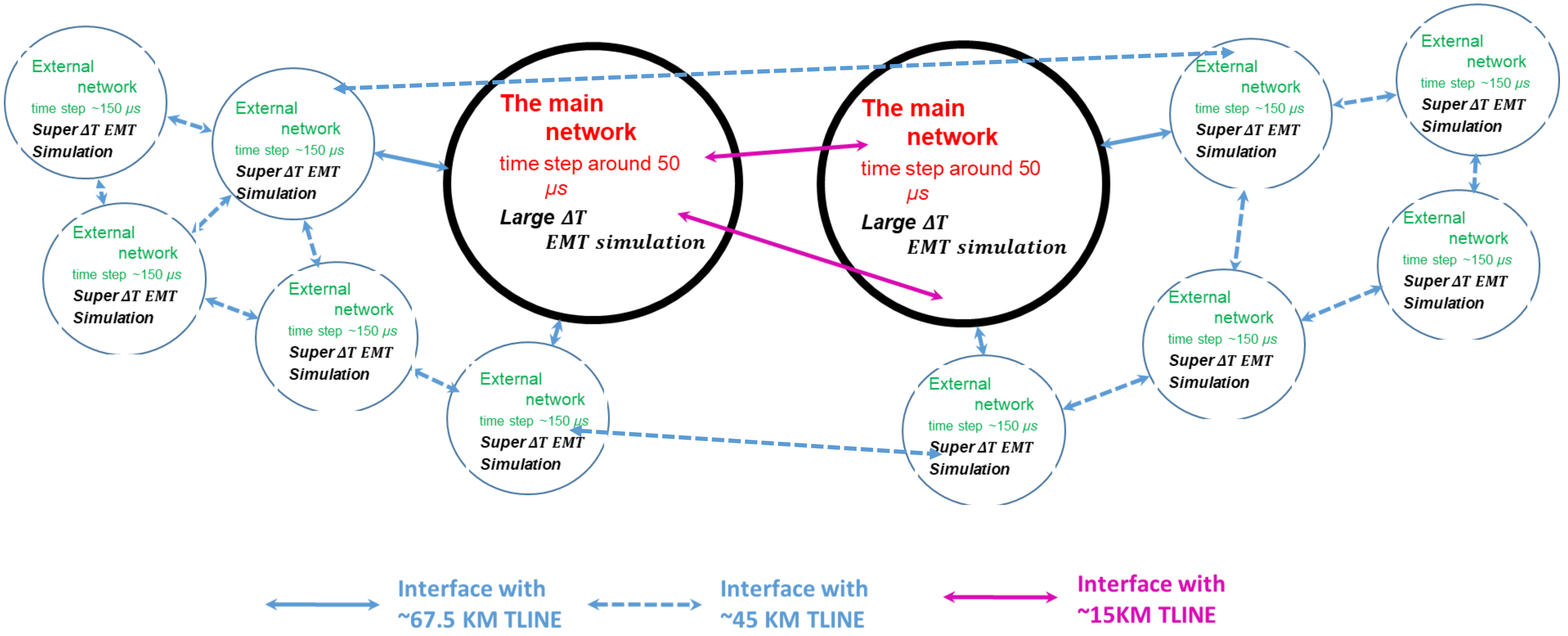


The System Solved by Superstep Solution

Multi-rate Boxes Connected with TLINES (Bergeron or FD Lines)

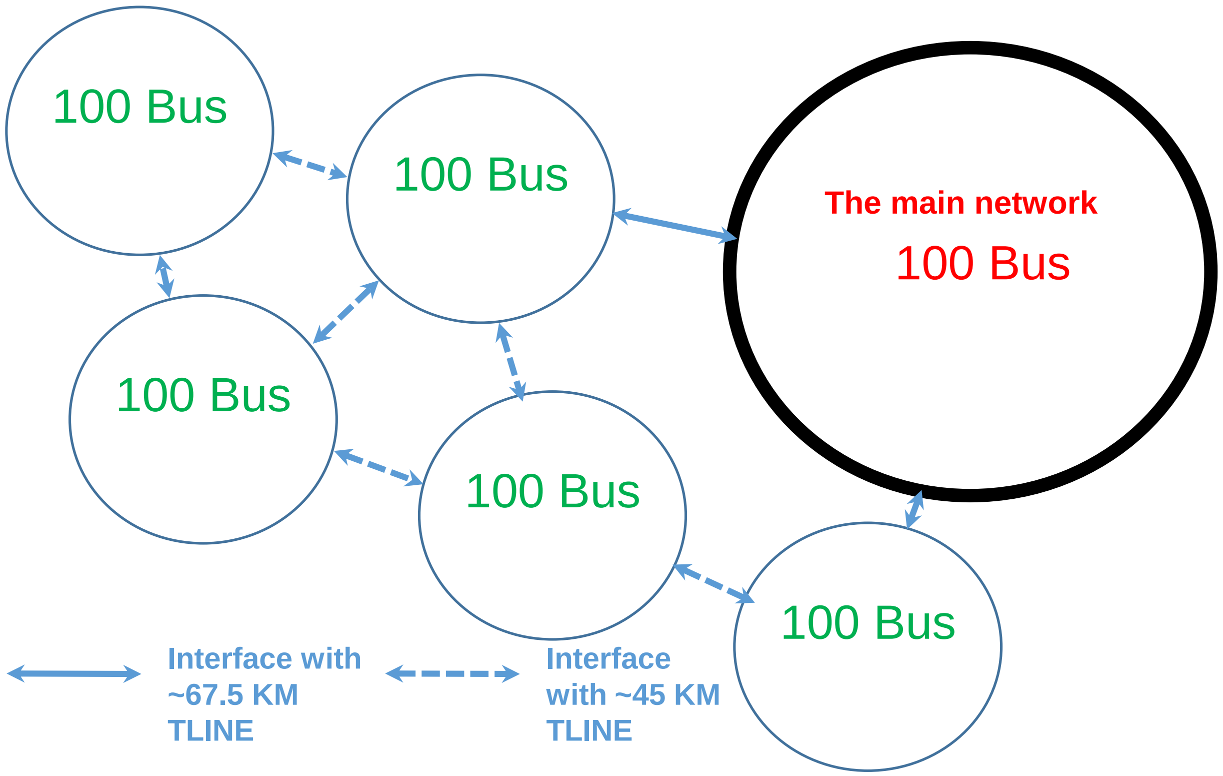


Multi-Chassis Super-step Case



The Architecture of Full EMT Simulation of Large Power Network

AC System Modelled by Super Step Approach

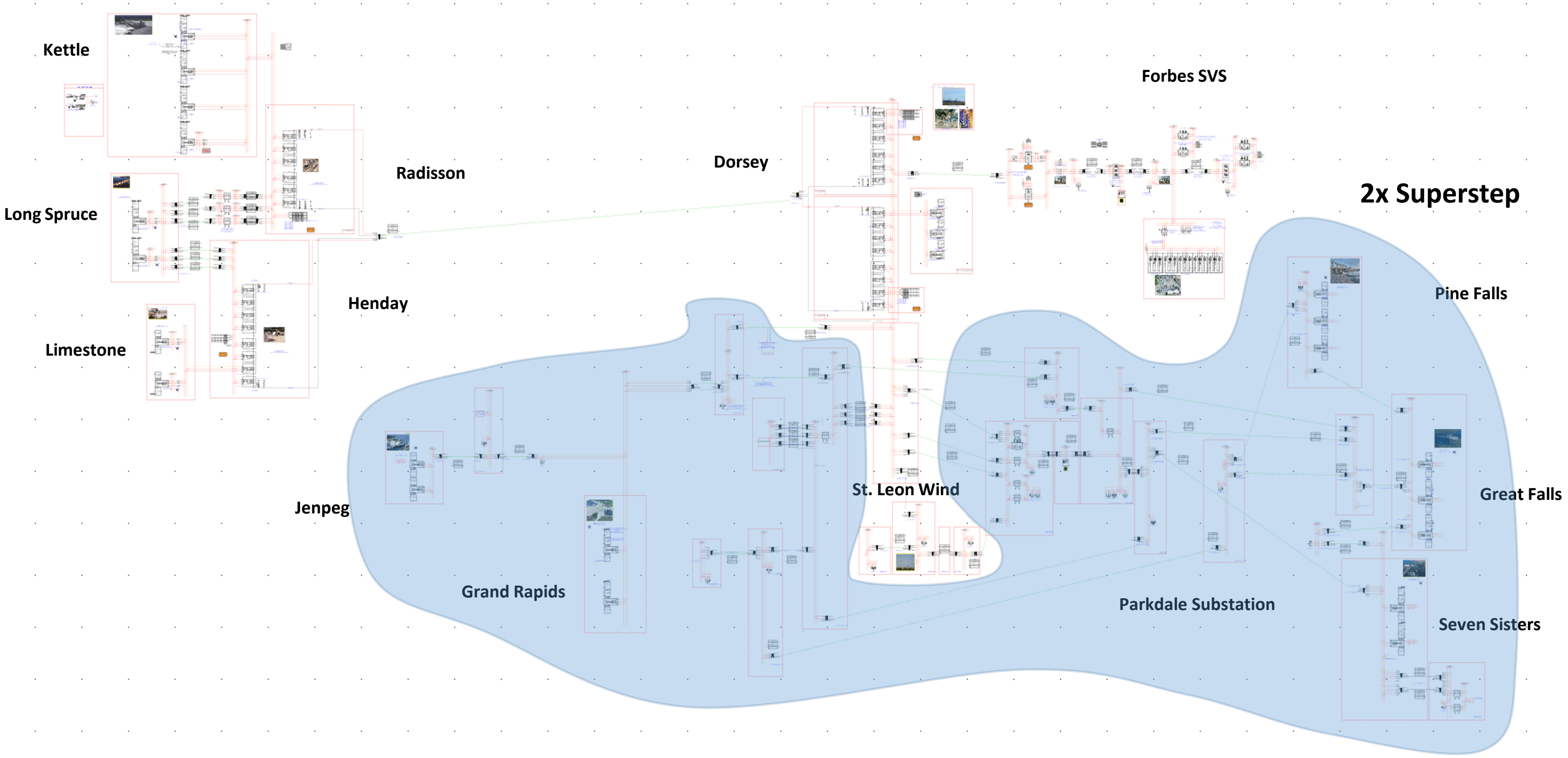


For an example:

- One NovaCor Chassis use 5 cores to model external network by super step box
- Assume the main network has 100 bus
- The total capacity of a NovaCor Chassis is to model 600 bus
  - ✓ 36 NovaCor Chassis can model:
  - ✓ 3600 main network bus
  - ✓ 18000 external network bus
  - ✓ All in EMT and in Real Time
  - ✓ Total 21600+ bus
  - ✓ Already a very large system

Example 1: Manitoba Hydro System

(218 single phase nodes)

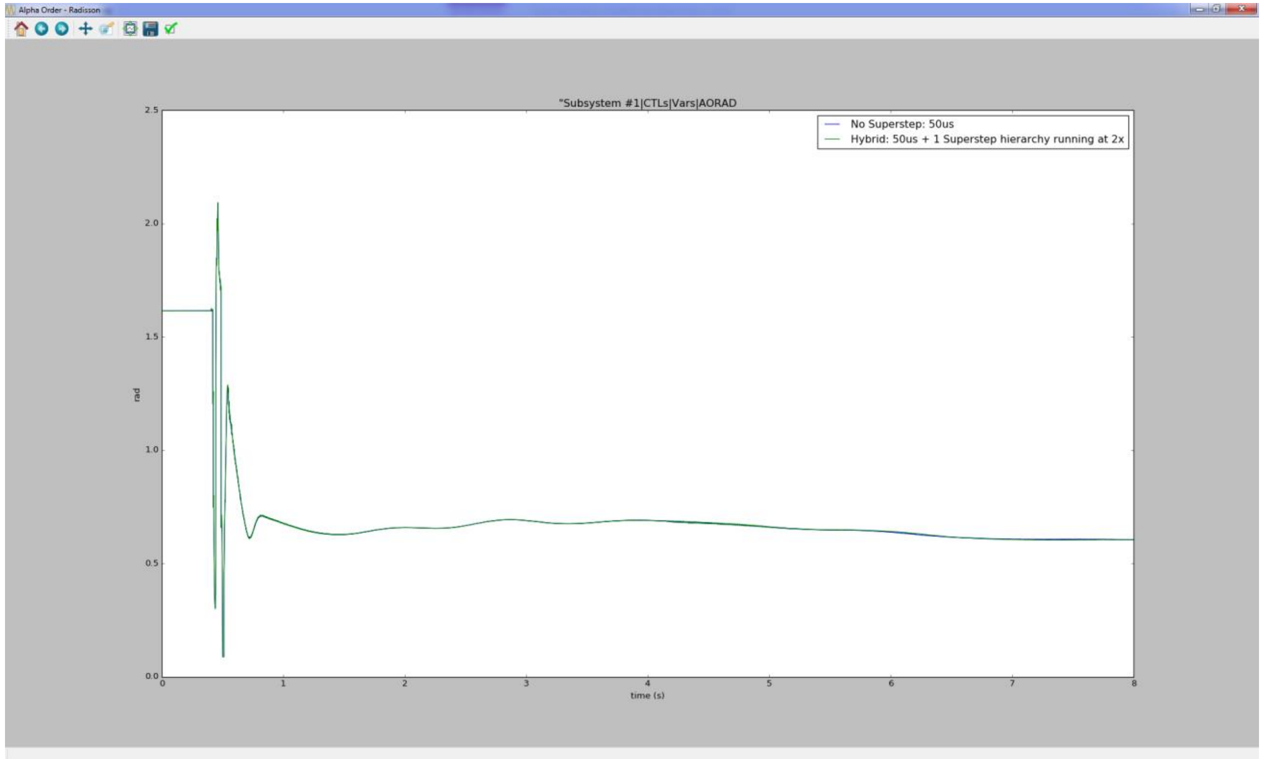


Manitoba Hydro System

- Signals for the start-up of Bipole 1 nine seconds into the simulation were compared for single-rate and multi-rate simulations.
- The Power order was set to 400 MW. Various signals in the vicinity of the HVDC converters were monitored including DC bus voltages, AC side voltages and some control signals. The results matched well.

Bipole 1 Start-up

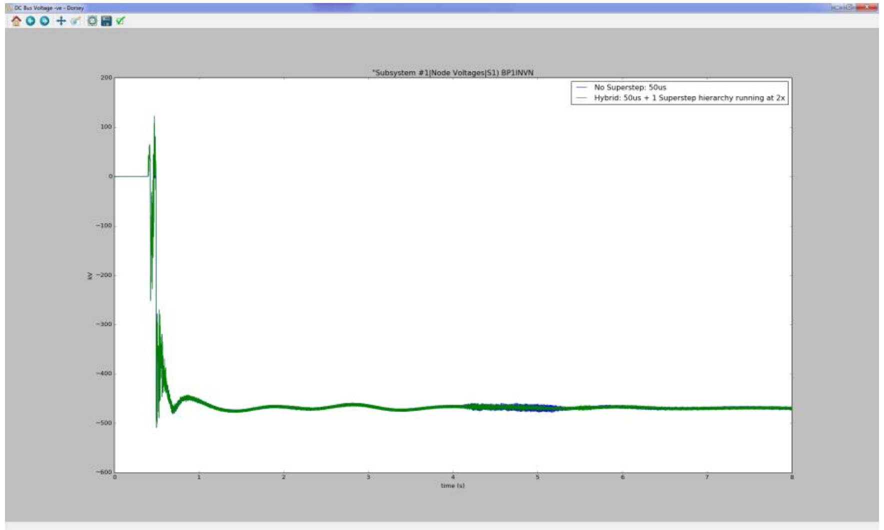
Alpha Order Radisson

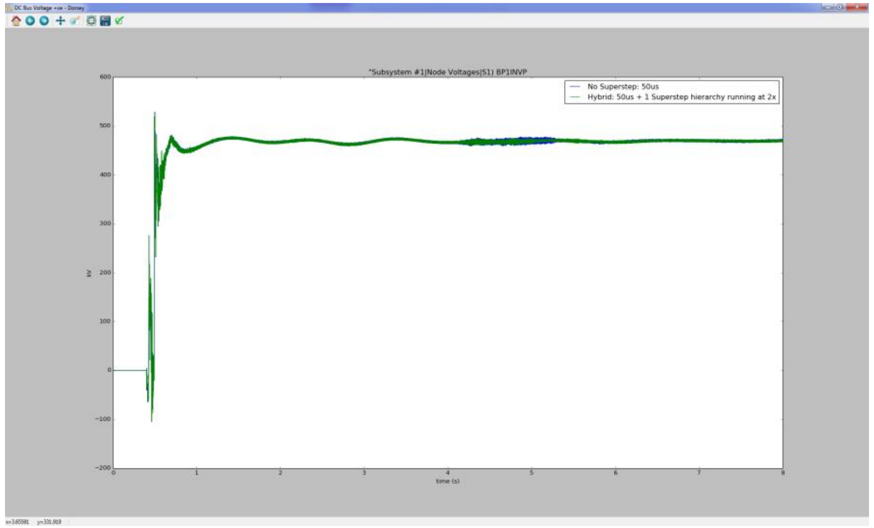


Manitoba Hydro System

Bipole 1 Start-up

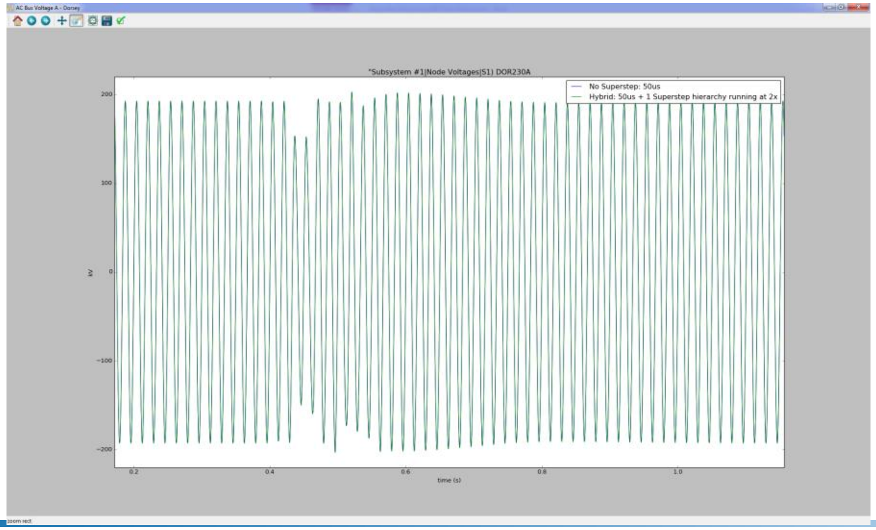
Positive and Negative DC Voltages at Dorsey





Bipole 1 Start-up

AC Bus Voltage (Dorsey)



Example 2: Illinois System

Illinois 200 bus system:

Test 1A: 200 ms ABC–G fault was applied at Bus # 187, near the system's largest generator.

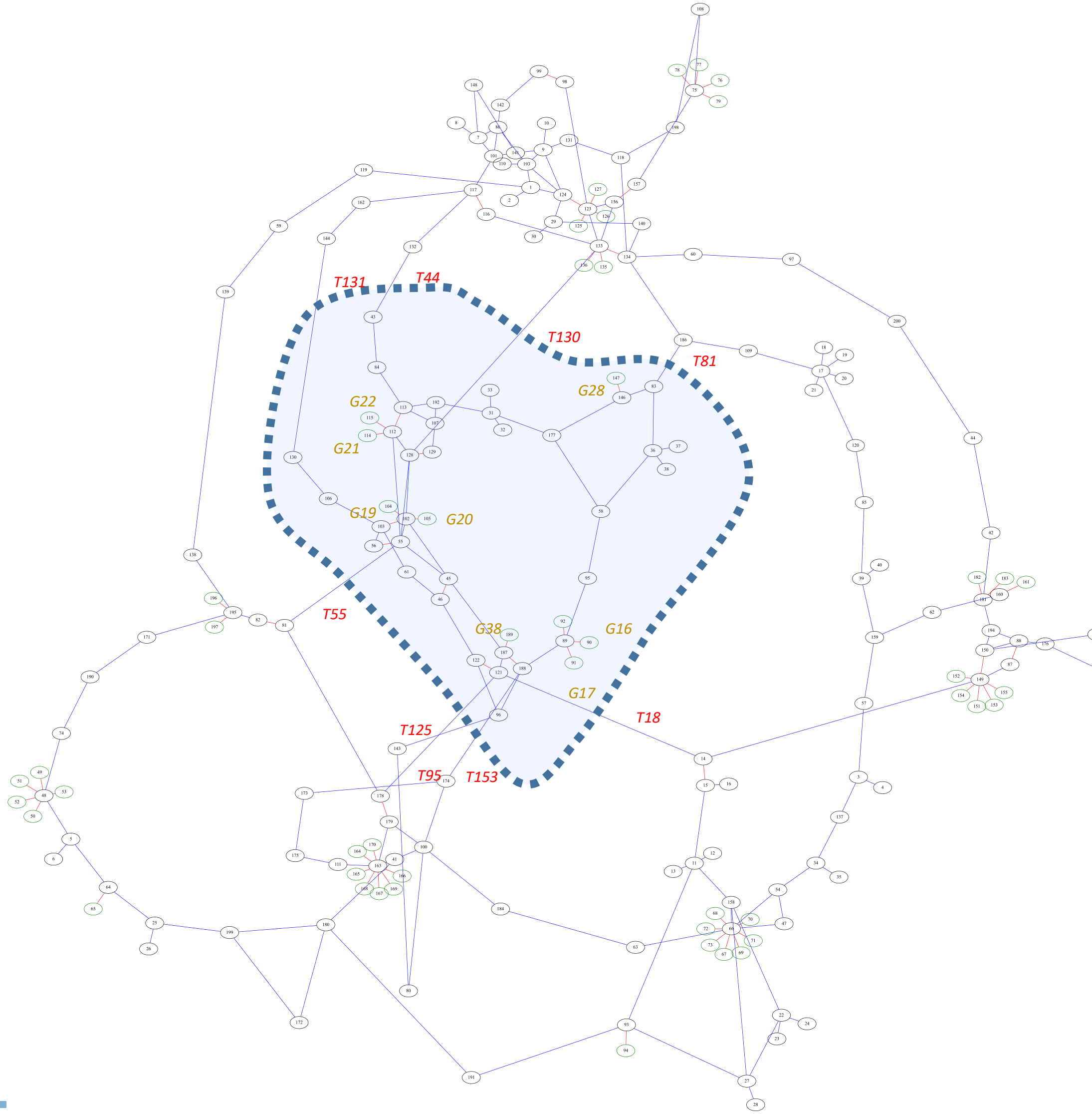
Test 1B: 200 ms AB–G fault was applied at Bus # 187

Test 1C: 200 ms A–G fault was applied at Bus # 187

Test 2: Four (4) multi-rate lines were successively tripped 100ms apart. (T55, T125, T95 and then T153) All 4 lines suffered 3 phase trips except for line T55, which had its B and C phases tripped.

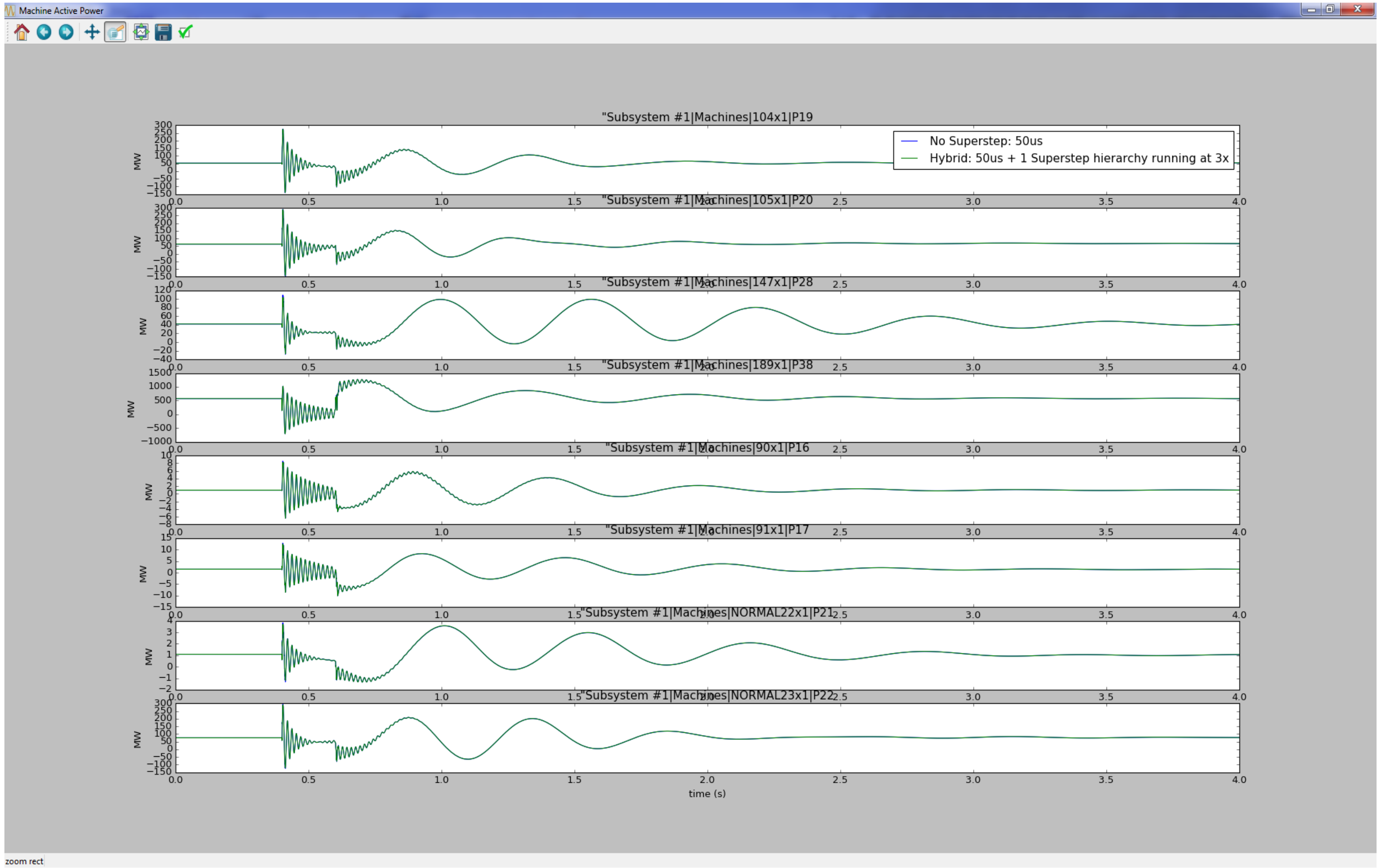
Test 3: A 200 ms ABC-G fault was applied at Bus # 187. The generator at that bus was tripped 150 ms after the application of the faults. This is similar to the test from the first report I sent – with the exception that now no lines are artificially lengthened.

Generally P, Q and ω of all machines modeled using 50μs was monitored. Bus voltages near those transformers were also monitored. The P and Q of the lines spanning the regular time-step and the super step was also monitored.



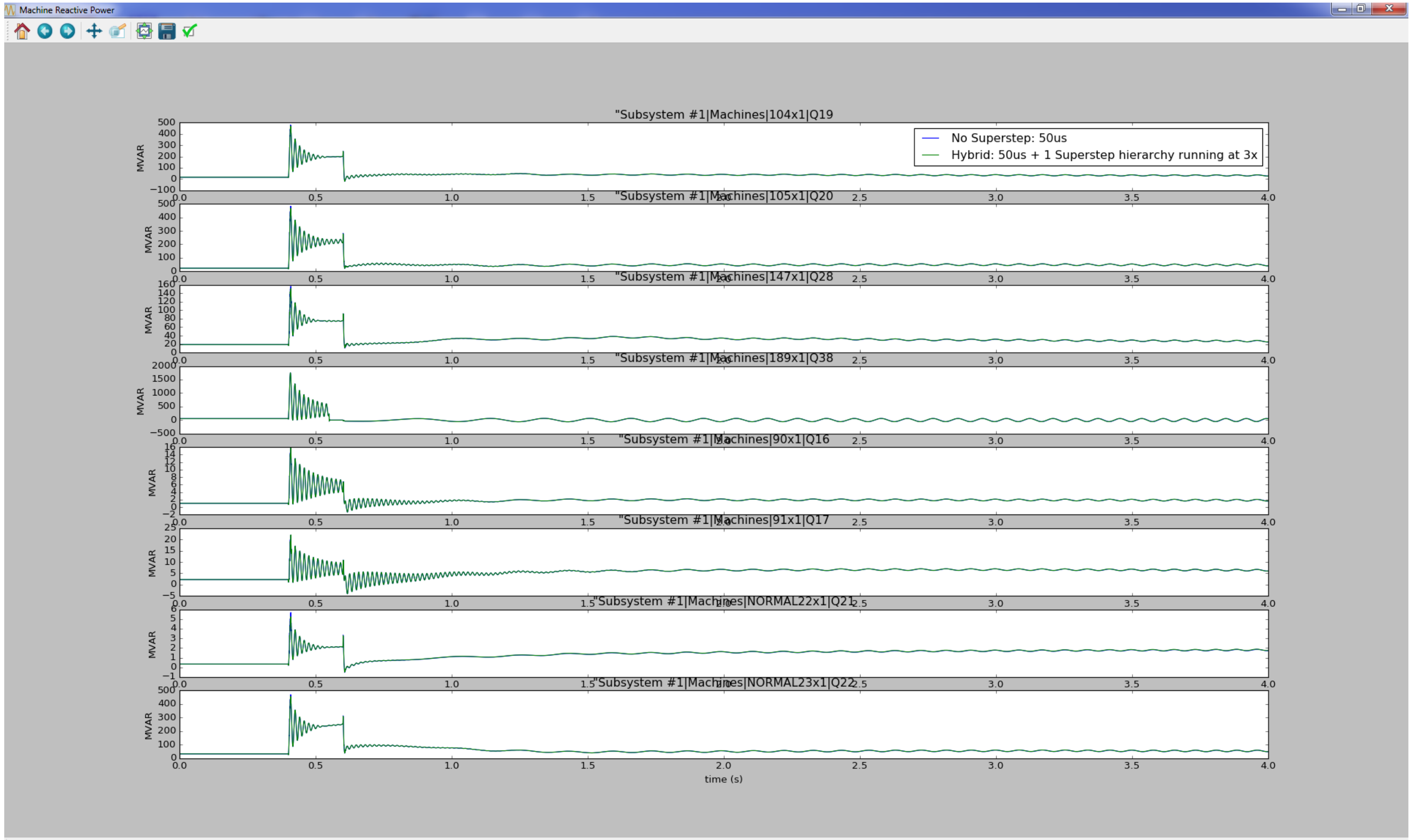
Illinois System

Test 1A: 200ms ABC-G fault applied at Bus # 187



Illinois System

Test 3: 200ms ABC-G fault applied at Bus # 187. Generator tripped after 150ms



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Restrictions

1. Available for NovaCor™ Only
2. 150 μs maximum superstep Δt
3. *Restricted Components*:
    - No components with variable G or switched G values
    - No Faults or Breakers
    - No IO components
    - No small timestep (power electronics) components

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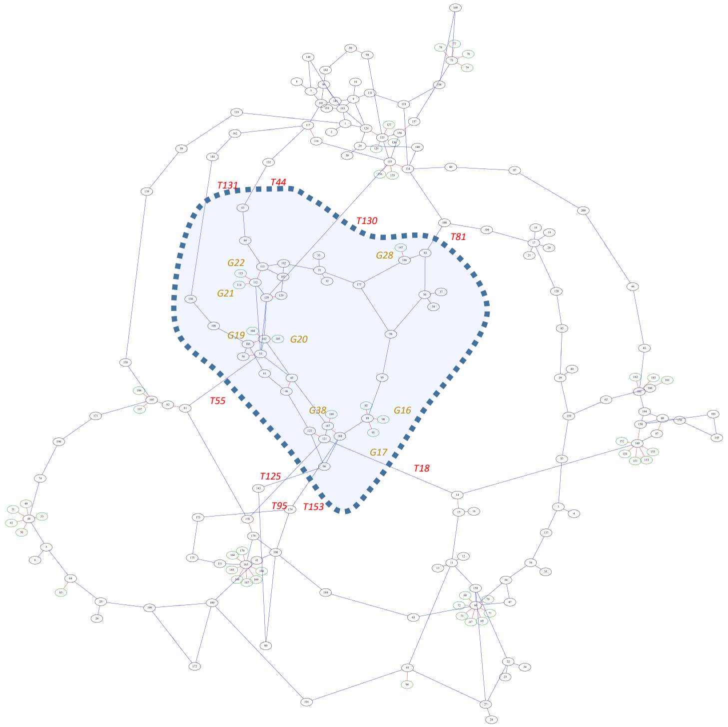
Challenges of Applications

Application in large meshed network are restricted, difficult to find long transmission lines to define super-step zone (67.5km)

– How determine optimal boundaries for network splitting



Challenges of Applications

Network splitting in practical systems

- Choose the main time step and superstep time step
- Define a concept of "mini" system – cannot be further split with transmission line
- The number of mini systems changes with time step

Max Number of Bus = int(superstep timestep) x 2
Max Load Unit = Super step timestep x 24

Time step of Super -Step	Number of Mini-Systems	Number of bus	Load Unit
150 us	12	100	3600
120 us	23	80	2880
100 us	47	66	2400

Challenges of Applications

Network Splitting of A Real System

150uS

1:	277
2:	623
3:	11
4:	5
5:	66
6:	15
7:	2
8:	13
9:	5
10:	3
11:	31
12:	2

120uS

1:	216
2:	2
3:	138
4:	11
5:	380
6:	5
7:	58
8:	2
9:	2
10:	15
11:	4
12:	2
13:	11
14:	25
15:	13
16:	48
17:	17
18:	5
19:	3
20:	17
21:	2
22:	14
23:	49

100uS

1	128	25	3
2	2	26	2
3	75	27	27
4	52	28	11
5	11	29	12
6	329	30	4
7	5	31	2
8	23	32	4
9	34	33	3
10	2	34	17
11	24	35	2
12	2	36	21
13	15	37	14
14	4	38	50
15	5	39	15
16	2	40	17
17	2	41	2
18	2	42	2
19	9	43	2
20	15	44	9
21	7	45	18
22	11	46	22
23	7	47	3
24	3		

Time step	150 us	120 us	100 us
Bus	153	305	499
Core	2	4	8

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Challenges of Applications

Future work: Automatic determination of superstep network layout

- Optimized network topology analysis
- Boundary selection and recommendation
- Best time step

Full EMT Simulation of Large Systems

New IEEE PES Task Force on "EMT Simulation of Large Power Systems"

- Data conversion from TS simulation to EMT simulation, to clarify the addition data needed for EMT simulation;
- Real Time Simulation vs Non Real Time Simulation for large system;
- Fast initialization or snap shoot techniques for EMT simulation
- Guideline to choose appropriate time step for power system with power electronics penetrations in EMT simulation
- Multi-rate simulation and interface techniques
- Possibility to use hybrid simulation between TS and EMT
- Vision and road map of contingency analysis of large power systems using EMT simulation

Full EMT Simulation of Large Systems

Confirmed Panelists
Name, e-mail, organization, presentation topic
Jose Marti, jrms@ece.ubc.ca, University of British Columbia, Advanced Hybrid SFA/EMTP Simulators for Power System Dynamics
Ani Gole, Aniruddha.Gole@umanitoba.ca, University of Manitoba, New Algorithms for EMT simulation of Large Power Systems
Jean Mahseredjian, jean.mahseredjian@polymtl.ca, Polytechnique Montréal, Sparse matrix based parallel computation of power system transients
Dharshana Muthumuni, dharshana@mhi.ca, Manitoba HVDC Research Centre, Integration of renewable generation to weak grids
Venkata Dinavahi, dinavahi@ualberta.ca, University of Alberta, Parallel High-Fidelity Electromagnetic Transient Simulation of Large-Scale Multi-Terminal DC Grids
Yi Zhang, yzhang@rtds.com, RTDS Technologies Inc., Real Time Full EMT Simulation of Large Power Systems: Challenges, Methodologies and Experiences in Some Real Systems
Jean Bélanger, jean.belanger@opal-rt.com, Opal RT Technologies Inc., The Importance of Data and Model Management for Very Large EMT and Phasor Simulation in Real-Time and Faster-than-Real-Time
Garth Irwin, gdi@electranix.com, Electranix Corporation, Large System Dynamic Performance Studies Using EMT Parallel Processing and Hybrid Simulation

Summary and Future Work

Super-Step Solution

- *Released with RSCAD V5.005*
  - *External network can be approximated by linear circuits without breakers*
  - *Network solution is simplified into forward and backward substitution, decomposition is not included*
  - *Linear AC networks allow large time step simulation, e.g. 120-150 us*
- *Limitations of Current Release*
  - *The cross chassis transmission line must from main step part of network (15km)* ***– to develop cross-chassis super step transmission line model***
  - *Application in large meshed network are restricted, difficult to find long transmission lines to define super-step zone (67.5km)* ***– to develop network splitting methods to determine optimal boundaries***

We Are Ready to Do Full EMT Real Time Simulation for Very Large Power Network with 20000+ Bus!

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Thank You.
Questions?