NASPI North American SynchroPhasor Initiative

Advancements in the Real-Time Simulation of Large Active Distribution Systems for PMU testing

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OPAL-RT

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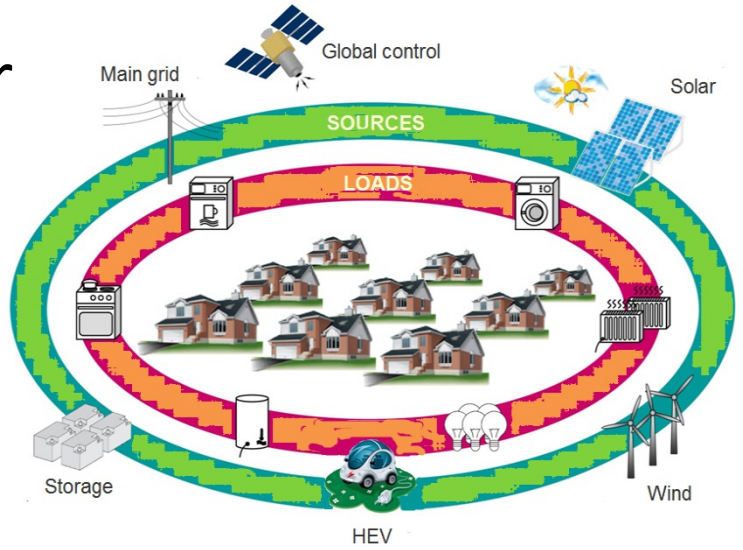
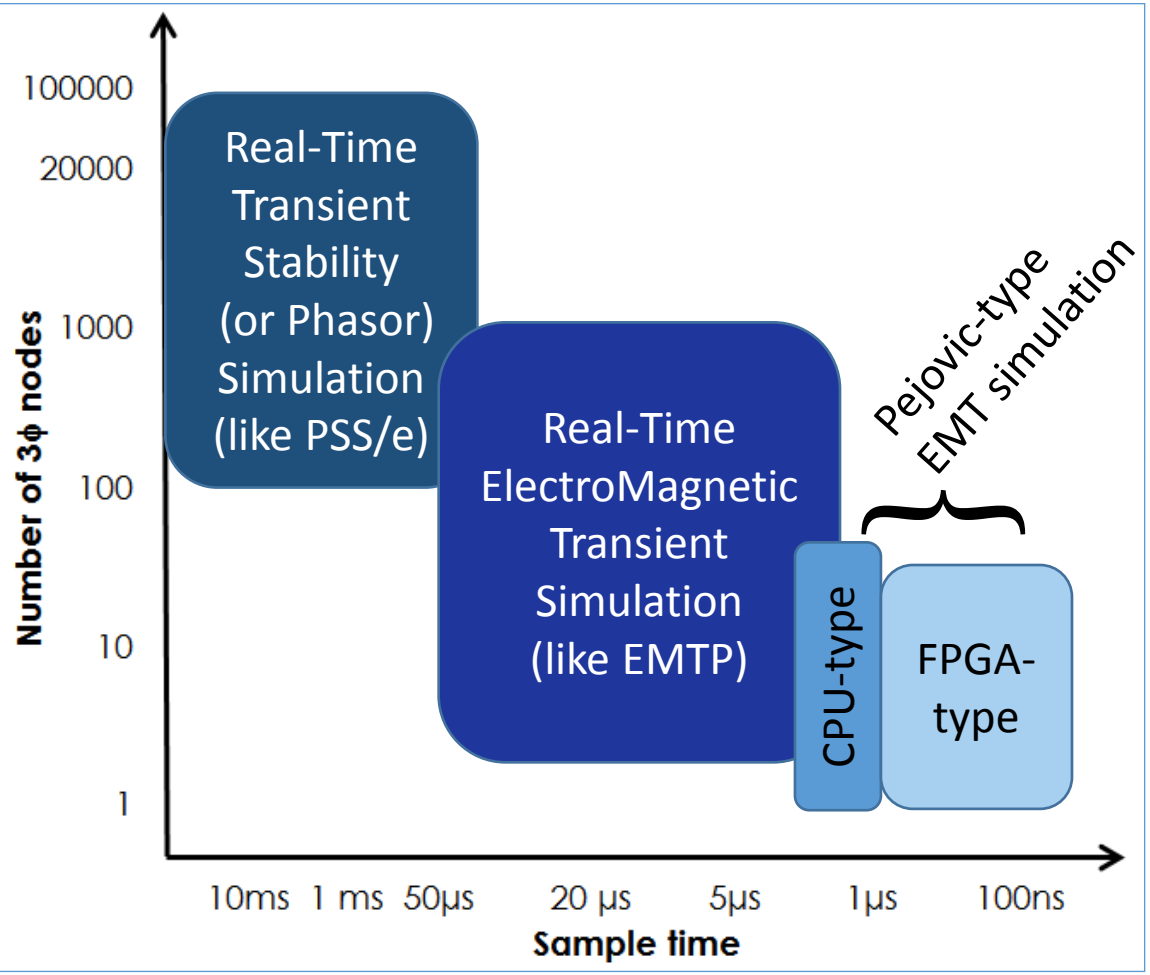
Revision 2

Presentation Objectives

- Show how real-time simulation technologies can help utilities and researchers to develop and test PMUs and PMU applications
- Show different solver for Digital Real-time Simulator (DRTS) such as:
  - Real-time Phasor (or Transient Stability) Simulation
  - Real-time Electromagnetic Transient Simulation
  - Special solver solutions like SSN for distribution systems.
- Show communication features of real-time simulator
  - Support of IEC-61850 protocols (Sampled Values, GOOSE)
  - Support of DNP3 protocol
  - Support of IEEE C37.118 protocol for PMUs
- Example cases from actual users.



Different solutions for different problem sizes



Opal-RT provides solutions for real-time Transient Stability simulation

- e*PHASOR*sim solver
- Sample time =1-10 milliseconds

Opal-RT also provides solutions for real-time Electromagnetic Transient Simulation:

- Hypersim and e*MEGA*sim with SSN
- Sample time= 10-100 µs

20 cores PC-based DRTS

Real-Time Transient Stability with e*PHASOR*sim**

- Biggest actual client case so far: 30000 busses (positive sequence)
- Support for 3 phase modeling. (More important in distribution grids)
- METIS routines used to partition admittance matrix for calculation on many processors

$$\dot{x}(t) = f(x,V) \qquad (1)$$

$$YV = I(x,V) \qquad (2)$$

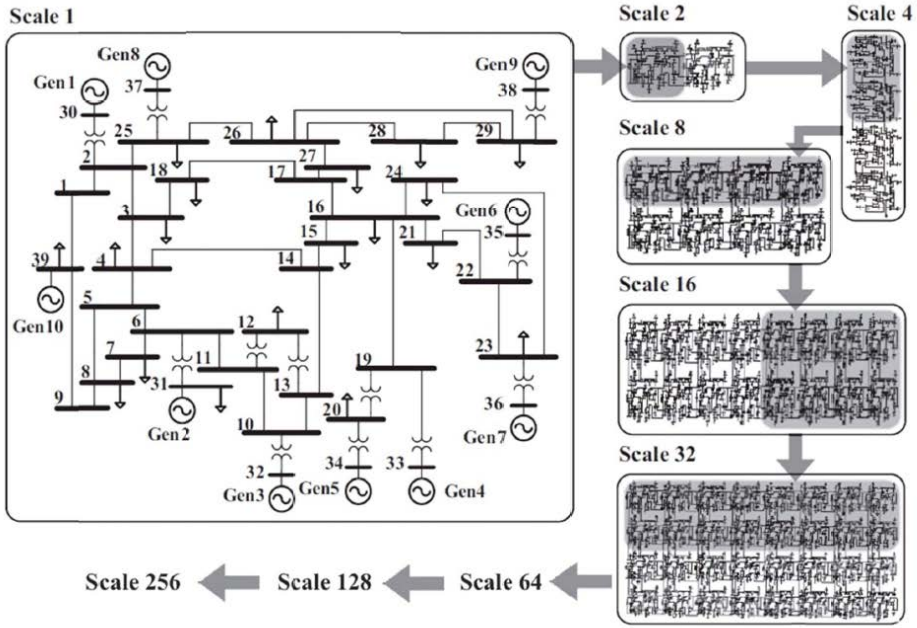
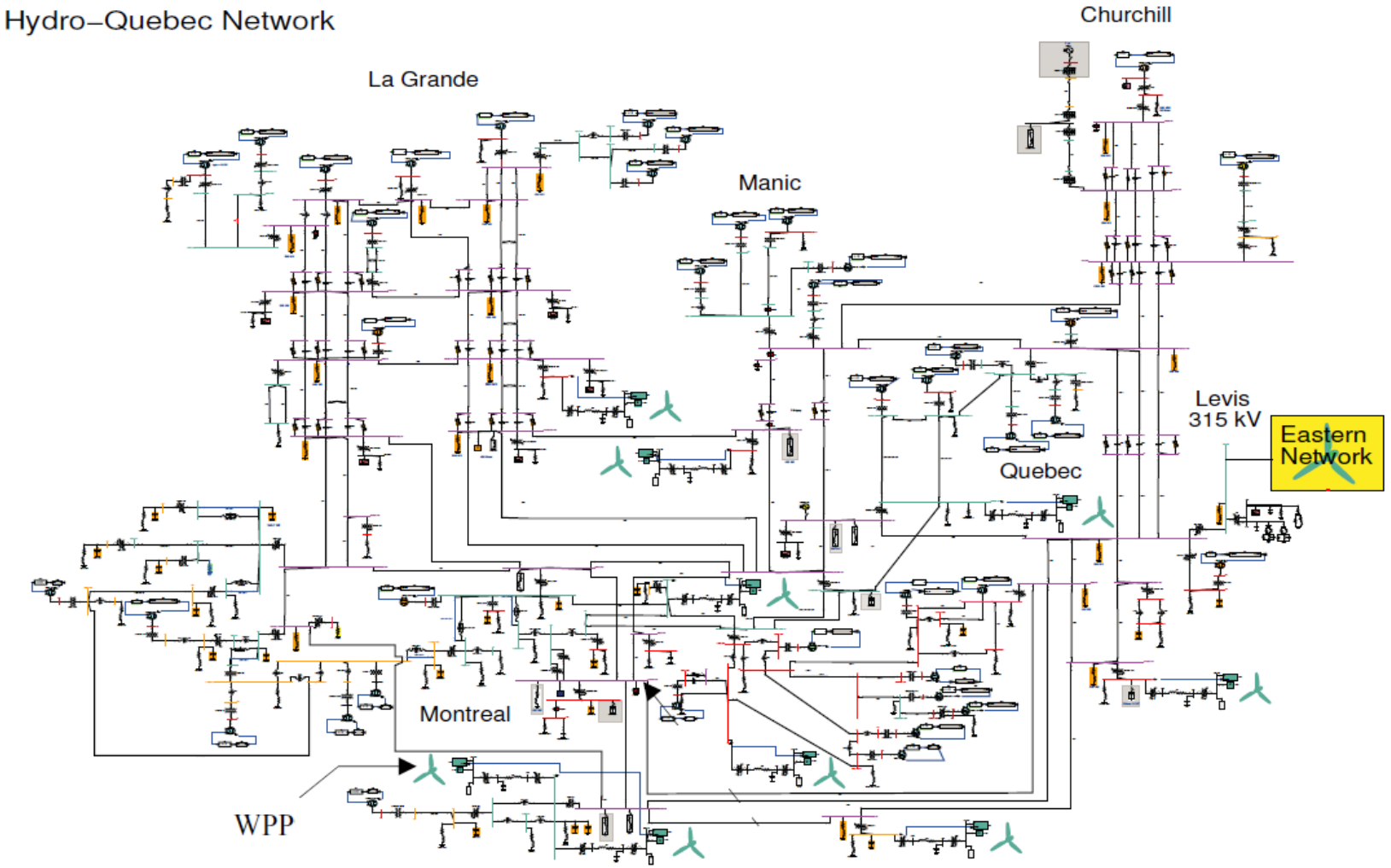


Fig. 2. Construction of test systems for transient stability simulations. The *Scale* 1 system shows the one-line diagram of the IEEE's New England Test System

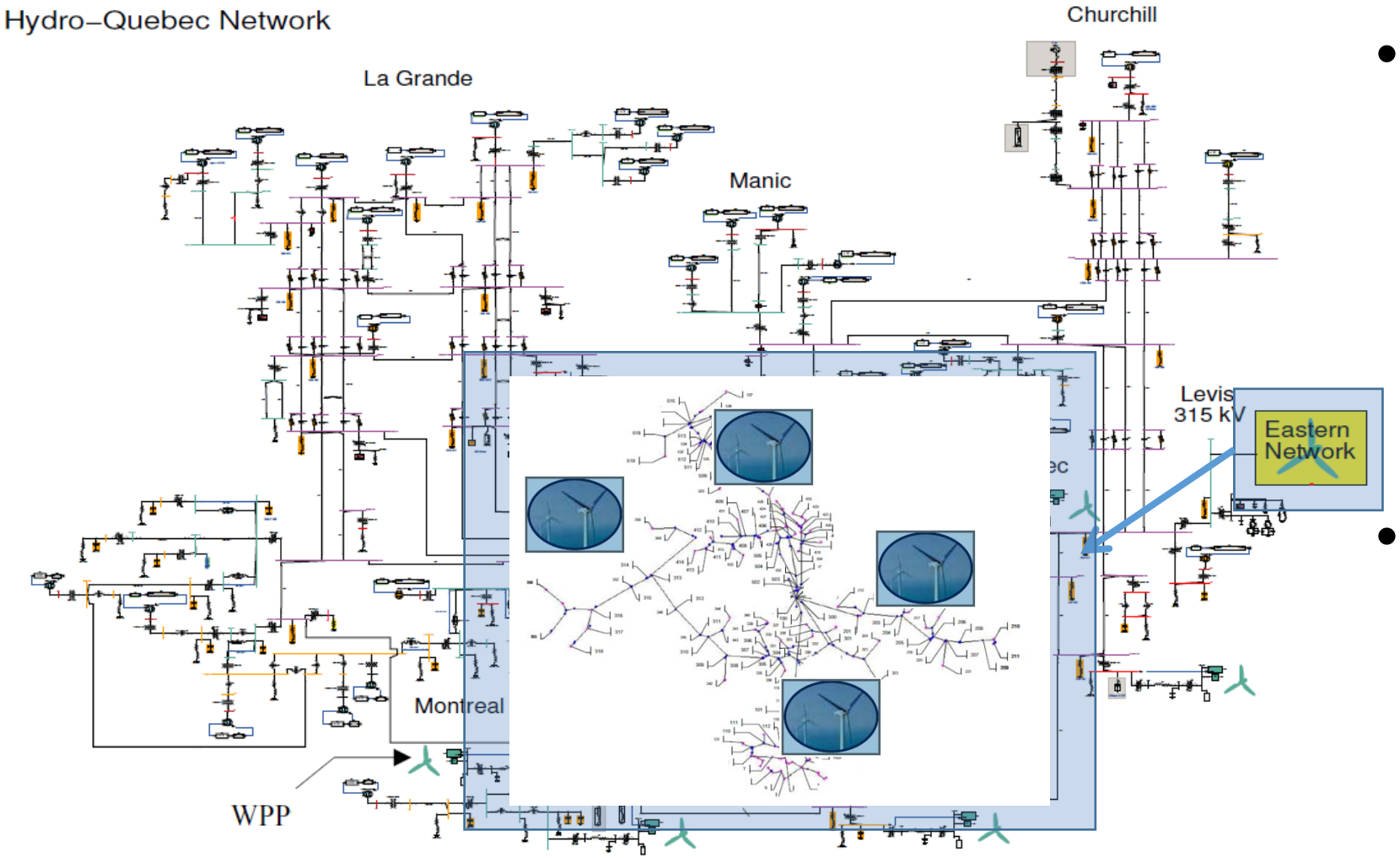
** V. Jalili-Marandi, E. Robert, V.Lapointe, J. Belanger, "A real-time transient stability simulation tool for large-scale power systems". 2012 PES General meeting, San Diego, USA, July 22-26, 2012.

Challenge of distribution networks with EMT-DRTS



- Transmission line delays allow large transmission system to run in real-time.
  - Ex: HQ grid run in real-time on 128 core on SGI computer
  - Automatic partition in Hypersim RT simulator

Challenge of distribution networks with EMT-DRTS

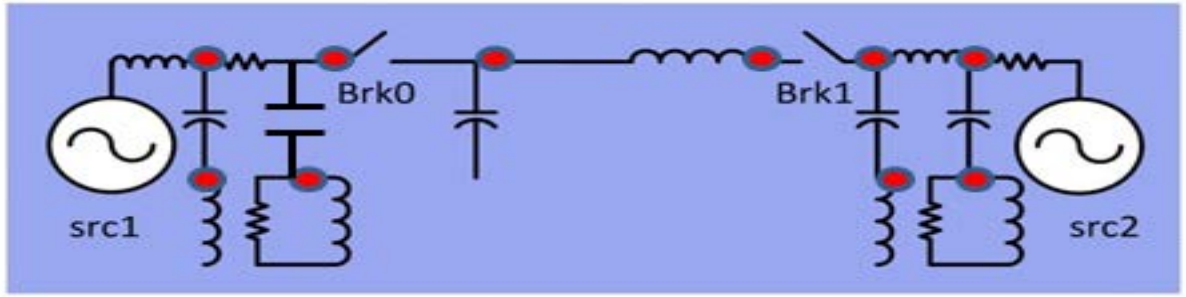


- Transmission line delays allow large transmission system to run in real-time.
  - Ex: HQ grid run in real-time on 128 core on SGI computer
  - Automatic partition in Hypersim RT simulator
- There is no such ‘long’ lines in distribution systems!
  - Cannot parallelize tasks like in transmission grids

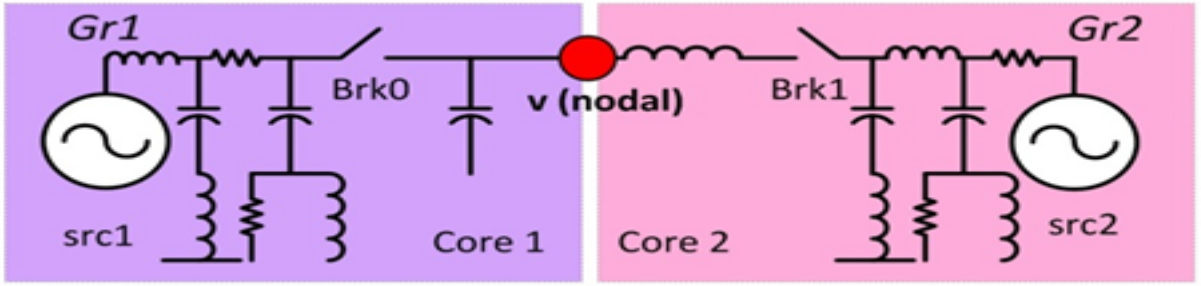
State-Space Nodal (SSN) Solver for Parallel EMT RT-sim

- Reducing the node number is critical for DRTS because the LU factorization of *Y* admittance matrix is an order $O(R^3)$ problem (*R* is rank of *Y*)
- SSN allow user to select the node location and limit the number of nodes.
- Less partitions make it easier to solve the equations on parallel cores, **without algorithmic delays**.

Using EMTP/RTDS/Hypersim: 10 nodes, 16 'partitions'



Using SSN: 1 node, 2 partitions!



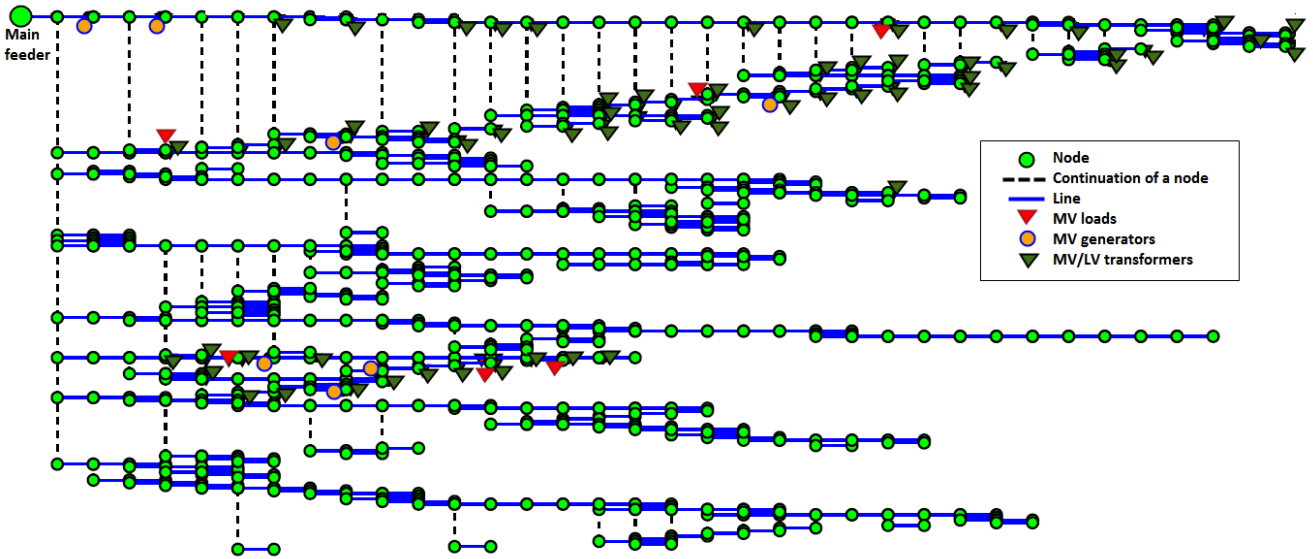
Comparison of node number for standard nodal admittance method and SSN

** C. Dufour, J. Mahseredjian , J. Bélanger, "A Combined State-Space Nodal Method for the Simulation of Power System Transients", IEEE Transactions on Power Delivery, Vol. 26, no. 2, April 2011 (ISSN 0885-8977), pp. 928-935

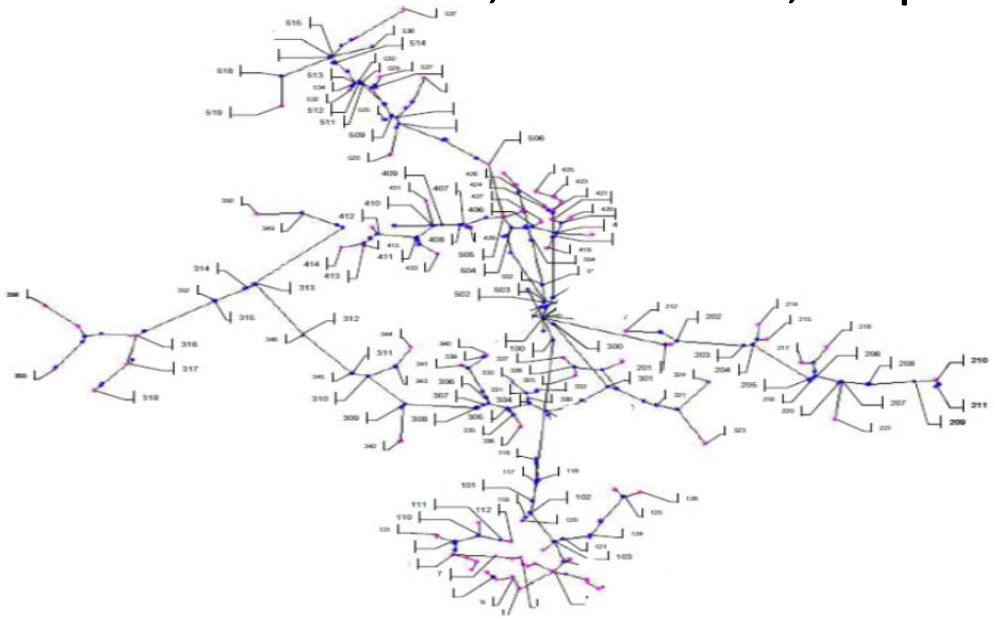
Extending the real-time EMT simulation with SSN

- SSN node aggregation and parallel calculation capabilities pushes the limit of real-time simulation of distribution grids

- ENEL Distribuzione, 750 nodes, 52 µs **



France Distribution, 650 nodes, 70 µs **

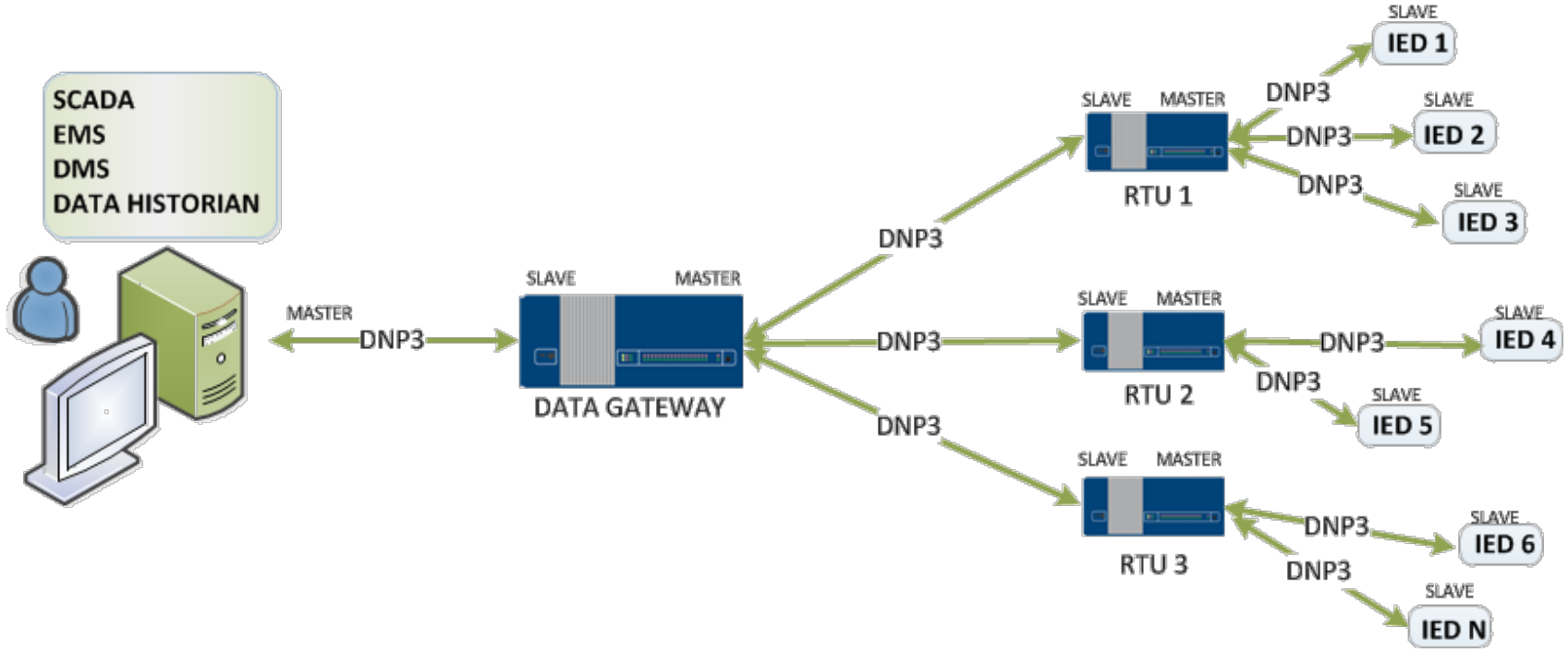


** Timing obtained using Intel-Xeon Processor-E5-2687W Xeon V3 and only 6 cores out of 20 available

** C. Dufour, S. Alma, S. Cuni, G. Scrosati, G. Valvo, G. Sapienza, "Renewable integration and protection studies on a 750-node distribution grid using a real-time simulator and a delay-free parallel solver", accepted for presentation at CIRED-2015, Lyon, France, June 15-18, 2015

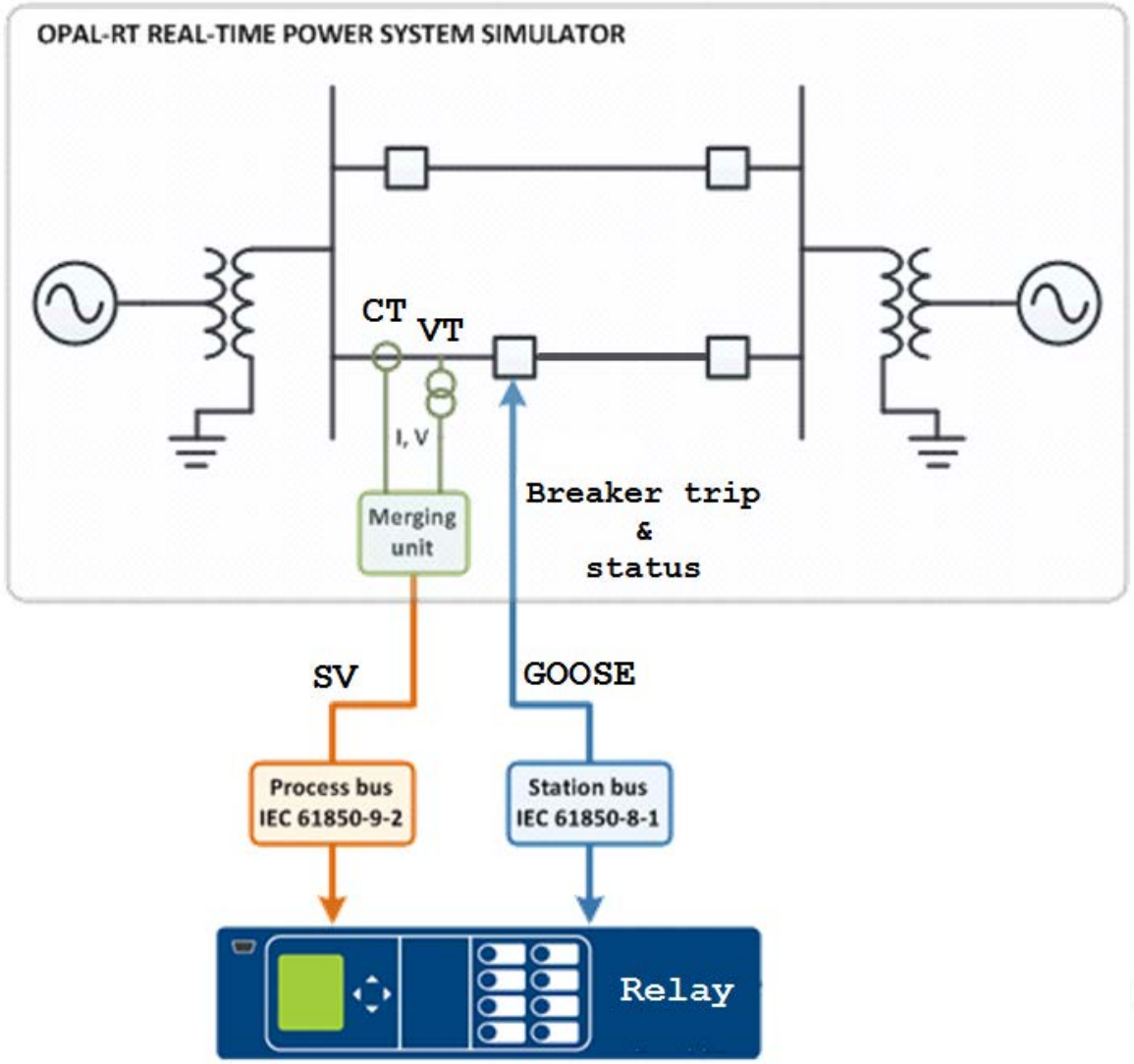
Supported Protocols (list not exhaustive)

- DNP 3 (Distributed Network Protocol)



Supported Protocols (list not exhaustive)

- DNP 3 (Distributed Network Protocol)
- IEC-61850
  - IEC-61850-8-1 GOOSE
  - IEC-61850-9-2 Sampled Values

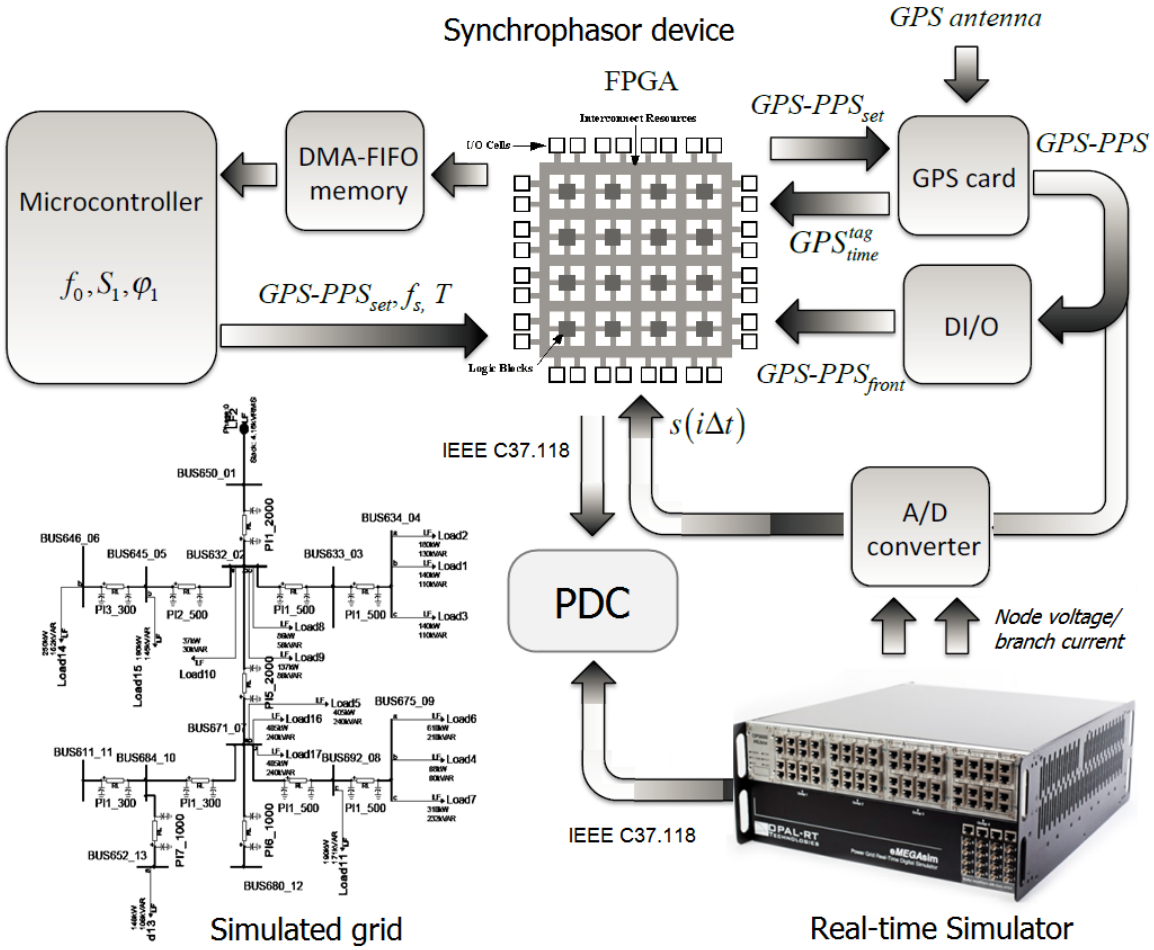


Supported Protocols (list not exhaustive)

- DNP 3 (Distributed Network Protocol)
- IEC-61850
  - IEC-61850-8-1 GOOSE
  - IEC-61850-9-2 Sampled Values
- C37.118-2005 (Synchrophasor protocol)
  - IRIG-B for GPS synchronization
  - More than 100 virtual PMU allowed
- IEC60870-5-104 (for SCADA systems)
- Modbus, Modbus-TCP
- OPC (Open Platform Communications)

Image curtesy of MEINBERG Radio Clocks GmbH
https://www.meinbergglobal.com

PMU development and testing in the lab using DRTS**



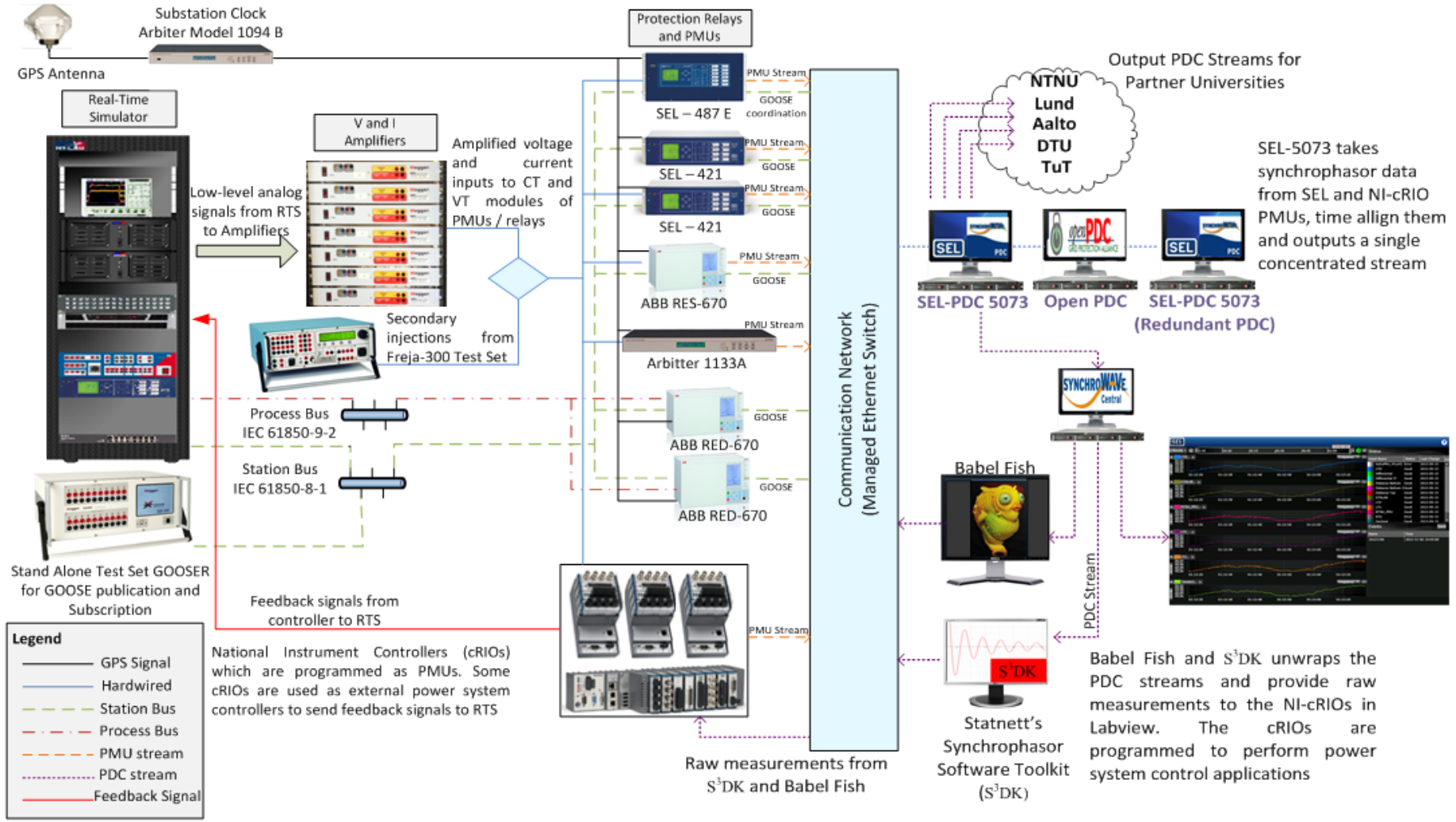
- EPFL in Switzerland developed an ultra-precise PMU for distribution systems
- Validation was made with real-time simulated IEEE 13 Bus test feeder system using SSN

  - Node voltages/currents are send by the analog outputs of the DRTS.
  - Read by the prototyped PMUs (11 total)
  - Other PMUs simulated in the DRTS.
  - 100 softPMU possible.
  - Produce IEEE C37.118 stream which are gathered by the Phasor Data Concentrator (OpenPDC)

** C. Dufour, J. Bélanger, "On the Use of Real-Time Simulation Technology in Smart Grid Research and Development", IEEE Transactions on Industry Applications, Volume 50, Issue 6, Nov/Dec 2014.

Complete WAMPAC laboratory with DRTS (SmarTS-LAB)

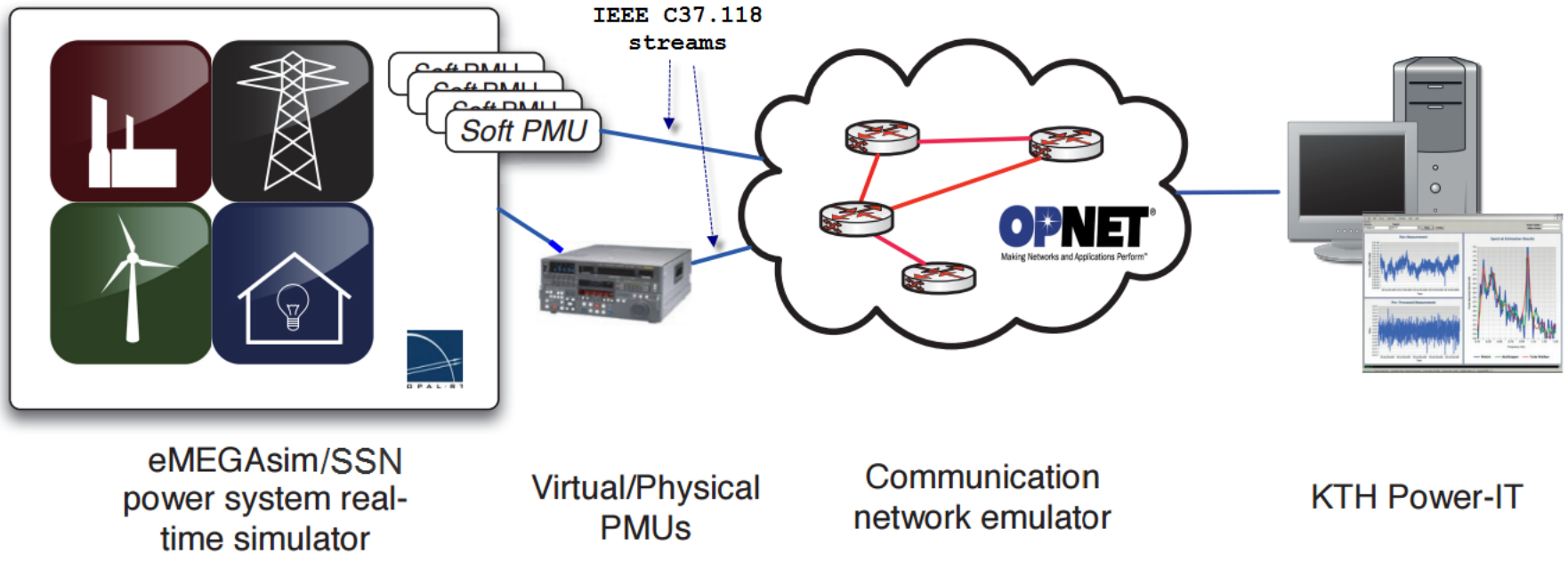
- KTH researchers build a complete WAMPAC laboratory with eMEGAsim DRTS
- Connects to physical PMUs, relays, other PDC streams, portable visualization tools…



Almas, M.S. ;Baudette, M. ; Vanfretti, L. ; Lovlund, S.; **"Synchrophasor network, laboratory and software applications developed in the STRONg²rid project",** 2014 PES General Meeting Conference & Exposition, Washington, USA, 27-31 July 2014

Synchrophasor test platforms with DRTS

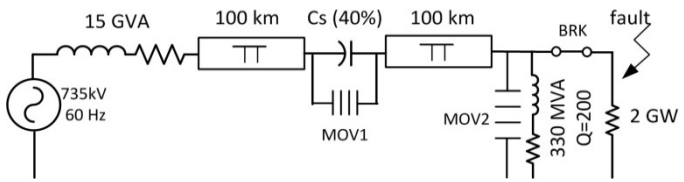
- Another group of researchers at KTH, Sweden, developed a test platform to validate PMU performance and IEEE C37.118 standard compliance.
- Can connect both virtual and physical PMUs.
- Many applications developed such as on-line mode estimation and WAMPAC.

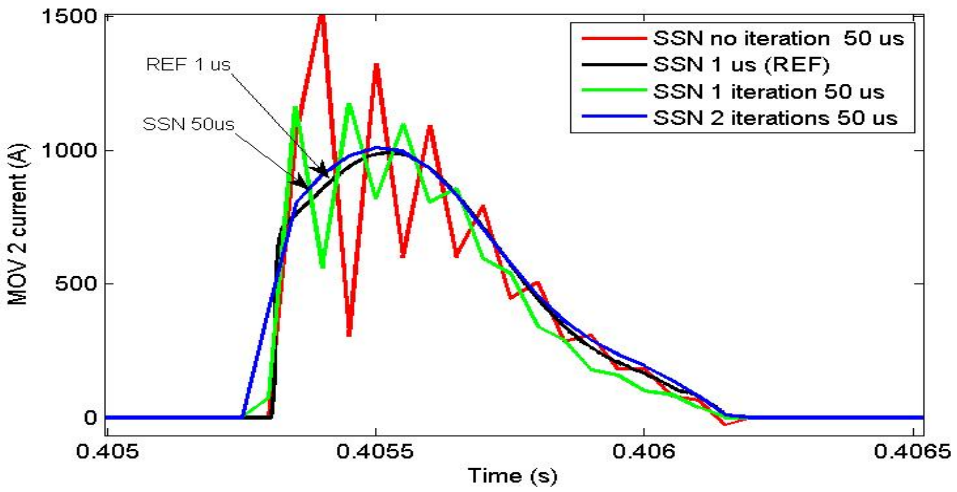


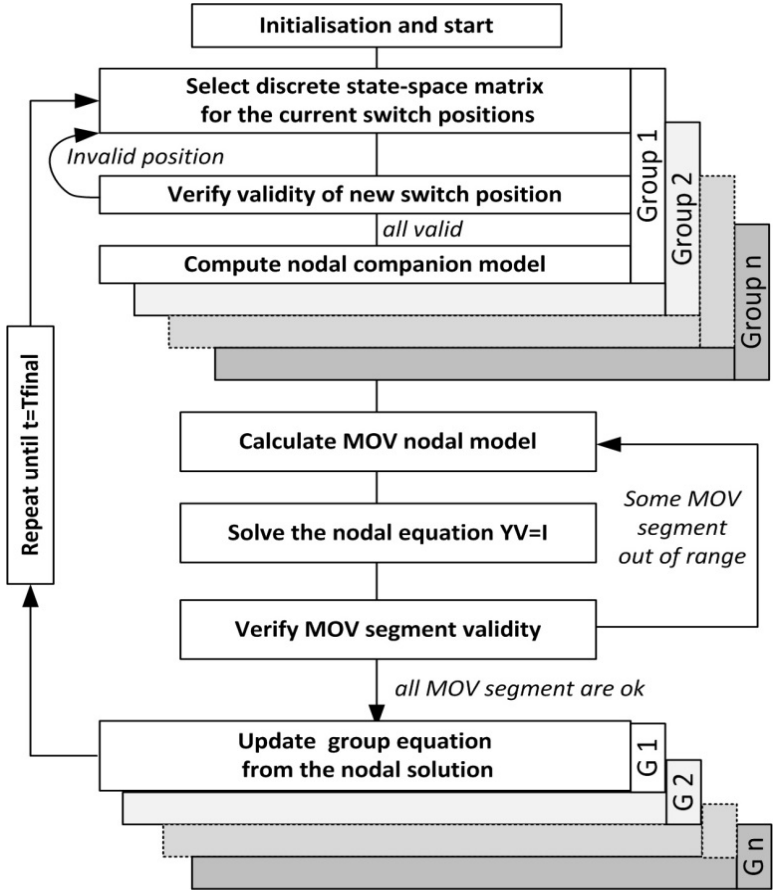
Zhu, K., Deo, S., Al-Hammouri, A., Honeth, N., Chenine, M. et al. (2013) "Test Platform For Synchrophasor Based Wide-Area Monitoring and Control Applications". ,IEEE PES General Meeting Vancouver 2013

Iterative methods in real-time simulators

- Iterative MOV enable precise real-time fault testing
- Unique feature in the DRTS market







C. Dufour, O. Tremblay, "Iterative Algorithms of Surge Arrester for Real-Time Simulators", 18th Power Systems Computation Conference (PSCC 2014), August 18-22, 2014, Wroclaw, Poland.

Conclusion

- The increased power of multi-core PC is enabling even more powerful testing methods for modern transmission and distribution grids.
  - Transient Stability (TS) and Electromagnetic Transient (EMT) methods available in RT
- Coupled with efficient circuit solvers like SSN, we can now simulate distribution grids of 750 nodes without algorithmic delays in EMT
  - Node count simply follows Moore's law, with new PCs.
  - Transmission network (with long transmission lines): no size limits a priori. Hypersim can EMT simulate the entire grid of the Province of Quebec on SGI with 128 cores.
- e*PHASOR*sim: like PSS/e but in real-time.
  - Actually support PSS/e files.
  - Sized for 50000 nodes max in 2015, following Moore's law.
- Communication protocols are important to make RT-sim of modern grids
  - Opal-RT simulators support communication protocols like C37.118 and IEC-61850

OPAL-RT RT15 REGIONAL USER GROUP EVENT

BERKELEY, CA ▪ MAY 13-14, 2015

RT-15 Opal-RT User Group Meeting

- Hosted by Lawrence Berkeley National Laboratory
- Free online Registration at www.opal-rt.com/realtime2015

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