The 9th International Conference on Real-Time Simulation Technologies
RT16, 7-8 June, Munich, Germany

Hydro-Quebec's Network Simulation Centre

Real-Time simulation using digital link communications for HVDC control replicas and 61850 IEDs

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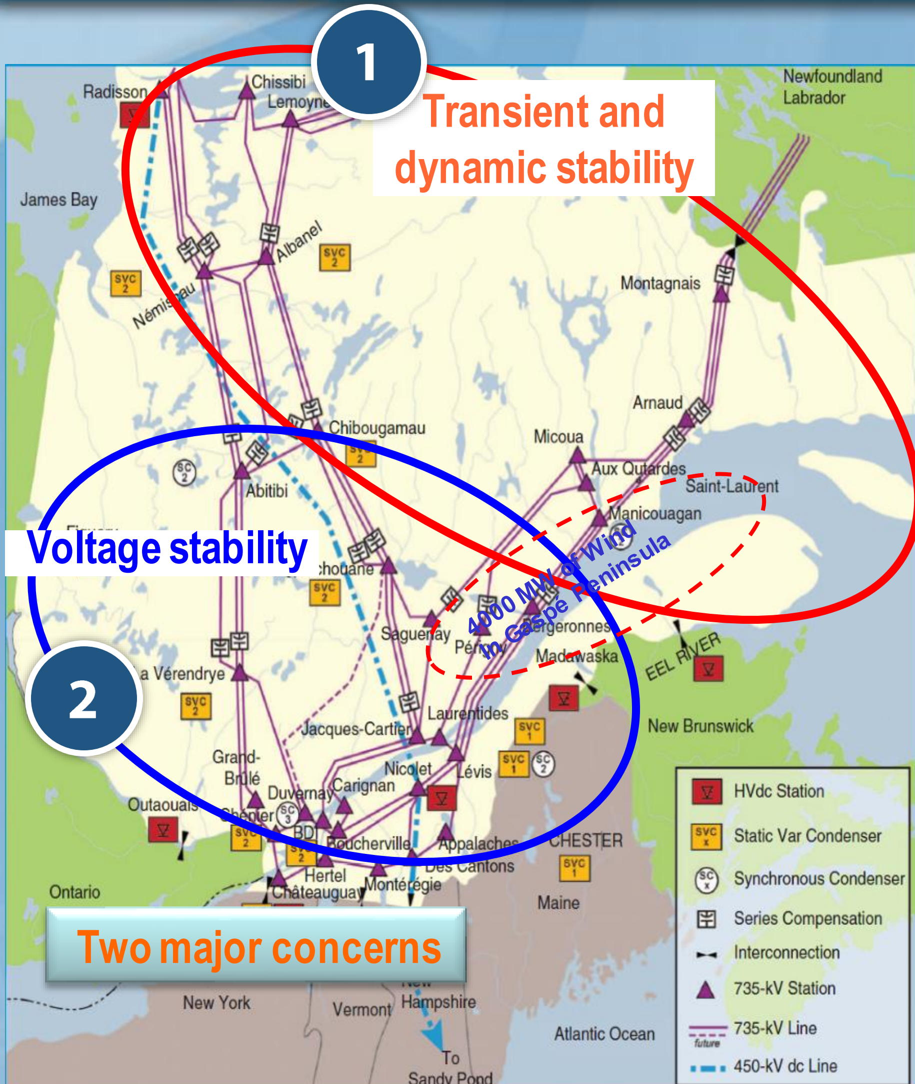
Two main research sites: Varennes and Shawinigan

- 526 employees including: 267 scientists (40% PhD, 40%MsC) and 125 technicians in 2013
- 60 main innovation projects in 2013
- CAD$135M annual budget in 2015

Hydro-Quebec Network is limited by fast stability phenomena requiring fast controls and detailed simulation

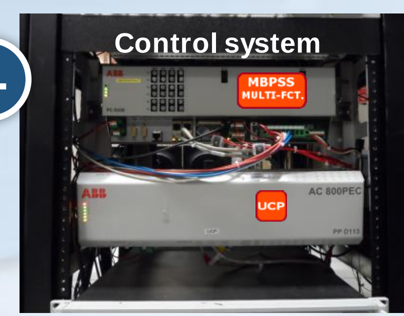


http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=7412828

An extensive set of distributed actuators for smart grid control

- **Network capacity increasingly sought: development rate 2 times slower than the peak power** (3.5% vs 7.8% during the decade 2002-2010)
- Increased south transit: 1500 MW / line in 1965-1970 to 2200-2700MW / online today (very high network performance standards)
- Net exports of 15.2 TWh in 2008 to 30 TWh in 2013: 26 dams/reservoirs with 175TWh storage capability
- 6 HVDC connections with eastern interconnection
- 30 Wind farms for about 4000MW (10% penetration at peak load)
- Shunt compensation installation: 9 Synchronous Condensers (CS) & 16 Static Compensators (SVC)
  - **Total capacity of 7000 MVAR capacitive and 4000 MVAR inductive**

+



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Major Field of expertise – EMT Simulation

- **Topics**

  Studies / Testing, multi-physics modeling and simulation, algorithms, high-performance computing, real-time systems, ergonomics, information processing and visualization.

- **Examples of applications :**
  - ***Simulation Software for Electromagnetic Transients***
  - ***Real-Time Digital Simulation (Hypersim)***
  - ***Component Modeling***
  - ***Commission studies of HVDC &SVC***
  - ***Hardware-in-the-Loop Testing***

Gilbert Sybille, Jean-Claude Soumagne, Richard Gagnon, Omar Saad, Pierre Giroux, Jean Lemay, Patrice Brunelle, « IREQ's Innovations in Power System Simulation» European journal of electrical engineering, VOL 13/5-6 - 2010 - pp.675-698: http://ejee.revuesonline.com/article.jsp?articleId=15487

EMTP-RV 2
The reference for power systems transients

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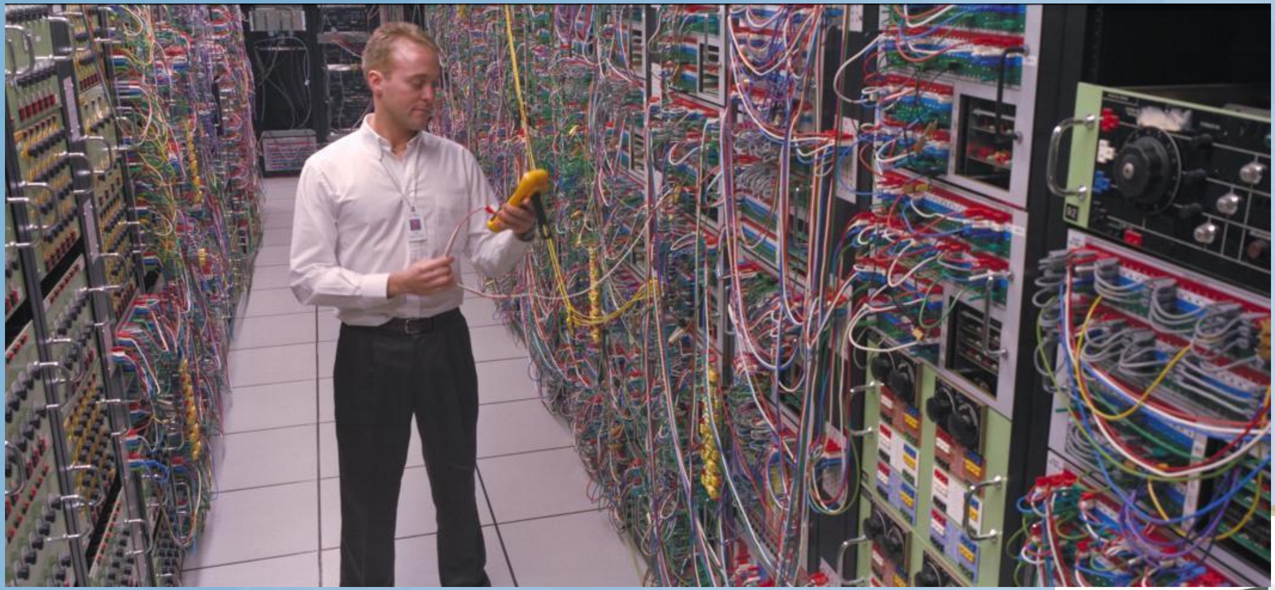
http://canrev.ieee.ca/archive/cr19.pdf

Hardware-in-the-Loop testing at Hydro-Quebec simulation labs…



1996
Analog simulator
(TNA)

2014
HYPERSIM
Digital simulator

« HYPERSIM gathers more than 30 years of experience in Real-time Power System simulation »

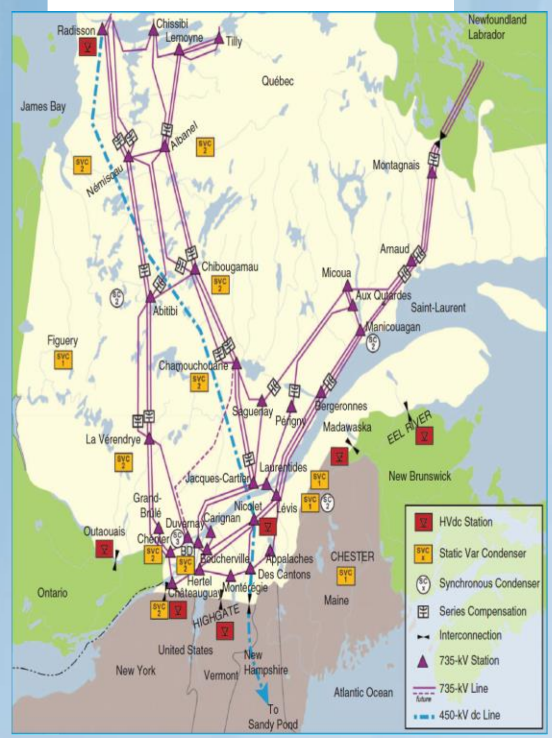
Applications of HIL simulation at IREQ (1975-1989)

- **The first IREQ simulator was commissioned in 1973, while Hydro-Québec was undertaking a major expansion of its 735-kV transmission system**
  - **Contrary to the first phase of the 735-kV transmission network, which used synchronous condensers, it was decided that 3000 Mvar of dynamic shunt compensation would be added using SVCs installed at five 735-kV substations.**
  - **Hydro-Québec was one of the very first utilities to apply the emerging SVC technology on a transmission network. The need to optimize the 735-kV transmission network, select proper SVC technologies and optimize their control system triggered the development of the IREQ simulator**
- **The first version of the simulator was fully developed by IREQ and used analog reduced-scale models. Typical scaling factors were 100 V rms representing transmission line-to-line voltage and 20 watts representing 1000 MW.**

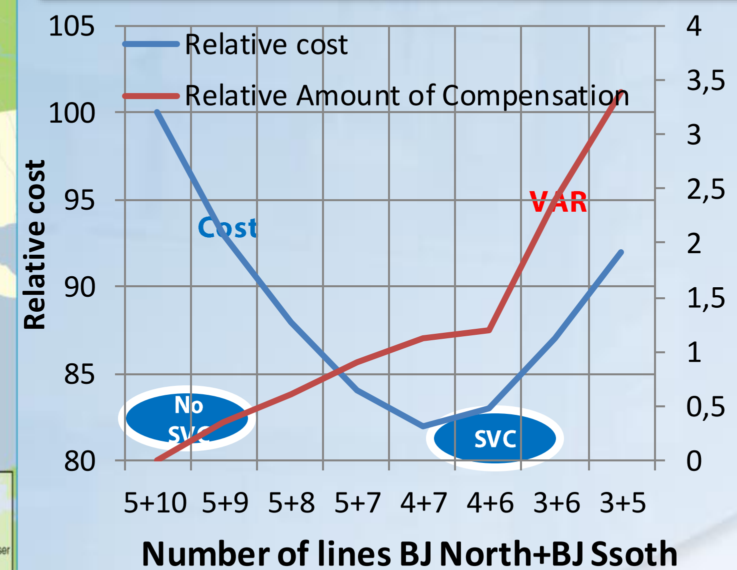
Typical studies performed with the analog simulator included:

- Determination of line and transformer breaker pre-insertion resistances for the James Bay 735-kV network (1980,1985)
- Controlled reactive-power compensation for the James Bay network. Study of various SVC topologies with leading manufacturers
- Control of overvoltages at load rejection on the 735-kV network

Planning the James Bay Network(1972-1973)



Massive SVC led yo 11 lines– instead of 15 without SVC. However TNA was required to design the new solution

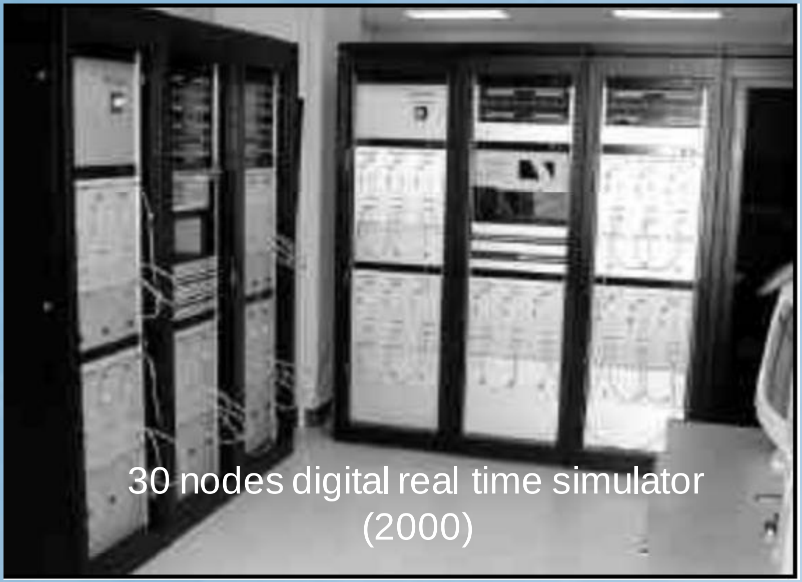


Gain of 4 lines in the 1972-1973 development stage

Applications of HIL simulation at IREQ (1989-2005)

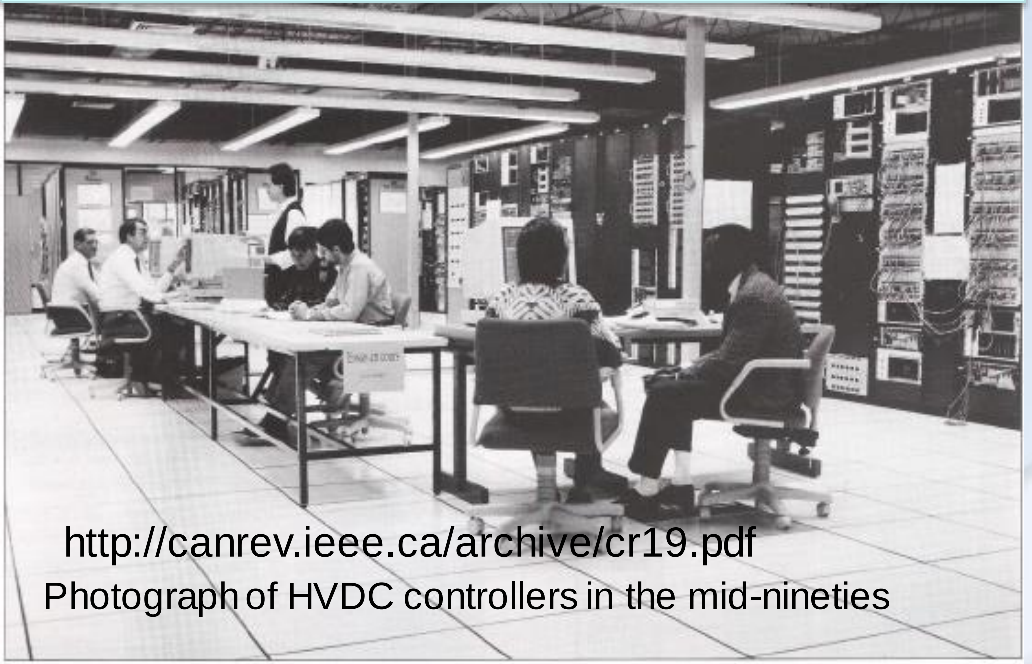
- Evaluation of overvoltage stresses in circuit breakers and energy stresses in metal-oxide varistors protecting series-capacitor banks in the 735-kV series-compensated system
- Evaluation of SVC performance, optimization of regulator gains and interactions with transformer saturation on the 735-kV series compensated system
- Extensive evaluation of protective relays to be used on Hydro-Québec's 735-kV series-compensated network
- Assistance with multi-terminal HVDC system commissioning and operation; control optimization
- Evaluation of performance of SVCs and their protection systems during geomagnetically induced currents (GIC) on Hydro-Québec's network

- Testing of static var system (SVS) installed at Forbes substation on NSP's system (USA)
- Testing of world's first Unified Power Flow Controller (UPFC) installed at Inez substation on the AEP system (USA)
- Testing of world's first Convertible Static Controller (CSC) installed at Marcy substation on NYPA's system (USA)


30 nodes digital real time simulator (2000)

http://canrev.ieee.ca/canrev34/FDRealtime.pdf

HQ Engineer: "The risk is too high, I need to see first!"


http://canrev.ieee.ca/archive/cr19.pdf

Photograph of HVDC controllers in the mid-nineties

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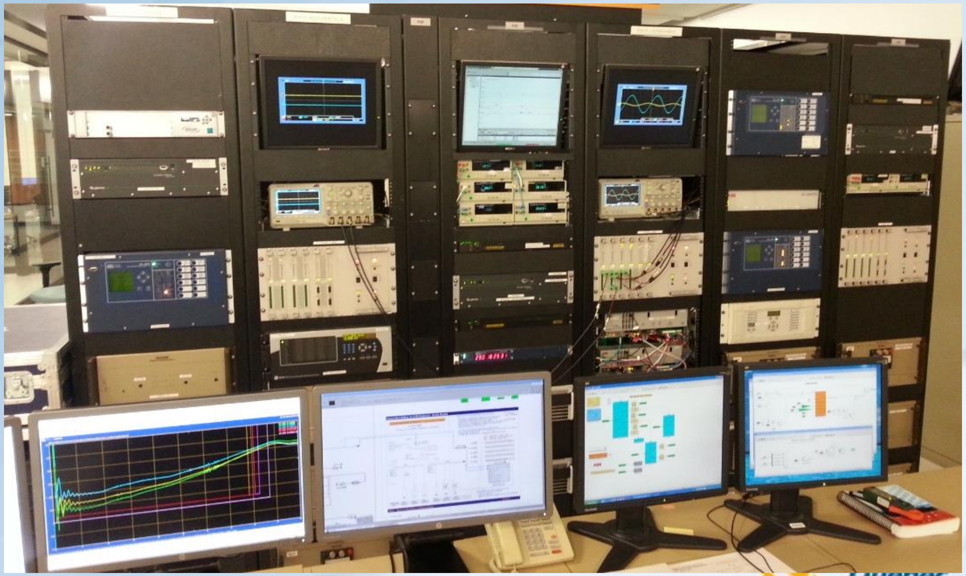
Applications of HIL simulation at IREQ (2005-2015)

- AREVA Levis Deicer/STATCOM controller.
- Chenier, Bout-de-L'Ile, Nemiscau, Figuery Static Var Compensators
- Variable Frequency Transformer (Quebec-USA)
- ABB Unitrol excitation system for Levis and Duvernay synchronous condensers.
- ABB HVDC controllers for the Chateauguay 2x500-MW back-to-back interconnection with NYPA's system – Protection System Studies
- ABB HVDC controllers for the Outaouais 2x625-MW back-to-back interconnection with the Ontario grid
- Refurbishing of Radisson-Nicolet-Boston Multi-terminal HVDC line (Quebec-USA)
- Refurbishing of Madawaska HVDC line (Quebec-New Brunswick)

- Alstom Grid MICOM P846 open-line detection relay and P848 loss of synchronism relay. These two relays are at the heart of Hydro-Québec's defense plan.
- Homologation of a Multi-Band Power System Stabilizer (ABB Unitrol MBPSS)
- Homologation of GE, Alstom, SEL and Cooper PMU, PDC, and SPDC
- Testing and Homologation of Vizimaz Controlled **Switching** Device (CSD)
- Wide-Area Voltage Control System (Pilot projet completed in Early 2014)
- Large Scale integration wind farms in Gaspesia Peninsula (2010 UVIG Industry Award)
- Protections studies for Distributed Generation Integration at Hydro-Quebec Distribution



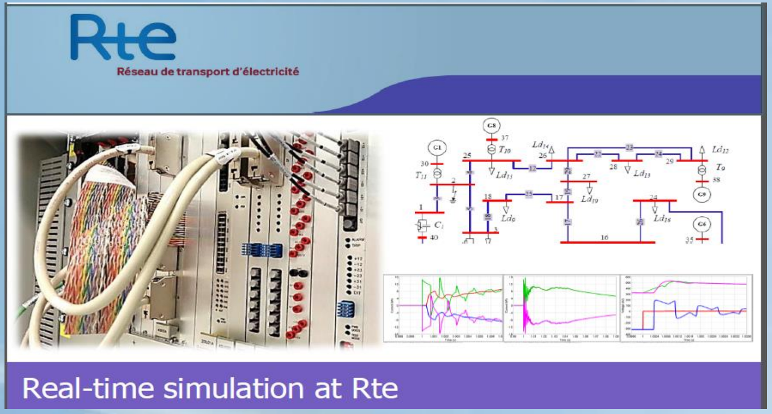
Québec

Through Collaboration - Leverage our strengths to reduce the costs of planning/operations studies

IREQ Simulator

CEPRI Simulator

Rte Simulator

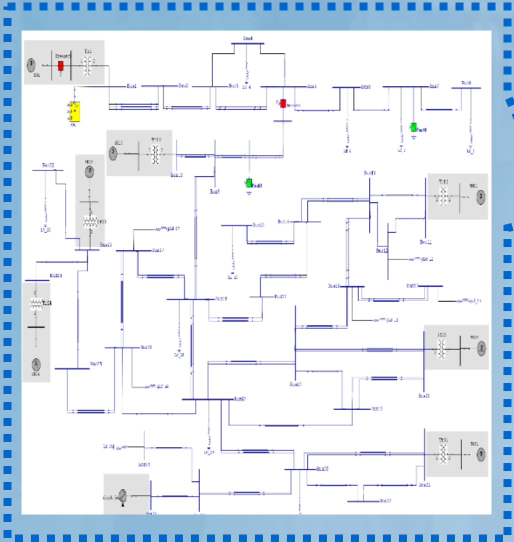


Real-Time Simulation HYPERSIM

- System switching events
- AC fault ride through
- Step Responses
- Converter Station Energisation
- AC & DC fault Responses
- GIC Network Impact Studies
- Multi-terminal operation
- Interaction Studies
- Harmonic Studies
- Sub-synchronous Oscillations

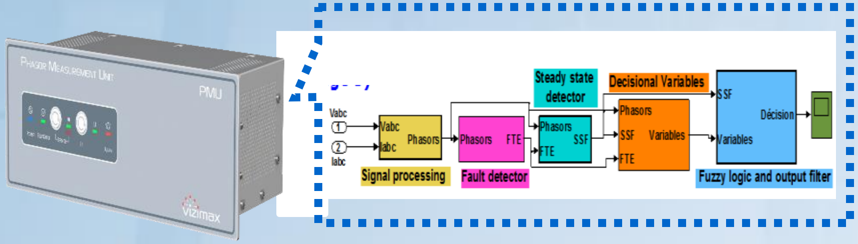
Other collaborations with IREQ

- **OPAL-RT and IREQ signed a strategic collaboration agreement for the shared commercialization and development of HYPERSIM (2012)**



- **Agreement for integration of estimation algorithms resulting from research at IREQ. Algorithms have been enhanced by VIZIMAX for accurate real-time estimation and standard compliance.**

https://www.vizimax.com/products-services/phasor-measurement-unit

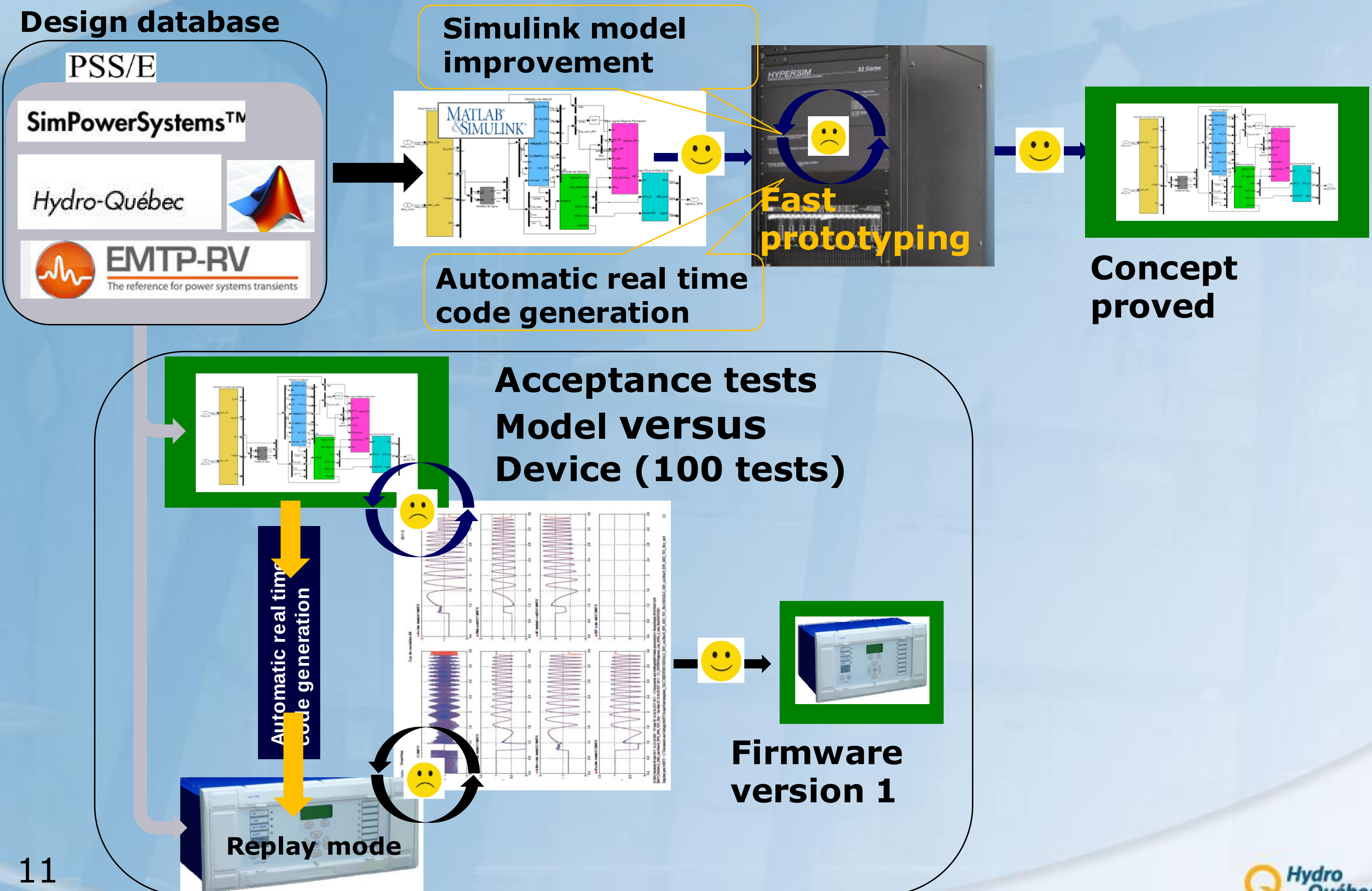


- **Other collaborations for validation of automation and control equipment and certification for use on the Hydro-Quebec grid.**

VIZIMAX /IREQ PMU is IEEE CERTIFIED (March 2016)
http://standards.ieee.org/about/icap/registry.html

Hydro Québec

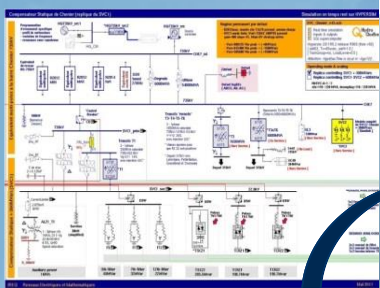
New SPS : development process

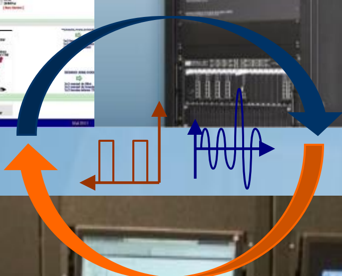


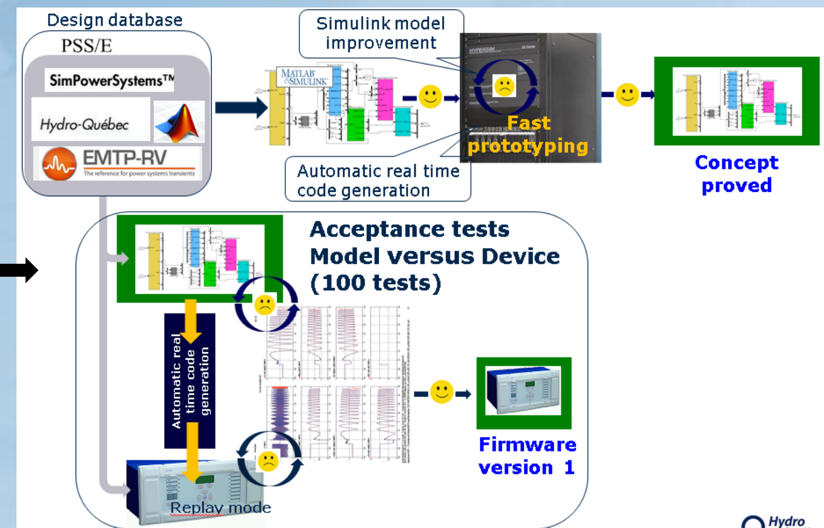
New SPS : development process

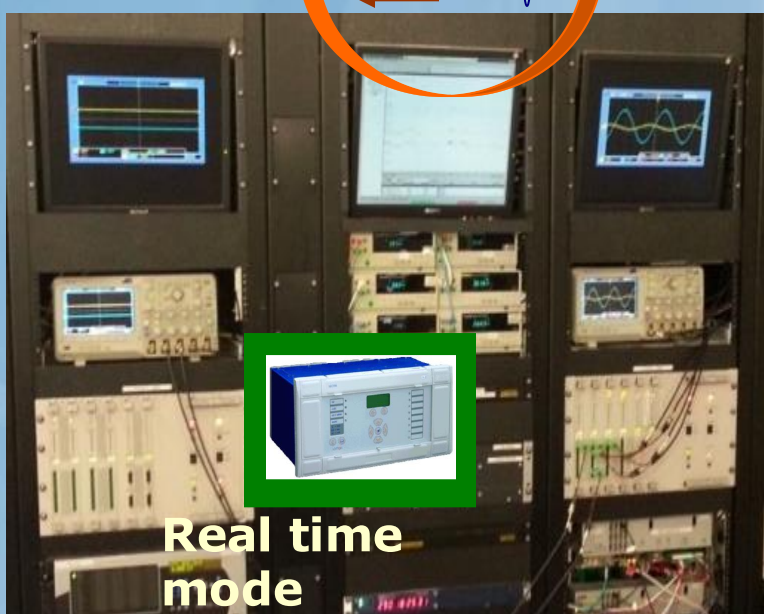
Homologation tests cases

New database









Power system instability detector

- **Local inputs**
  - **Three phase voltage (Vabc) at the substation**
  - **Three phase current (Iabc) of one of the line connecting the substation to the network)**
- **Instability detection time**
  - **Average 15 cy after the fault**
- **Application**
  - **Gaspésie peninsula (3000MW of wind power)**
- **First deployment**

> **ALP4000 Gentec**
> **td average = 10 cycles**
> **Efficiency of remedial action = 100%**
> **Security**

Hydro-Quebec's Network Simulation Centre

Integration of 61850 in Real-Time ElectroMagnetic Transients (EMT) Simulation at Hydro-Quebec

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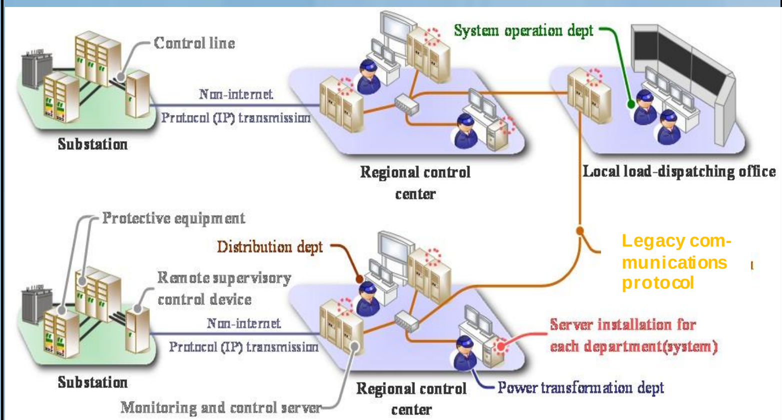
"Next Generation SCADA/EMS" – TEPCO Requirements

- Consistency of supervisory control operation from the bulk transmission to the distribution system by developing interoperable SCADA function for each operational purpose
- Flexibility and sustainability uner changing organizations through server consolidation
- Scalability by adopting international standards

Current monitoring control system

- Monitoring control with original legacy non-internet protocol.
- A server in each department's control center.

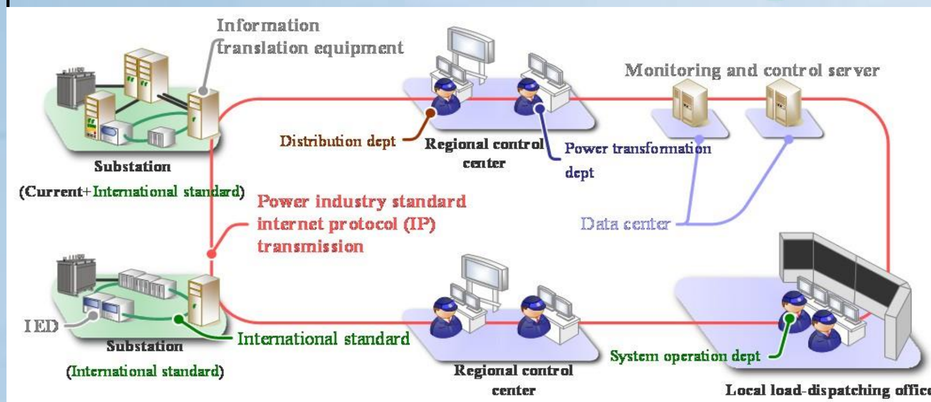
Legacy architecture



"Next Generation SCADA/EMS"

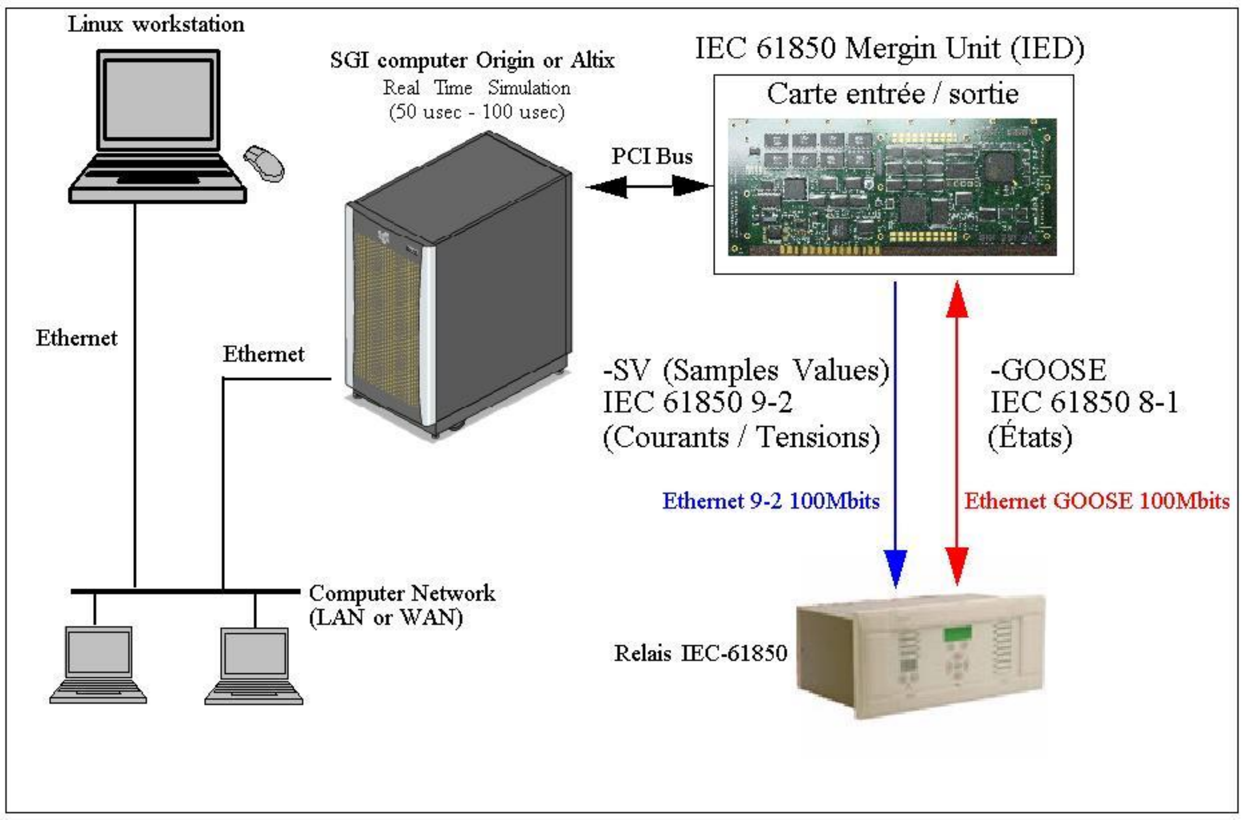
- Standardization of network communications protocol
- Be independent from particular organizations or locations by integrating servers into a server base.

Internet of Things



Hypersim – IEC 61850

- **Goal:**
  - **Implement IEC 61850 8-1 (GOOSE)? And IEC 61850 9-2 (SV) in the Hypersim Real time environment**



- **Benefits:**
  - **Real time data exchange (Currents / Voltages / digital status) with external equipment via the IEC 61850 protocol**
    Ex: Line protection relay, PMU
  - **Reduce the material needed during the validation testing and approval of equipment with Hypersim**
    - **Signal conditioning boxes and wires**
    - **Current Amplifiers / tensions**
    - **Transformers**
  - **IEC 61850-1 GOOSE**
    - **Replace Hypersim digital output and input signals**
  - **IEC 61850 9-2 SV**
    - **Replace Hypersim analog signals: 80 to 256 samples/cy**

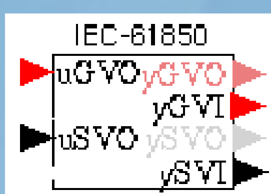
Hypersim Integration

- **Hardware Components**

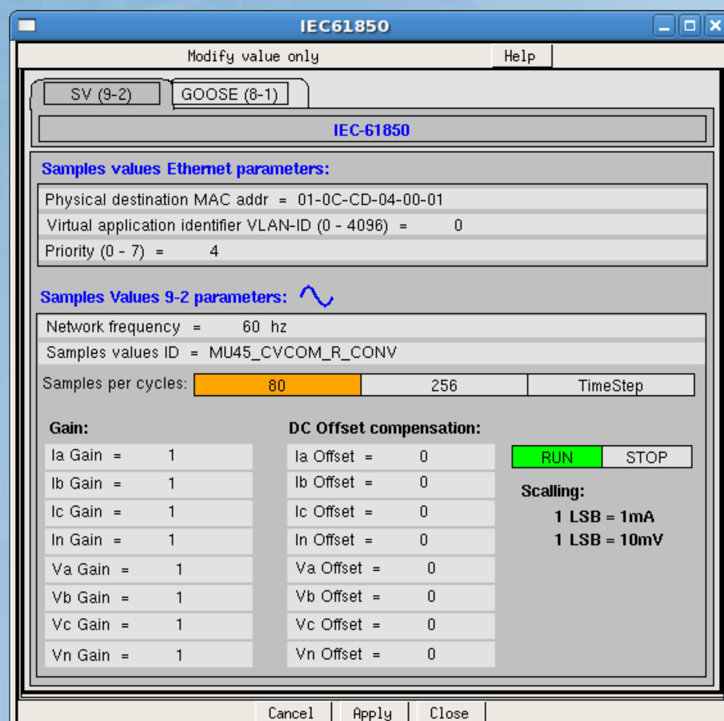
Carte PCI Alphi MFIO

Carte Ethernet D.SignT

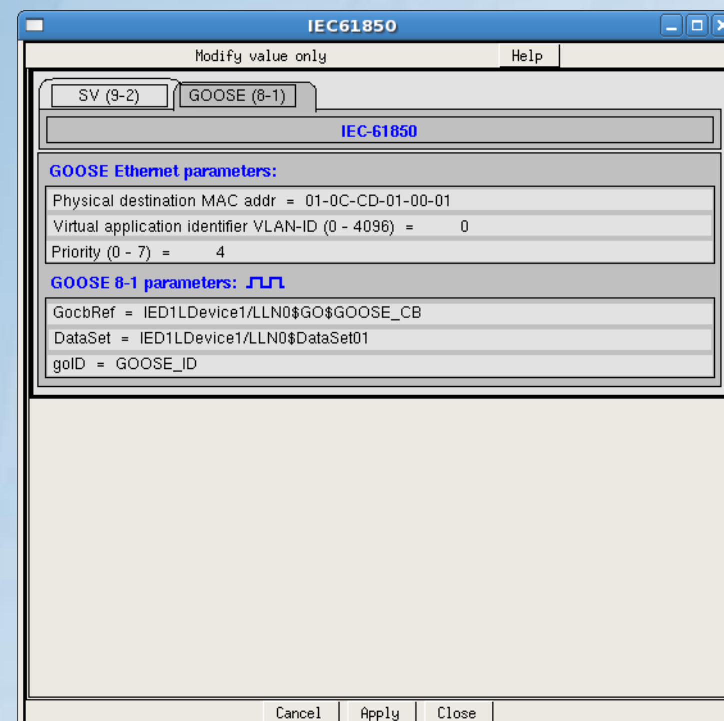
- **Software Elements & forms**



Éléments GUI



SV (9-2) Parameters form



GOOSE (8-1) Parameters form

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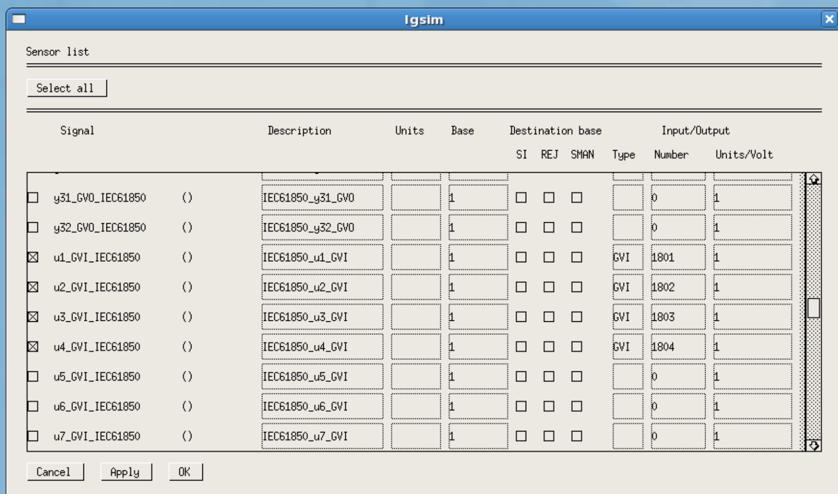
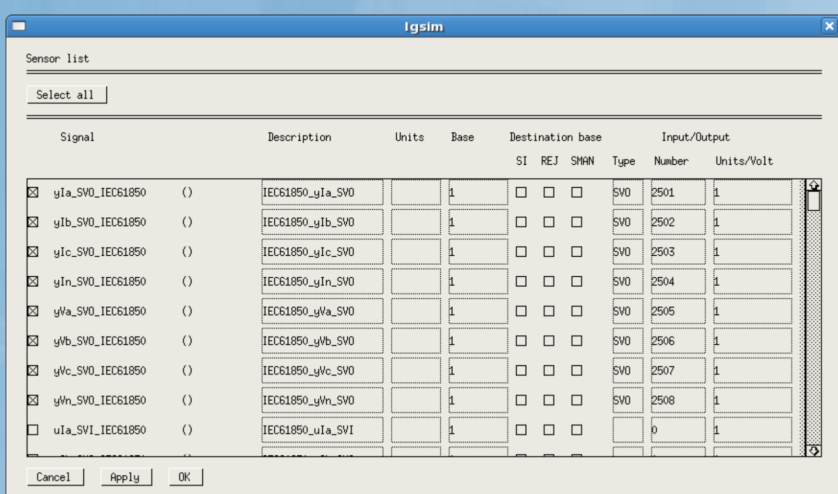
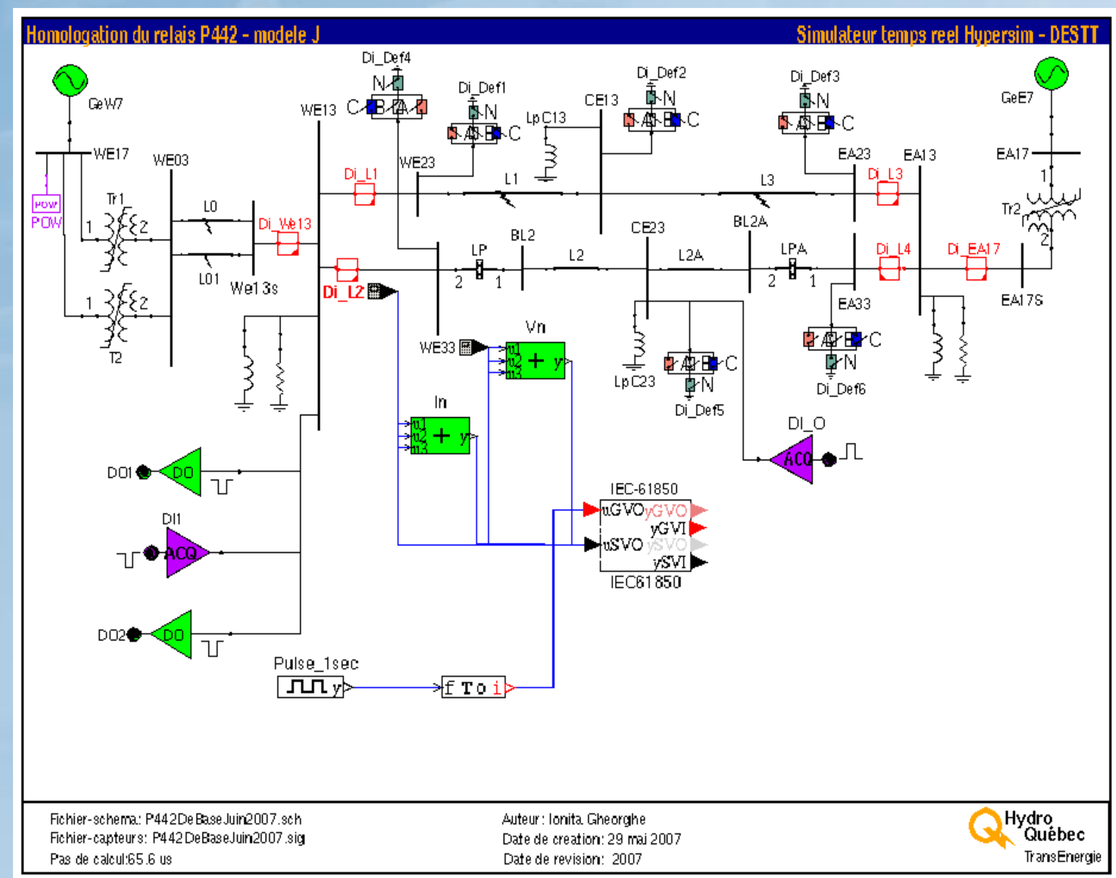
Integration in Hypersim Network



Configuration of GOOSE input signals



Configuration of SV 9-2 output signals



Hypersim Network with IEC 61850 elements

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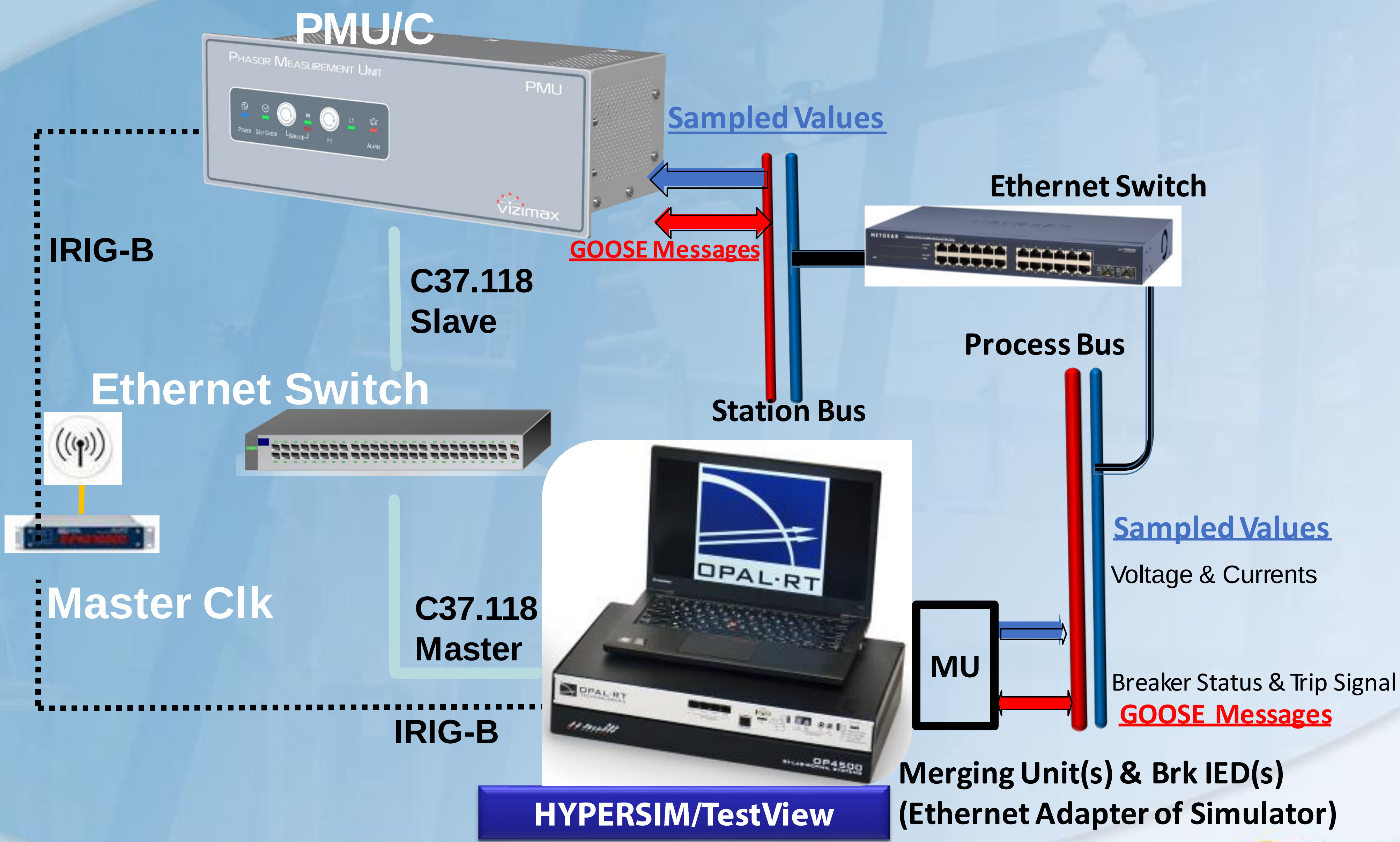
PMU testing using Hypersim - 61850



Hydro Québec

Real-time simulator using digital link communications for HVDC control system

Hydro-Quebec’s Network Simulation Centre

Introduction

- **HVDC control systems are now fully digital**
  - Control
  - Protection
  - Measurement

- **Conventional testing of HVDC control systems with real-time simulator requires a huge number of**
  - Analog-to-digital converters
  - Logical signals

Challenges and Objectives

- **HVDC control systems are now fully digital**
  - Control
  - Protection
  - Measurement

- **Conventional testing of HVDC control systems with real-time simulator requires a huge number of**
  - Analog-to-digital converters
  - Logical signals

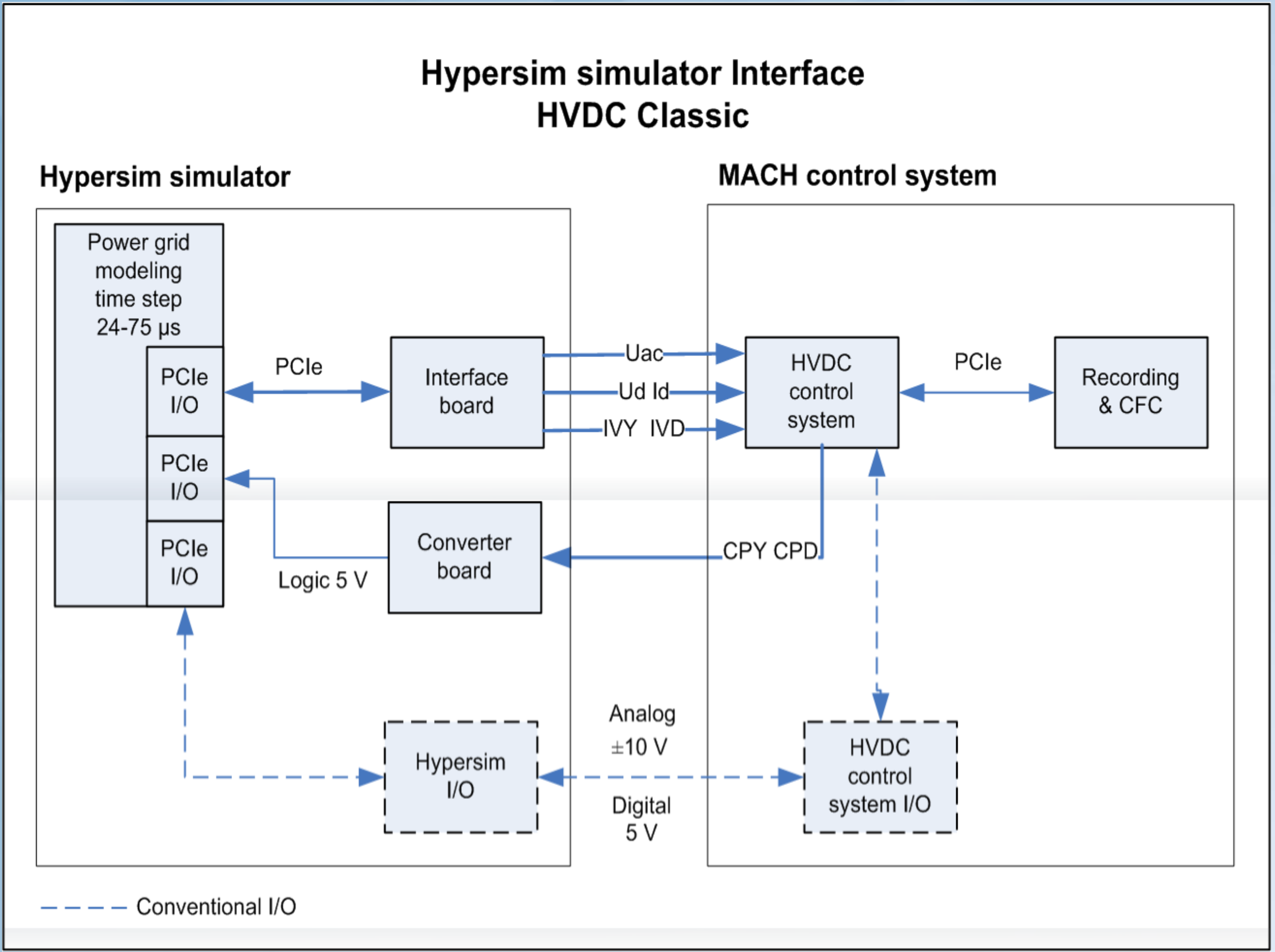
> **Interface MACH (Modular Advanced Control HVDC) control system to real-time simulator using digital link**
- HVDC Classic
- VSC-HVDC (not developed yet)

> **Remove the MACH IO's needed by control system for simulator interface**
- UAC, Id, Udl, current transformers, etc.
- Breaker status/operation, tap changer position, etc.
- Same software version for field and simulator testing

> **Use standard PCIe interface**

Method & approach

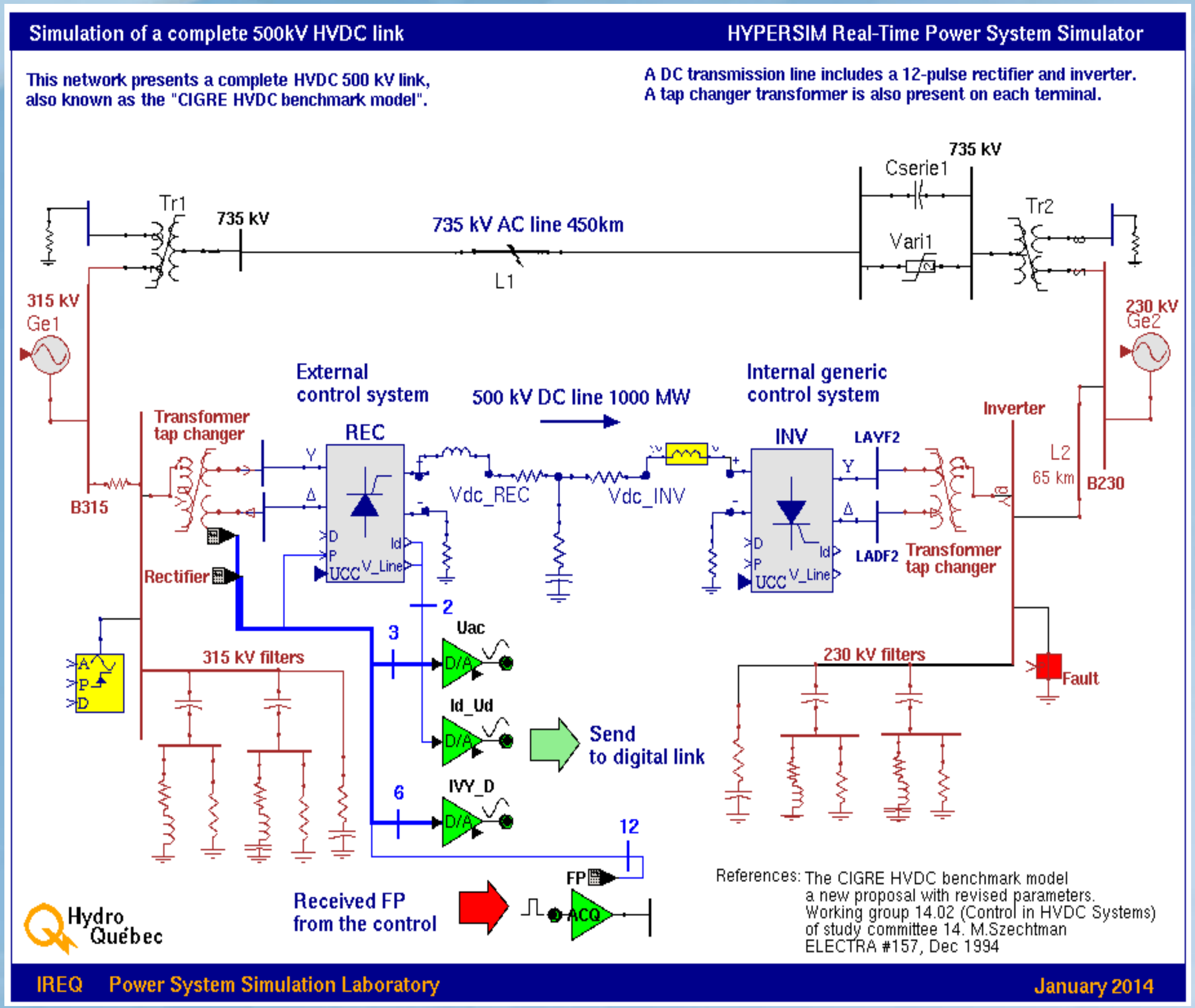
- > Direct PCIe digital link (Peripheral Component Interconnect Express)
- > EDMA (Enhanced Direct Memory Access) used to optimize PCIe access and to offload the CPU in real time
- > No scaling factor is needed for analog values
- > Voltage and current data 32-bit floating point



Interface between Hypersim and MACH HVDC control

Hydro Québec

Benchmark application

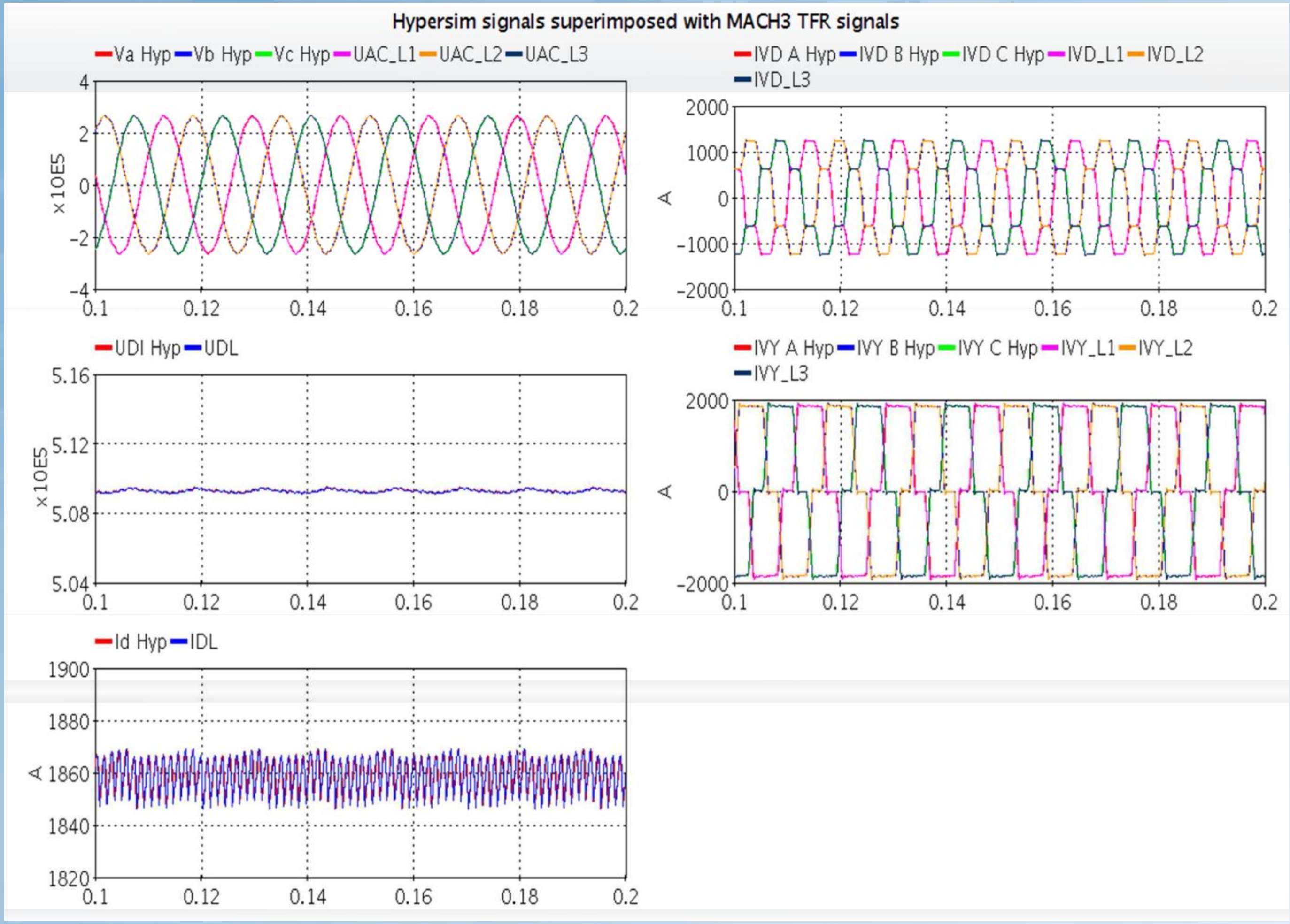


- HVDC CIGRÉ benchmark model
- MACH system is connected and running as rectifier control
- Inverter is simulated with an internal generic control

Results

- Loopback delay around two time step and compensated inside MACH control system

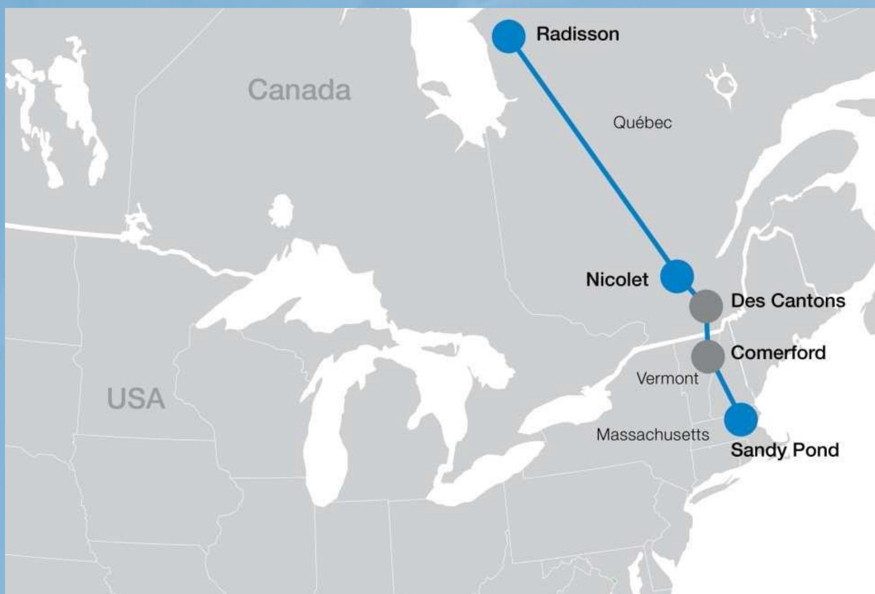
- Transfer time approximately 5 µs (1KB / 197,820 KB/s for PCIe x1 Gen2)



Hypersim signals superimposed with TFR signals

MTDCN refurbishment

> Refurbishment of the control & protection in 2015-16



	DI	DO	D/A
Nicolet DC Pole 1:	175	212	88
Nicolet AC Pole 1:	80	123	91
Nicolet DC Pole 2:	175	212	85
Nicolet AC Pole 2:	94	150	91

MTDC system data	
Years commissioned:	1990–1992
Power rating:	2,000 MW (multi-terminal)
Number of poles:	2
AC voltage:	315 kV (Radisson), 230 kV (Nicolet), 345 kV (Sandy Pond)
DC voltage:	±450 kV
Length of overhead DC line:	1,480 km
Main reasons for HVDC:	Long distance and asynchronous networks
Application:	Connect remote generation to load centres

> Numbers of I/O for Nicolet replica station

→ Same numbers of I/O is required for Radisson & Sandy Pond replica station

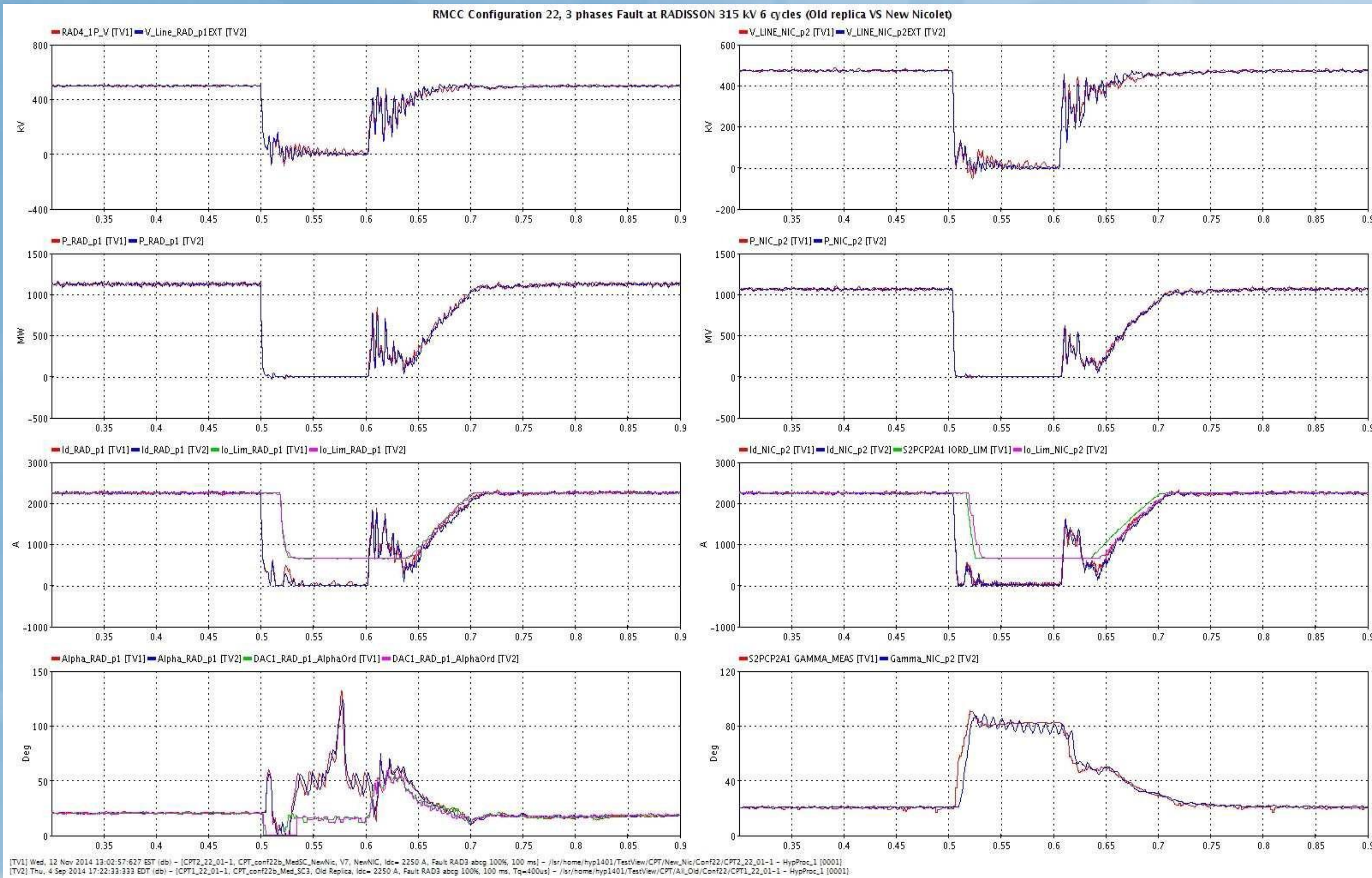
Conclusion

> **Advantages of using digital link communication in a real-time simulator environment:**

- Connections between the simulator and the equipment is greatly simplified
- No amplifiers or calibration needed for current and voltage
- Commissioning time and cost of replica are reduced
- Space area of the equipment is reduced
  since no I/O cubicles are needed
- Maybe an attractive approach for VSC-HVDC control system

MTDCN refurbishment

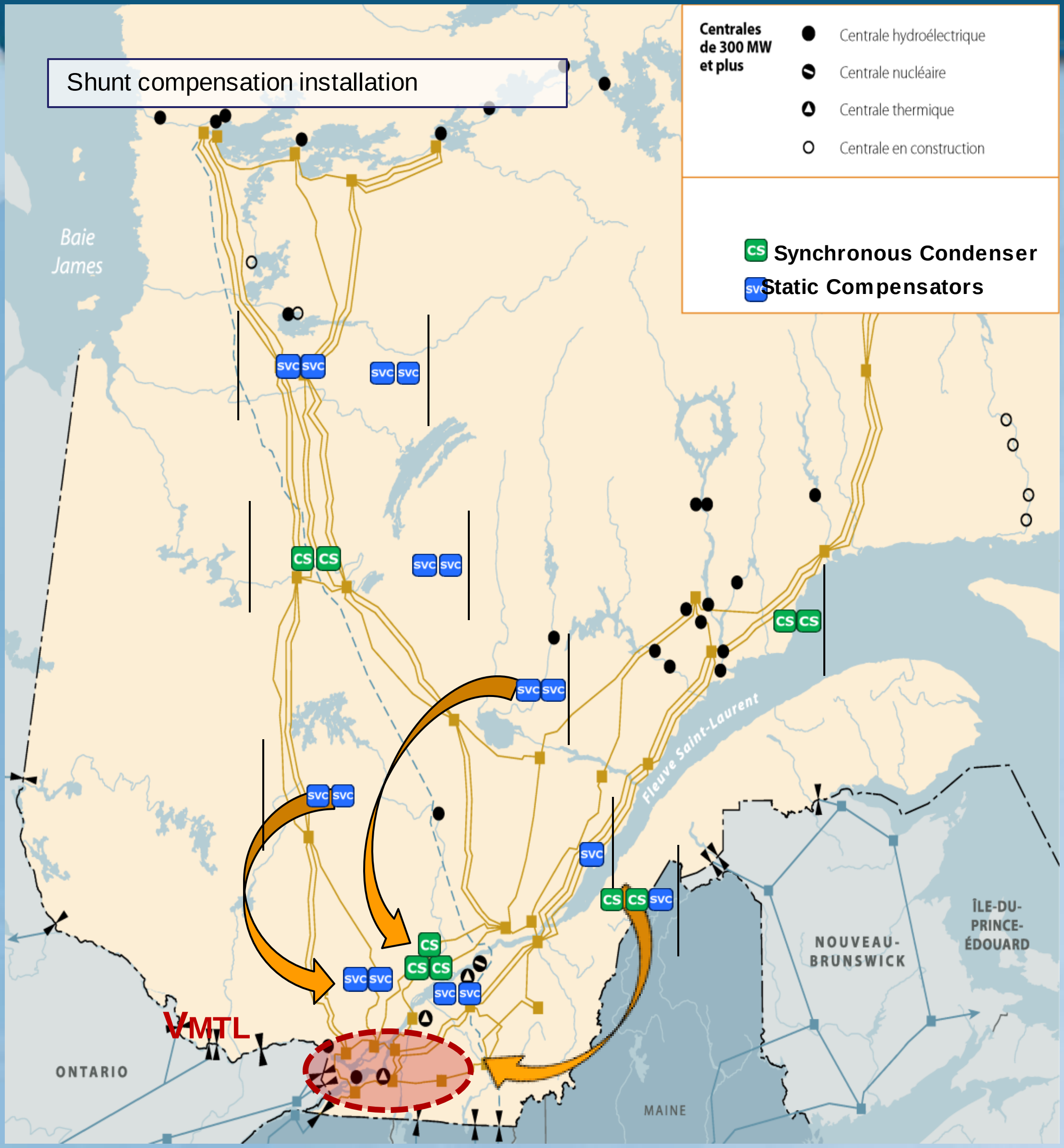
> **Old replica (blue) vs New replica (red)**

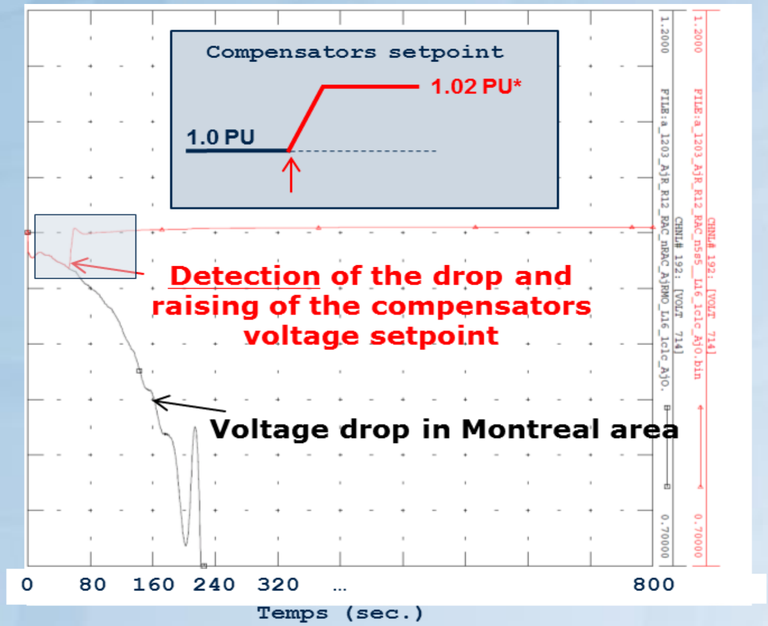


Applications : Wide-Area Control of Hydro-Quebec System & Eastern Interconnection

Hydro-Quebec's Network Simulation Centre

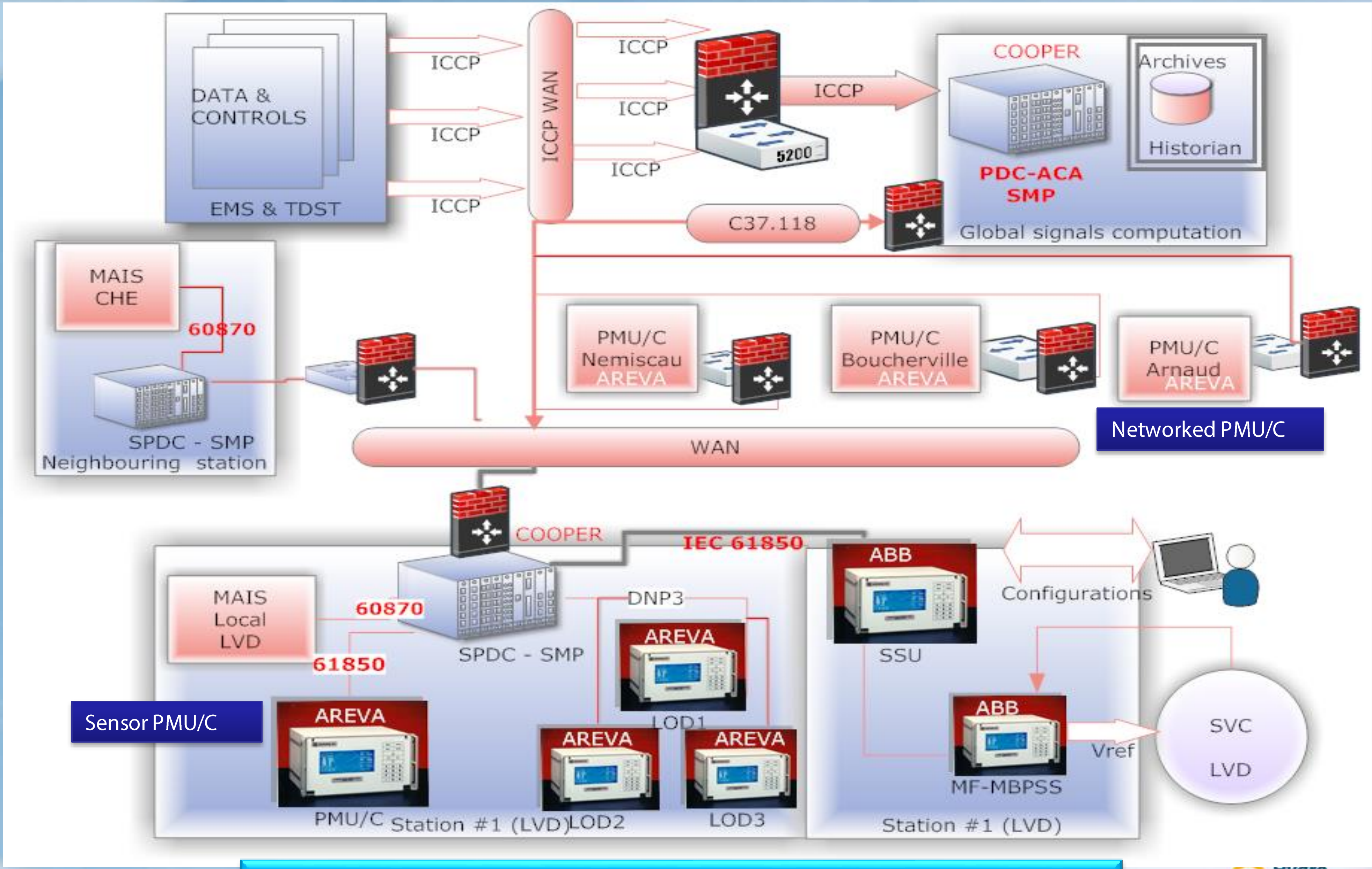
WACS Solution to Voltage Stability





GLOBAL CONTROL	LOCAL CONTROL
▪ **Use of V_{MTL}**	▪ **Estimation of V_{MTL}**
▪ **Telecommunication**	▪ **Local PMU for V, I**
▪ **PDC & SPDC**	▪ **PMU & SPDC**

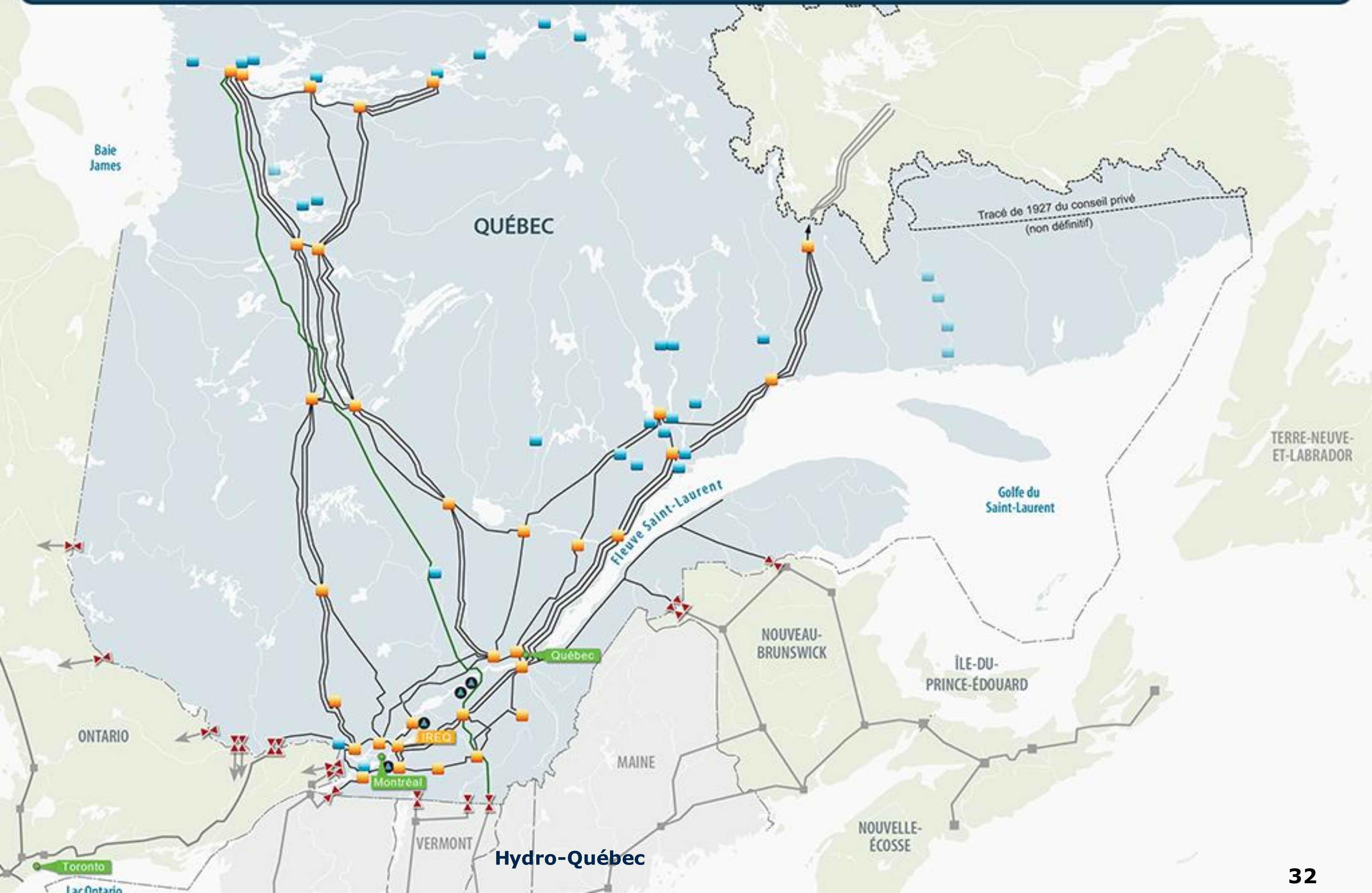
Standards Based WACS Data Flow – Pilot project
Private IP-VLAN



Interoperable PMUs, Relays and IEDs, from Three Vendors

Hydro Québec

Pilot trial to demonstrate wide-area and local control at Hydro-Québec (2014)

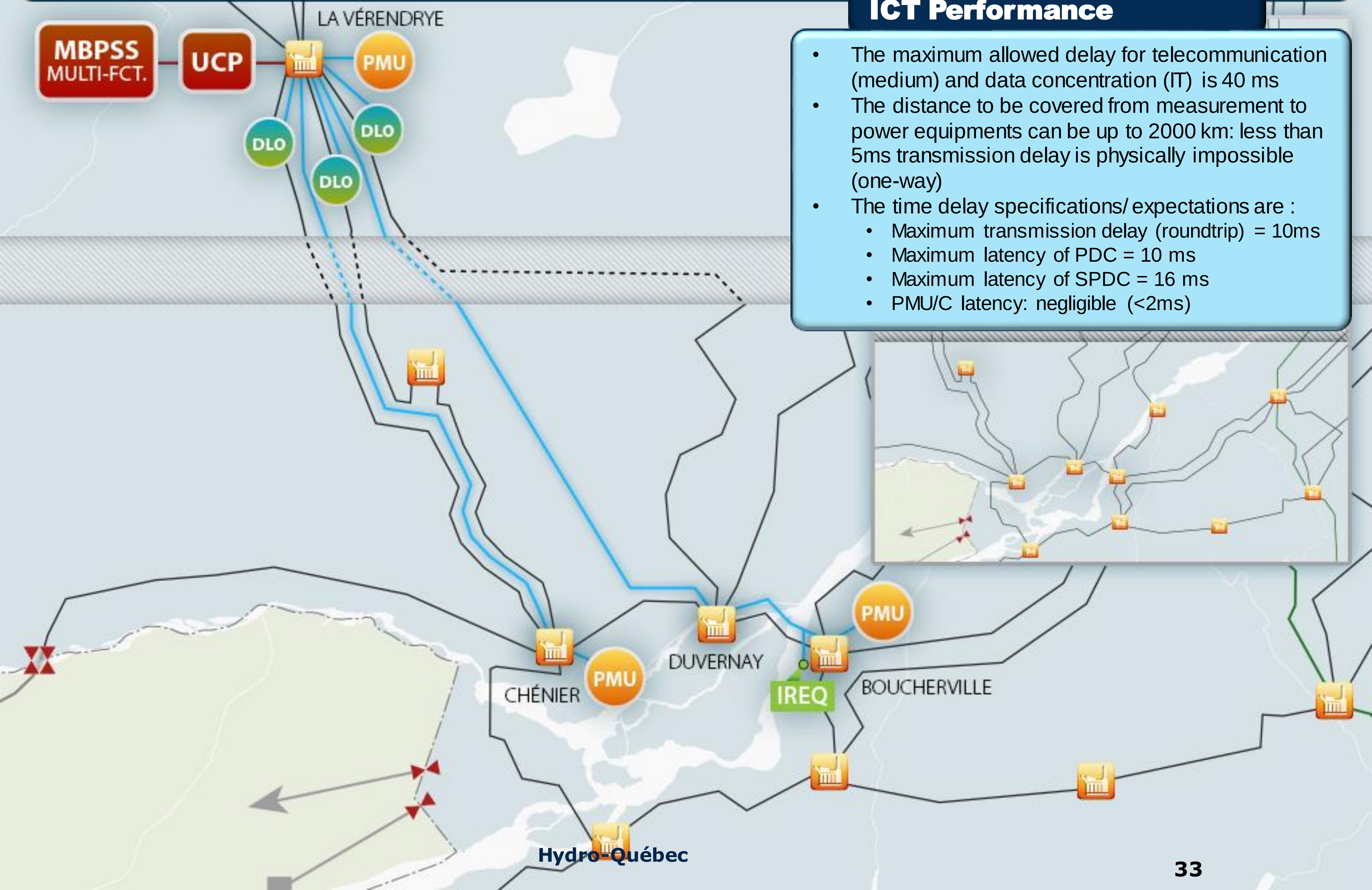


Hydro-Québec

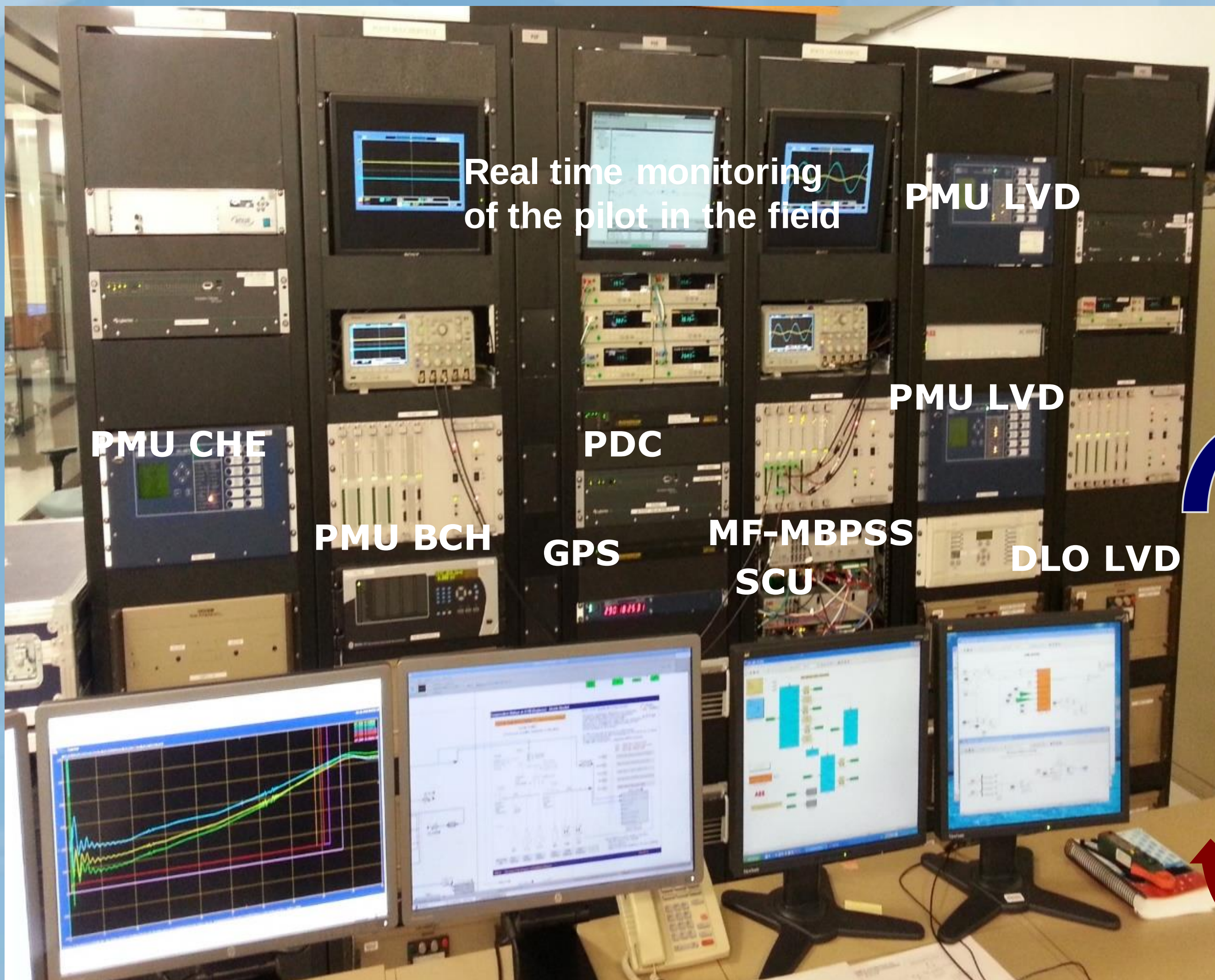
Equipment deployed on grid (cont.)

ICT Performance

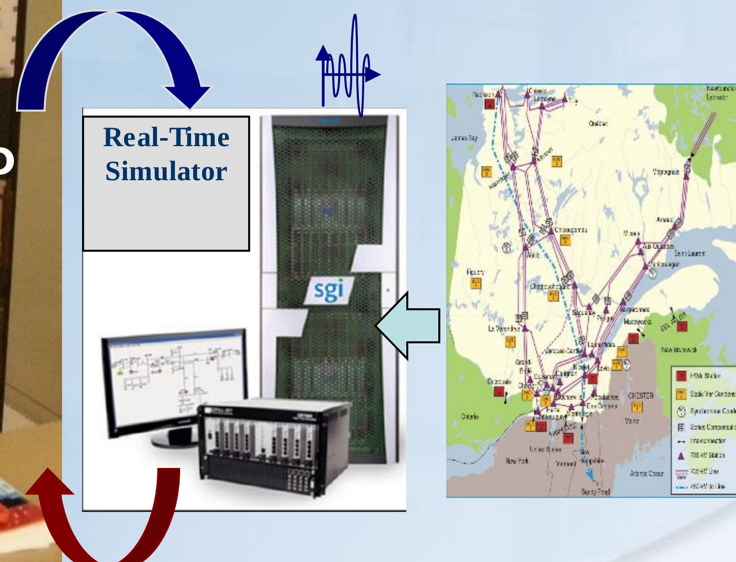
- The maximum allowed delay for telecommunication (medium) and data concentration (IT) is 40 ms
- The distance to be covered from measurement to power equipments can be up to 2000 km: less than 5ms transmission delay is physically impossible (one-way)
- The time delay specifications/ expectations are :
  - Maximum transmission delay (roundtrip) = 10ms
  - Maximum latency of PDC = 10 ms
  - Maximum latency of SPDC = 16 ms
  - PMU/C latency: negligible (<2ms)



Wide-Area Control Systems (WACS) Replica of the Demonstration Project



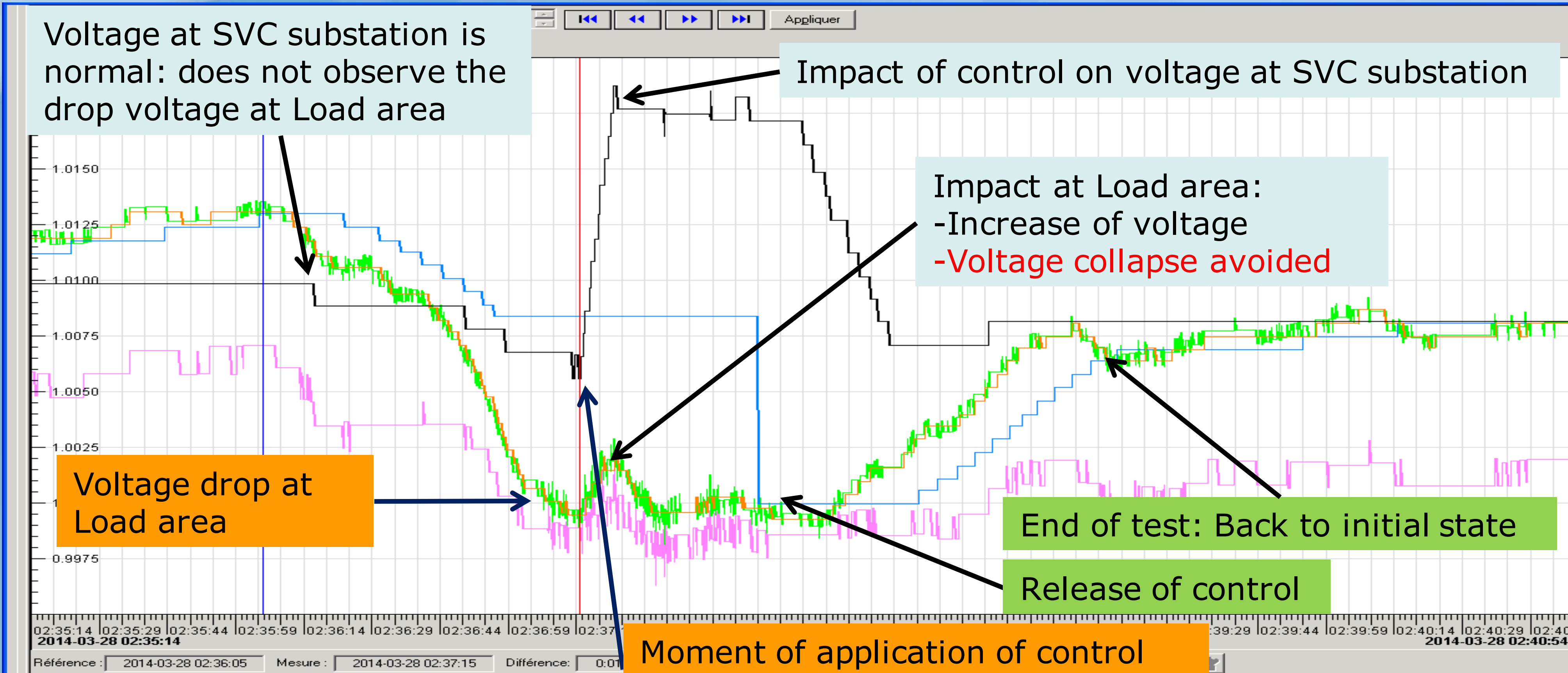
- Control and IED Components
  - PMU «Phase Measurement Unit»
  - PDC «Phasor Data Concentrator»
  - SPDC «Substation Phasor Data Concentrator»
  - SCU «Substation Control Unit»
  - Multi-Band PSS (IEE4B PSS)



Hypersim Simulations of Hydro-Quebec Network: 300-Buses

Local and wide area voltage control of shunt compensators (CGLC)

Pilot project : Closed loop field results



> In partnership with ABB
> In deployment on HQ network
- 9 Synchronous Condensers (CS)
- 16 Static Compensators (SVC)

Benefits:

- 400MW to 2000MW increase of southern-transfer limit
- Deferral of investment in one SVC in Montreal (60M$)

Thank you

http://www.theglobeandmail.com/technology/connected-world-the-internet-of-things/article24587017/

Power System Technologies Higlight at IREQ

735 kV lines near the 5 616MW Robert-Bourassa generating station