OPAL-RT TECHNOLOGIES

HYPERSIM

Application of Real-Time Simulation in power systems

By: Benoit Marcoux
OPAL-RT Business Development Manager Asia

Date: October 30th for NEDO, Japan

OPAL-RT IN BRIEF

- Established in **1997**
- Over **450 employees** worldwide
- More than **2200 customers**
  - Universities
  - Industrial
  - R&D organisations
- 20% of turnover reinvested in R&D

- President, CEO & CTO and founder: **Jean Bélanger**
  (25 years at Hydro-Québec Research Institute (IREQ))

Real-time simulation and Hardware-in-the-loop (HIL) for:

✓ **Power systems**
✓ **Power electronics**
✓ **Aerospace**
✓ **Automotive**

OPAL-RT IN BRIEF

HYPERSIM

- Headquarters located in **Montréal, Canada**
- OPAL-RT offices in ***Michigan, Paris, Bangalore, Beijing, Chile***
- Distributors located in *Brazil, China, Colombia, Japan, Korea, Mexico, Pakistan, Russia, Singapore, Malaysia, Taiwan, Australia, Vietnam*

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S&C
Hydro Québec
ENERCON ENERGIE FÜR DIE WELT
SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL® Company
New York Power Authority
Entergy®
GE
EMBRAER
PRATT & WHITNEY DEPENDABLE ENGINES
LIEBHERR
Hamilton Sundstrand
A United Technologies Company

Pacific Northwest NATIONAL LABORATORY
Sandia National Laboratories
NREL NATIONAL RENEWABLE ENERGY LABORATORY
MIT Lincoln Laboratory
Argonne NATIONAL LABORATORY
Rockwell Automation
EATON
Johnson Controls
MITSUBISHI ELECTRIC
HITACHI
TMEIC
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WESTERN
WASHINGTON UNIVERSITY

CSUB

WSU
WICHITA STATE UNIVERSITY

TU
TENNESSEE TECH UNIVERSITY

THE UNIVERSITY OF TENNESSEE
KNOXVILLE

NC STATE UNIVERSITY

HOWARD UNIVERSITY
1867

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THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

UNC CHARLOTTE

UNM

ATM
TEXAS A&M UNIVERSITY

UNIVERSITY OF ARKANSAS

TUSKEGEE UNIVERSITY

CENTER FOR ADVANCED POWER SYSTEMS
FSU

University of West Florida

UF
UNIVERSITY of FLORIDA

THE UNIVERSITY OF TEXAS AT AUSTIN

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HYPERSIM® Customers

Since 1997, OPAL-RT has earned the trust of over 800 customers, including Fortune 500 companies, academic institutions and laboratories. More than 2000 users currently run OPAL-RT in 40 countries around the world.

HYPERSIM® provides engineers with a range of solvers and toolboxes, through an advanced real-time simulation platform featuring Hardware-in-the-Loop (HIL) testing. Whether you're developing, integrating or testing, or simply tired of waiting hours for a few seconds of simulation, HYPERSIM provides the solution.

HYPERSIM

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- California State University, Bakersfield
- Dominion Energy
- Georgia Institute of Technology
- Illinois Institute of Technology
- National Grid
- National Renewable Energy Laboratory (NREL)
- New York Power Authority (NYPA)
- Pacific Northwest National Laboratory
- Rensselaer Polytechnic Institute (RPI)
- Sandia National Laboratories
- Siemens Industry
- Southern California Edison
- Southern Company
- Texas Tech University
- University of Central Florida
- University of Florida (UFL)
- University of Illinois at Urbana-Champaign
- University of North Carolina Charlotte
- University of Rhode Island
- University of St. Thomas
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- Edutelsa
- Instituto de Energias Renovables (IER)
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CANADA

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- Concordia University
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- Hydro Québec
- Institut de recherche d'Hydro-Québec (IREQ)
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- University of Toronto

Latin America

BRAZIL

- CEPEL
- COPPE-UFRJ
- Enel
- Instituto Militar de Engenharia (IME)
- ITAEE
- Operador Nacional do Sistema Elétrico (ONS)
- Universidade de Brasília (UnB)
- Universidade Federal de Santa Maria

CHILE

- Universidad de Concepción

COLOMBIA

- XM

COSTA RICA

- Universidad de Costa Rica

Middle-East & Africa

ALGERIA

- ENPO

PAKISTAN

- National Transmission & Despatch Company

TECHNOLOGIES

Different Simulation Applications

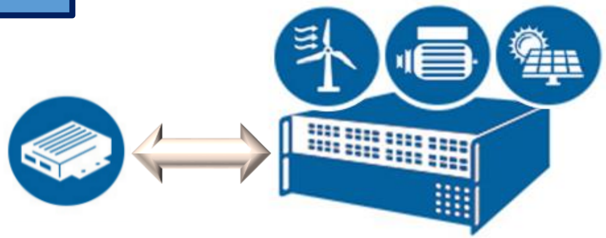
HYPERSIM

MIL or SIL

100% simulation

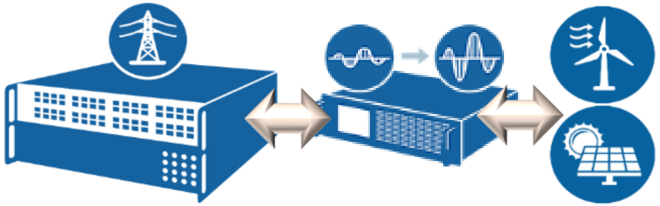
For off-line simulation or real-time simulation

HIL



Real **control**, simulated **plant**

PHIL



Real and simulated **plant**

For real-time simulation only

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MAIN APPLICATIONS

HIL Test in CEPRI and examples for MMC links

HYPERSIM

CEPRI uses HYPERSIM to simulate the backbone of AC and DC power grids in China. The simulated power system consists of 8 HVDC links and 800 buses.

CEPRI has recently expanded their Hardware-in-the-Loop (HIL) capabilities by acquiring 30 OPAL-RT OP5607 I/O expansion chassis. Ten are currently connected to a SCADA system and control replica (ABB).

CEPRI are in the process of adding OPAL-RT's FPGA-based Modular Multilevel Converter (MMC) capabilities to their overall setup

CEPRI
中国电力科学研
CHINA ELECTRIC POWER RESEAR

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HIL Test in CEPRI and examples for MMC links

HYPERSIM

Xiamen (State grid): Bi-pole MMC ±320 kV, 1000MVA HVDC for city power supply

NanAo (China Southern grid): Three-terminal ±200 kV 200 MVA HVDC for renewable energies collection

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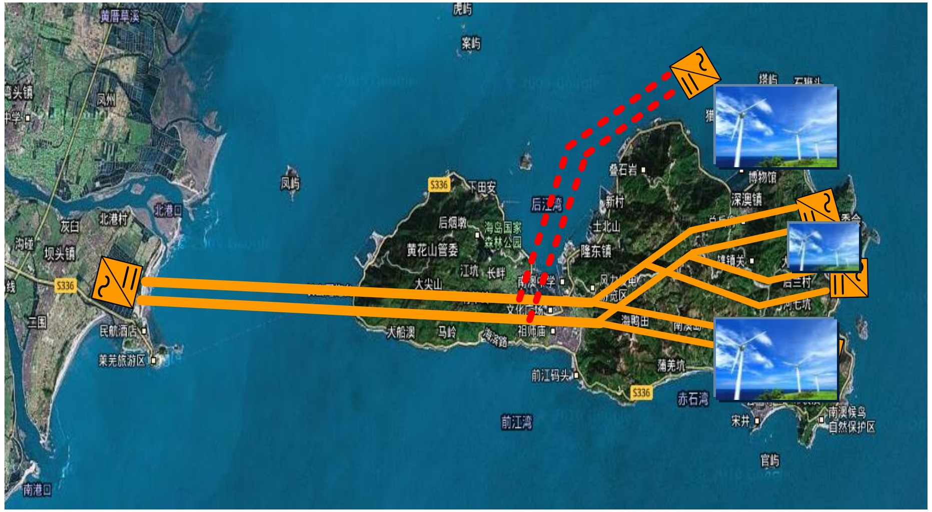
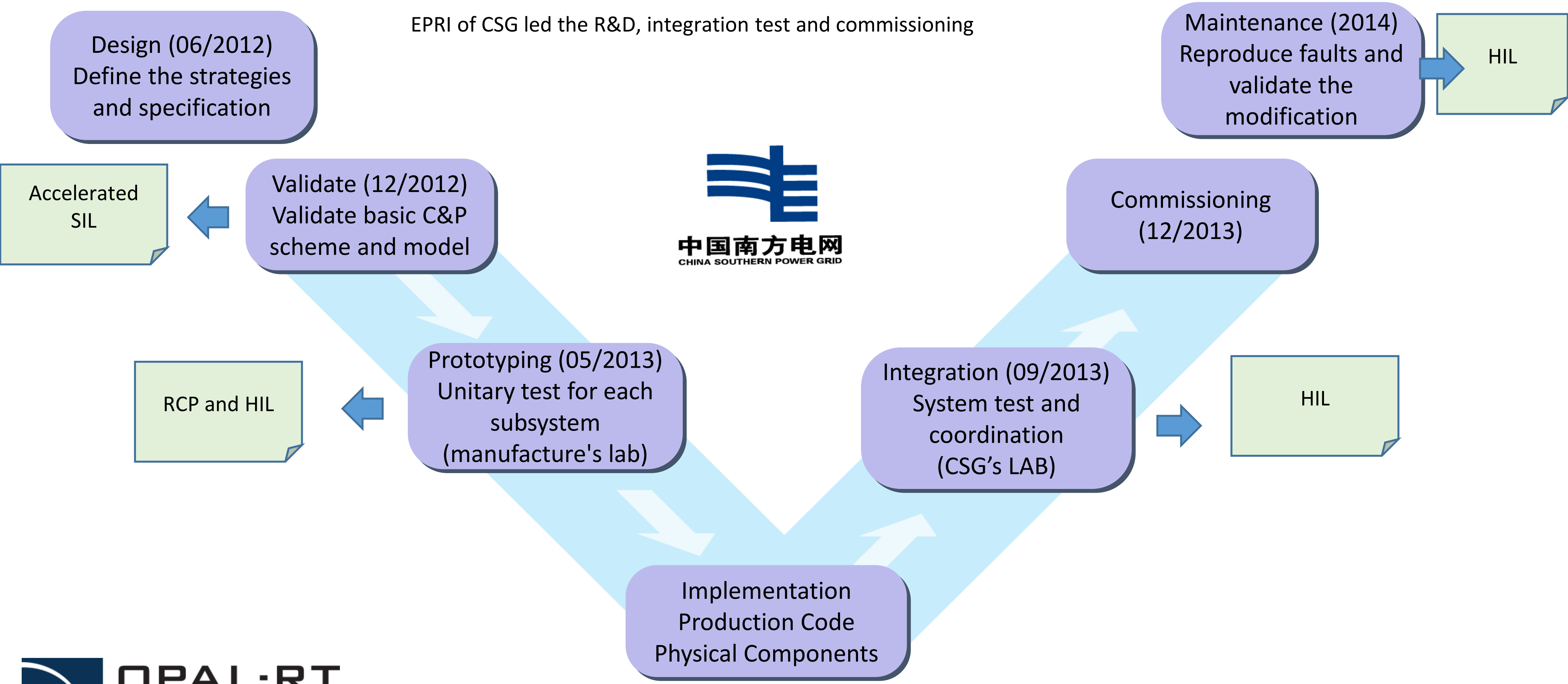
HIL Test in CEPRI and examples for MMC links

HYPERSIM

- The first multi-terminal MMC-HVDC system in the world
- ±160kV/200MW MMC-HVDC Transmission System
- The control and protection system is quite complicated:
  - ✓ Hierarchical structure (multi-layers)
  - ✓ Multiple time scale
  - ✓ More than 10 suppliers
  - ✓ More than 25 cabinets interconnected



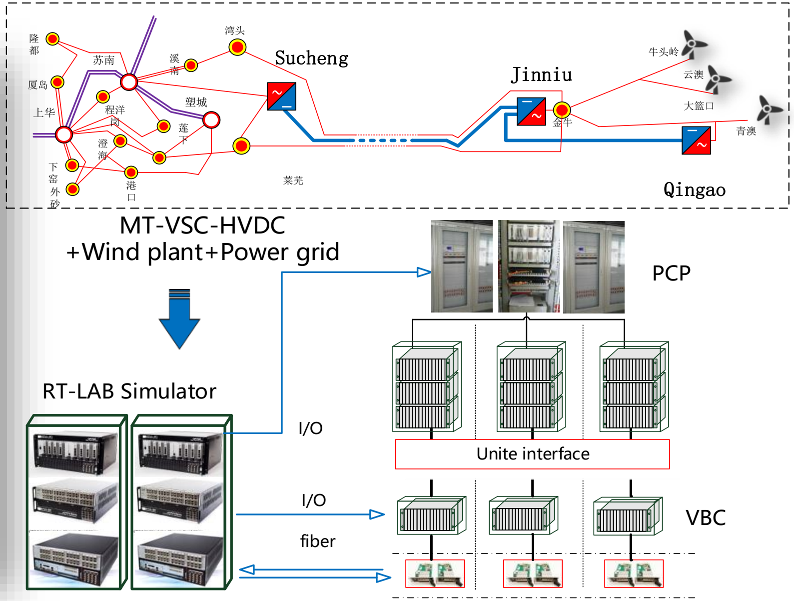
HIL Test in CEPRI and examples for MMC links



HIL Test in CEPRI and examples for MMC links

HYPERSIM

- An OPAL-RT real-time HIL simulator was built to test the static and dynamic performance of the control system
  - Detailed MMC Model (3×1200 sub-modules) was used, and the valve controller is connected to the simulator by fast serial (Aurora) protocol
  - Time step: 250ns for MMC valves and 25μs for wind plant and power grid
  - 561 scenarios have been tested repetitively on the HIL system



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HIL Test in CEPRI and examples for MMC links

Impressive Short Circuit Test!!

The HIL test bench demonstrated very high fidelity and also helps the utility for accident analysis

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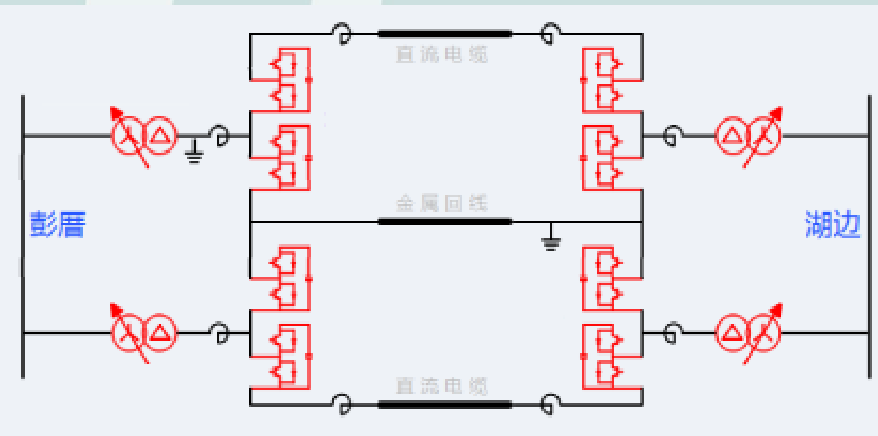
HIL Test in CEPRI and examples for MMC links

HYPERSIM

- The first bi-pole MMC-HVDC system in the world
- ±320kV/1000MW MMC-HVDC Transmission System to supply power to Xiamen (a large city in an island)
- The control and protection system consisting of more than 50 cabinets supplied by two different manufacturers



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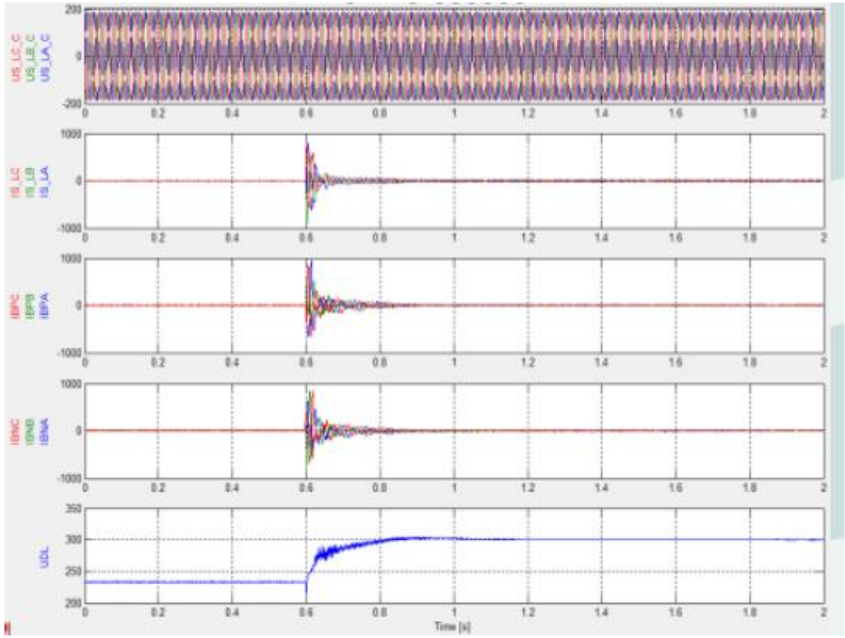
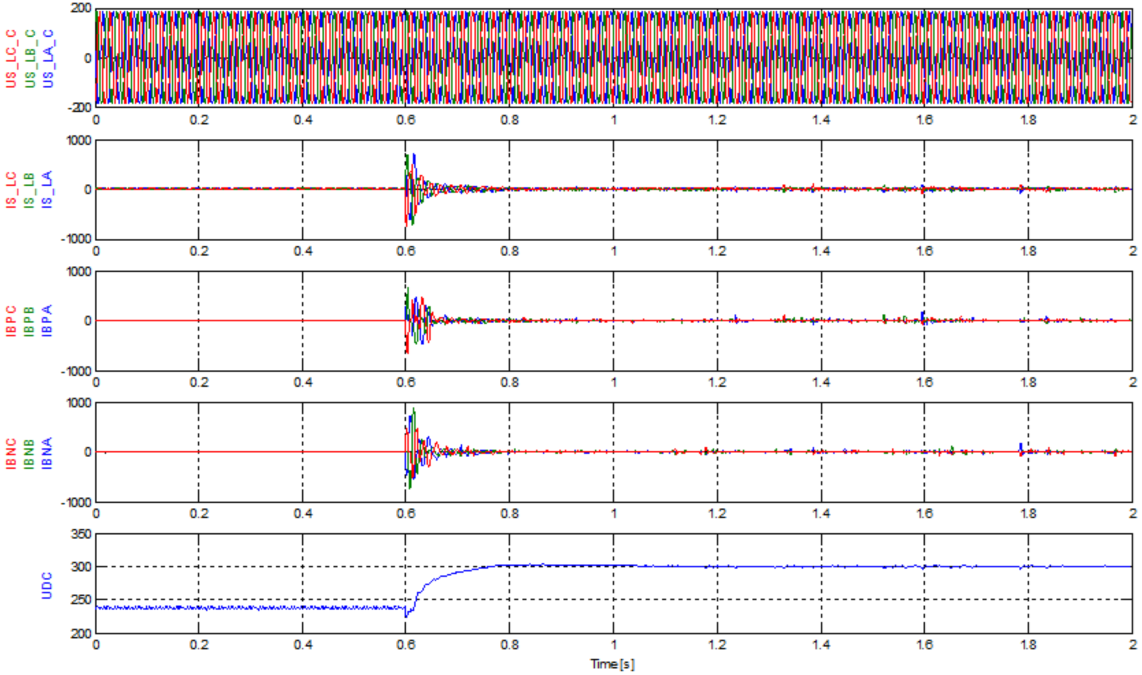
HIL Test in CEPRI and examples for MMC links

HYPERSIM

Test results of deblocking the sending end MMC valve



Combined HIL and SIL Tests



Field Tests

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HVDC Link France-Spain validation

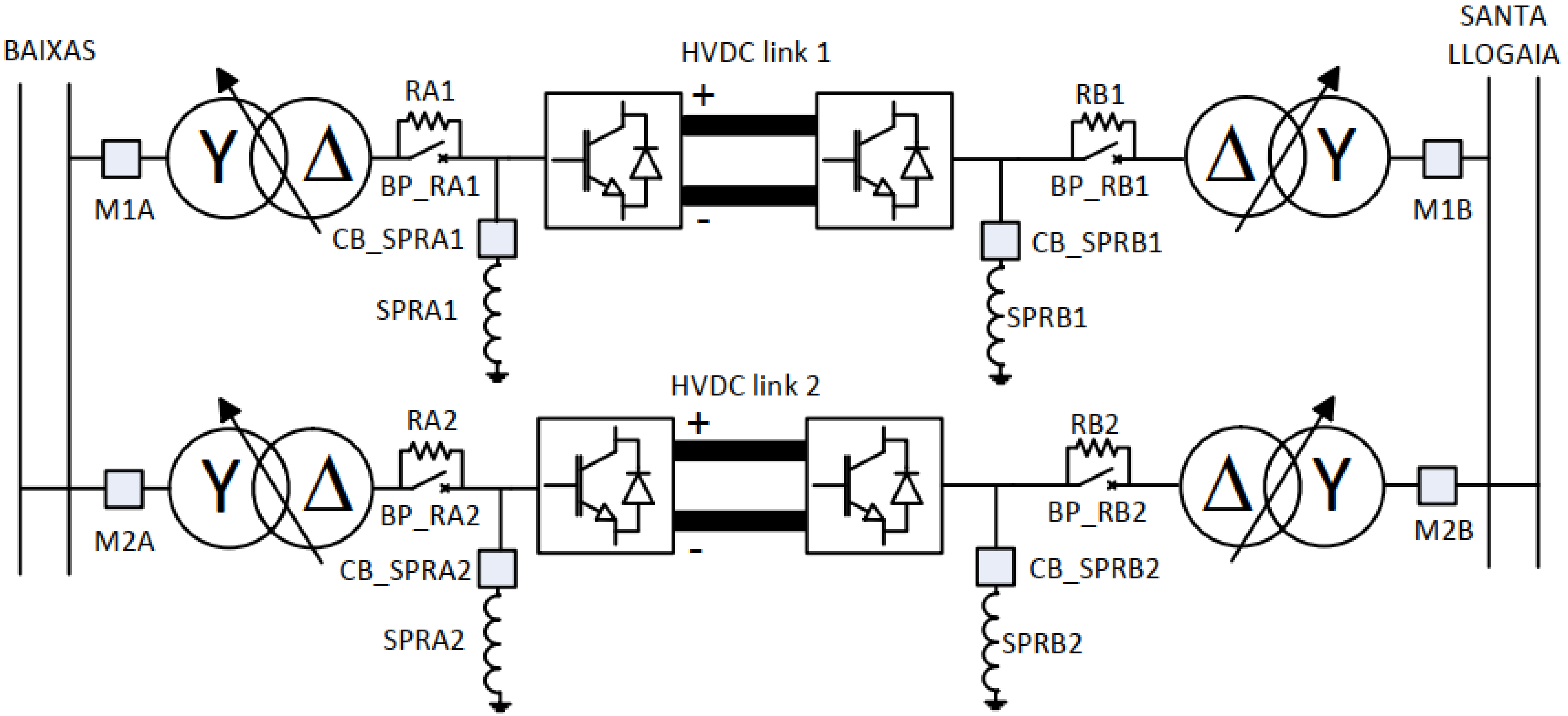
HYPERSIM

The underground electricity interconnection between Baixas (France) and Santa Llogaia (Spain) is a globally pioneering project.

This project allowed the interchange capacity to be doubled from 1,400 to 2,800 megawatts (MW), while also increasing the security, stability and quality of electricity supply in the two countries as well as in the rest of Europe.

HVDC Link France-Spain validation

HYPERSIM



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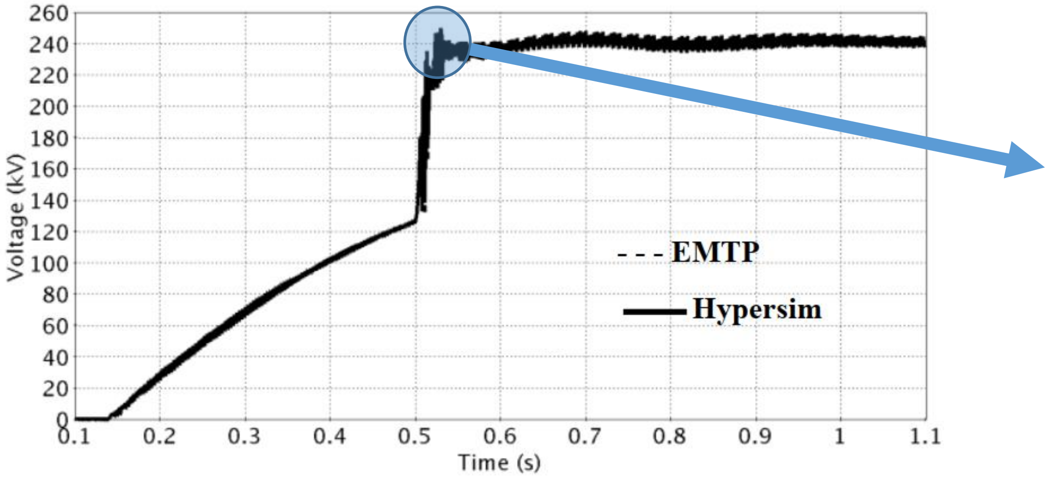
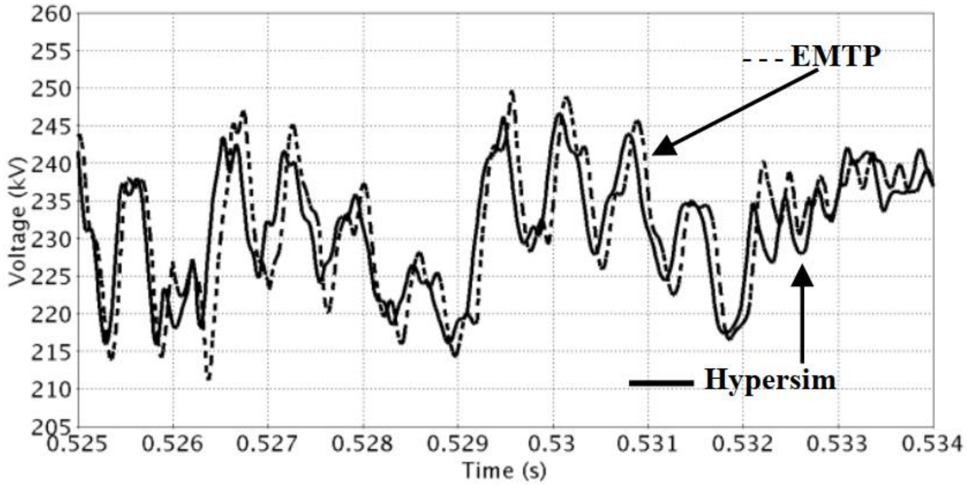
HVDC Link France-Spain validation

HYPERSIM



Positive pole voltage at cable terminal during starting sequence



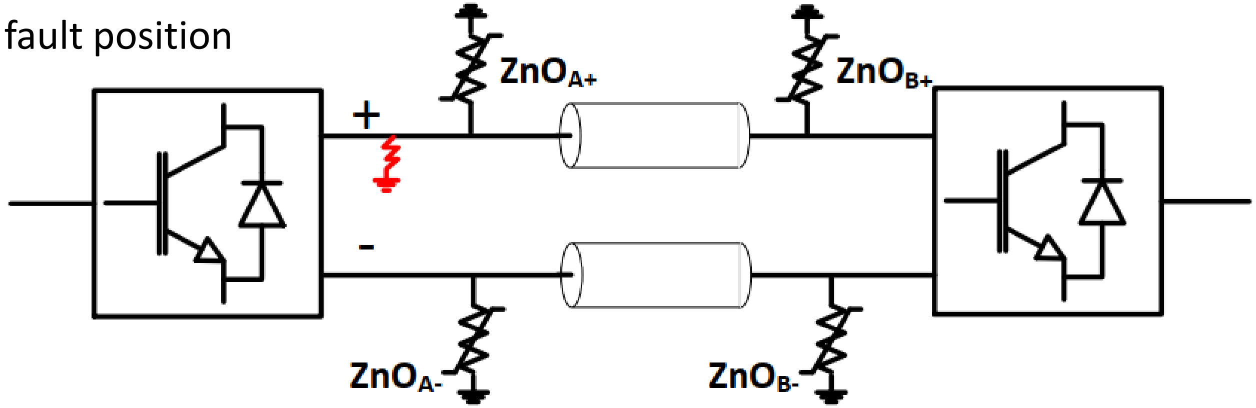
Zoom on positive pole voltage at cable terminals during starting sequence

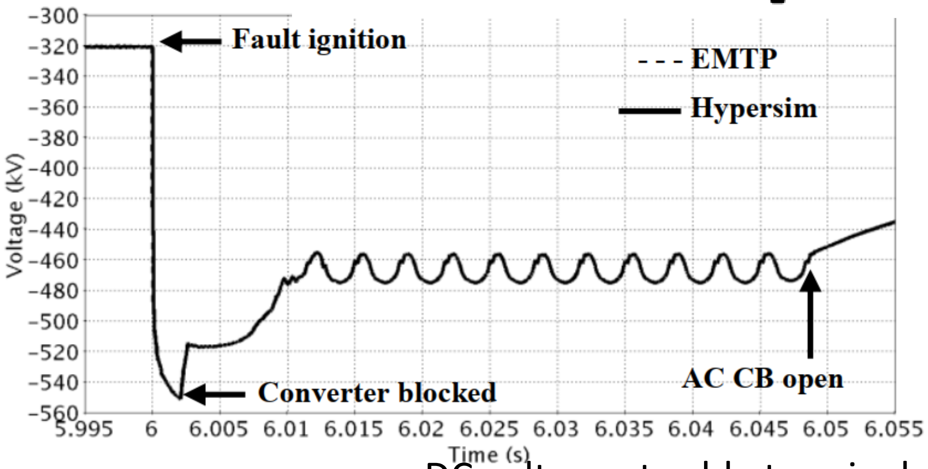
OPAL-RT TECHNOLOGIES

HVDC Link France-Spain validation

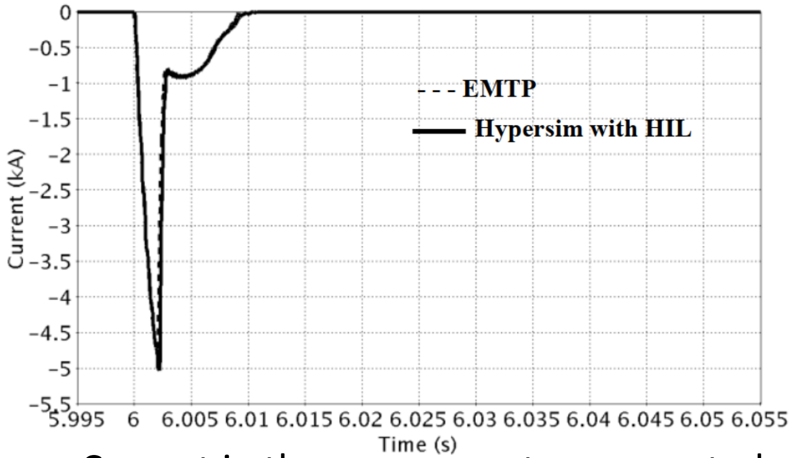
HYPERSIM

Pole-to-ground fault position





DC voltage at cable terminals (healthy pole) during pole-to-ground fault



Current in the surge arrester connected to the healthy pole

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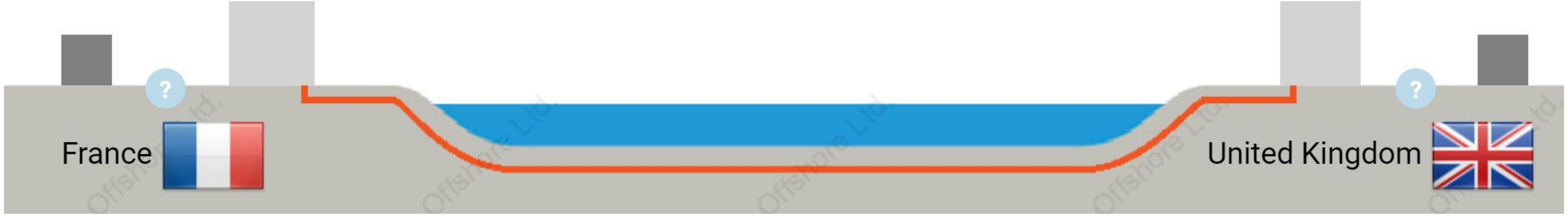
HVDC Link France-UK validation

HYPERSIM



2000 MW +/- 270kV

45 km Submarine and 26 km Underground HVDC Line

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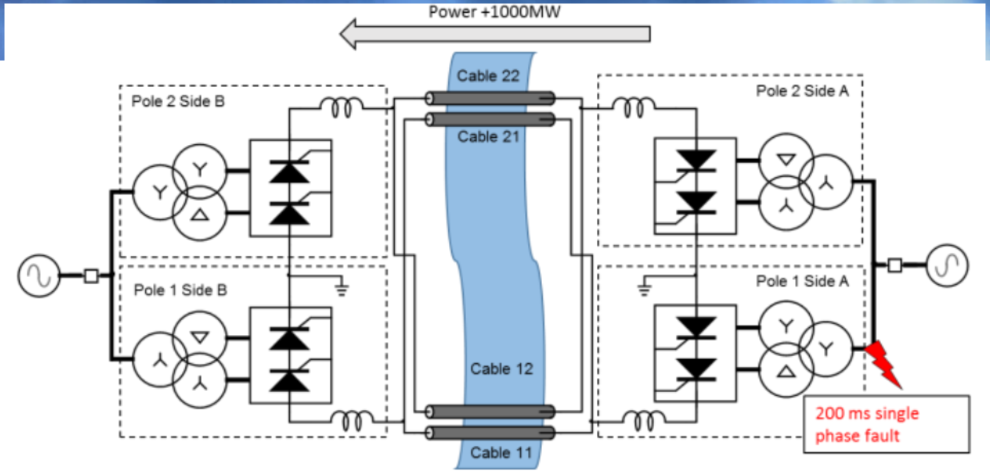
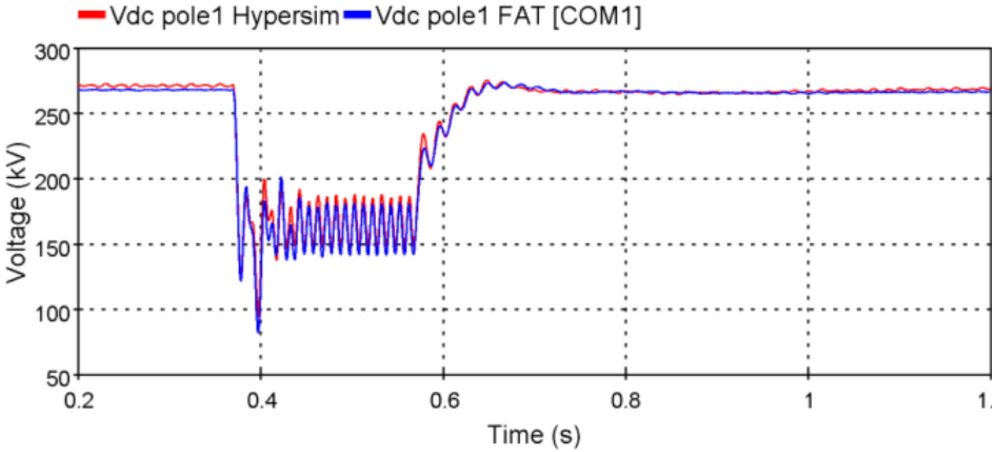
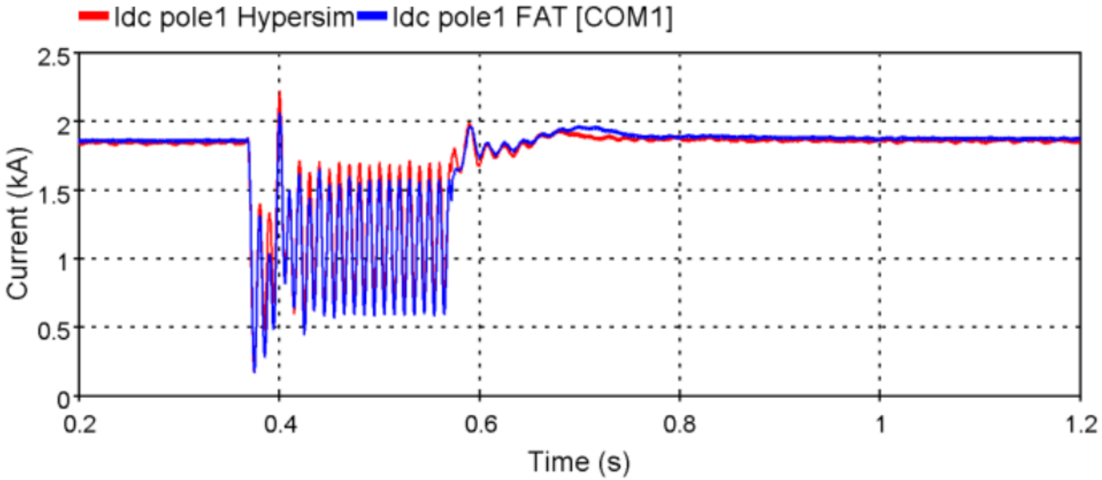
HVDC Link France-UK validation

HYPERSIM





Comparison of DC line voltage at pole 1 for AC single phase short duration fault test



Comparison of DC line current at pole 1 for AC single phase short duration fault test

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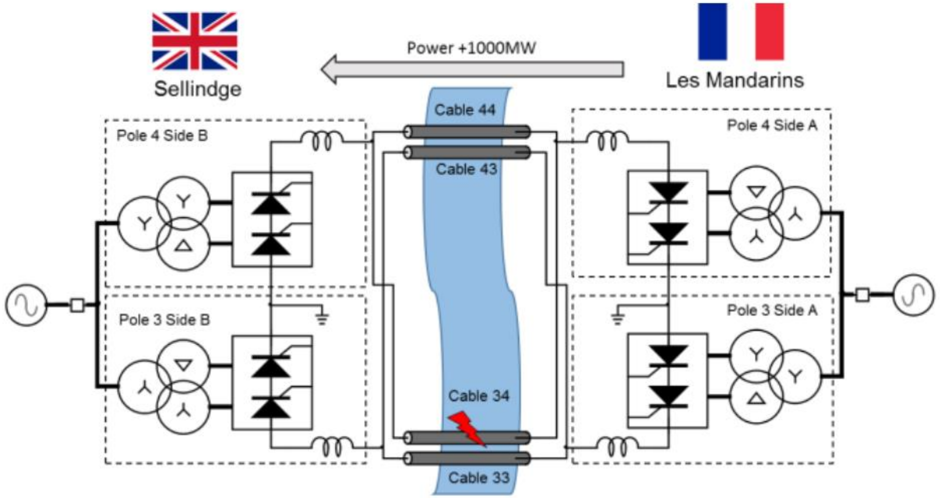
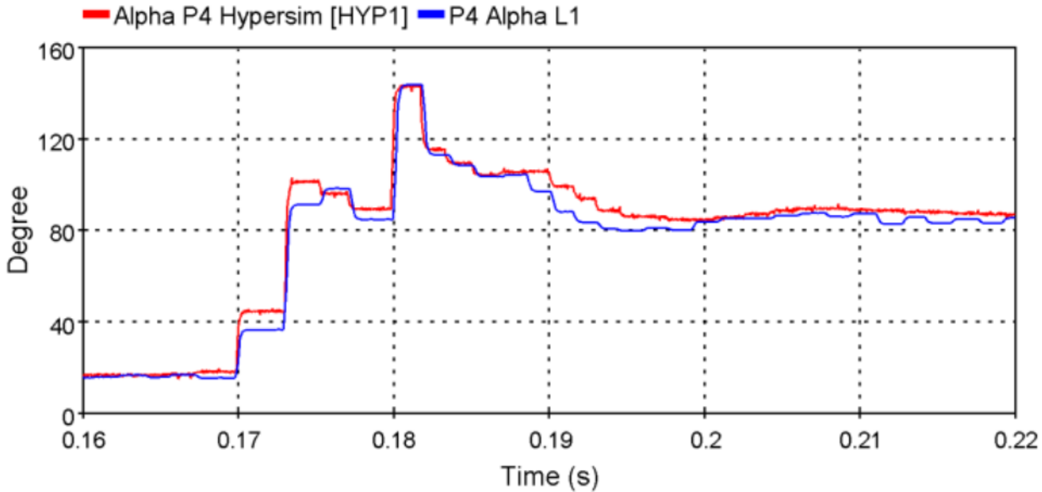
HVDC Link France-UK validation

Pole-to-ground fault position

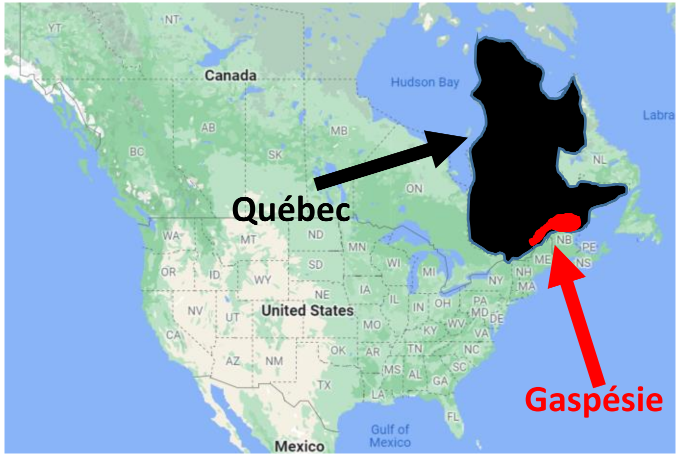


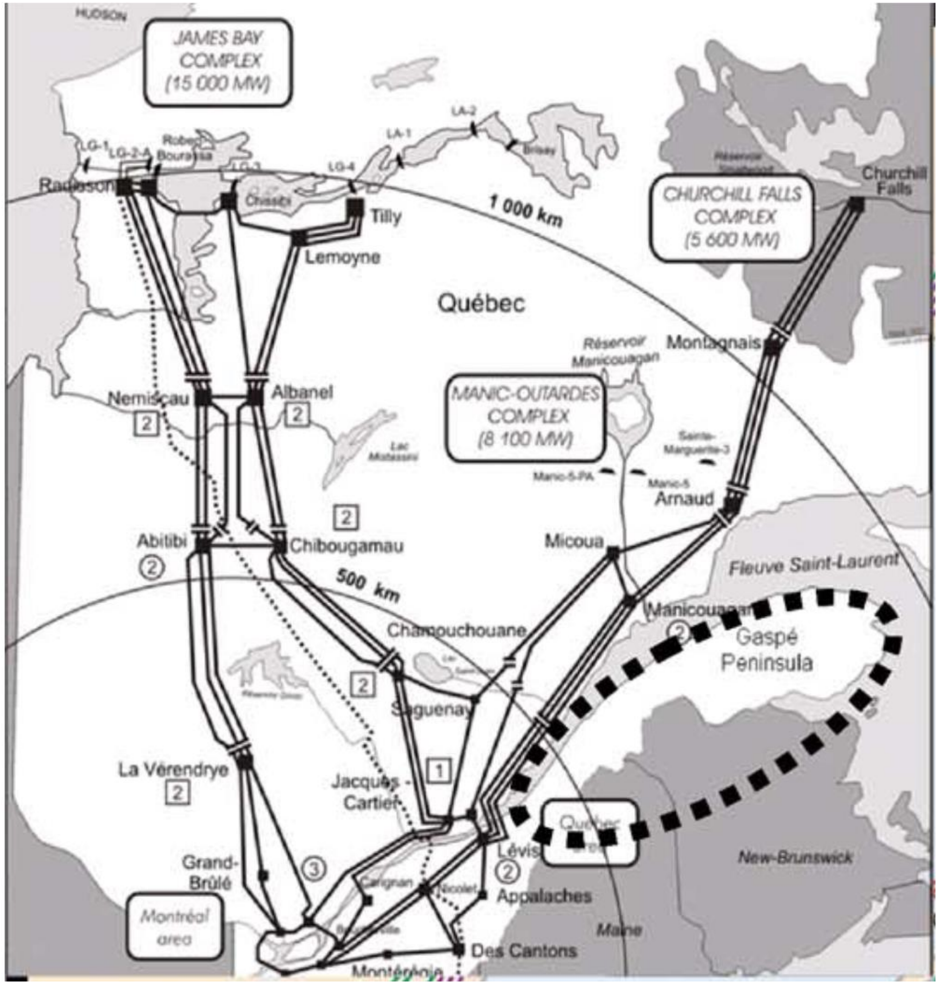


Comparison of alpha angle at pole 4 during the cable fault

Wind Power Plant Integration

HYPERSIM





Difficulties and Complexity

- Very Long Transmission Lines
- Low Short Circuit Ratio
- Big temperature variations

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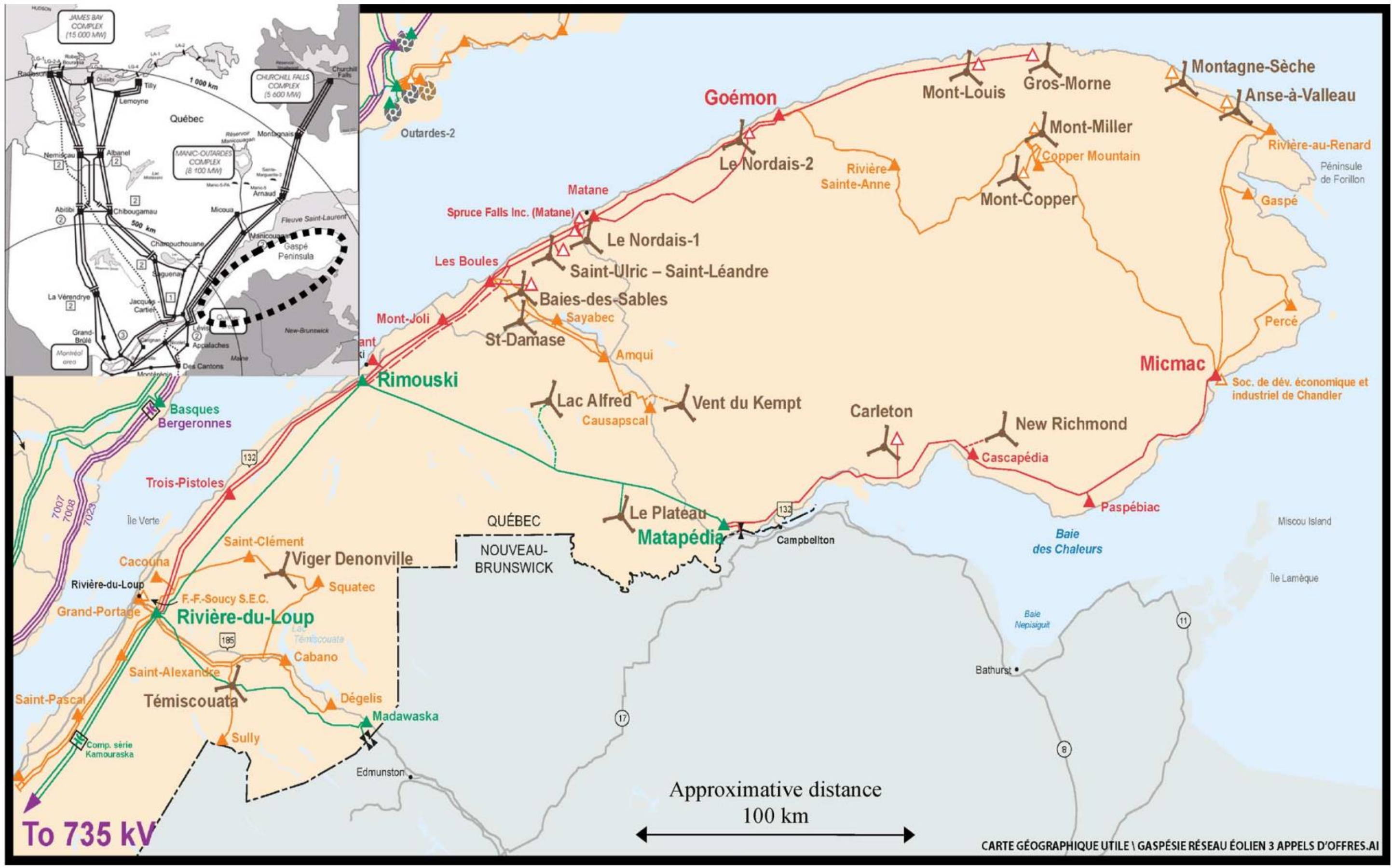
Wind Power Plant Integration

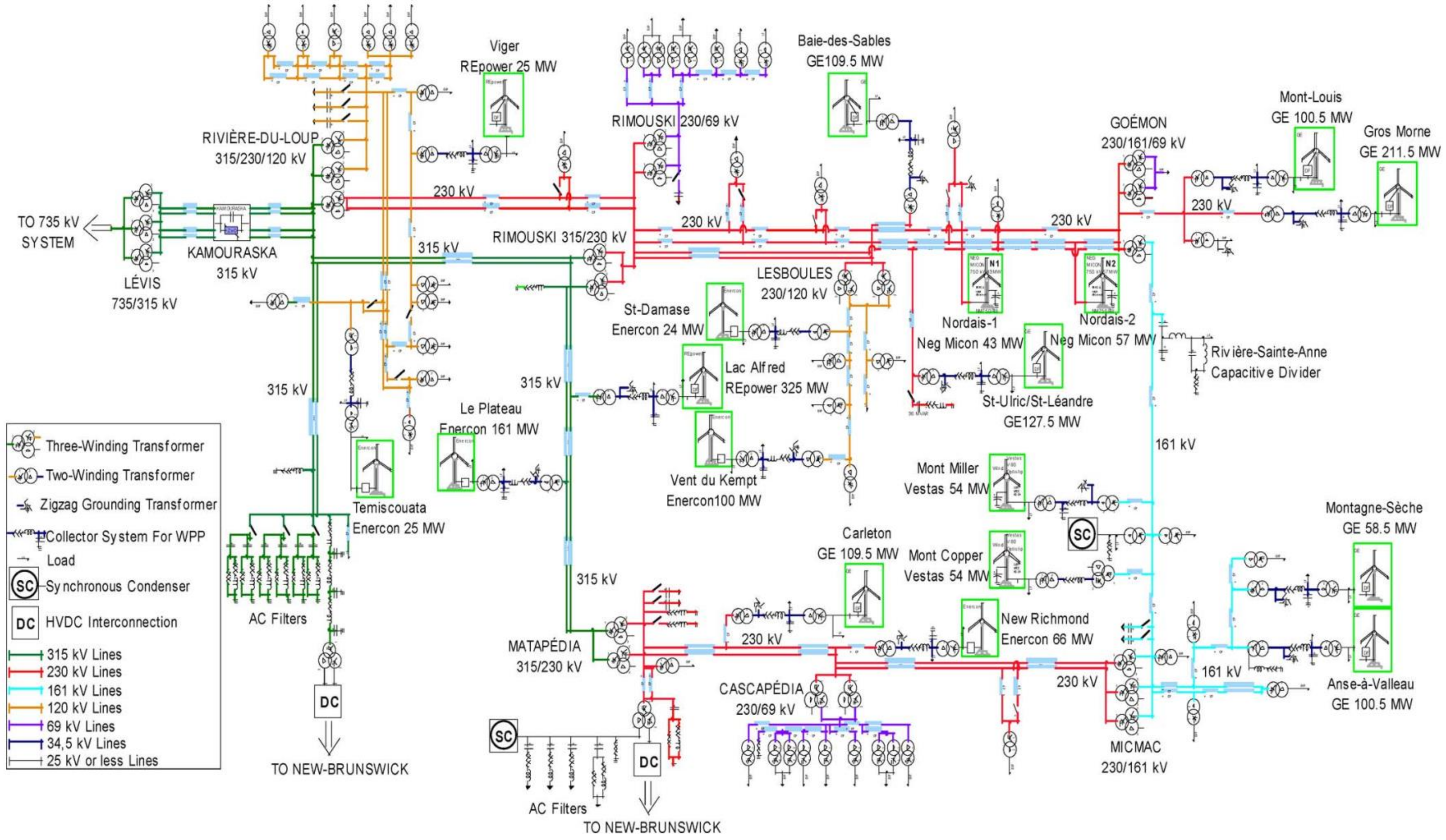
Main characteristics of the Gaspésie system

- Full transmission system 315, 230, 161, 120, and 69 kV
- 4 series-compensated 315-kV lines (60% compensated)
- 68 substations (18 are WPPs)
- 300+ busbars
- 130 power transformers with surge arresters
- 2 HVDC interconnections with New Brunswick (2 350 MW)
- 4 synchronous condensers
- load range 300 ->1200 MW (summer) -> (winter)



Total 1750 MW from wind generation

Wind Power Plant Integration



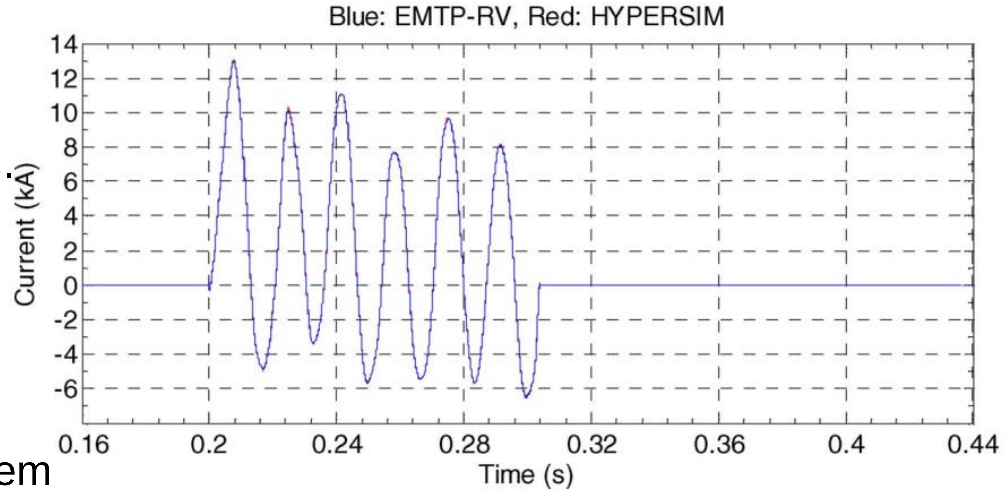
Wind Power Plant Integration

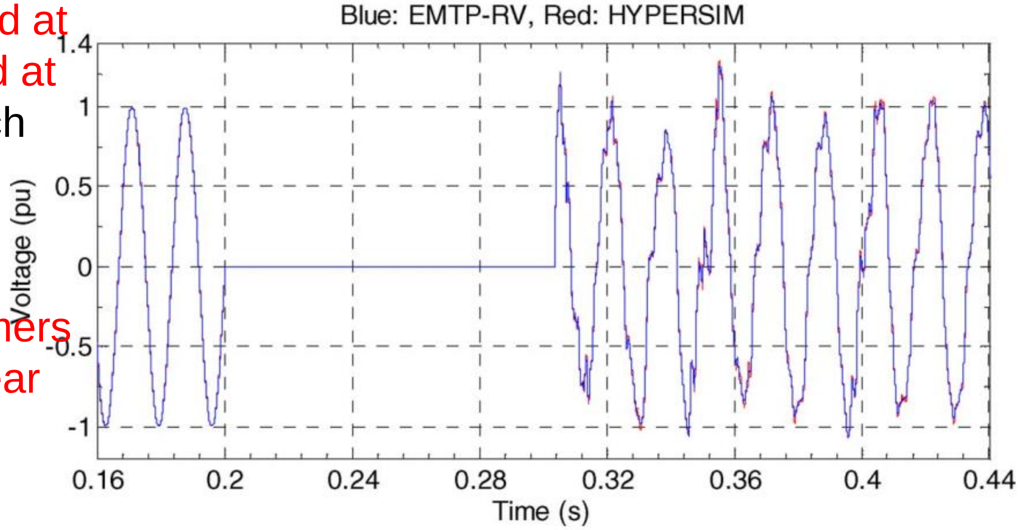
The validation procedure performed on the Gaspésie transmission system consists in simulating more than 15 faults at various buses with multiple timings and conditions.

The conformity of the Hypersim results with those of EMTP-RV for each simulation confirms the validity of the Hypersim implementation

An example that illustrates this good conformity is the system response to a six-cycle three phase-to-ground fault applied at a 230-kV bus. The fault is applied at t=0.2s and eliminated at t=0.3 s. See Phase A current and voltage waveforms which are identical between EMTP-RV and HYPERSIM.

As shown in these figures, the comparisons of the results are excellent despite a high number of saturable transformers and surge arresters. These devices exhibit severe nonlinear characteristics





Different Simulation Applications

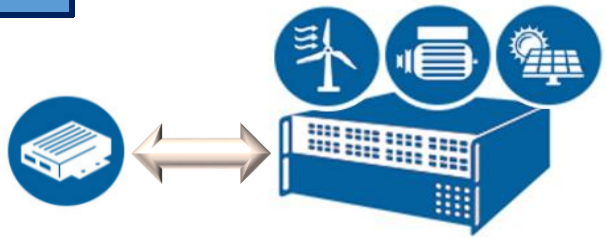
HYPERSIM

MIL or SIL

100% simulation

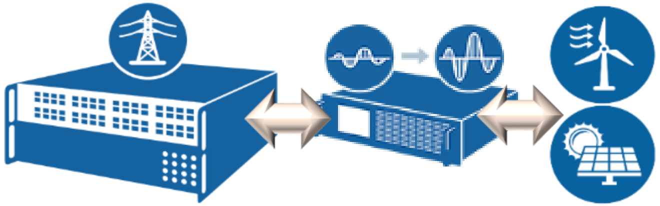
For off-line simulation or real-time simulation

HIL



Real **control**, simulated **plant**

PHIL



Real and simulated **plant**

For real-time simulation only

PHIL Testing for Island Frequency Improvement

HYPERSIM

Island Grids :

- **Weak Grid**
- **One grid operator (TSO+DSO)**
- **Fossil fuel power plant**
- **Integration of renewable energy distributed generation**

Restriction factor to the integration of renewable energy generation

More and more of renewable energy

Reduction of the power system inertia

Primary reserve allocation problem

Fossil fuel Power Plant used on a non-optimal point => Pollution increase

L2EP Laboratoire d'électrotechnique et d'électronique de puissance de Lille

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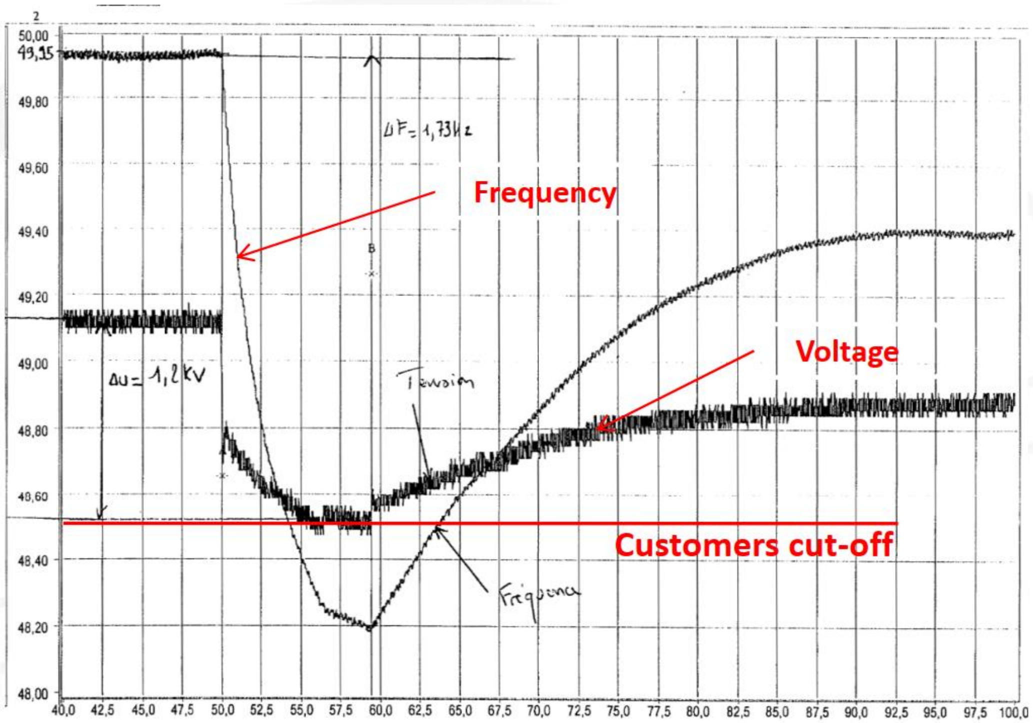
One solution : Connect DESS to the island grid

PHIL Testing for Island Frequency Improvement



Frequency response in Guadeloupe Grid after a power plant fault

Main Goal

To Test using PHIL application the advantage to connect supercapacitor device to island grid

Application case : Medium voltage network of Guadeloupe island (63kV)

PHIL Testing for Island Frequency Improvement

HYPERSIM

- ✓ Coal Power plant fault producing 22.7MW of a total consumption of 140MW
- ✓ Supercapacitor storage device virtual insertion in Sainte Anne substation

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Storage objectives : **Peak frequency and dynamic transient settling time reduction**

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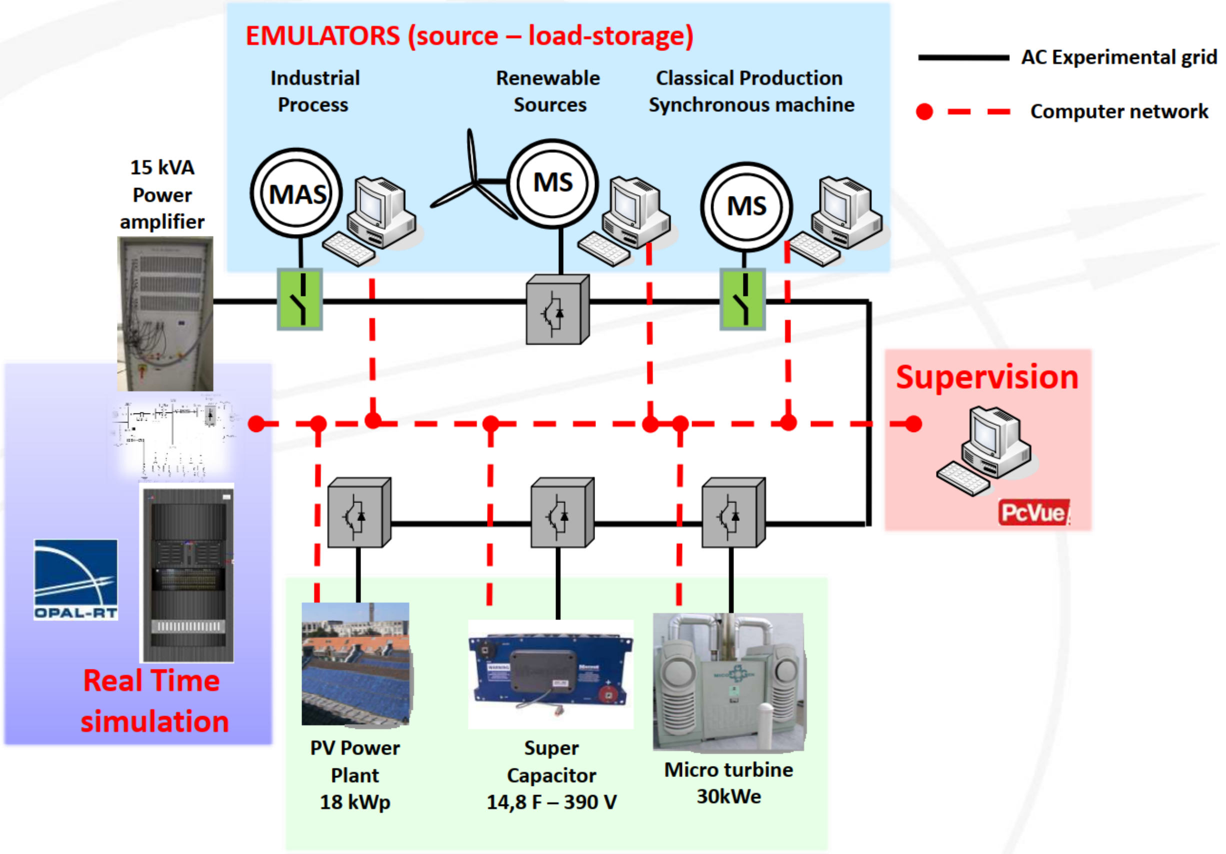
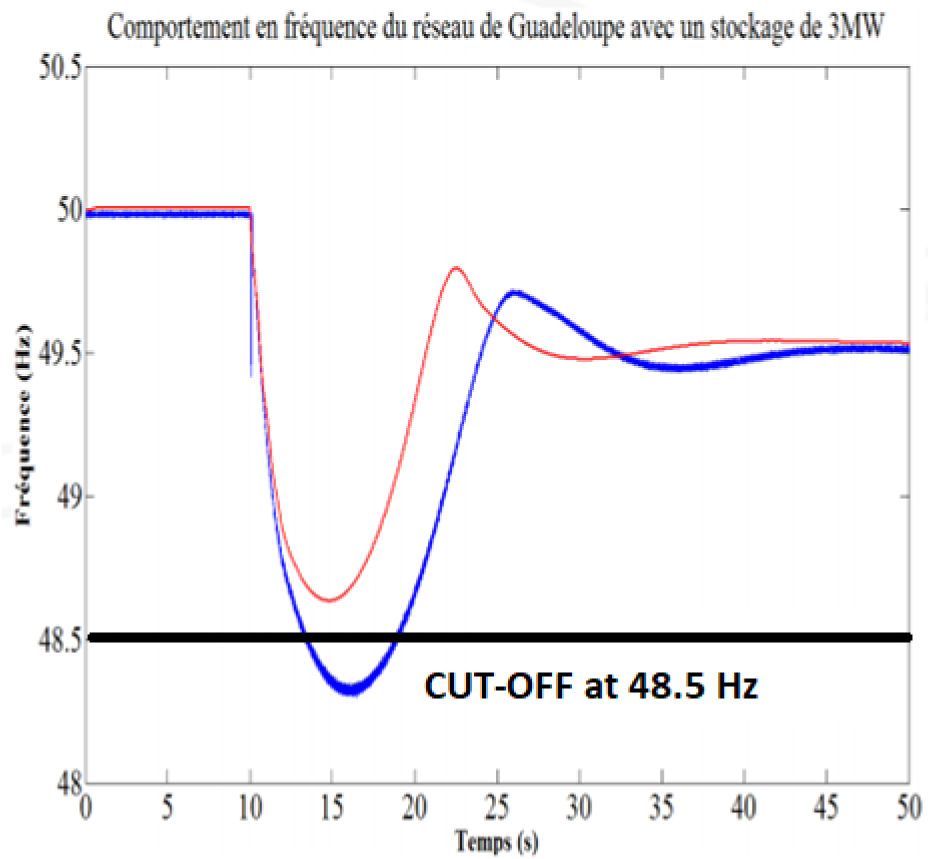
PHIL Testing for Island Frequency Improvement

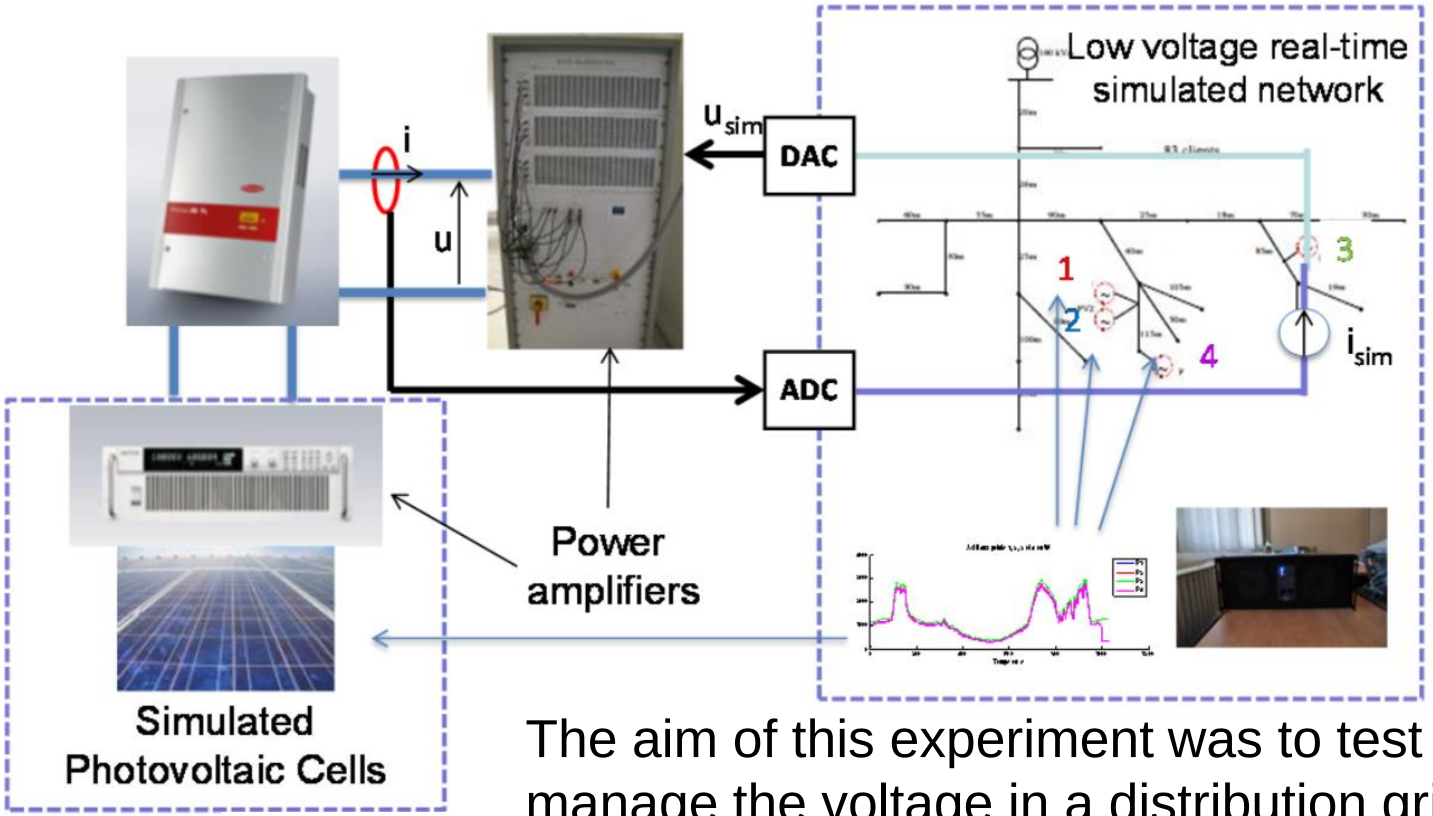


PHIL Testing for Island Frequency Improvement



PHIL Testing for PV Inverter Reactive Power control

HYPERSIM



The aim of this experiment was to test capability to manage the voltage in a distribution grid.

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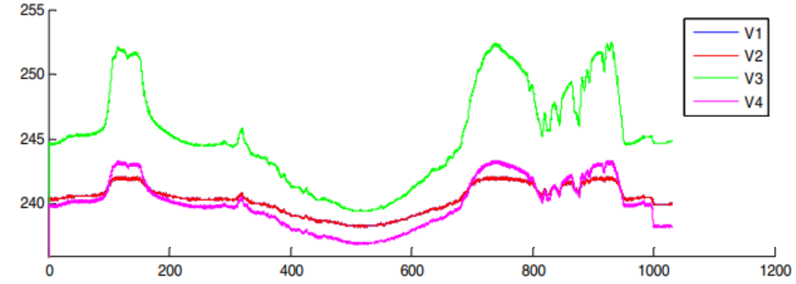
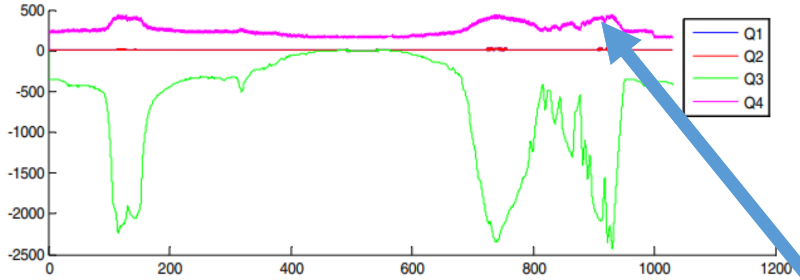
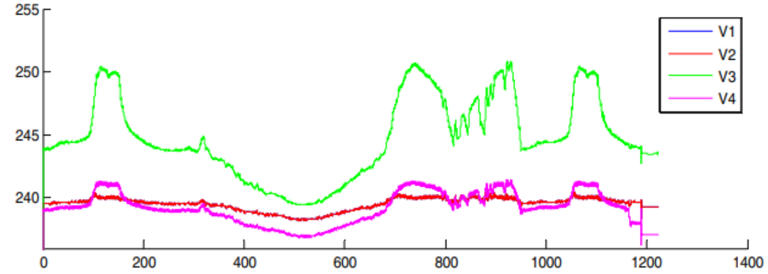
PHIL Testing for PV Inverter Reactive Power control



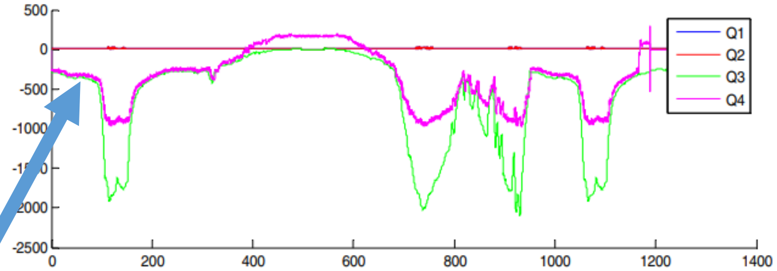
a) Voltage in point 1,2,3,4



b) Reactive power in point 1,2,3,4



a) Voltage in point 1,2,3,4



b) Reactive power in point 1,2,3,4

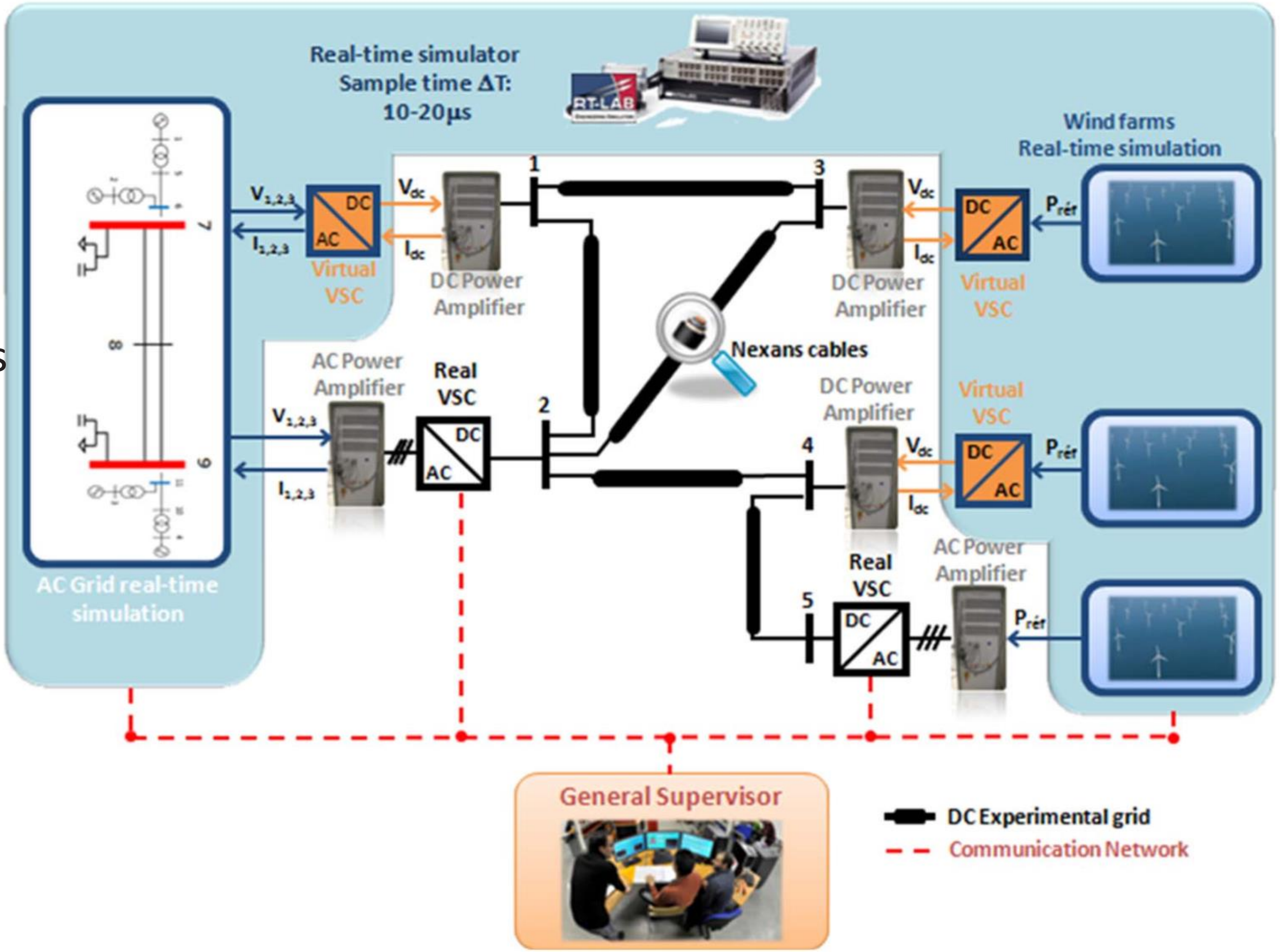
As expected, the 2nd inverter adjusts its reactive power to the voltage which induces a slight decrease on the voltage.

PHIL Testing for DC grid fault management

HYPERSIM

Rte
Réseau de transport d'électricité
L2EP
Laboratoire d'électrotechnique et d'électronique de puissance de Lille
RSE
Ricerca Sistema Energetico

And many other groups



OPAL-RT TECHNOLOGIES

PHIL Testing for DC grid fault management

HYPERSIM

Réseau de transport d'électricité

Laboratoire d'électrotechnique et d'électronique de puissance de Lille

RSE Ricerca Sistema Energetico

And many other groups

- A PHIL setup has been developed within Twenties European project to test the fault detection and management of the power in a 5 terminal DC grid

- Several types of coordinated control strategies between the wind farm side Voltage Source Converters (VSCs) and the grid side VSCs have been tested on the proposed PHIL system. The goal is to test the remote control algorithm for its optimization and safe operation of the whole system in normal operation with different wind profiles at each stations.

- Tests results show that the control strategy with coordination between different substations greatly reduces the voltage variations of the grid.

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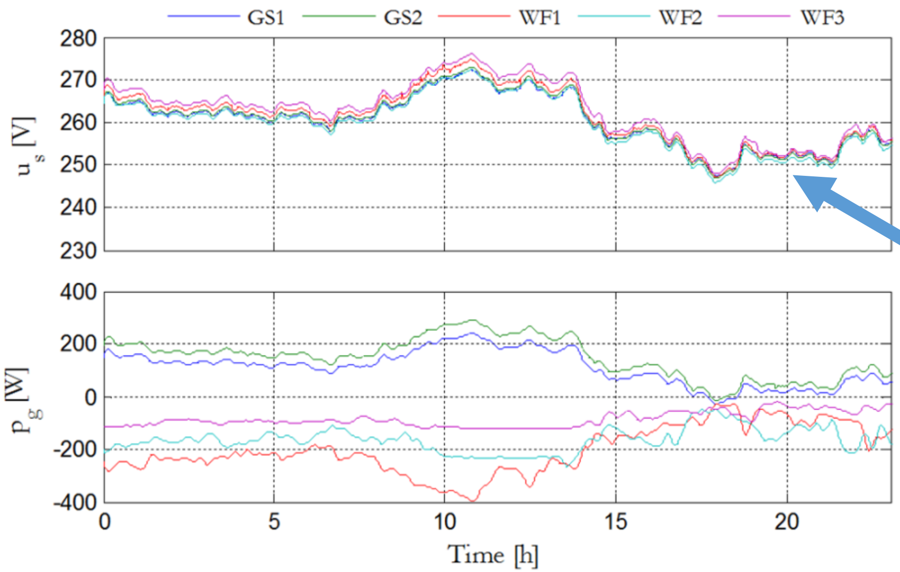
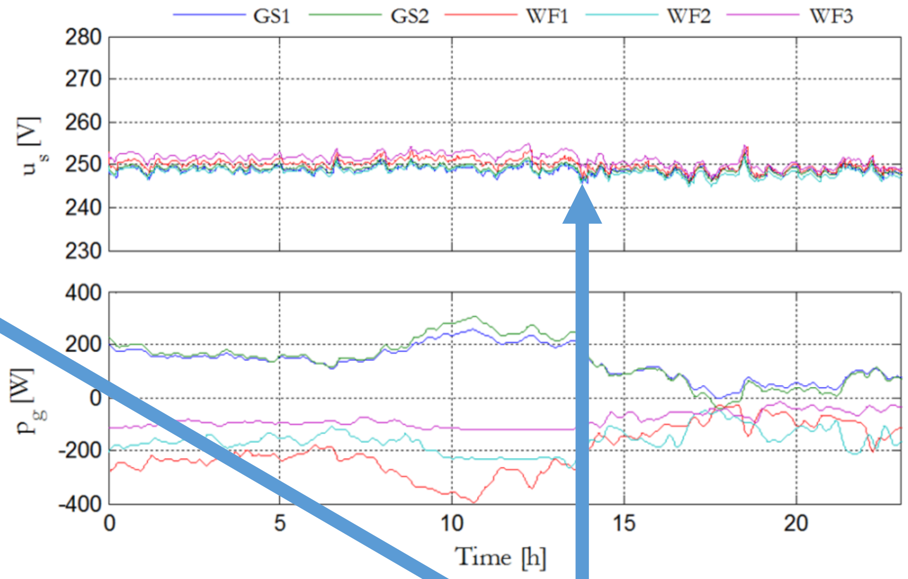
PHIL Testing for DC grid fault management

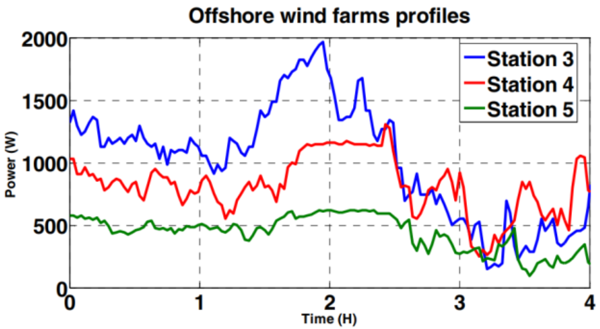
HYPERSIM



a) Without coordination



b) With coordination



The control strategy with coordination between different substations greatly reduces the voltage variations of the grid

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Dynamic Voltage Restorer (DVR)

HYPERSIM

- New paper factory to be built if utility can guarantee Plant voltage stability
  - Factory must operate if 2 phases faults occurs
- Paper mills typically use DC Motor with Direct Drives (no gearbox)
- Normal Operation is slow speed (usually 100-500 rpm)

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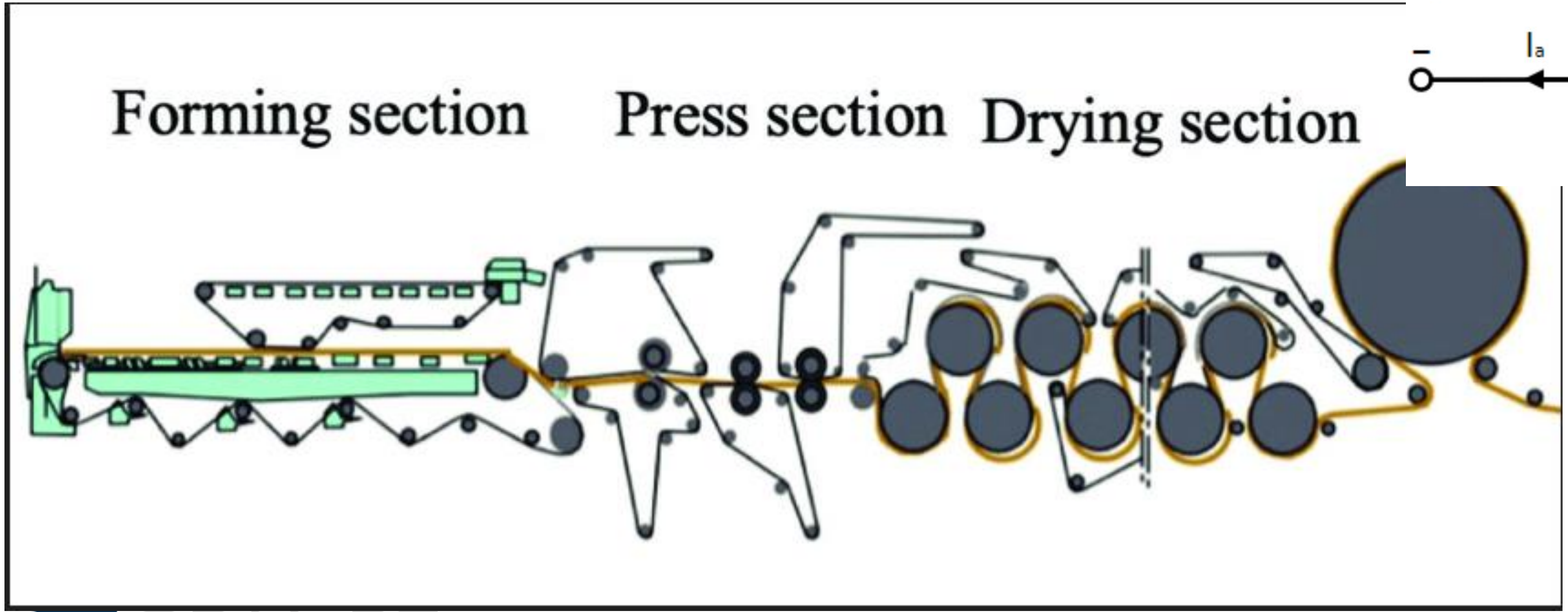
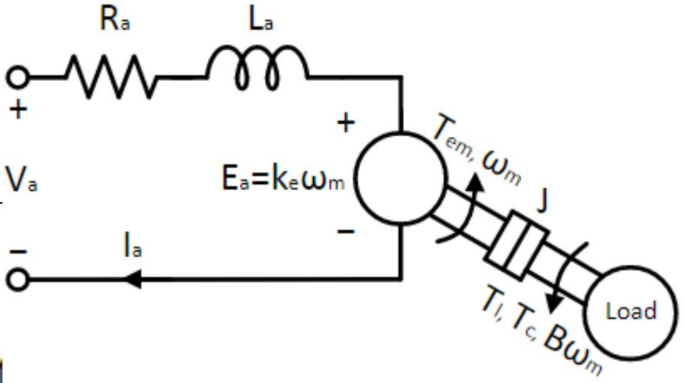
Dynamic Voltage Restorer (DVR)

- Any major voltage variations causes motors speed to change abruptly
- Those speed variations ultimately break the paper
- Complete restarting process cost time and money



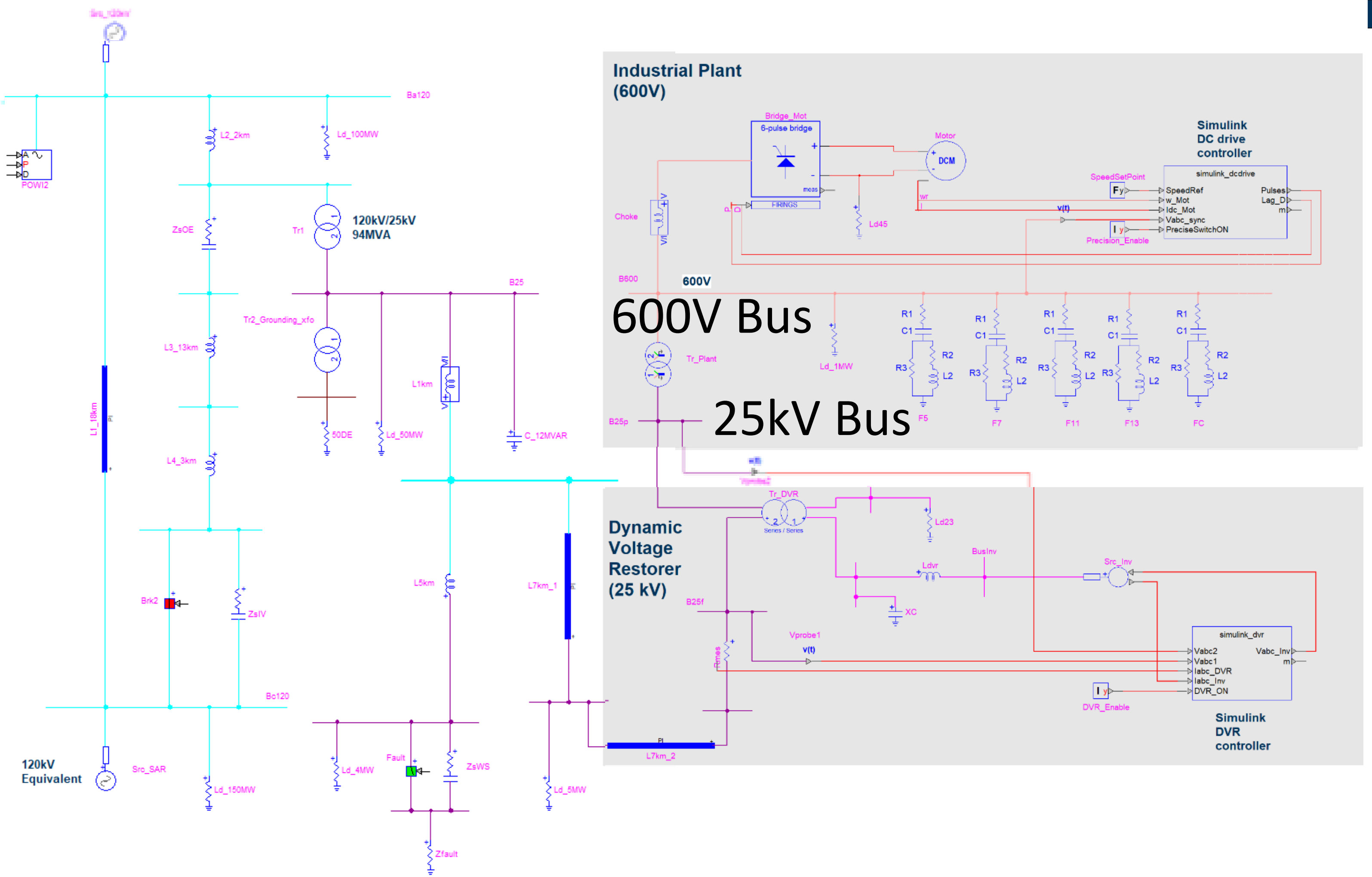


Dynamic Voltage Restorer (DVR)

HYPERSIM

Work Scope

- Make Model includes
  - AC Grid
  - Industrial Plant
  - DVR
- Perform 2-phase fault with-without DVR
- Submit specifications to manufacturer
- Test HIL before on-site installation



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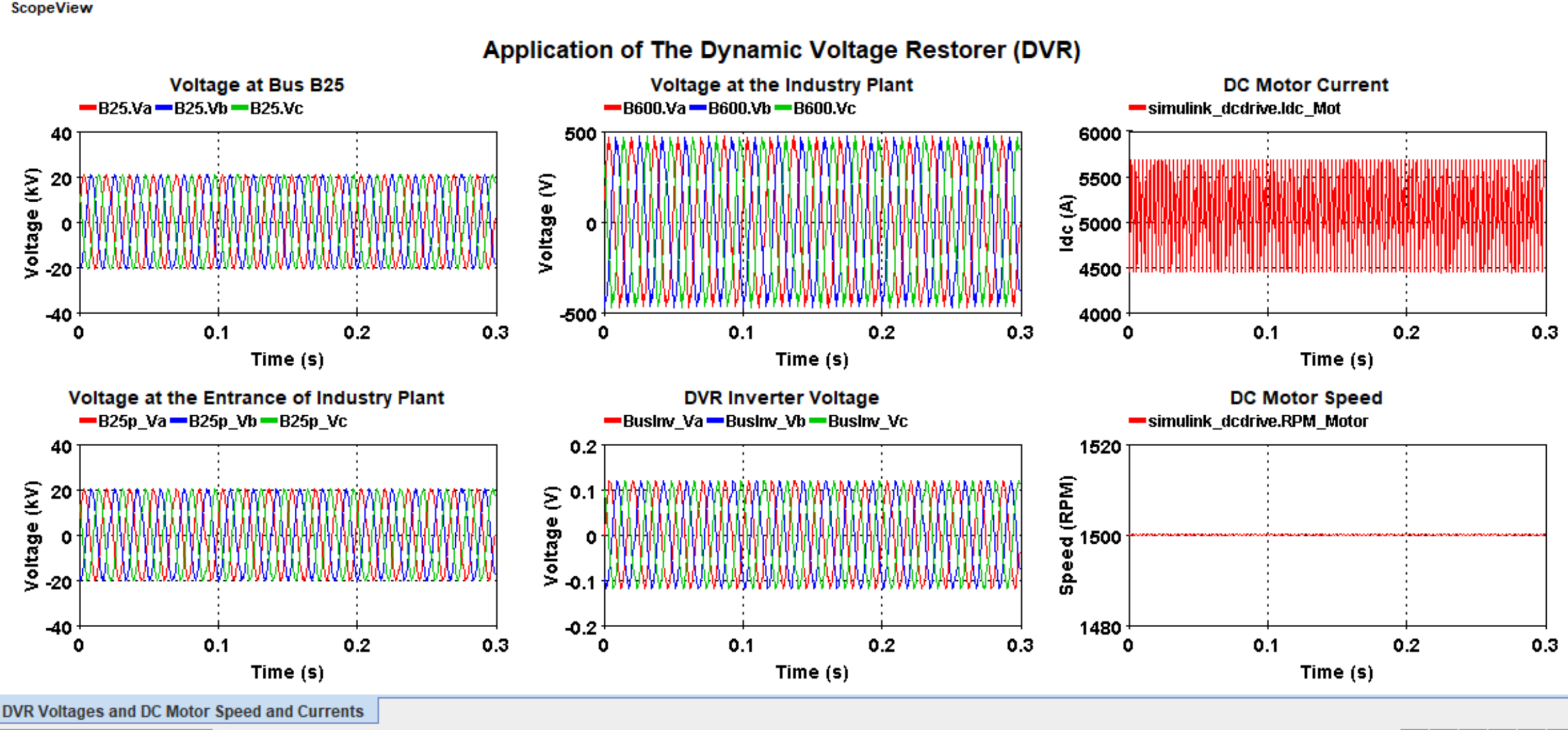
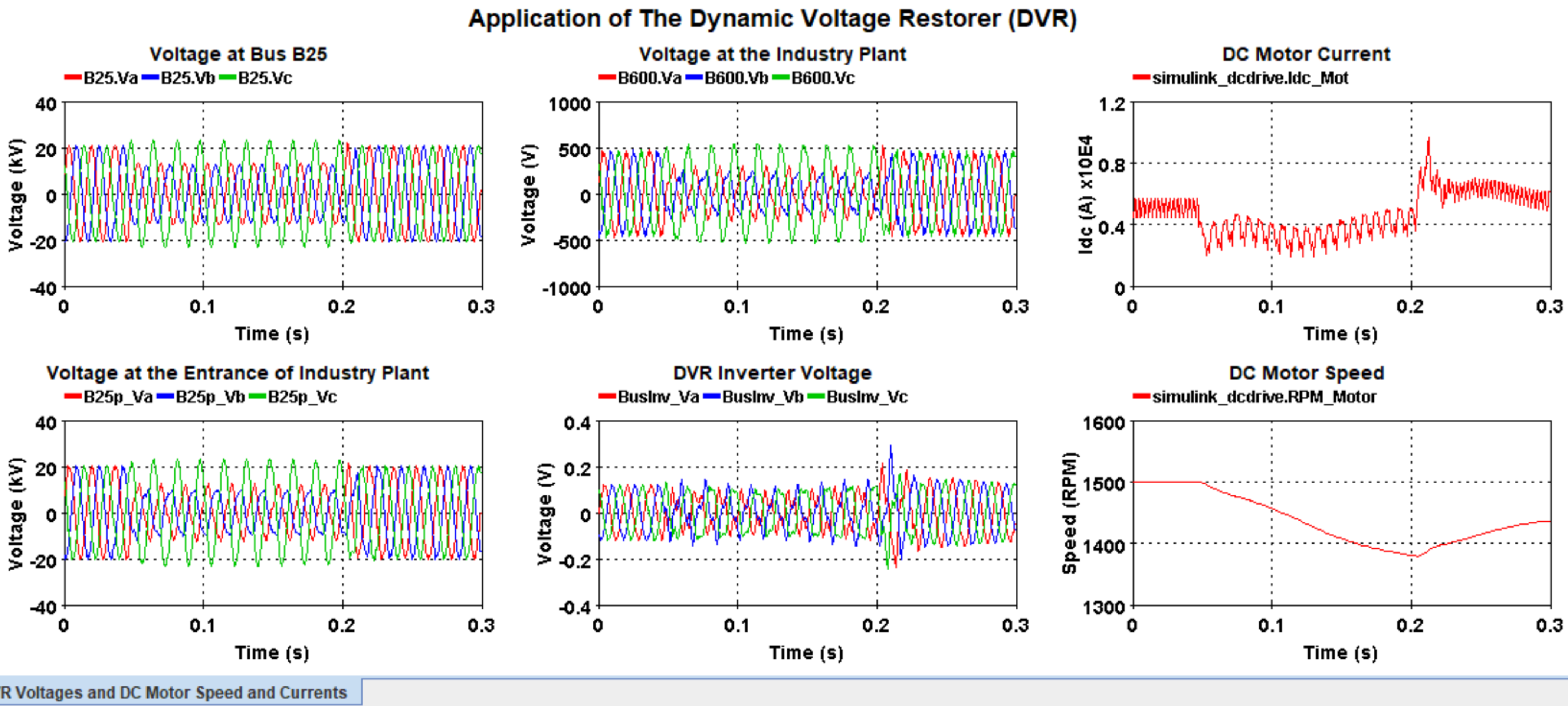
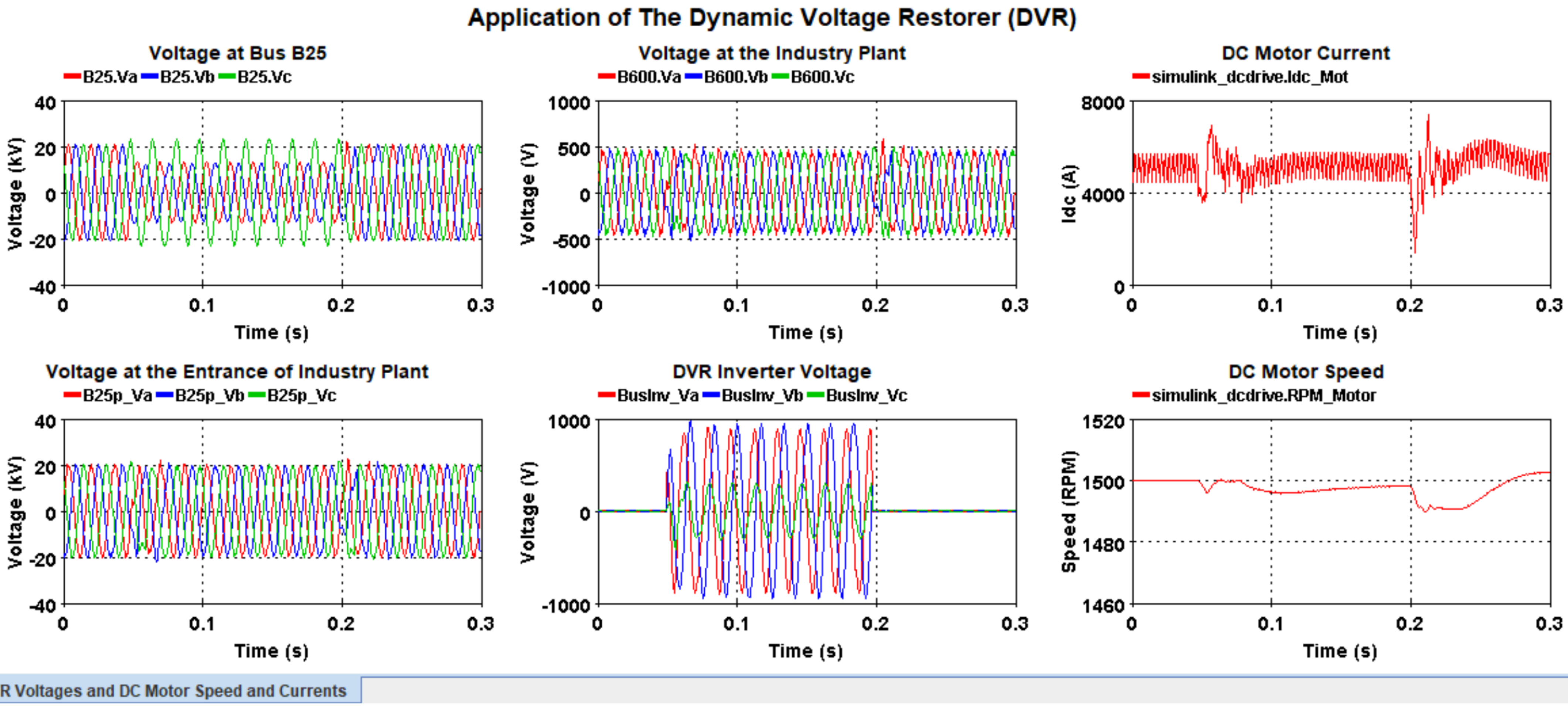
Dynamic Voltage Restorer (DVR)



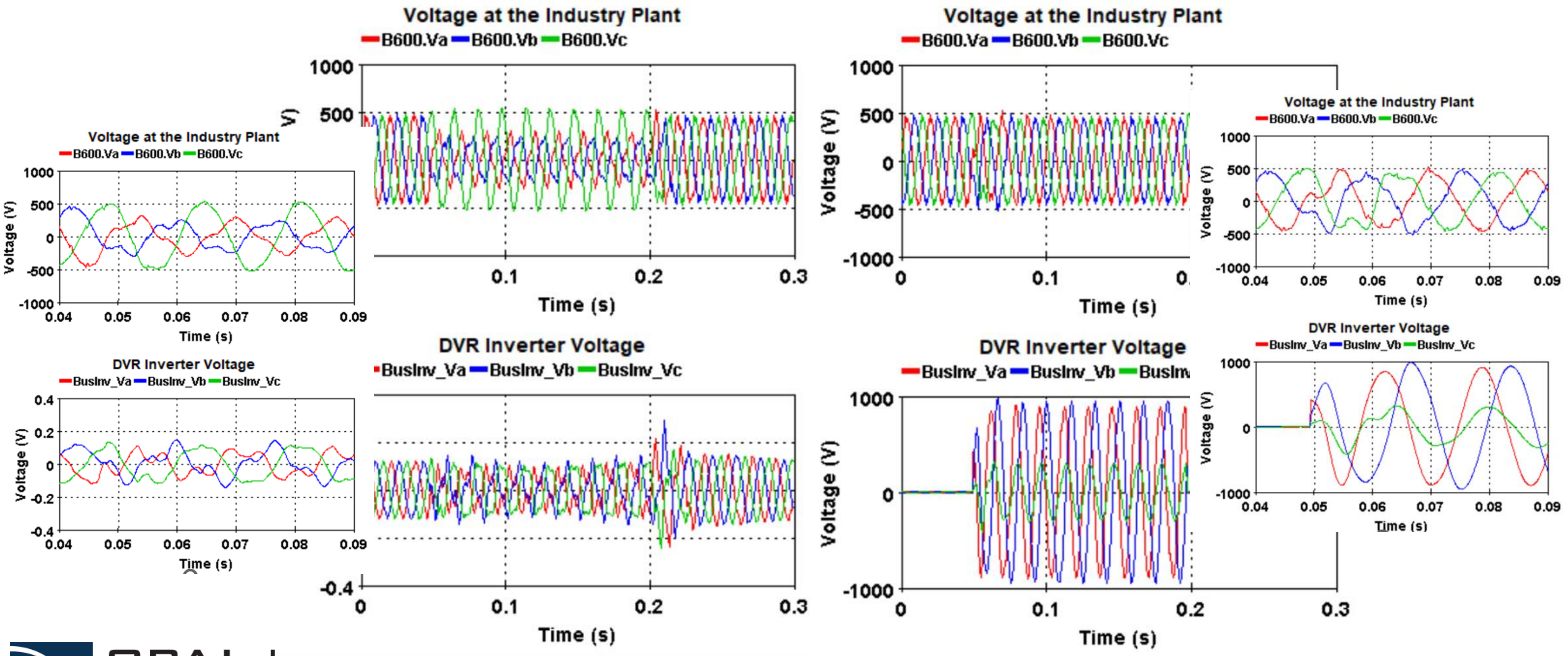
Dynamic Voltage Restorer (DVR)



Dynamic Voltage Restorer (DVR)



Dynamic Voltage Restorer (DVR)

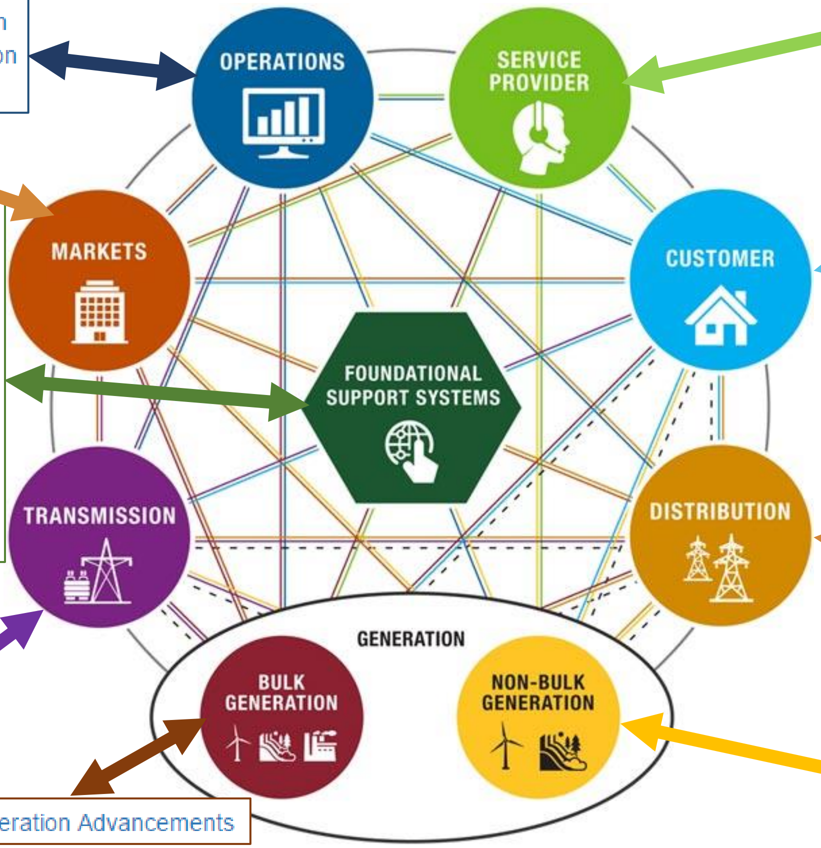


What must be studies about SMART Grid?

HYPERSIM

- Too Many Topics!!!

IEEE Smart Grid Domains & Sub-domains



Operations:
- Distribution Operation
- Field Device Operation
- Transmission Operation
- Visibility and Control

Service Provider:
- Service Provider Enablement

Markets:
- Market Enablement

Customer:
- Advanced Protection
- Asset Management and Optimization
- Customer Enablement
- Demand Response
- Micro-Grid and Nano-Grid
- Plug-in Vehicles
- Smart City
- Smart Metering Systems
- Substation Automation
- Transmission and Distribution Planning

Foundational Support Systems:
- Architecture (Interoperability, Usability, etc.)
- Business Process Re-engineering
- Communication Systems
- Economic Justification, Cost Recovery Models
- Education and Training
- Environmental Impacts and Efficiency
- Information and Data Management
- Strategy, Policy, Procedure and Standards
- System Resiliency (Cyber Security, Critical Infrastructure Protection, Reliability Compliance)

Transmission:
- Advanced Protection
- Asset Management and Optimization
- Micro-Grid and Nano-Grid
- Smart City
- Substation Automation
- Transmission Automation
- Transmission and Distribution Planning

Distribution:
- Advanced Protection
- Asset Management and Optimization
- Distribution Automation
- Micro-Grid and Nano-Grid
- Power Quality Management
- Smart City
- Substation Automation
- Transmission and Distribution Planning

Bulk Generation:
- Generation Advancements

Non-Bulk Generation:
- Distributed Energy Resources
- Distributed Generation
- Energy Storage Systems

Secure Communication Flows (solid line)
Electrical Flows (dashed line)

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CONCLUSION

HYPERSIM

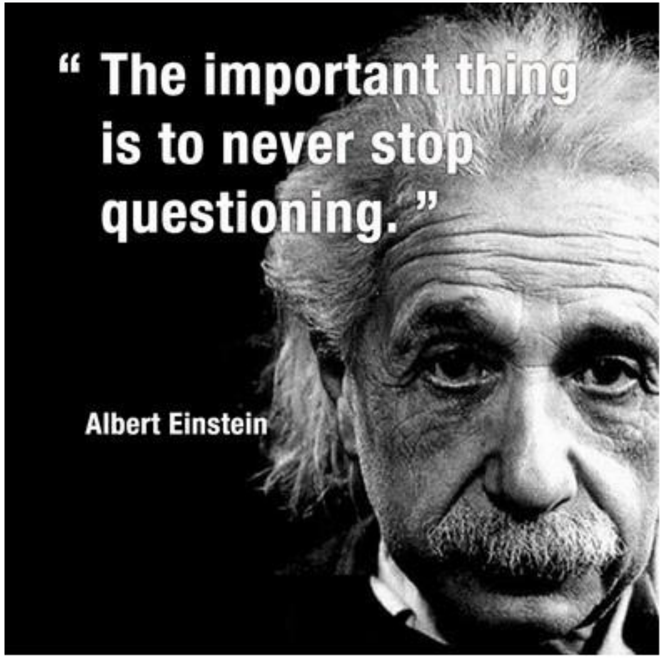
- Simulation tools capable of MIL/SIL, HIL or PHIL are essential to cover all phases in project: from original idea, to concept, to prototype, to final system

- EMT Simulation is the only method to accurately reproduce real world results as shown in the presentation's examples.

- Automatic Testing tools are key to obtaining results that cover all possibilities by performing hundreds of thousands of tests

- Only guaranteed method for Grid Owners is to perform HIL testing of all power system devices before field installation. And having a simulation group.
    - Thus greatly reducing on-site work, cost and risk of failures.

Questions…?


“ The important thing
is to never stop
questioning. ”
Albert Einstein

RT24 in Tokyo

HYPERSIM

・開催期間 ： 2024年11月29日（金） 午前10:00～午後5:00（日本時間）
・費用 ： 無料（複数名様でのお申し込みも歓迎いたします）
・会場 ： TKP品川ガーディンシティPREMIUM品川高輪口　ホール A3
・講演① ： 電力中央研究所　上田紀行様 「IEC 61850適用保護・監視制御・計測システムのHILテスト」
・講演② ： 川崎重工業　桑代慎吾様 「大規模電源システム開発の効率化に向けたP-HILS活用事例」
・講演③ ： 日立製作所/日立産機システム　石丸哲也様/松永俊祐様 「系統連系インバータHILS試験の自動化と実機比較」
・講演④ ： eVooster/大阪大学　太田豊様 「電気自動車と電力グリッドのHIL」

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日本語紹介ページ： https://www.neat21.co.jp/EV_RT_NEAT

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