SHANDONG UNIVERSITY

IEEE PES Power & Energy Society Jinan Chapter

4th International Symposium on Smart Grid Methods, Tools, and Technologies

Jinan, China

29-30 October, 2021

http://www.intesgmt.sdu.edu.cn/

Active management of decentralized and sustainable electricity networks

Innocent Kamwa, IEEE Fellow

Canada Research Chair in Decentralized Sustainable Electricity Grids for Smart Communities

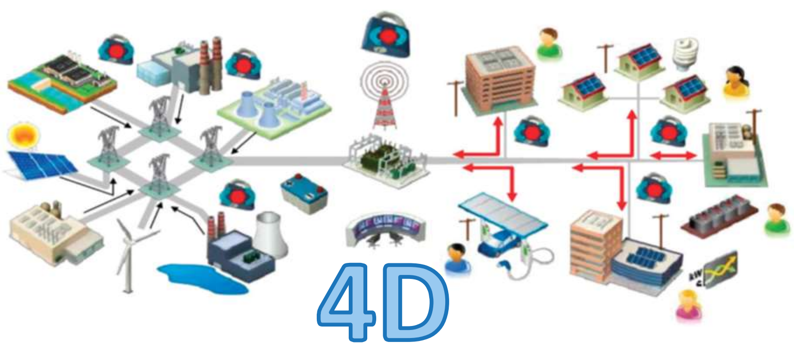
Virtual Talk | **Montreal Time** | **9h00-9h45 PM** | Thursday, **28 October**

4th International Smart Grid Symposium, October 2021, Jinan, China

UNIVERSITÉ LAVAL

Agenda

1. Decarbonized, decentralized, digitized and democratic electricity networks (4D)
2. Research action plan on Active Management of 4D power grids
3. Roadmap for digital transformation of electricity networks via the 61850 standard
4. 4D Scripting with awareness of electricity networks and markets
5. Real-time simulation laboratory for training in 4D electrical networks



1. Emergence of 4D electrical systems: why and how?

Agenda

Electricity consumption will more than double by 2050, from 27 PWh/year in 2018 to 60 PWh/year

- **Covid19 changes likely to continue: ↓ demand for aviation, commuting travel and offices**

Renewable energies will provide +60% of the mixed electricity: wind and solar at 50-50%.

- IEA: 90% of new capacity worldwide in 2020.

Deep decarbonization also requires energy efficiency: 3 times less energy consumed / % of GDP

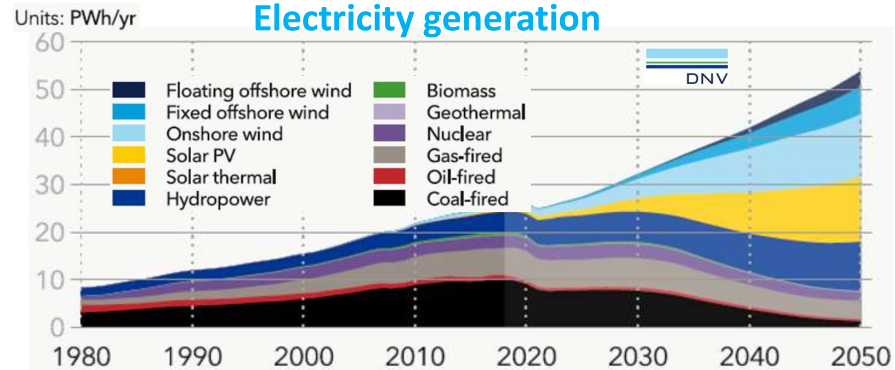
In Quebec, 100% of electricity is renewable but represents only 40% of the energy used

- **It will be necessary to electrify to decarbonize the energy mix**

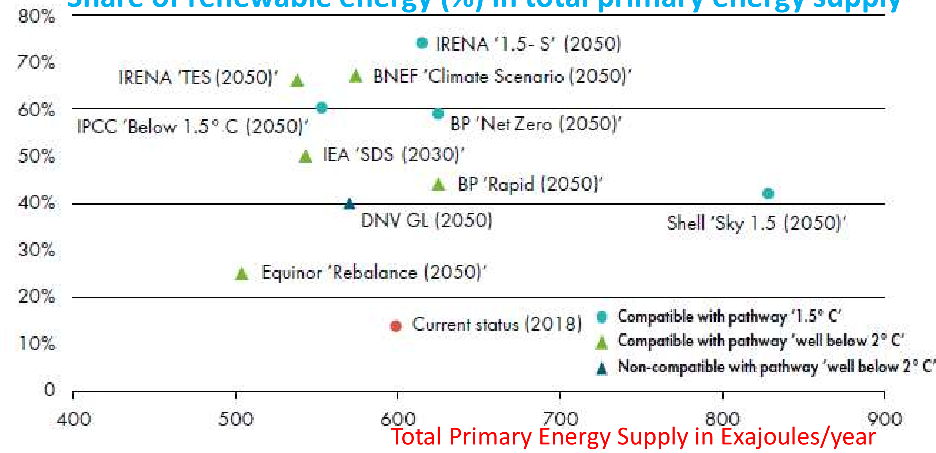
While we installed a record 82 GW of new wind capacity in 2020, we need to be installing around 180 GW per year to get to where we need to be. Every year we fall short, the mountain to climb gets higher.

Global Wind Report 2021

Electricity generation



Share of renewable energy (%) in total primary energy supply



UNIVERSITÉ LAVAL

Electricity networks to propel a future in 4D: Context

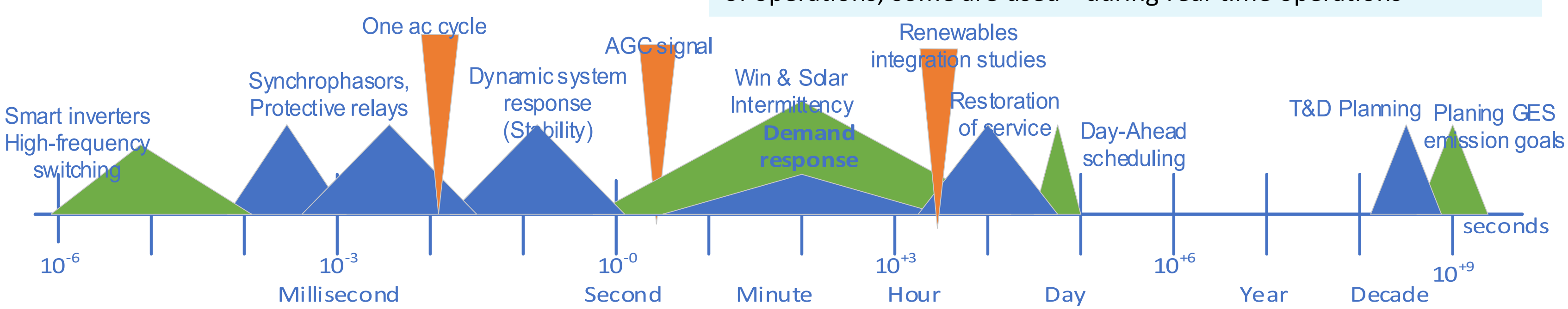
Massive integration by power electronics of decentralized production with zero marginal costs: intelligent but without inertia, changes the economic situation

Cyber-physical systems of systems: large number of technologies integrated at the edge of the network, with two-way energy flow, with partial autonomy

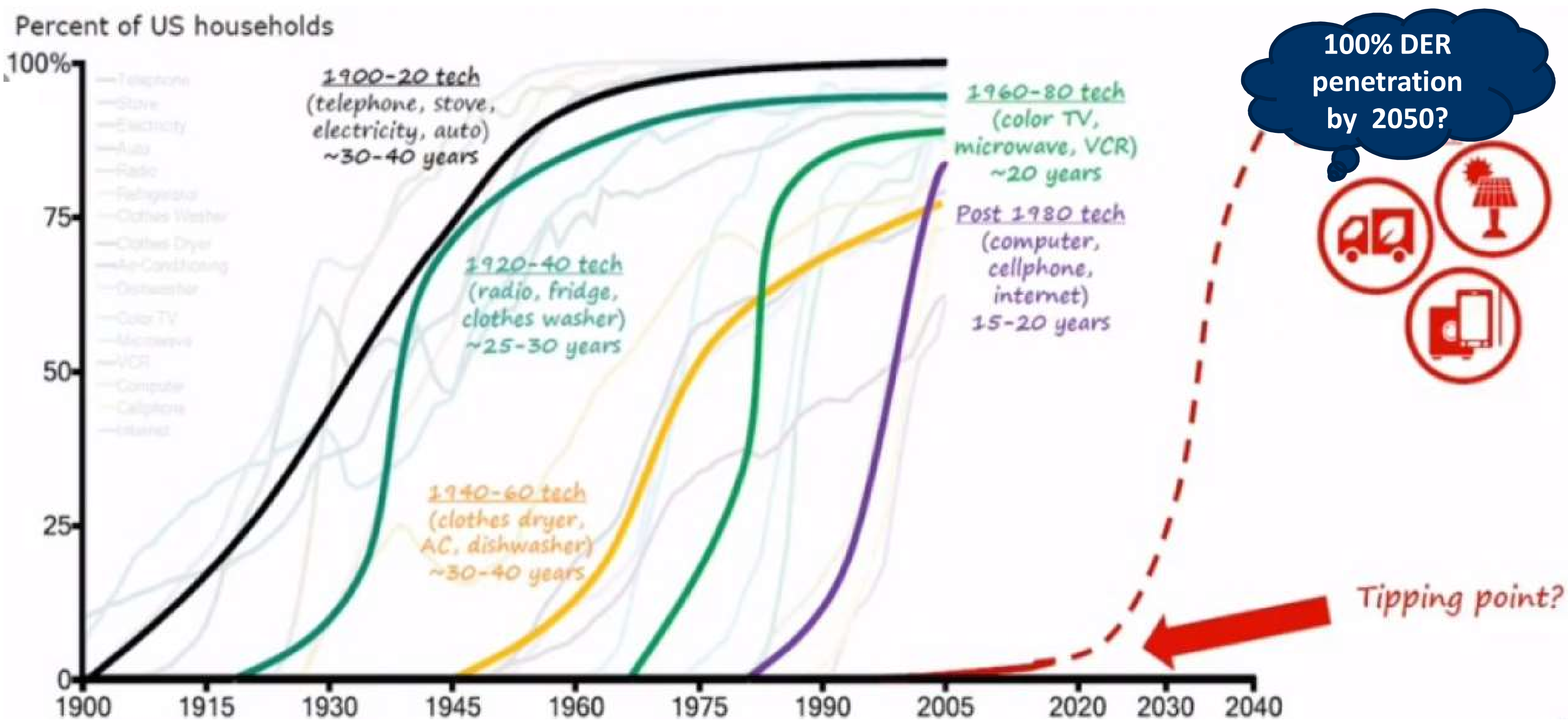
Low systemic observability / controllability of intermittent REDs -> Electrical storage and intelligent loads essential for supply-demand balance

Disruptive developments, rendering historical design assumptions obsolete: But we have 20 years to adjust ... Phew!

Distinct classes of planning tools are used to support operations over each of these time scales - most are used "off-line" long in advance of operations, some are used " during real-time operations



Time for DER technologies to reach 100% penetration



Managing uncertainties related to DER: Yes, but how?

Costly operating margins and / or preventive actions based on solving very complex stochastic optimization problems

- Monitor and analyze the operating conditions of a system of cyber-physical systems
- Identify your true security boundaries and make / execute decisions in seconds, balancing network cost vs security and stability.

Fewer humans in the loop, more automatic closed-loop control systems

- Humans too slow to coordinate / execute multiple actions in real time (1min).
- Replace them with artificial intelligence machines trained to make "good" decisions by imitating humans while evaluating the associated operational risk.

Installation of 50,000 battery racks and 132 inverters at the Manatee Energy Storage Center at Florida Power & Light.

Largest solar energy storage project in the world: 409WW / 900MWh (August 26, 2021)

Active 4D Grid Management : Gap Analysis

Perceived Gaps

Vision for desired end-state is not clear

- An integrated system-wide (region-wide or greater) control perspective has not been formulated
- Widespread deployment of intelligent electronic devices has not occurred, nor has a universal interface
- Integrated communications infrastructure is missing
- Availability of data is limited
- Cost of sensors (e.g. ITs) is too high
- Slow state estimation; supercomputers not employed

What to do?

In future Grids, with limited increase of transmission capacity:

- **Capture a modest share of the safety margin (say 5% of the total) while counting in last resort, on a wide-area intelligent SPS as an automatic safety net?**
- **Compute the operational limits using the actual conditions, focusing on contingencies really threatening over the next operating time-frame?**
- **Consider changing the way operational reliability is assessed and used, to include probabilistic « risk management » aspects?**

Key Technologies

Advanced Control Methodologies

- **Advanced operations and protection algorithms**
- **Integrated Probabilistic Risk Assessment (PRA) in real-time operations**

Decision Support & Human Interfaces

- **Semi-autonomous agent software (decision assistants)**
- **Dynamic simulators for training**

Part of the answer resides in: Integrated, More Automated Power Grid Control

Urgent tasks to start … right NOW

Improve the Wide-Area Network Visibility through FSM: Fast Modeling and Simulation

- Real-Time Operational Security Margin assessment following an outage: We have a 15-mn time-window to perform computer analyses and make preventive decisions
- Situational awareness for operators through early warning systems based on zonal angular separation and transient voltage profiles
- Wide-Area Phasor Measurements Systems (WAMS) used in Fast Computation Schemes to provide
  - Tracking mode vulnerability assessment (e.g. Damping and Synchronizing strengths)
  - Post-Contingency (on-demand) vulnerability assessment (e.g. post-fault disruption energy and voltage dips)

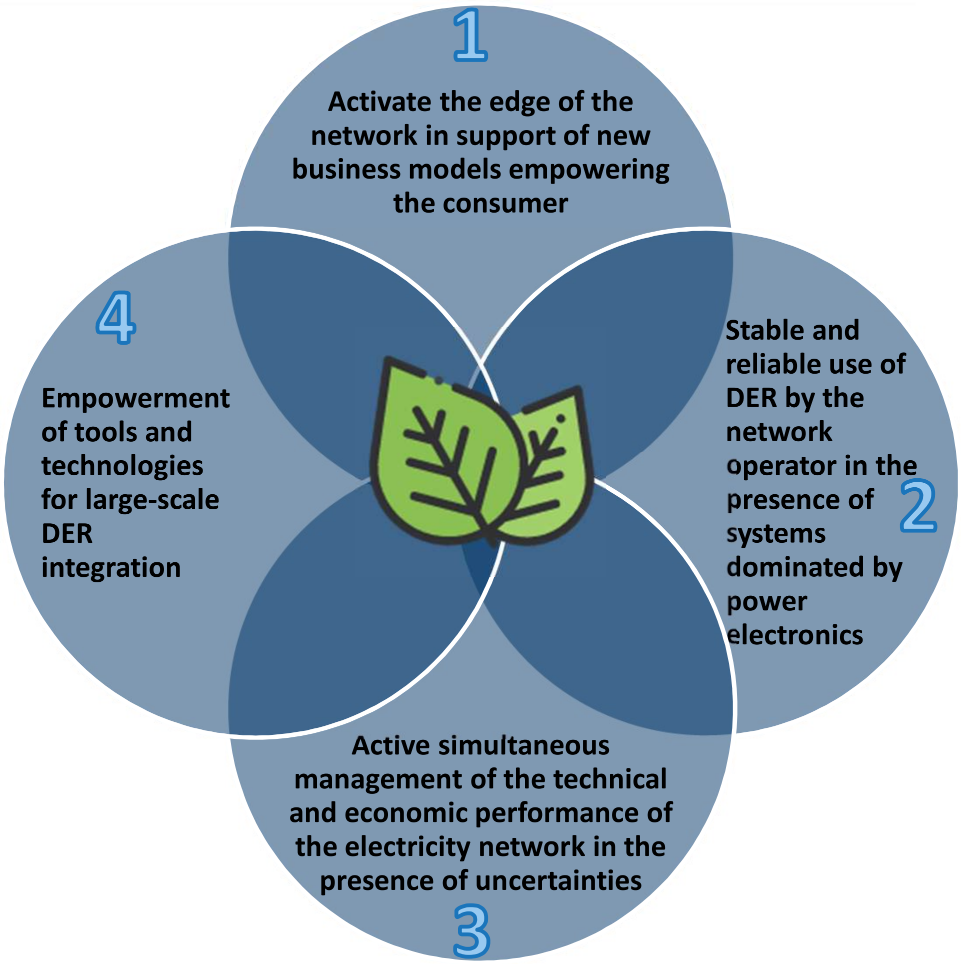
What Software is Inside?

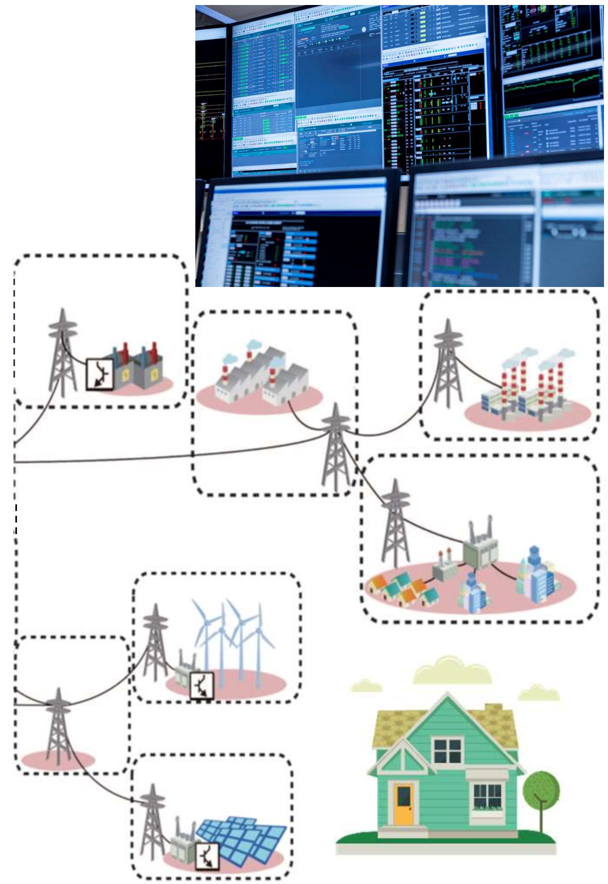
How are Automatic Controls Executed over a Wide Area?

Why Not Hierarchical-Decentralized/Distributed Decision and Control?

UNIVERSITÉ LAVAL

2. Action plan for sustainable DER-dominated networks





UNIVERSITÉ LAVAL

Research tracks for sustainable DER-dominated networks

1 Activate the edge of the network in support of new business models empowering the consumer

- 1.1 P2P control of micro-grids to establish clustered dynamic virtual production plants
- 1.2 Tendering strategy for multi-layered decentralized markets;
- 1.3 Electric hybrid vehicles + hydrogen as a deep decarbonisation pathway;
- 1.4 Advanced management system for battery storage with multiple network services.
- 1.5 Benefits of Network Conscious P2P Energy Storage Sharing and Trading

2 Stable and reliable use of DER by the network operator in the presence of systems dominated by power electronics

- 2.1 Predictive hierarchical control of DERs for system frequency and voltage
- 2.2 Detection, localization and attenuation of oscillations in networks dominated by power electronics
- 2.3 Grid-forming converters: optimal placement, storage integration and inertia emulation
- 2.4 Autonomous micro-grids, in clusters and virtual DC power plants, optimized and powered by AI
- 2.5 High-resolution, time-synchronized network monitoring and measurement devices
- 2.6 Understand / explain through AI the underlying mechanism of instability in electronic dominated systems

3 Active simultaneous management of the technical and economic performance of the electricity network in the presence of uncertainties

- 3.1 Robust optimization of the flexibility needs of a 100% renewable network
- 3.2 Simulator of a system of systems for the integration of millions of DERs aware of the limits of the network
- 3.3 Electric hybrid vehicles + hydrogen as a deep decarbonization path
- 3.4 Emergency automatisms based on DER, powered by AI and big data,
- 3.5 Remove humans from the loop using machines imitating operators and powered by AI

4 Empowerment of tools and technologies for large-scale DER integration

- 4.1 Aggregated models of DER considering network topology, operational constraints and uncertainty
- 4.2 Estimation/machine learning of the dynamic state of dynamic virtual power plants
- 4.3 Integration of EMS/SCADA applications in real-time simulation for network digital twins
- 4.4 New approaches to real-time simulation of systems dominated by DER using extended dynamic phasors
- 4.5 Power simulation of network services from electric-hydrogen hybrid vehicles
- 4.6 Digital twins of electric machines and DERs on a real-time simulator

UNIVERSITÉ LAVAL

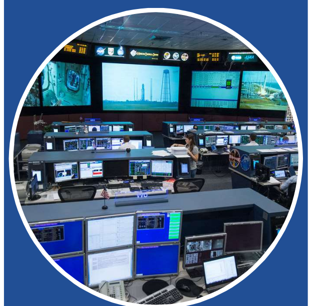
Global Power System Transformation (G-PST) Consortium's **Research Agenda**

Inverter Design

- Development of capabilities, services, design methodologies and standards for IBRs.

Stability Tools & Methods

- Development of new tools and methods, as well as modifications or supplements to existing tools and methods, required to ensure reliability, security, and stability in power systems.



Control Room of the Future

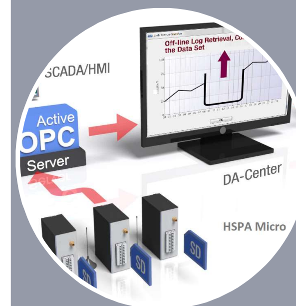
- Development of new technologies and approaches for enhanced real-time visibility and analysis in power system operator control rooms.

Planning

- New planning metrics, methods, and tools to capture the characteristics and influence of a changing resource mix.

Restoration & Black Start

- Creating new procedures for black starting and restoring a power system with high or 100% IBR penetrations.



Services

- Quantifying the technical service requirements of future power systems to maintain the supply-demand balance reliably and at least cost.

Inverter Design	Stability Tools & Methods	Control Room of the Future	Planning	Restoration & Black Start	Services
11	8	17	15	1	7

No of research questions in each Track

Agenda

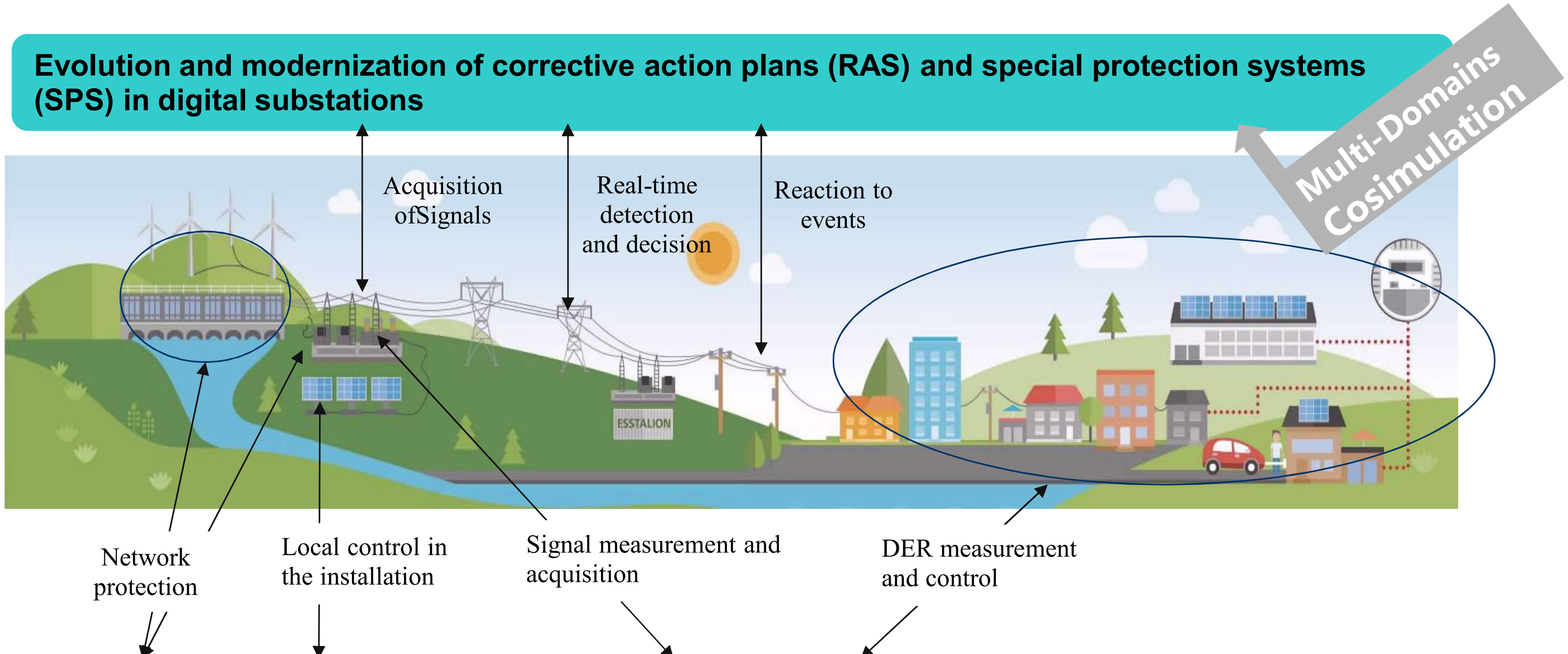
3. Digital transformation of power grids via 61850

Telecom

CyberSecurity

OT/IT Convergence

Evolution and modernization of corrective action plans (RAS) and special protection systems (SPS) in digital substations

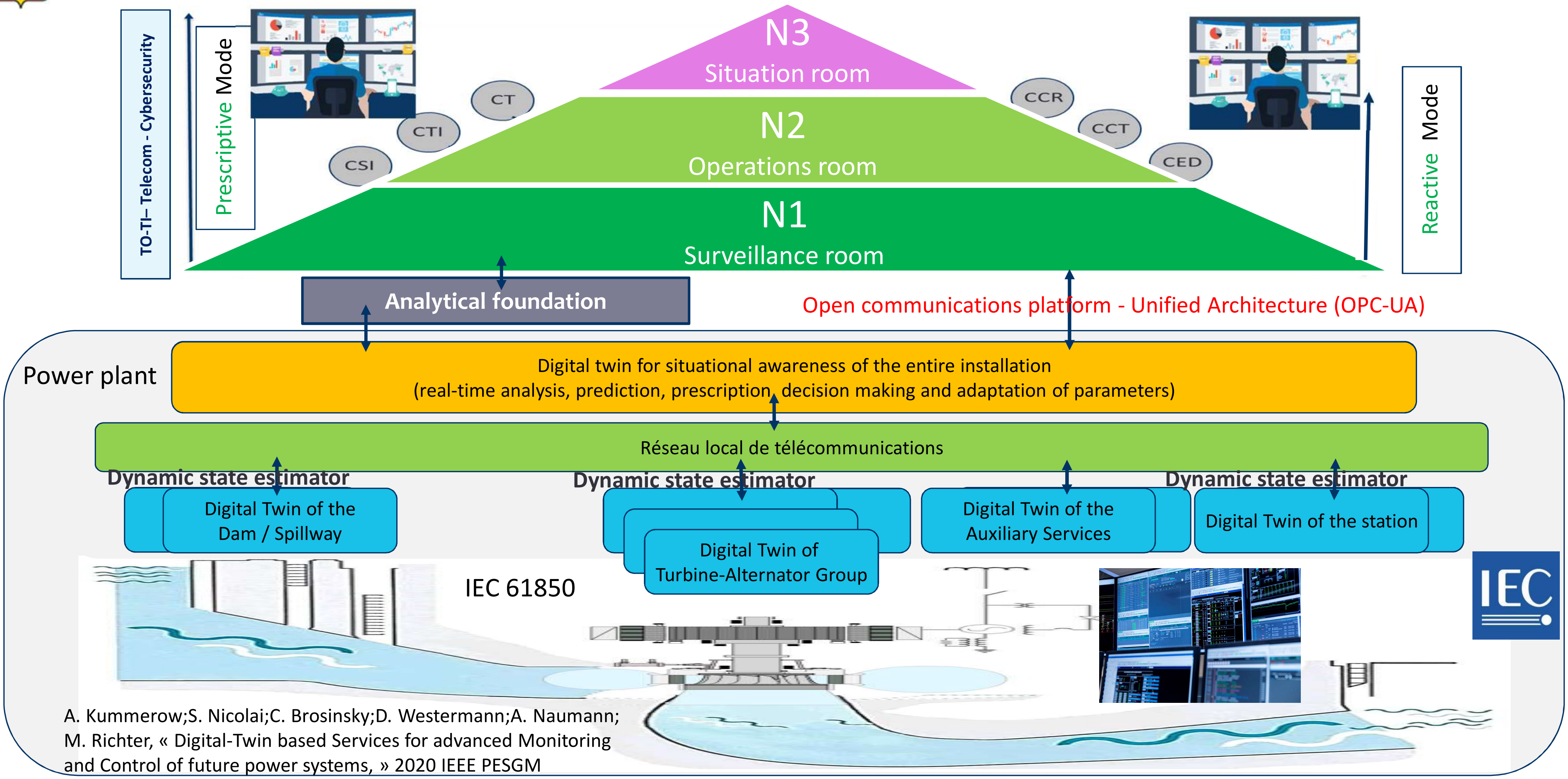


Evolution and Modernization of Automation Systems in Power Plants and Substations - Situational Awareness

Evolution of the integrated asset management system and the converged control center (operation and maintenance)

Source: IEC TC 57 AG22 (Jean Raymond, Convener 2021)

Dynamic situational awareness in converged control centers



Source: IEC TC 57 AG22 (Jean Raymond, Convener 2021)

Prerequisite for Removing Human from the Loop in 4D Grids Operations

Phase 2

Phase 3

Build on a converged and upstream architectural approach

Implement the architectural approach

Develop, design and define the reference architecture of each phase

Deploy an infrastructure and advanced operating tools (center layer)

Develop, automate and implement the IEC 61850 data model of the substations

Deploy an analytical infrastructure

Centralize and process a unique IEC 61850 data

Implement a generic HMI tool

Enhance the automated data model by inserting other types of substation

Develop and implement an automated and converged event analysis

Develop, define and implement a converged tool for time delay simulation

Develop and implement automated remote monitoring

Asset management

Develop and implement management of unified data model

Define and implement a dynamic automated asset inventory

Develop and implement remote maintenance and teleconfiguration

Implement knowledge bases

Implement a generic converged HMI tool

Enhance the automated data model by inserting all types of substation

Develop and implement a collaboration tool with market analysis

Implement augmented reality tool

Remote Actions

Network Operation
Implement the time synchronization

Implement a generic converged HMI tool

Implement the new SCADA

Implement the tools for control of RAS and SPS

Enhance the time synchronization

Enhance the tools for control of all RAS and SPS

Define, develop and implement WAMPACS

Enhance the time synchronization

Develop and implement real-time simulation (digital twin)

Define, develop and implement network dynamic adaptation

Deployment of infra

Collect, transport and analyze actual and future data in a centralized way

From the substation, perceive, analyze, predict and make decision

Use an interoperable, autonomous and adaptive infrastructure over time (substation layer)

IEC 61850 Digitization of substation

Deploy a telecom infrastructure

Deploy the time synchronization

Collect and transport an IEC 61850 unique data

Implement a generic HMI tool

IEC 61850 Digitization (process bus & higher level of voltage)

Enhance the time synchronization

Define, develop and implement a new IEC 61850 RAS and SPS (RPTC)

Implement a generic converged HMI tool

Define and deploy IoT in the courtyard

Deploy optical current transfo

Deploy MU

Define and implement a gateway (legacy inputs IEC 61850 outputs)

Technologies

IEC 61850 Digitization of all types of substation

Deploy a converged telecom infrastructure

Enhance the time synchronization

Deploy massively IoT in courtyard, lines, etc.

Define and implement
- Separation of software from hardware
- New 61850 RAS and SPS
- Synchrophasor (F,P,C,V, etc.)
- Intelligent MU
- Optical Voltage Transfo
- Augmented reality
- Artificial intelligence
- Other

Analytic

Deploy an analytical infrastructure

Define, develop and implement a centralized protection control system

Centralize and process all types of data

Develop and implement an automated and converged event analysis

Define and implement a dynamic Automated asset inventory

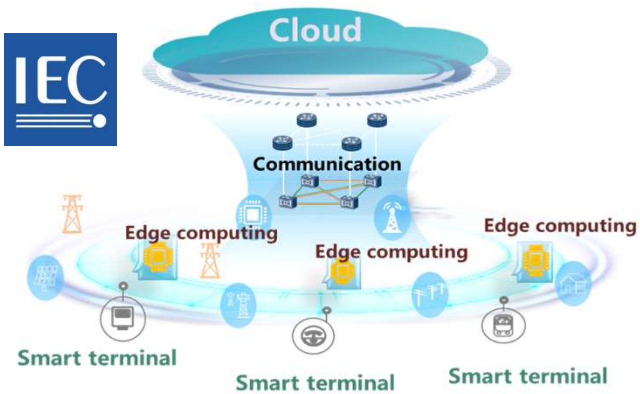
Develop and implement a collaboration tool with market analysis

Situational Awareness (software)

Define, develop and implement
- Advanced algorithms (calculus, prediction, decision making, etc.)
- Dynamic state Estimator
- Dynamic load prediction
- Web-of-cells
- Power electronic
- DERMS
- Adaptive protection and RAS
- Other

Substation

IoT architecture conducive to proliferation of RED - towards an IEC standard

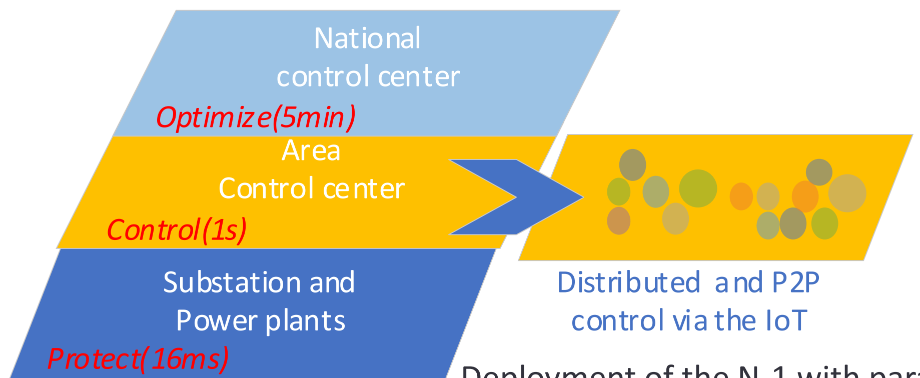


- Cloud computing, big data and machine learning
- Transmission between the "cloud", the "edge" and the "terminal"
- Distributed intelligent agent close to the data source
- Provides the operating status of the distribution network to the "edge" or "cloud". Execution of commands and controls.

Use case of IoT architecture for distribution network

Smart integration and management of REDs

- Planning and optimization of the operation of EV charging stations
- Real-time assessment of equipment condition and predictive maintenance
- Precise isolation of fault location and restoration of service
- Real-time analysis of regional line losses

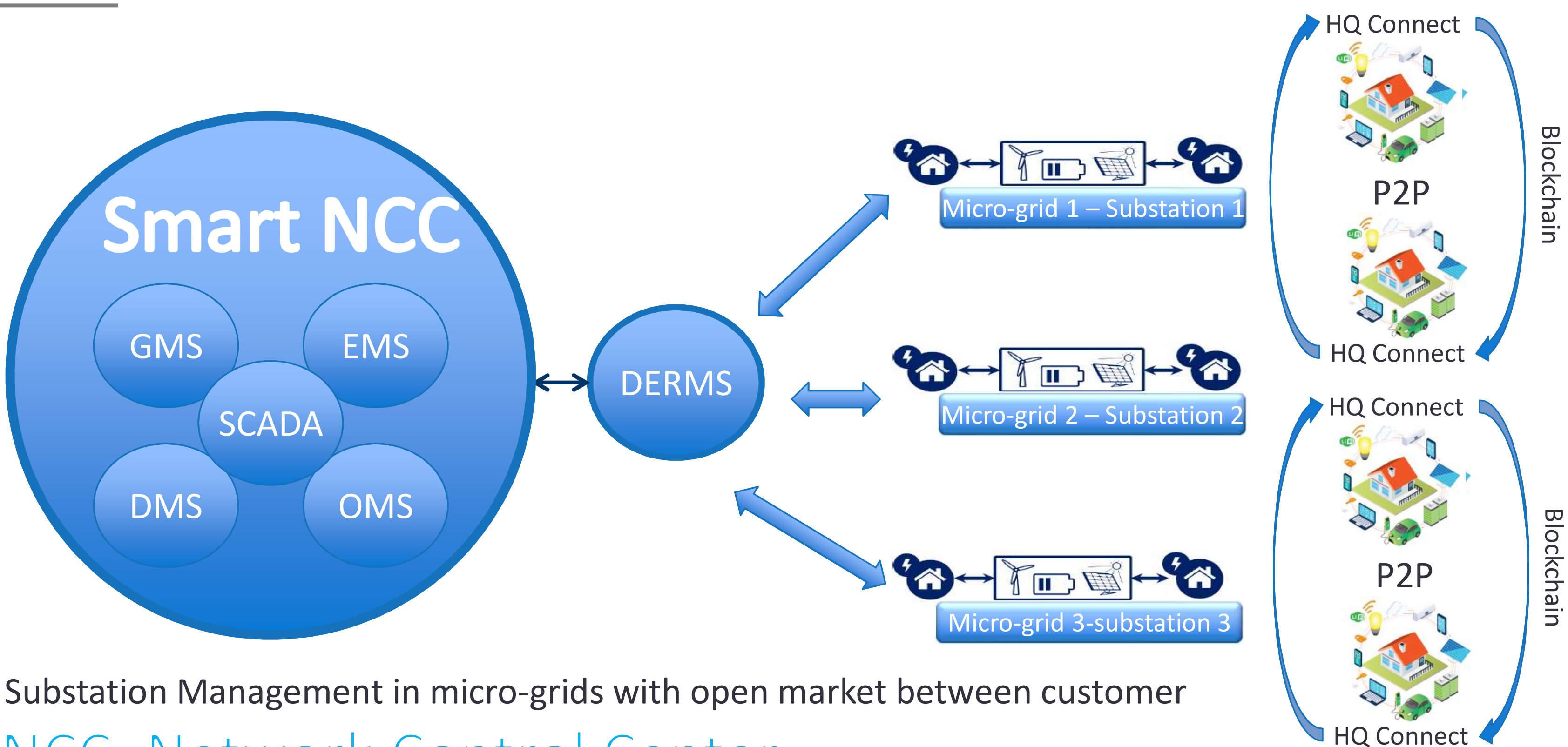


Deployment of the N-1 with parades

https://www.lfenergy.org/

Possible 4D Grid-Edge Architecture

Hilo v3

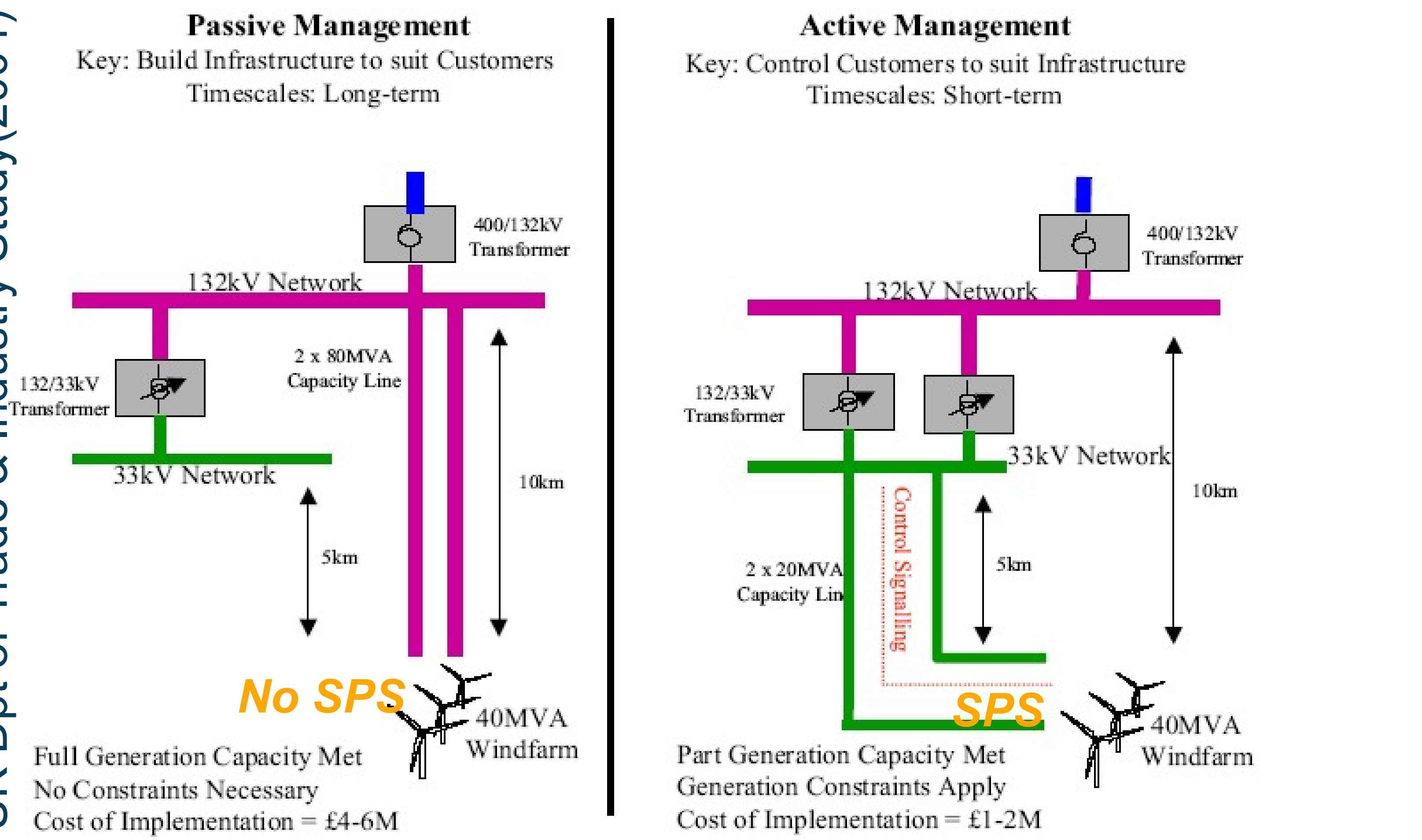


Substation Management in micro-grids with open market between customer

NCC=Network Control Center

Active Grid Management Under Constrained Resources

UK Dpt of Trade & Industry Study(2004)



UNIVERSITÉ LAVAL

Wrapping-UP : AGM « Why » issues

AGM is required to improve the overall grid efficiency through cost-effective Non-Wires solutions

- From the ERO viewpoint, AGM is required to stop the growing trend of blackouts
- Improved Network Conditions Visibility and Anticipation to guide/advice the operator during difficult times
- Preventive Control in the operations time frame: A probabilistic risk assessment of security/reliability to enable the « looking before leaping » strategy
- Adaptive Defense Schemes: "unmanned" safety nets more and more required for stressed grids

In long term, AGM is required to enable the old dream of a Smart Grid with

- Added-value applications built on top of "interoperable":
  - Sensor network,
  - Advanced communications and controls,
  - Intelligent demand and distributed renewable resources

Wrapping-Up : AGM « How » answers

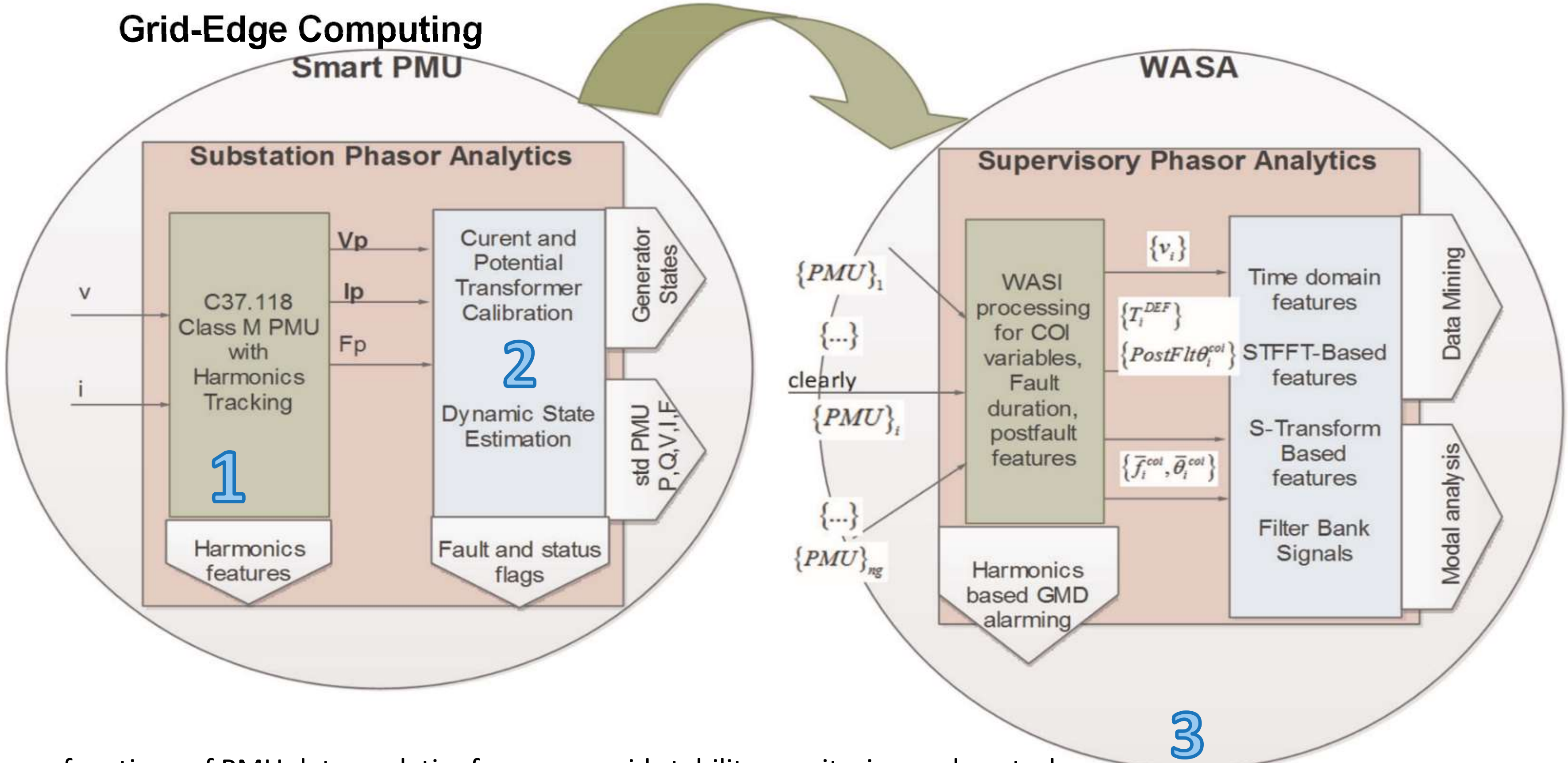
Favored Technology Options – Generic Tools

- Grid/Cluster Computing for naturally parallel problems
- Intelligent Software exploiting Decision Trees/ Fuzzy Logic & Agent Technology to speed-up naturally parallel problems and provide Actionable Decisions
- RTDS for faster than real-time stand-alone grid Stability and Dynamic Simulators for Operator Training

Next Generation of Value-Added Applications

- Multi-Agent Power Grid Control Simulator, in the renewable energy driven electricity market context
- Probabilistic Risk-Based Assessment of Dynamic Security/Reliability in the operations time frame
- Adaptive/Response-Based Special Protection Systems
- Intelligent Demand as Resources for Power Grid Control

Use Case #1: Wide-Area Situational Assessment (WASA)

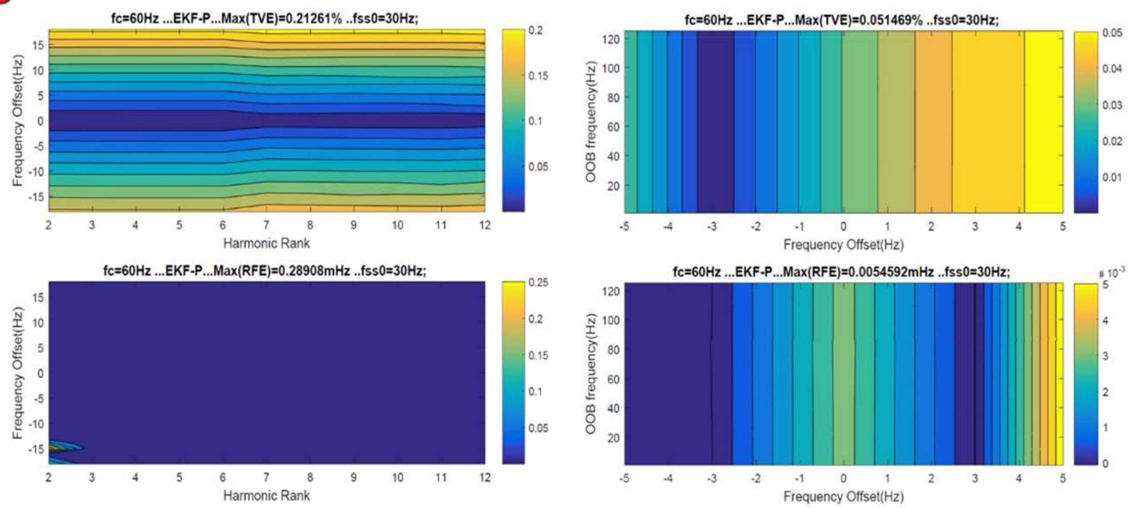


Summary functions of PMU data analytics for power grid stability monitoring and control:
1-Smart PMU; 2-Dynamic state estimation; 3-Data digestion for actionable information

I Kamwa, L Geoffroy, SR Samantaray, A Jain Synchrophasors data analytics framework for power grid control and dynamic stability monitoring, IET Eng. Technol. Ref, 1-22

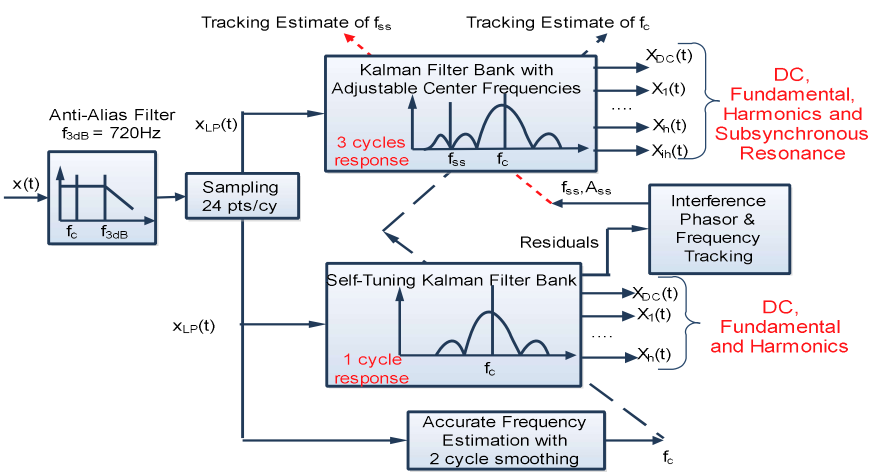
PMU for Control: Key Enabling Technology for EMCS

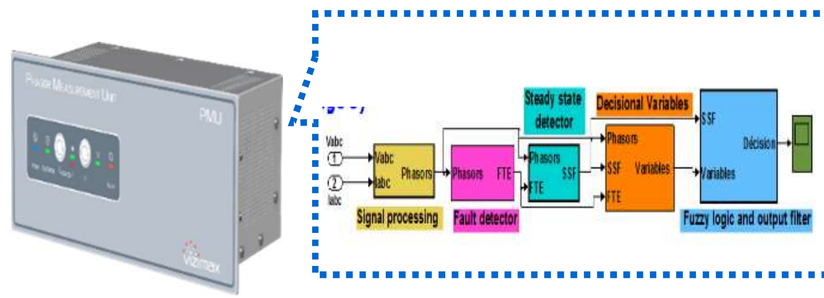
UNIVERSITÉ LAVAL



→ **PMU/C is an IEEE certified PMU with Class P speed, and Class M accuracy:**

- Frequency range of +-20Hz
- 0.2% Harmonic rejection and 0.05% OOB rejection at 10% interference
- AM & PM modulation pass-band 9Hz
- 31ms response time and 25 ms Latency
- Very fast Frequency and ROCOF measurements: M-class accuracy with better than P-Class reporting at 240Hz (4 samples/cycle)

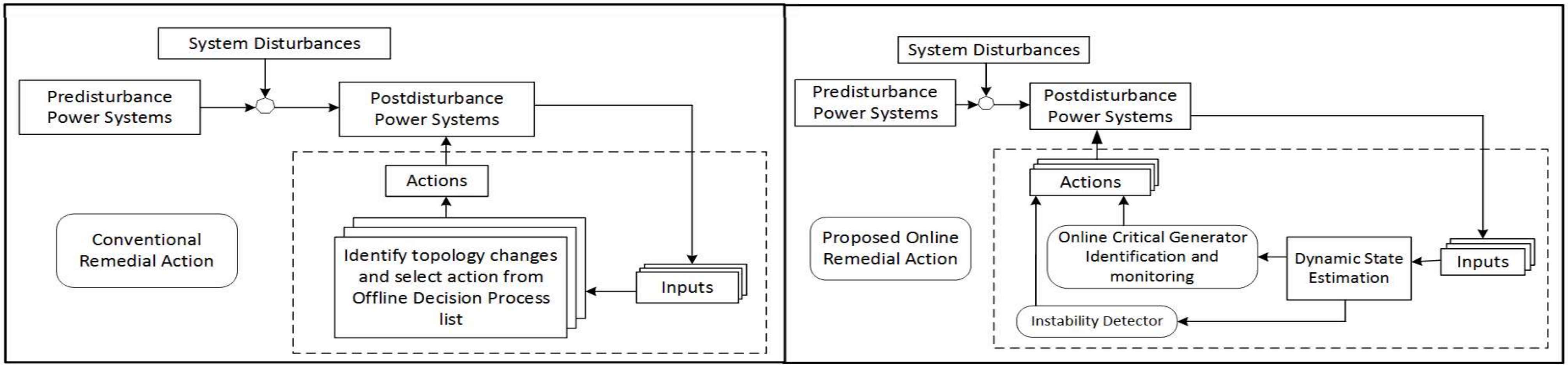




PMU/C

I. Kamwa, S. R. Samantaray, and G. Joos, "Wide Frequency Range Adaptive Phasor and Frequency PMU Algorithms," *IEEE Trans. on Smart Grid,* vol. 5, pp. 569-579, 2014.

DSE based RAS in the WASA Framework



Design a response-based RAS from dynamic states

- Using ensemble Decision Trees or LTSM based Deep-Learning of sliding windows features: Determine impending instability from online measurements
- Determine corrective actions in real time and implement in incremental steps

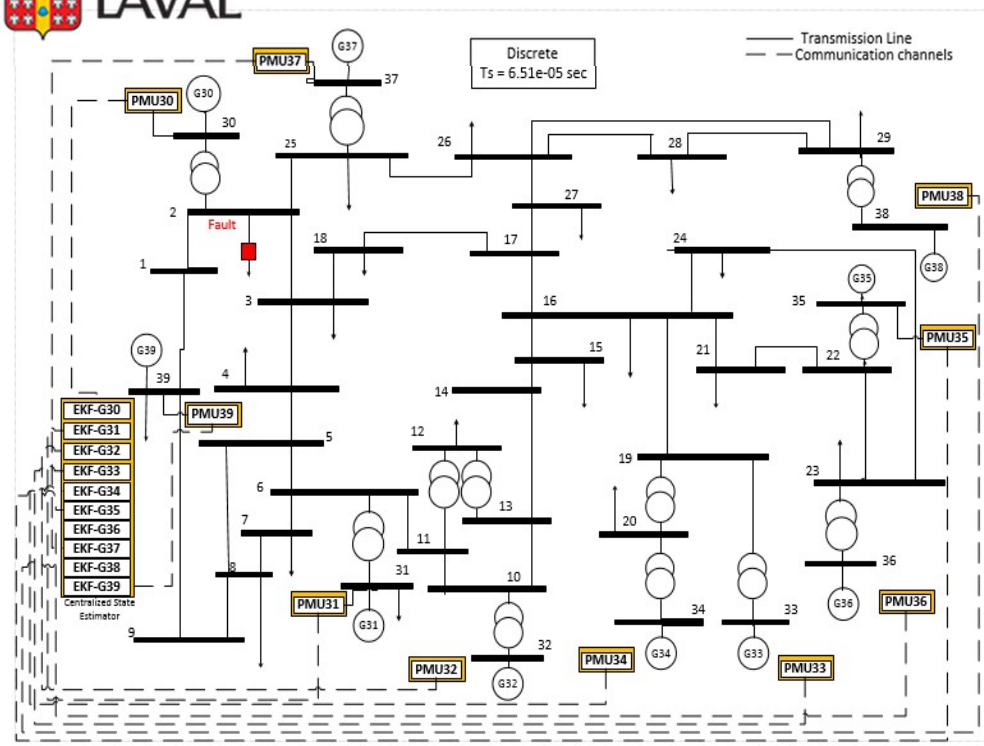
Proposed RAS offers the advantage of

- Online detection of instability
- Detection of critical generator and operating on the fly
- Requires individual generator dynamic states to operate

Future work involves

- Making DSE robust to data quality issues and cyber attacks
- Extending instability detector to other forms of instability eg. voltage and frequency
- Extending scope of possible actions eg. generator run-back, shunt capacitor etc.
- Evaluating RAS performance under massive amount of renewable energy penetration

Network Wide DSE



Test System : IEEE 39 bus network with 10 generators
Communication channel data transmission

Data transmission fidelity $\lambda_k = 90\%$

Individual Generator Energy

$$W_i^T = W_i^{KE} + W_i^{PE}$$
$$= \frac{1}{2} M \left(\frac{d\delta}{dt} \right)^2 + W_i^{21} + W_i^{24} + W_i^{25} + W_i^{26}$$

Generator Components

$$W_i^{21} = -P_m \left(\delta - \delta_0 \right)$$

$$W_i^{24} = \frac{1}{2} \left[\left(i_d^2 - i_{d0}^2 \right) x_d' + \left(i_q^2 - i_{q0}^2 \right) x_q' \right]$$

$$W_i^{25} = \int_{E_{q0}'}^{E_q'} i_d dE_q' \quad W_i^{26} = -\int_{E_{d0}'}^{E_d'} i_q dE_d'$$

Load Bus Components

$$W^{22} = \sum_{i=1}^{N_L} \int_{t_0}^{t} P_{Li} \frac{d\delta_i}{dt} dt$$

$$W^{23} = \sum_{i=1}^{N_L} \int_{V_0}^{V} \frac{Q_{Li}\left(V_i\right)}{V_i} dV_i$$

Assumption (during fault)

$$W^{21} = \sum_{i=1}^{N_G} W_i^{21} = W^{22}$$

$$W^{23} \sim 0$$

Caveat : assumptions valid for few cycles after fault initiation

Centralized and Decentralized DSE based Instability Predictors

Recent indicators from centralized state estimator would result in a robust detection of instability.

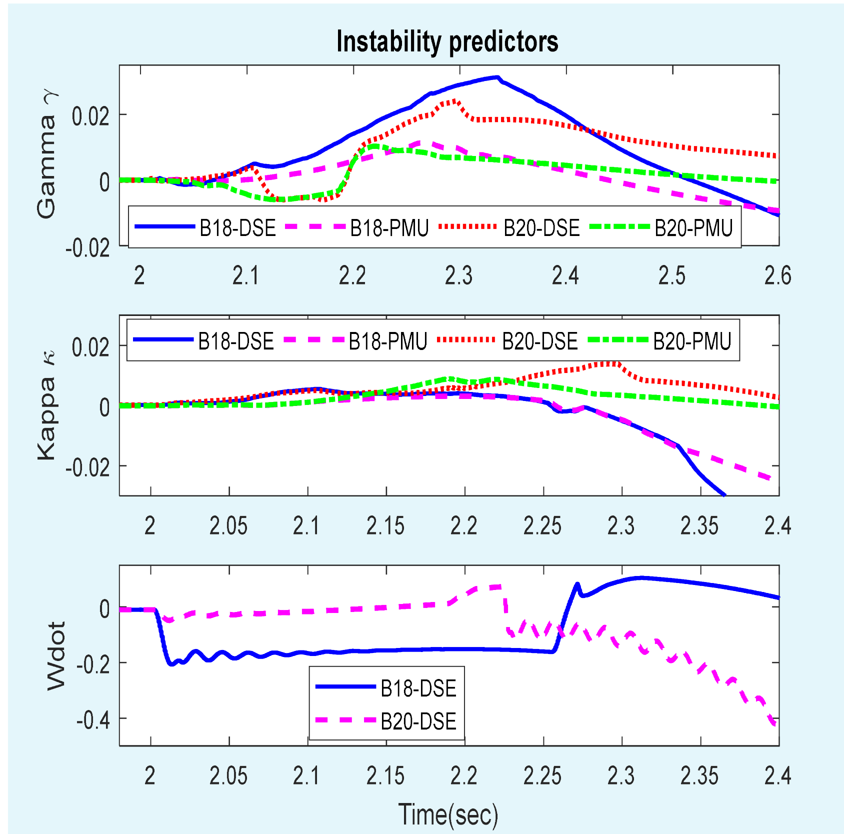
$$\gamma_{COP} = \sum_{i=1}^{NG} \delta_i \left(\omega_i - \omega_i^{COP} \right)$$

$$\kappa_{COP} = \sum_{i=1}^{NG} \omega_i \left(\delta_i - \delta_i^{COP} \right)$$

$$W_{di} = \frac{dW_i}{dt} = -\left[\frac{T'_{doi}}{\left(x_d - x'_d\right)} \left(\frac{de'_{qi}}{dt} \right)^2 + \frac{T'_{qoi}}{\left(x_q - x'_q\right)} \left(\frac{de'_{di}}{dt} \right)^2 \right]$$

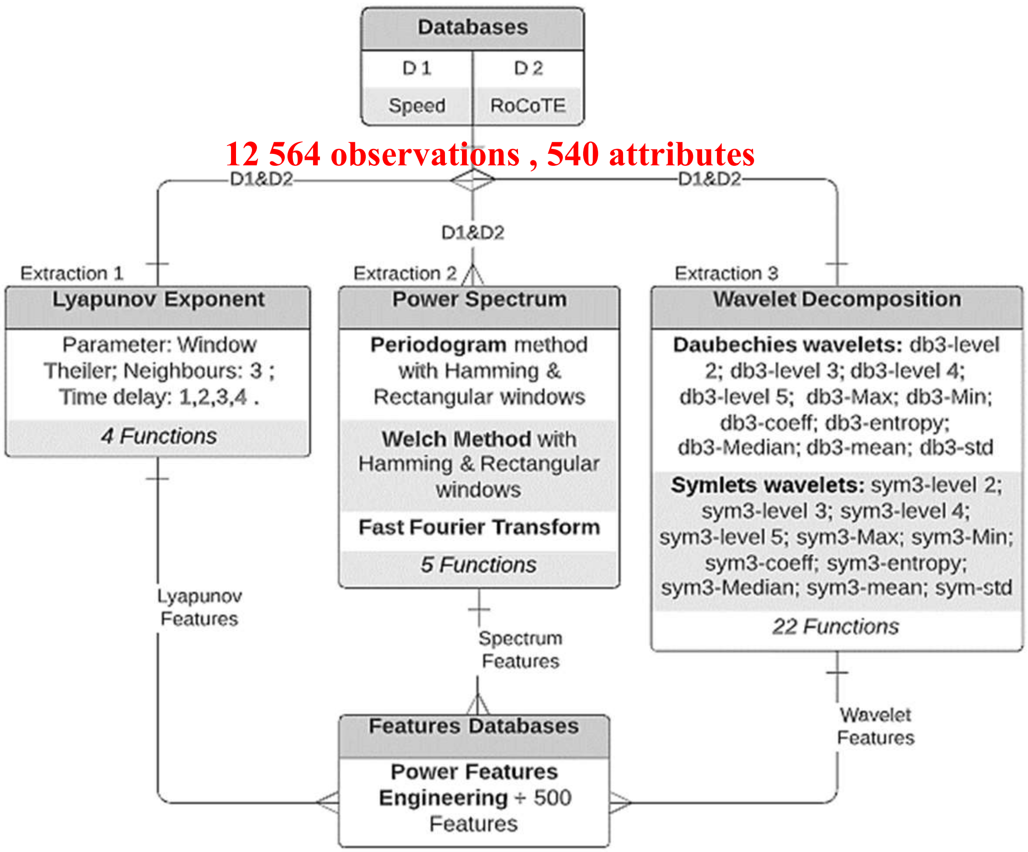
$$Wdot = \frac{dW}{dt} = -\sum_{i=1}^{NG} \left[\frac{T'_{doi}}{\left(x_d - x'_d\right)} \left(\frac{de'_{qi}}{dt} \right)^2 + \frac{T'_{qoi}}{\left(x_q - x'_q\right)} \left(\frac{de'_{di}}{dt} \right)^2 \right]$$

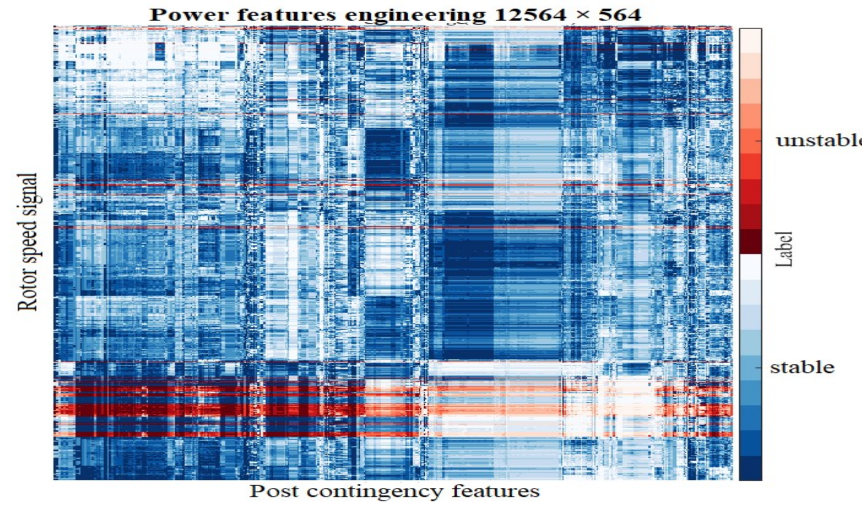
$$\forall i = 1, 2, \ldots N_g \ and \cdots \omega^{COP} = \sum_{k=1}^{NG} \omega_k P_{ek} \Big/ \sum_{k=1}^{NG} P_{ek} \ and \ \delta^{COP} = \sum_{k=1}^{NG} \delta_k P_{ek} \Big/ \sum_{k=1}^{NG} P_{ek}$$



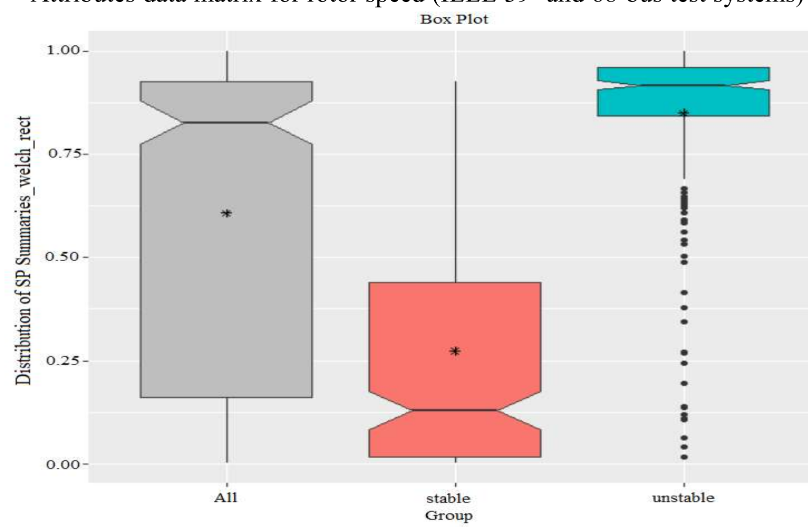
W_i is total energy of generator *i*

Generalized features extraction for instability detection in New-England Test System



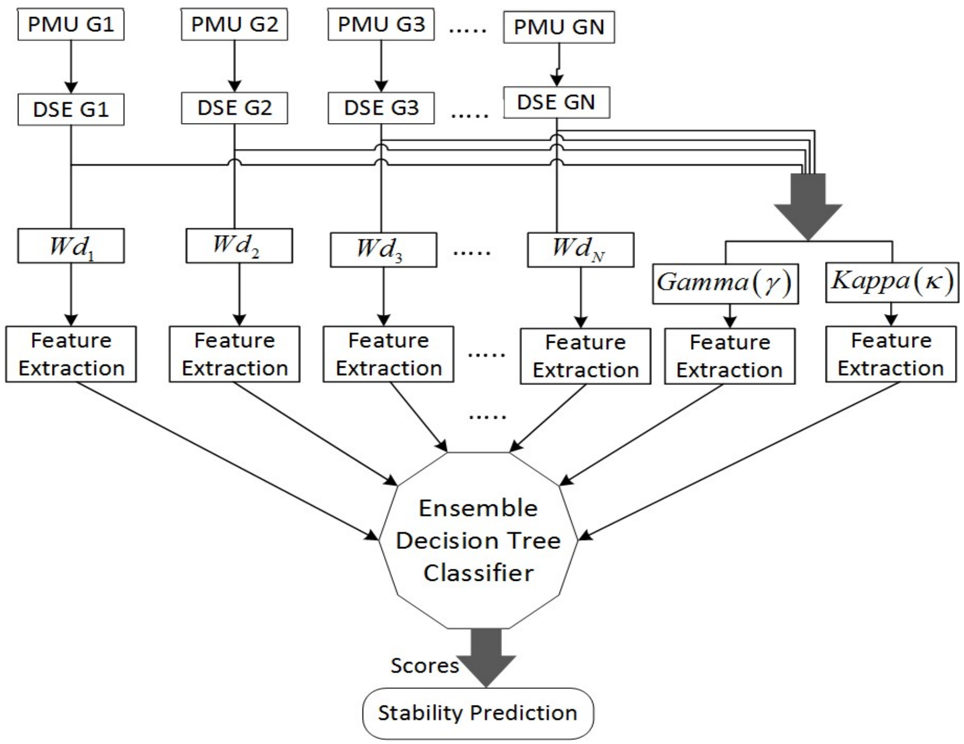


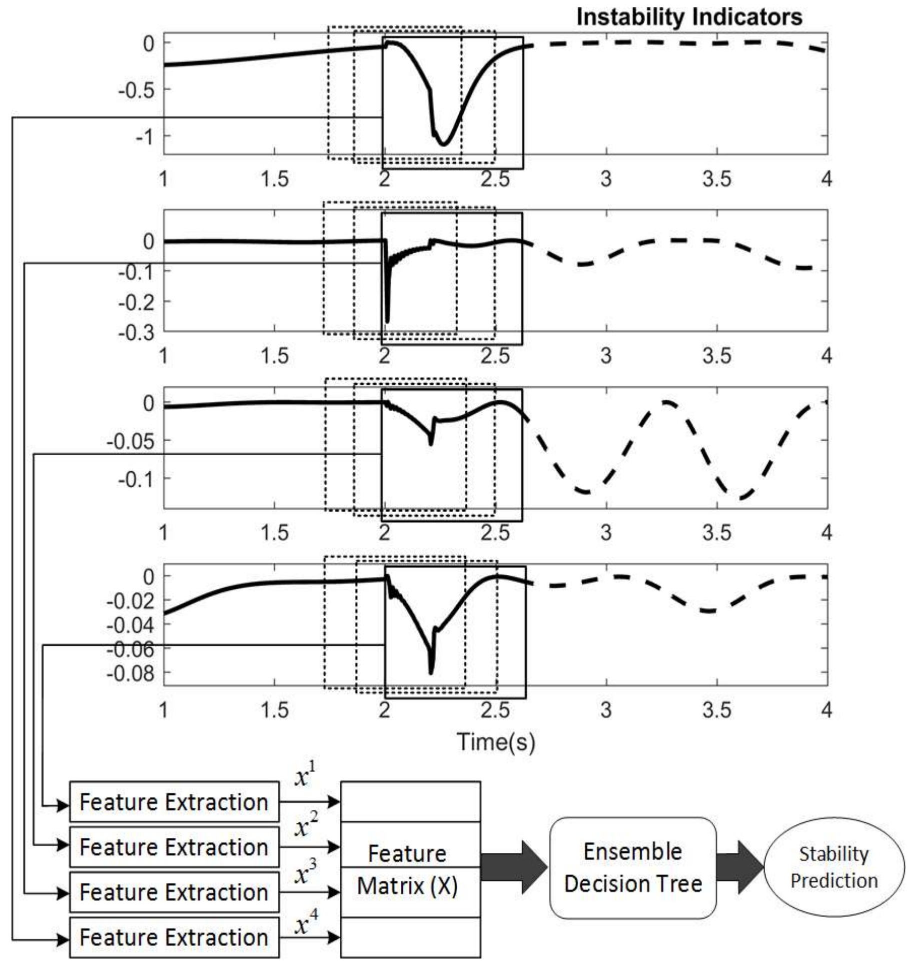
Attributes data matrix for rotor speed (IEEE 39- and 68-bus test systems)



RT Dabou, I Kamwa, CY Chung, CF Mugombozi, Time Series-Analysis Based Engineering of High-Dimensional Wide-Area Stability Indices for Machine Learning, IEEE Access 9, 2021

Instability Detector : Ensemble DT for One-shot Decision

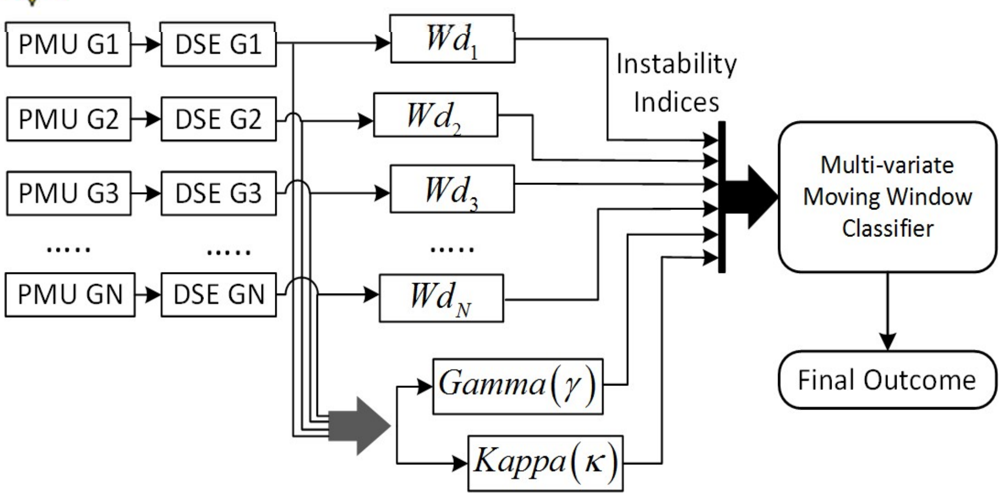




These three indices γ_{COP}, κ_{COP} and $Wdot$ enabled by the centralized state estimator would result in a robust detection of instability.

Extracted features are based on Fourier operation, but HDSI can be used as well which makes the feature space of a very high dimension

Instability Detector : Attention - LSTM

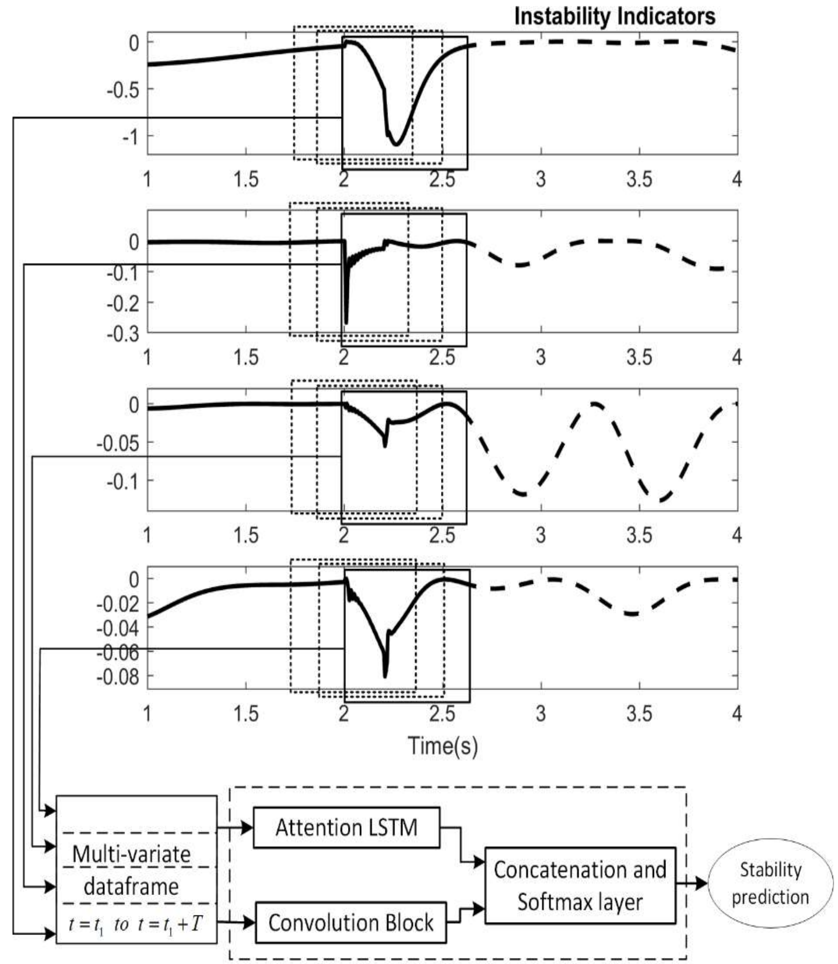


Does not require feature extraction

Training time higher than Ensemble DT

Prediction time lower than Attention - LSTM

Classifier details	Values(Testing set)		Values(Robustness set)	
Classifier Type	**MLSTM**	**Ensemble DT**	**MLSTM**	**Ensemble DT**
Accuracy	99.86 %	99.59 %	98.15%	97.60%
Reliability	99.99%	99.86 %	99.69%	99.14%
Security	99.87%	99.73%	98.47%	98.45%



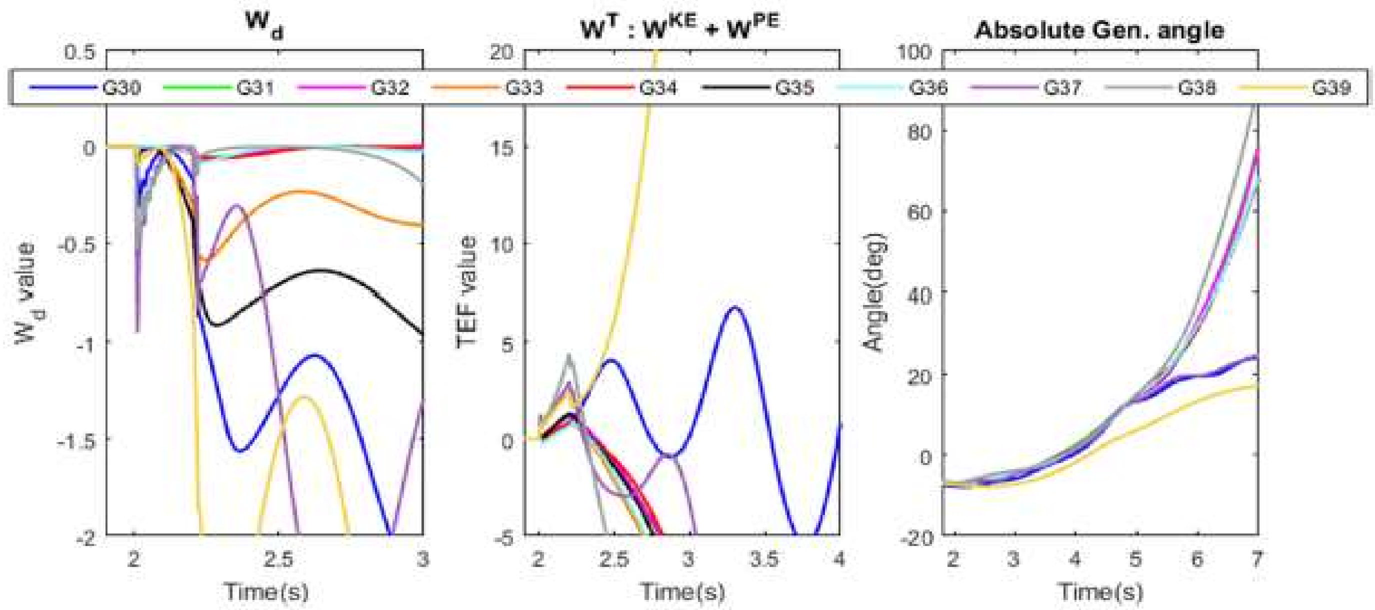
Multivariate Attention LSTM FCN

Instability Detector : Results for 39-bust test system with 200 ms decision window

Proposed Remedial Action

Steps :

- Compute individual generator energy W_i^T
- Identify critical generators from W_{di}, W_i^T
- Identify critical generators and rank them based on W_{di}, W_i^T
- If instability predicted, trip the first generator in ranked list
- Monitor critical generators through coherency matrix and Instability predictor
- Trip subsequent generators if instability persists

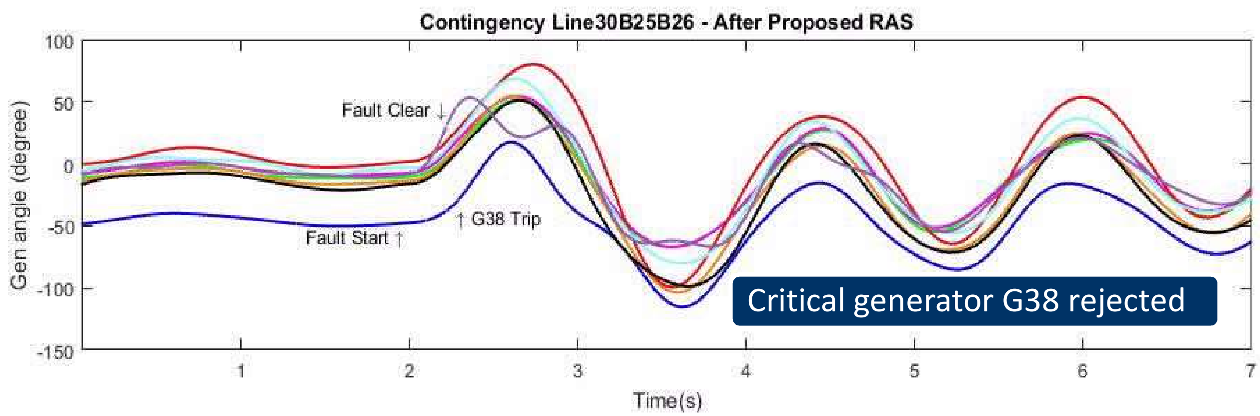


Comparison of instability index (W_d), transient energy function and rotor angle of individual generator following a 3 phase fault on Line30B25B26.

The Instability detector predicts an impending instability at t = 2.3 s with critical generator G38

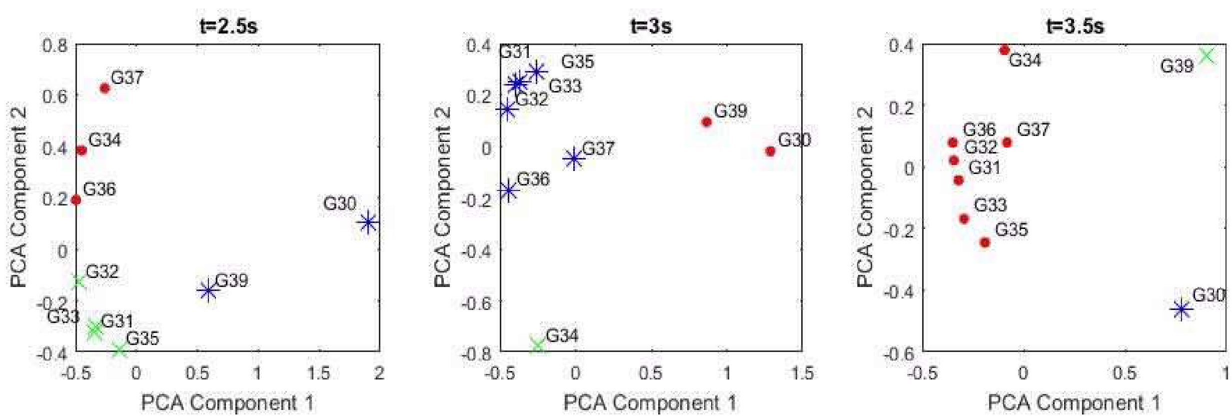
Results : Proposed Algorithm Performance

Identified critical generators(order of priority) : G38 , G37



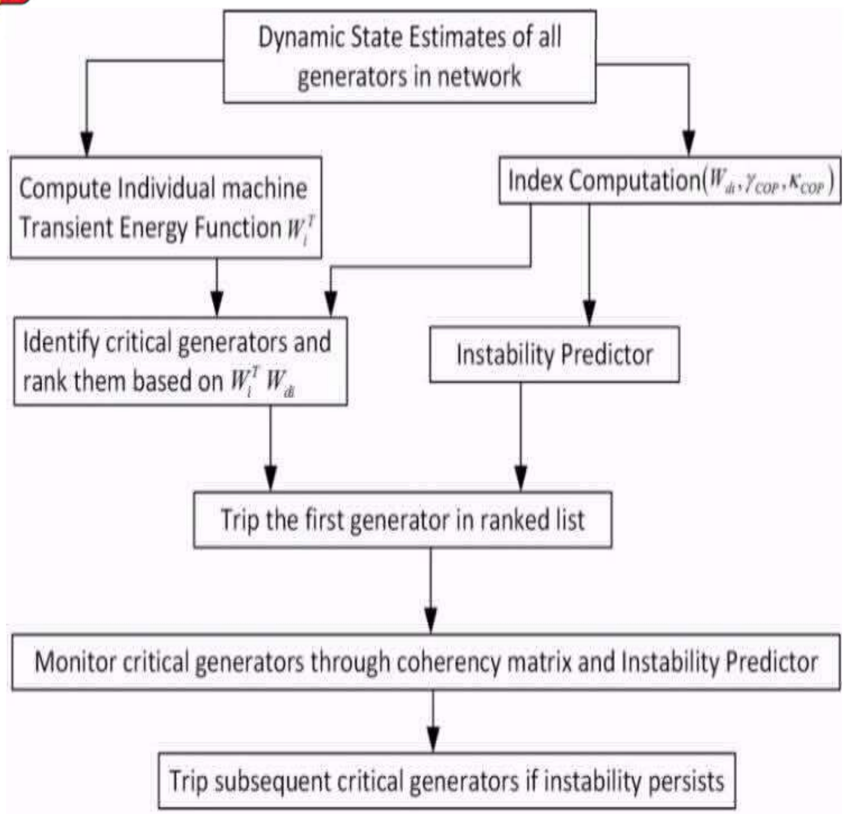
- Generator number n,l = 1,2 ..... N_g

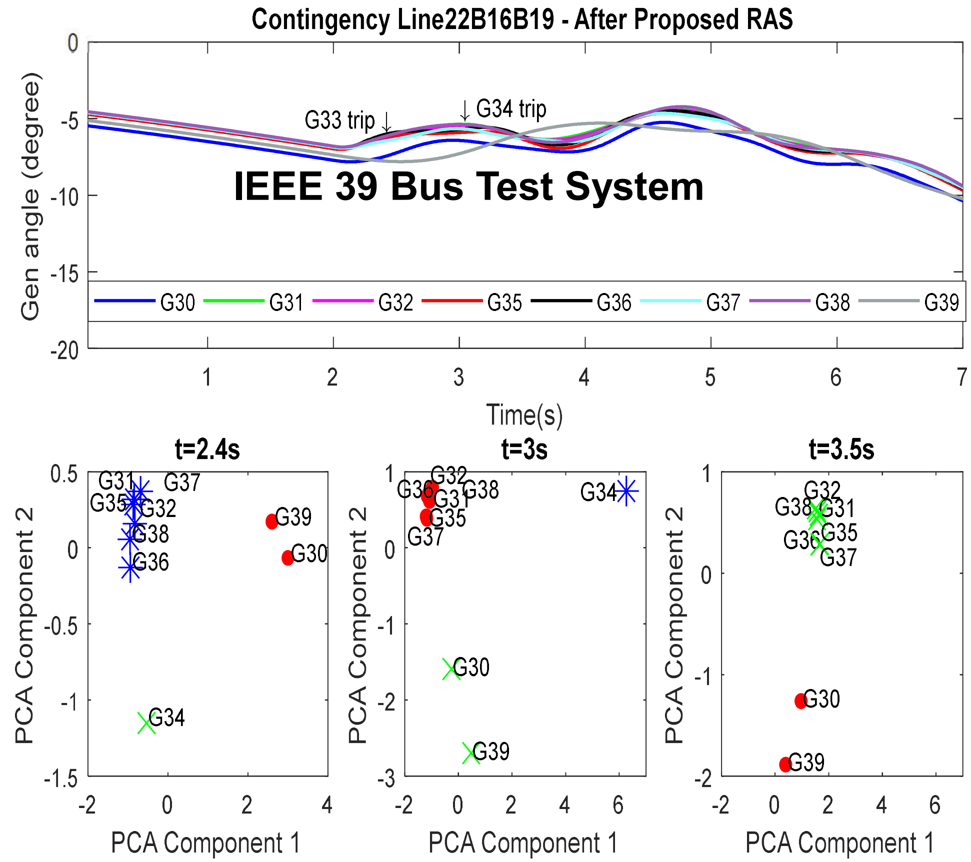
$$CM = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & \cdots & \alpha_{1N_g} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & \cdots & \alpha_{2N_g} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & \cdots & \alpha_{3N_g} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \alpha_{N_g1} & \alpha_{N_g2} & \alpha_{N_g3} & \cdots & \alpha_{N_gN_g} \end{bmatrix}$$



- Plot the first two principal components, cluster generators and monitor distances between them

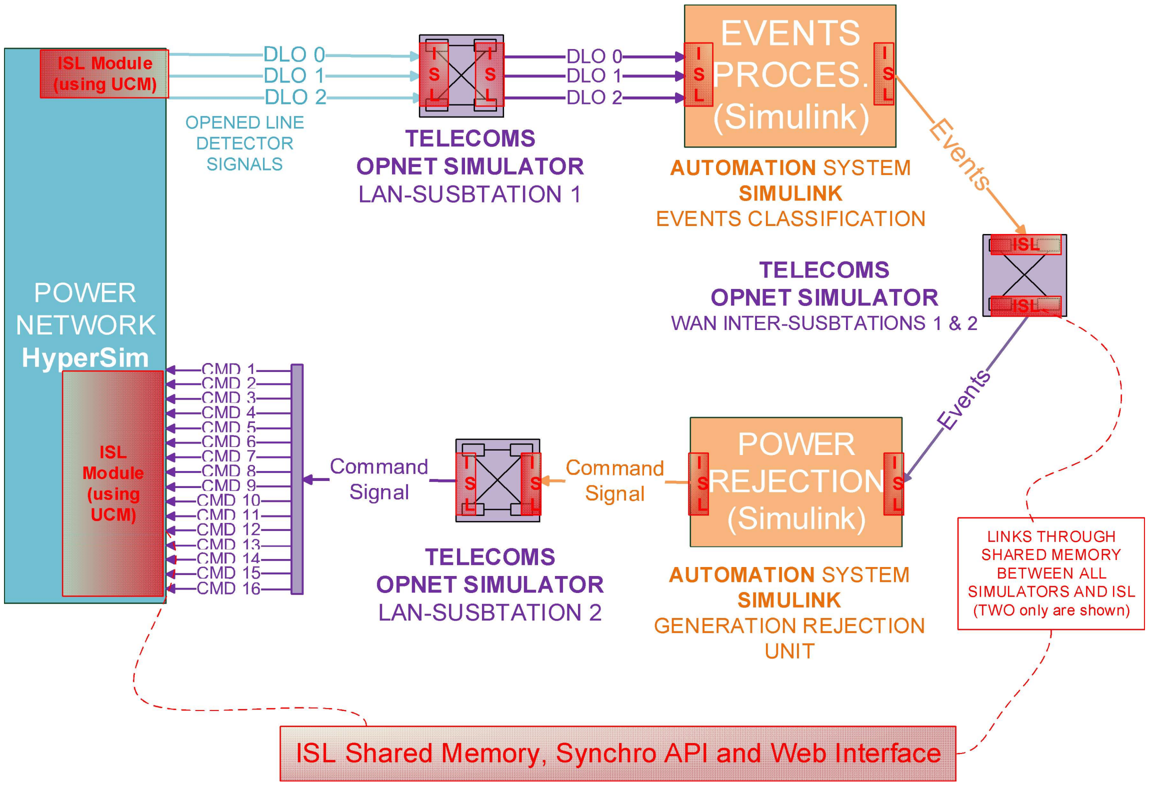
Centralized DSE-Based Multi Shot RAS





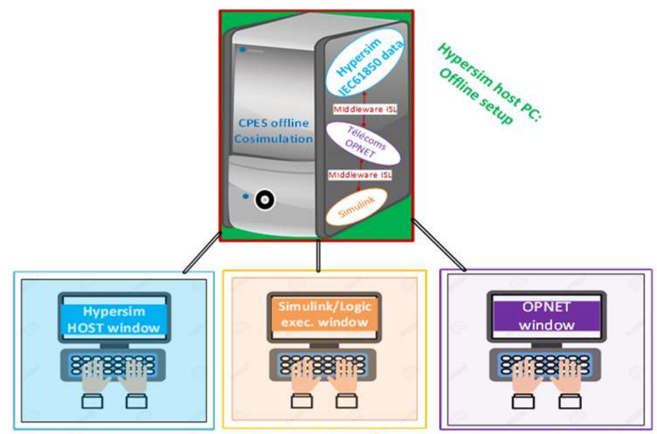
Network stabilization through multi-shot RAS scheme following a 3-phase fault and subsequent clearing by tripping Line22B16B19 and coherent generator group monitoring at t=2.4,3,3.5 s after first critical generator tripping

Use Case #2: Co-Simulation of Grid + Automation(SIL)+ICT
Fully Digital RAS to prevent blackout after the loss of three lines



Simulink blocs can be replaced by actual SEL Real-Time-Automation Controller (RTAC) devices for HIL-Simulation

- InsystemLab (ISL) is adopted: middleware with support of FMI/ HLA protocols, based on shared memory https://www.esims.tech/?lang=en
- Hypersim RTDS is synchronized with telecoms and Simulink at each time step.
- IEC 61850 GOOSE packet is formed within ISL in telecoms simulator to ensure proper load traffic and routing
- De facto parallel/distributed setup
- White-box co-simulation, using off-the-shelve preferred expert's simulators

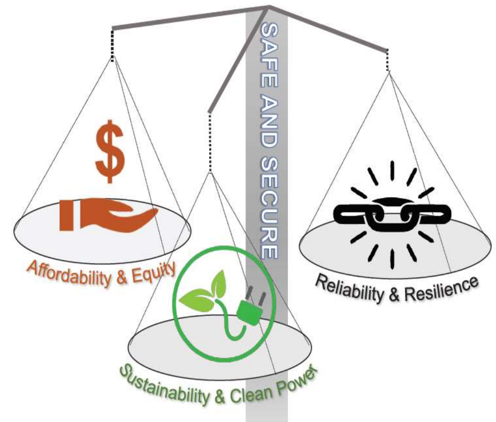


4. Scripting of 4D trajectories with awareness of the physical constraints of electricity networks and markets

Need: In the event of an explosion by the millions of DERs, script the optimal set of assets to replace, upgrade, move, or add in exploitable 4D networks

- Exploitation and planning studies considering millions of DERs, in millions of scenarios, with stable and exploitable network schemes:
  - DER everywhere, often behind the meter
  - Prioritizing the rehabilitation of the assets of an aging network
  - Decentralization via Transactive Energy and P2P Controls
  - Robust modeling of uncertainties at DER: prosumers, aggregators, ...
  - Digital communications and cybersecurity

Answer: Integrated simulation of production, transmission, distribution and consumption (PTDC)



Safety vs Affordability, Sustainability and Resilience: Unstable Balance?

Texas governor calls for investigation into grid operator over 'unacceptable' power outages 02/16/21 02:24 PM EST

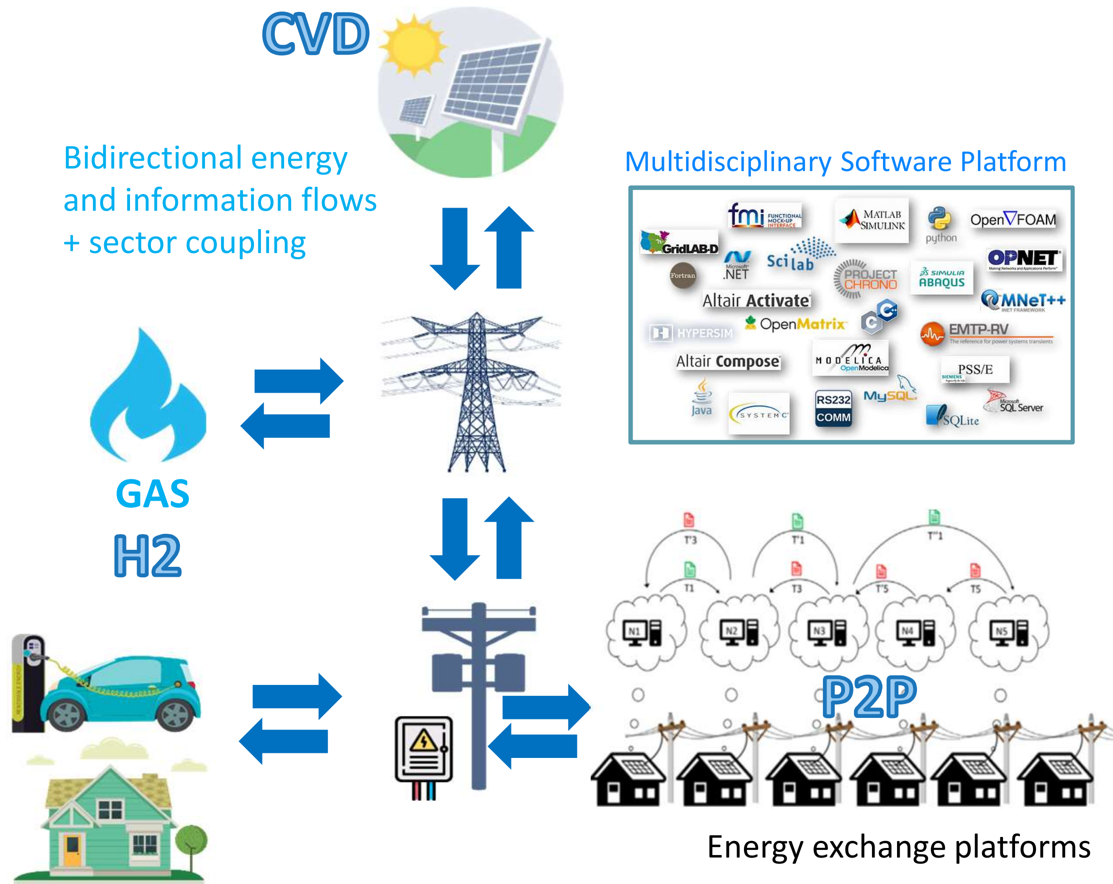
SM Mohseni-Bonab, A Hajebrahimi, I Kamwa, A Moeini, Transmission and distribution co-simulation: a review and propositions, IET Generation, Transmission & Distribution, 14(21), Nov. 2020, p. 4631 – 4642

The future of electric power in the United States - National Academy of Sciences (2021)

PTDC simulator as a demonstrator of emerging 4D concepts

- Cosimulation and co-optimization techniques with network and market constraints
- Uncertainty simulation techniques and robust probabilistic approaches
- Large-scale integration of hydrogen electric or hybrid vehicles
- Grid-aware P2P energy transactions and multi-layer electricity market modeling
- Iterative coupling to ensure precise convergence at T&D interfaces (compared to decoupled P-T and D-C cosimulation models)

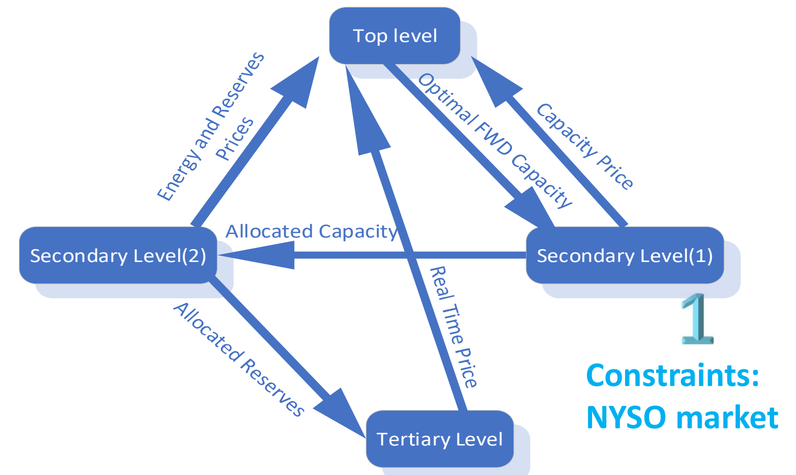
Maximizing 4D innovations



E. Sahraie, I Kamwa, A Moeini, Two-Layer Structure for Initial Settings of Power-To-Hydrogen Devices in the Electricity System, IEEE Canada Electric Power Conference, Toronto, Oct 2021

Network and Markets Conscious Storage Scripting

- Income: Market auctions Capacity, Day-Ahead + Real time, Operating reserves + Emergency reserves
- Costs: investment, operation, replacement, Day-Ahead + Real-time energy markets

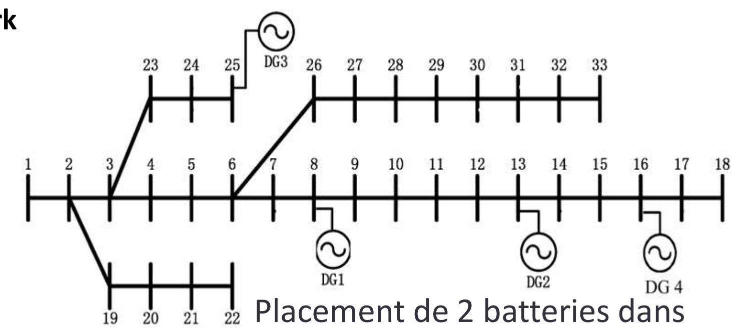


1) Investment Decision: Optimal Size (NYISO)

Maximize profit	ROR	NPV	ROI	Decision
Investor	1.82	76M$	6.27	50 MW
System Operator	2.86	1 422M$	5.33	491 MW

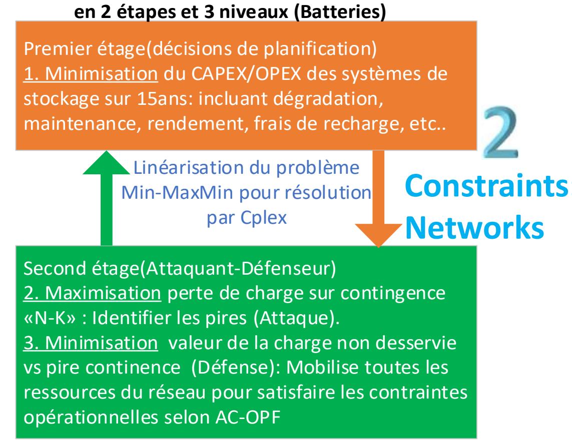
2) ↑ Resilience in an active distribution network

Scenario: Loss of 1, 2, ... 6 lines	Avec Stockage
	Perte de charge
$N-1$	-9%
$N-2$	-29%
$N-6$	-27%



Placement de 2 batteries dans le réseau IEEE 33 bus test system

Allocation du stockage par optimisation Min-MaxMin, en 2 étapes et 3 niveaux (Batteries)

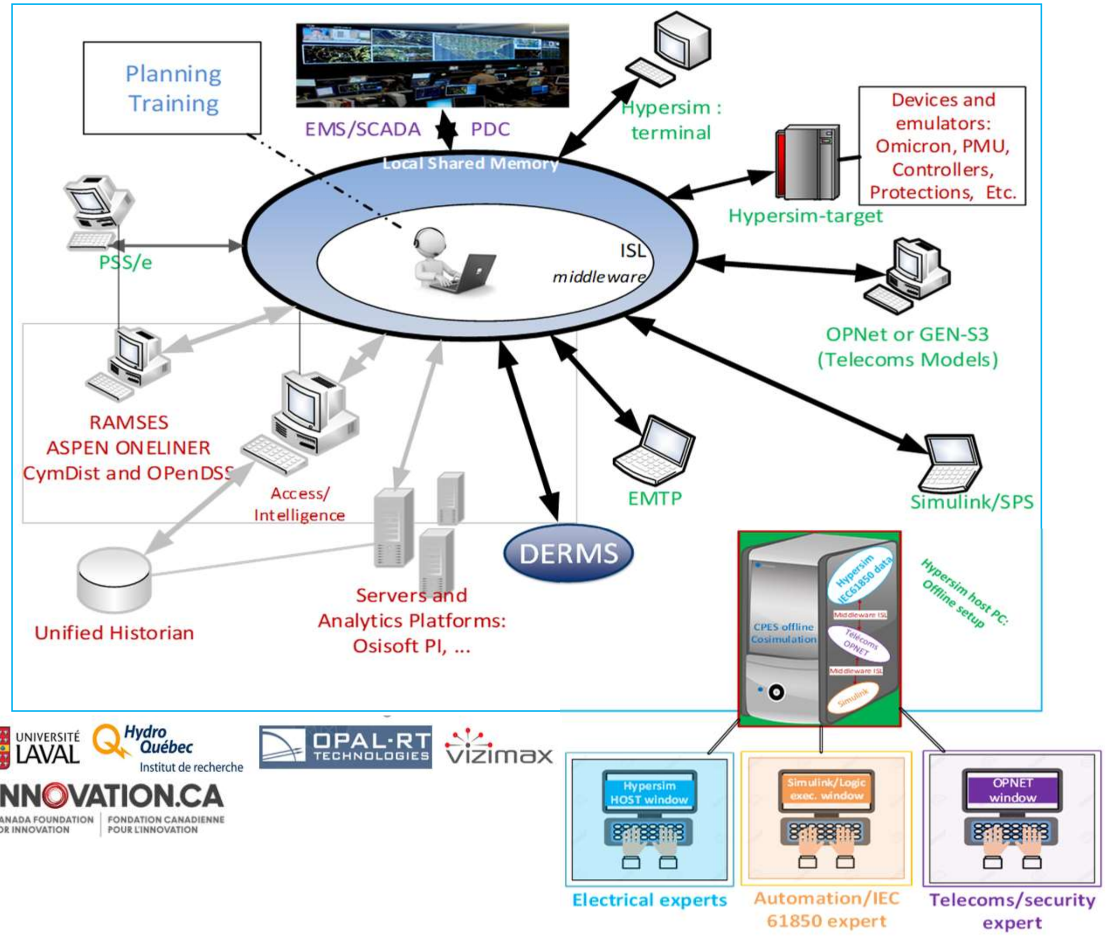


A. Alizadeh, I. Kamwa, A. Moeini, M. Mohseni-Bonab, Toward A Consensus on Financial Assessment of Battery Energy Storage System, Technical report, Ulaval, June 2021

5. Co-simulation platform for the training of qualified personnel in 4D networks

Simulation of electrical systems + telecoms + bulk and P2P markets + Controllers, EMS, SCADA

- Replicas of central energy management systems (EMS, DERMS) in // with zone coordinators and local inverter controls >>> simulations with very precise representation of each dynamic range of T&D
- Detailed representations of DER, micro-grids, bulk and telecom networks with their interrelationships
- The high fidelity of this platform makes it a true digital twin of the smart grid.

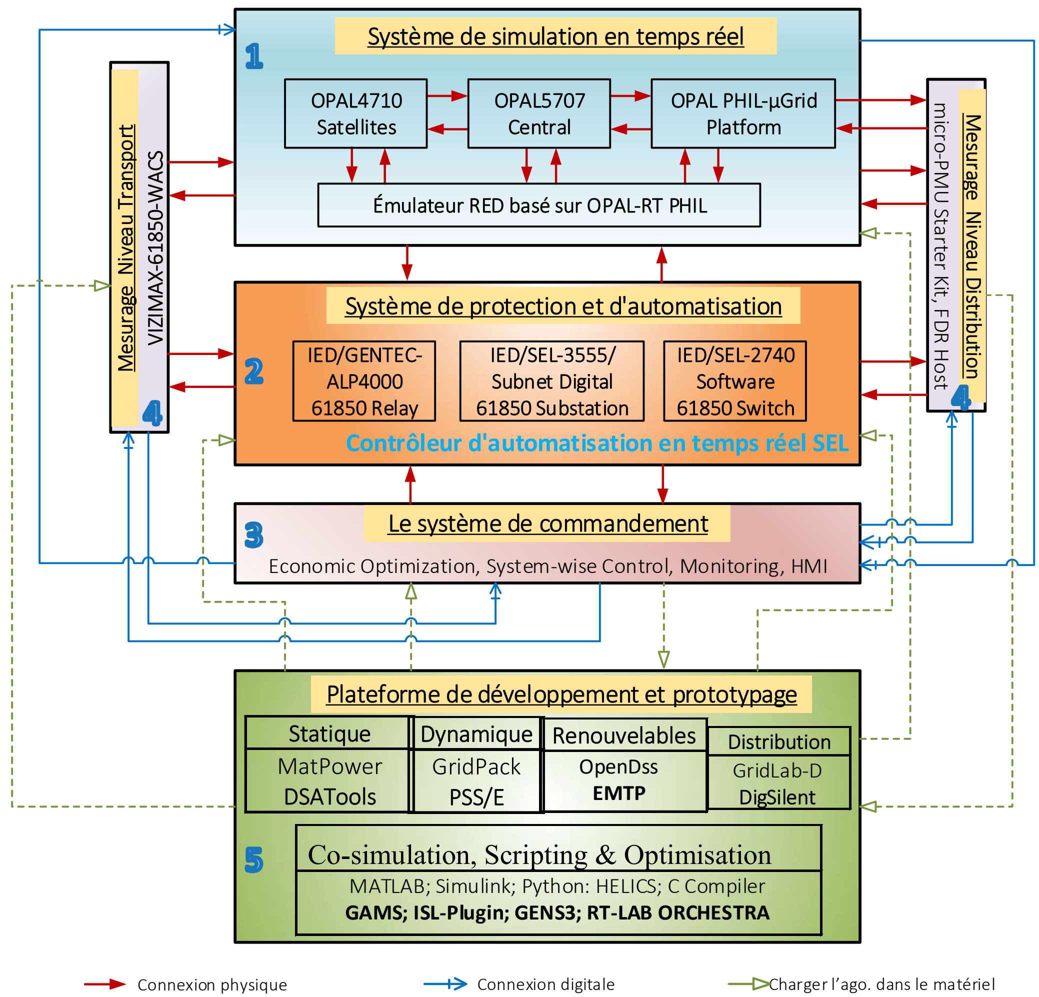


D Rimorov, J Huang, CF Mugombozi, T Roudier, I Kamwa , Power Coupling for Transient Stability and Electromagnetic Transient Collaborative Simulation of Power Grids, IEEE Transactions on Power Systems, Early Access June 2021

Research infrastructure at Laval University (650k$CAD)

- **Already exists:**
  1. Real-time simulation subsystem
  2. Protection and automation subsystem
  3. The control subsystem
  4. Measurement subsystem
  5. Development and prototyping platform

- **Will be developed:**
  1. µPMU algorithm for distribution level measurement (ROCOF)
  2. Grid-forming converters with storage on the PHIL-µGrid platform
  3. AI-inspired control and protection applications for the command system
  4. AI-powered autonomous and clustered DC microgrids



Concepts
For real-time simulation

Back to overview

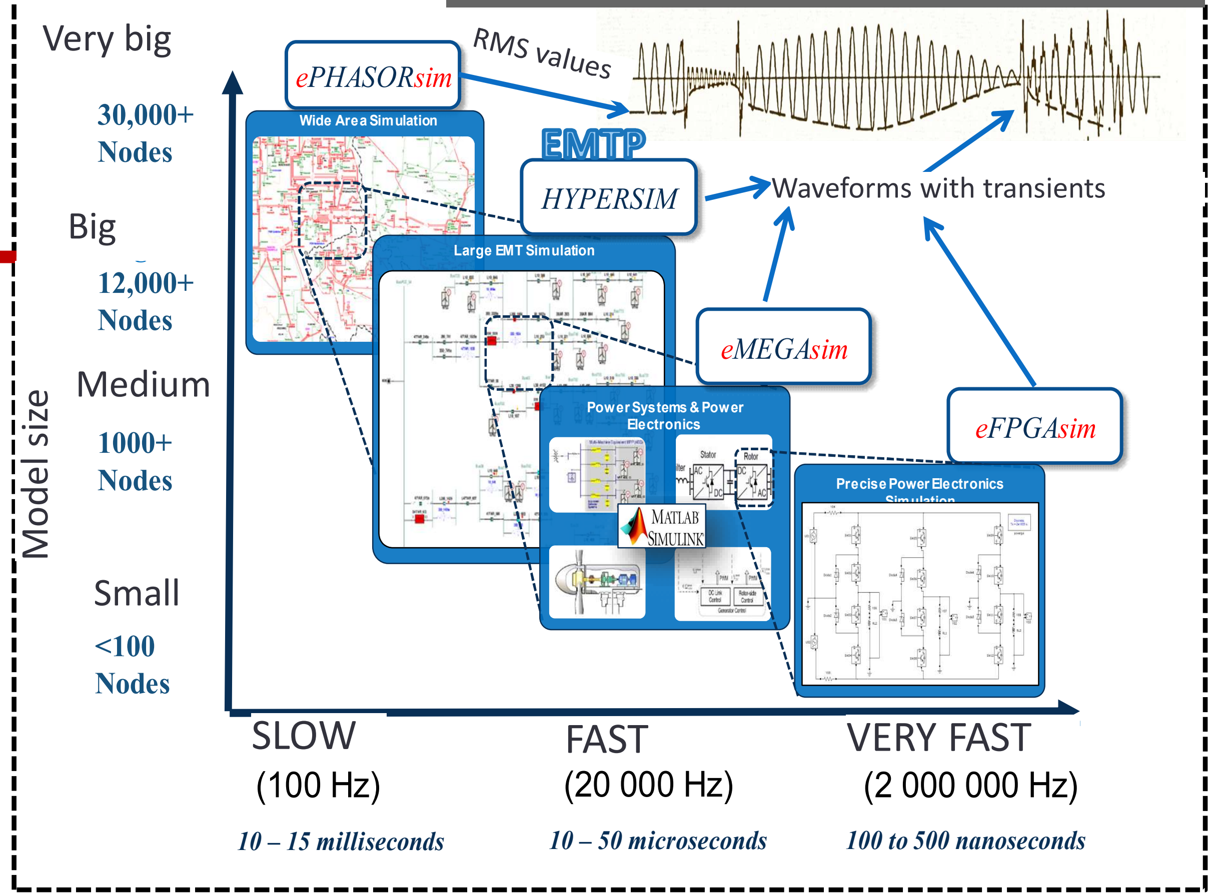
A large simulator with 16 processors to simulate a large power network

More than 1200 single-phase nodes simulated with a step of 3msec

Different simulation requirements

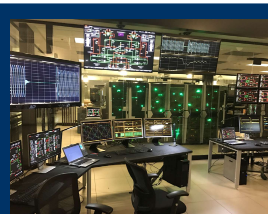
Three small 4-core simulators to simulate single or cluster REDs

Software suite for real-time simulation of power grids by OPAL

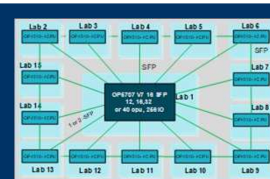


Unique laboratory in academia Serving the teaching of engineering sciences

The only university infrastructure offering a real-time simulation environment that can accurately represent the temporal dynamics of real-world 4D networks



Multi-rate simulation capability, from µs to min in this unique platform



Its high scalability allows up to 25 HQPs working simultaneously to study a wide range of decentralized smart grid issues.

With high quality components, such as OPAL-RT simulators, SEL IEDs and Vizimax PMUs, the platform can produce credible research results..

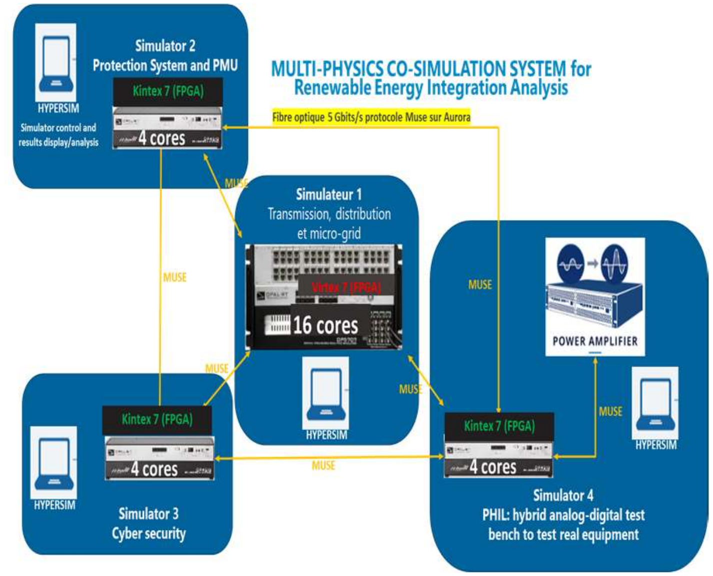
Engineering Sciences

- Electrical system planning, operations, stability control and resilience assessment.
- Algorithms for signal processing, data analysis and machine learning
- Control techniques: “retrofit control”, “model predictive control” and “AI based control” approaches.
- Robust multi-objective optimization using the scenario tree approach and uncertainty modeling.
- Real-time simulation of electrical networks with power equipment in the loop.
- Cosimulation of electrical, IT and telecoms infrastructures.

Université Laval | Hydro Québec Institut de recherche | OPAL-RT Technologies | Vizimax | Innovation.ca Canada Foundation for Innovation / Fondation canadienne pour l'innovation

Technological outcomes

Intelligent, autonomous and cluster power systems capable of forming networks	• to enable new ways to maximize the benefit of variable energy resources and propel sustainable mobility
Decentralized transactional systems that empower electricity consumers	• by transforming them into active participants equipped with green energy supply technologies behind the meter.
Planning and operations tools and strategies maximizing the use of flexibilities offered by new technologies	• by ensuring the security of the network without spills of wind / solar energy or equipment overload, and its resilience in the presence of uncertainties
Data-driven measurement, control and automation systems	• to maintain dynamic stability and reliability of systems dominated by smart inverter DERs



Agenda

https://scholar.google.ca/citations?user=1f6ZwegAAAAJ&hl=en
https://ulaval.academia.edu/InnocentKamwa
https://www.researchgate.net/profile/Innocent-Kamwa
https://www.linkedin.com/in/innocent-kamwa-1a543423/

4th International Symposium on Smart Grid Methods, Tools, and Technologies

Jinan, China

29-30 October, 2021

http://www.intesgmt.sdu.edu.cn/