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Towards Digitalization in Smart Grids

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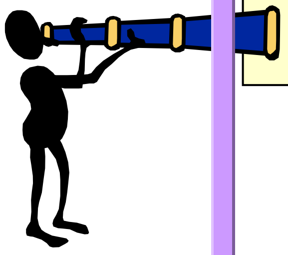
CEA Liten – INES (National Institute for Solar Energy)

Workshop Digitalization, Stability and Protection
Grenoble, 11 -12 June 2025

PLAN



Introduction

Digitalization via applications

- Forecasting (Load, PV, Wind)
- Co-simulation
- Digital Twin
- Distributed & edge cloud control
- Stability
- Protection
- Optimization; Energy management
- Storage
- EV
- DC grid
- Demonstrations

Conclusion

Solar PV energy development - World

		Cum.Capa. 2024 (GW)	2024 Prod. (TWh) Prod./cons (%)	Cum. Capa. 2023 (GW)	2023 Prod. (TWh) Prod/cons (%)
1	China	(+277) 938		(+ 216,88) 609,92	584.15 (6.2%)
2	USA	(+50) 180		129.21	238.12 (5.6%)
3	Japan	(+6.2) 93.27		87.07	96.99 (9.6%)
4	Germany	(+17.4) 99.1	72.2	(+14.3) 81.7	61.22 (12.1%)
5	India	(+30.7) 100		73.11	113.41 (5.8%)
6	Australia	(+3) 37		33.68	44.99 (16.5%)
7	Italy	(+6.8) 37.5		29.8	31.01 (11.8%)
8	Brasil	(+18.9) 56.4		37.45	51.48 (7.3%)
10	South Korea	(+2.5) 30		27.05	29.37 (4.8%)
11	Spain	(+8.7) 40		31.02	45.08 (16.7%)
9	Netherlands	(+3.1) 27		23.9	19.99 (16.6%)
12	Vietnam	~20		18.6	25.70 (9.3%)
13	France	(+3.2) 23.7	23.3	20.5	23.25 (4.5%)
	World	(+600) 2000		1419.0	1632.33 (5.5%)

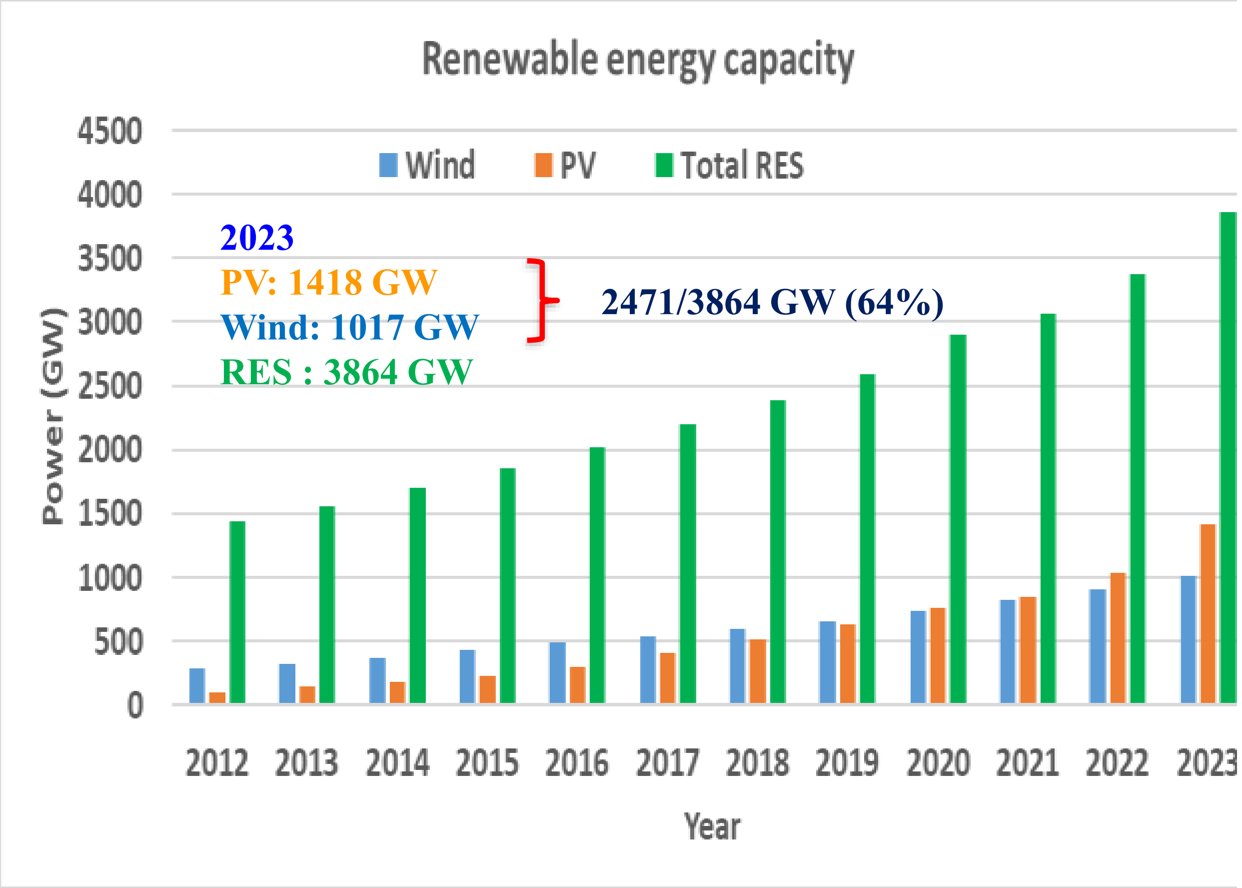
World installed 600 GW of solar in 2024, could be installing 1 TW per year by 2030

Source: https://www.solarpowereurope.org

Installed capacity in 2020

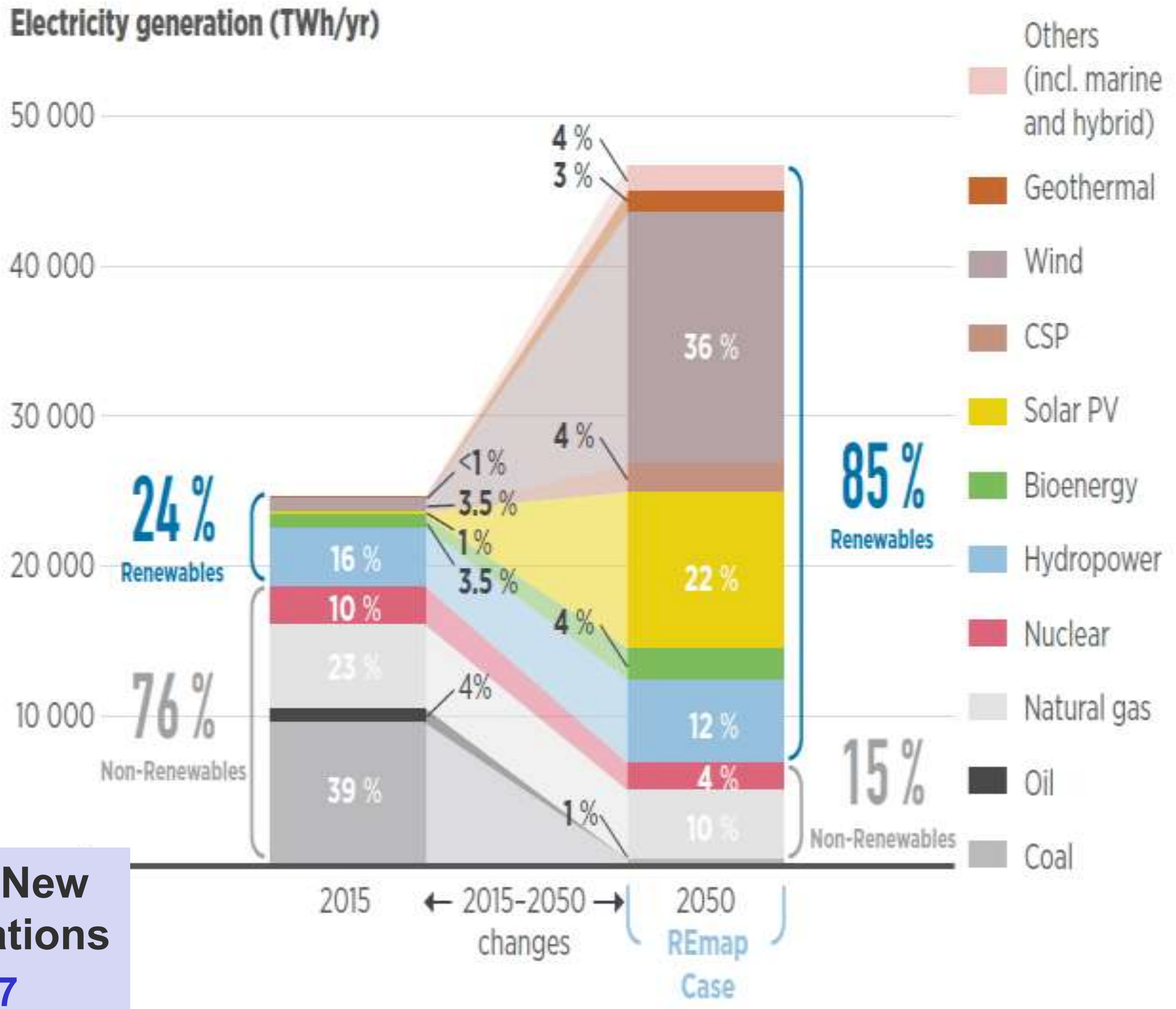
Ranking	Country	P_Installed	P_Accumulated
1	China	49.655	254.355
2	United States	14.890	75.572
3	Vietnam	10.909	16.504
4	Spain	5.378	14.089
5	Germany	4.583	53.783
6	India	4.122	39.211
7	Japan	4.000	67.000
8	Netherlands	3.488	10.213
9	South Africa	3.429	5.990
10	South Korea	3.375	14.575
	World total (GW)	**133.210**	**760.000**

Source: wikipedia



https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2023.pdf

Forecast for renewable energies until 2050 (IRENA)



chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fwww.irena.org%2F-%2Fmedia%2FFiles%2FIRENA%2FAgency%2FPublication%2F2018%2FApr%2FIRENA_Report_GET_2018.pdf&clen=4135242&chunk=true

Worldwide	Wind Total Capacity	Wind New Installations	Solar Total Capacity	Solar New Installations
2024 (GW)est	1170	150	2200	597
2023 (GW)	1017	111	1418	365

Digitalization in smart grids – Why

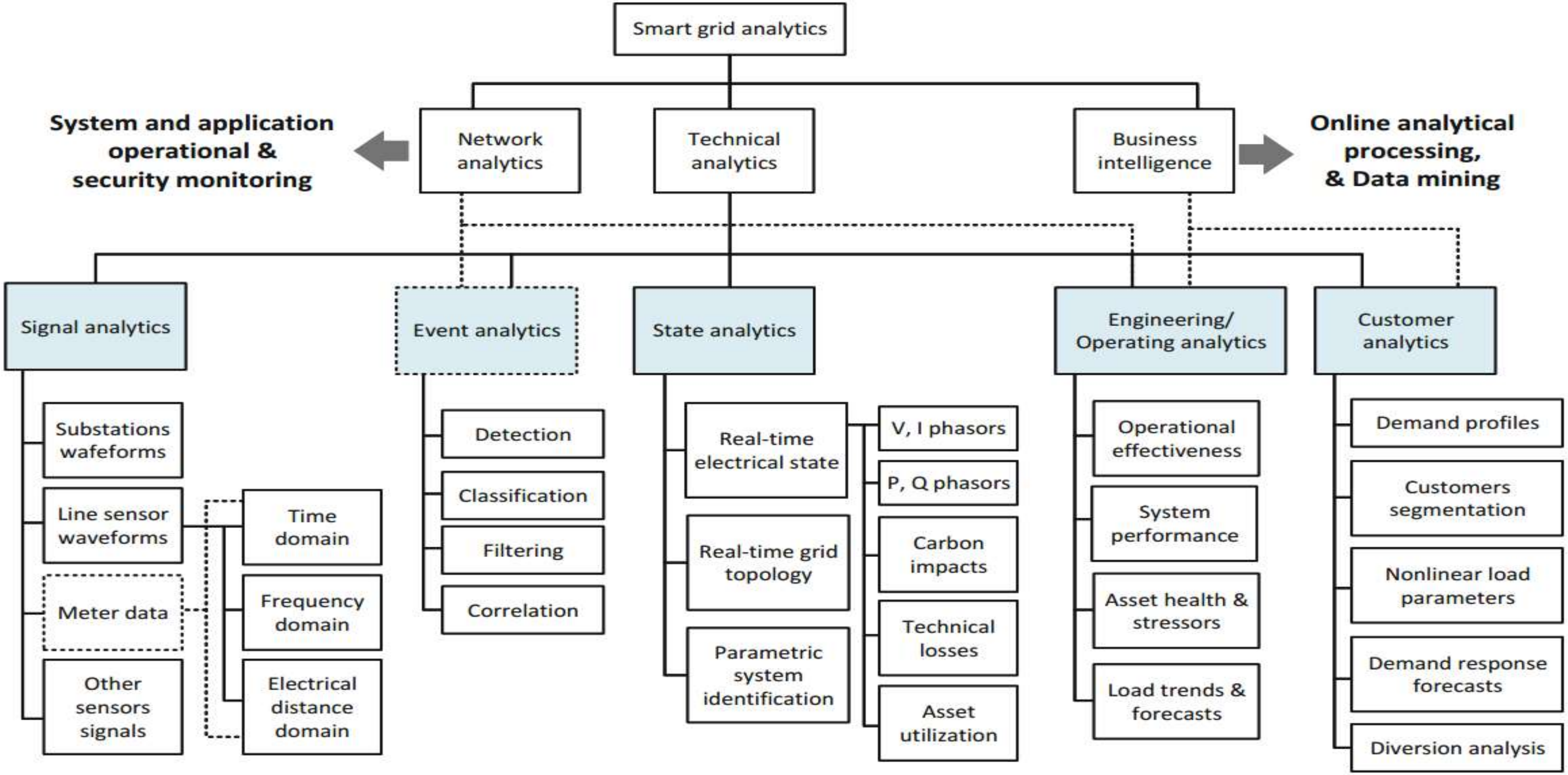
Digitalization transforms traditional power grids into intelligent, more soustainable, more flexible, safer, more efficient, and more resilient systems

- Complexity of Modern Power Systems
  - Multi-energy (elec, head,…)
  - Distributed Energy Resource (DER as RES) integration and
  - Electric vehicles, storage and load control
  - Different actors, markets…
- Real-Time Monitoring and Control
- Demand Forecasting and Energy Management
- Interoperability and Flexibility
- Cybersecurity
- Clean energy transitions (Net zero)
- …

Digitalization - Applications

- Integration of renewable energy, Real-time balancing of variable solar and wind energy
- Support for Distributed Energy Resources (DERs) Integration: RES, batteries, EV, …
- Real-Time Monitoring and Control (monitoring and control of voltage, frequency, load, fast fault detection, isolation, and self-healing)
- Advanced Data Analytics & AI use of big data and machine learning for demand forecasting, outage prediction, and asset management; AI-driven decision-making for grid optimization and predictive maintenance
- Dynamic grid control to stabilize supply and demand
- Smart Meters (ex: Linky)
- Protection, Grid Automation and Self-Healing Systems
- Real-time simulation and co-simulation
- Digital Twin
- Supports the transition to low-carbon and net-zero energy systems

Ex: Smart Grid analytics

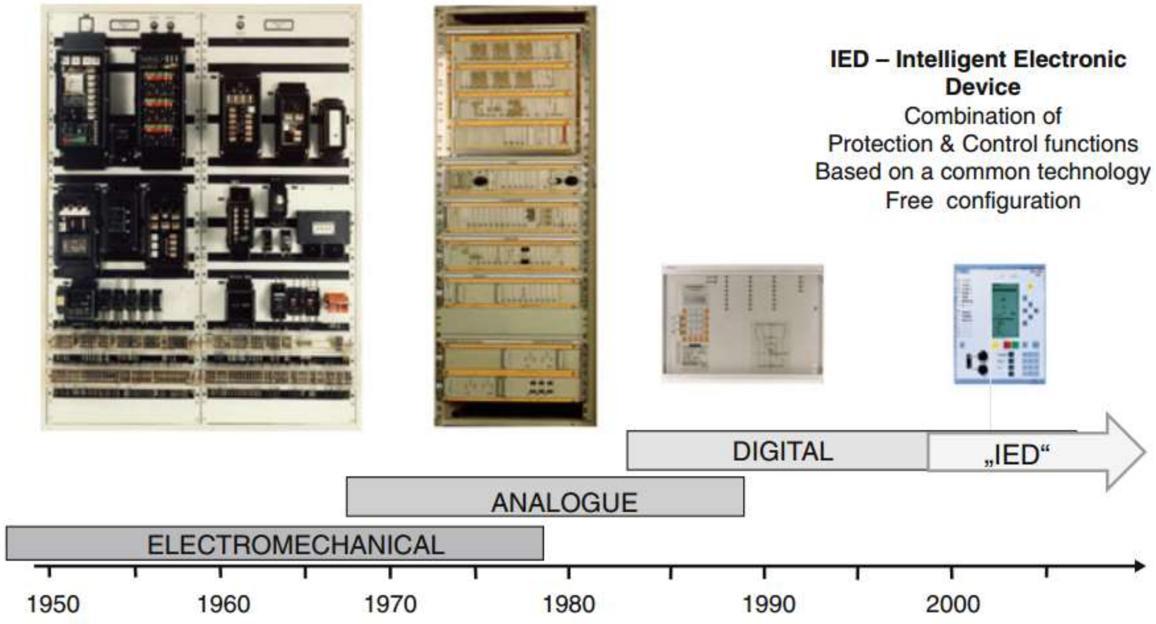


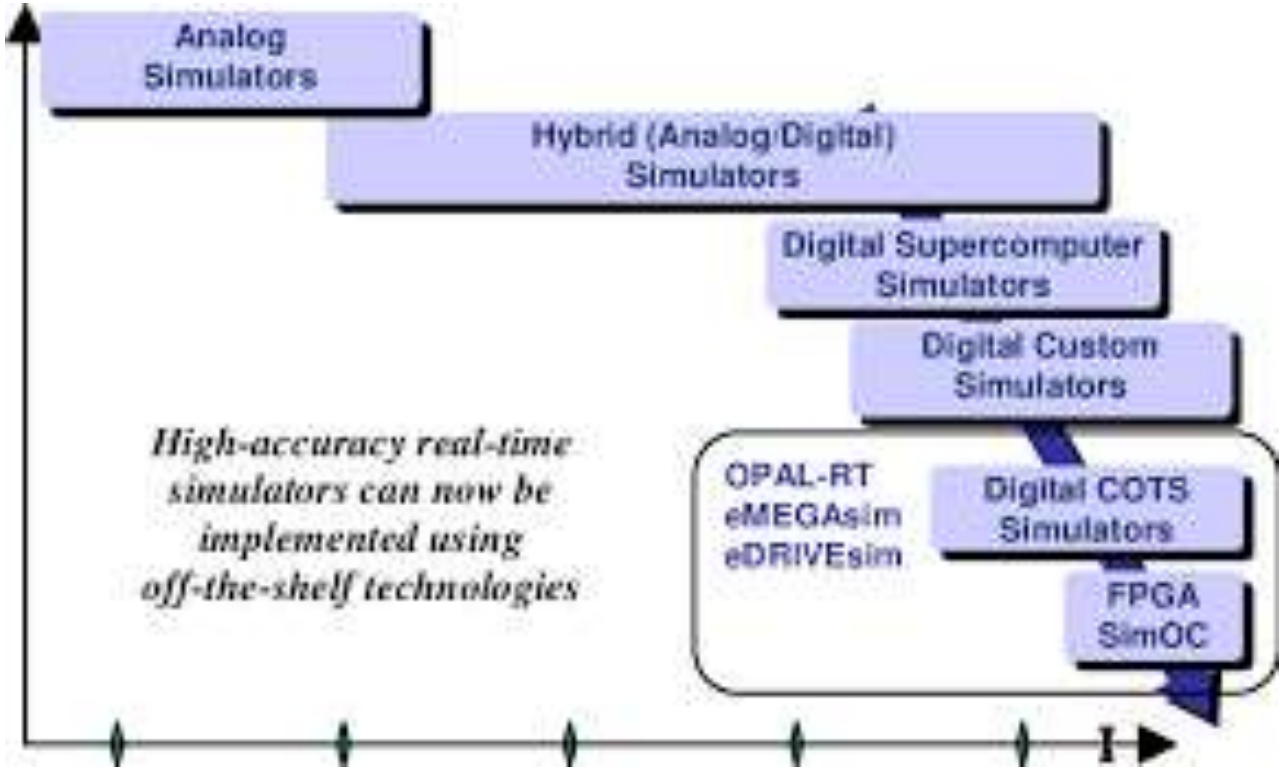
AI applications for smartgrid

- Forecasting
  - *Load Forecasting*
  - *PV Forecasting*
  - Wind *Forecasting*
- Energy management
- Advanced Control (ex: VoltVar Control, edge-cloud)
- Power Grid Stability Assessment
- Protection; Faults Detection
- Smart Grid Security
- Diagnostic

…

Evolution from analog & mechanical to digital solution





Relays
Meters
Simulators (OPAL, Morgat, EMTP…)
Digital twin
…

En France EDF: Morgat, Arene

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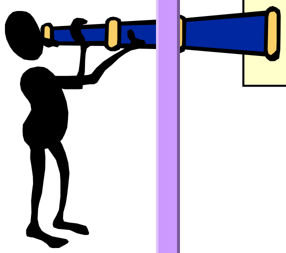

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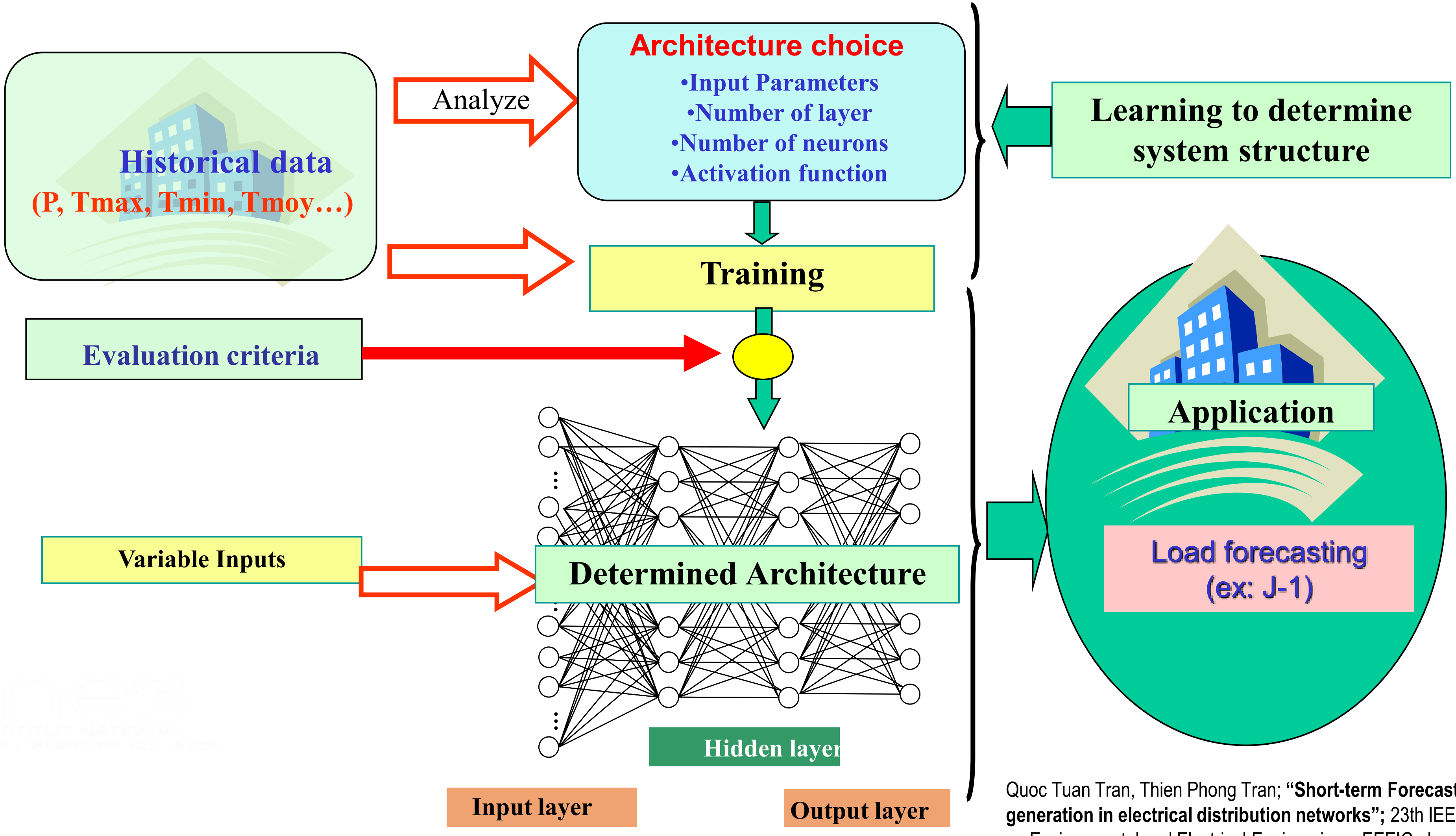
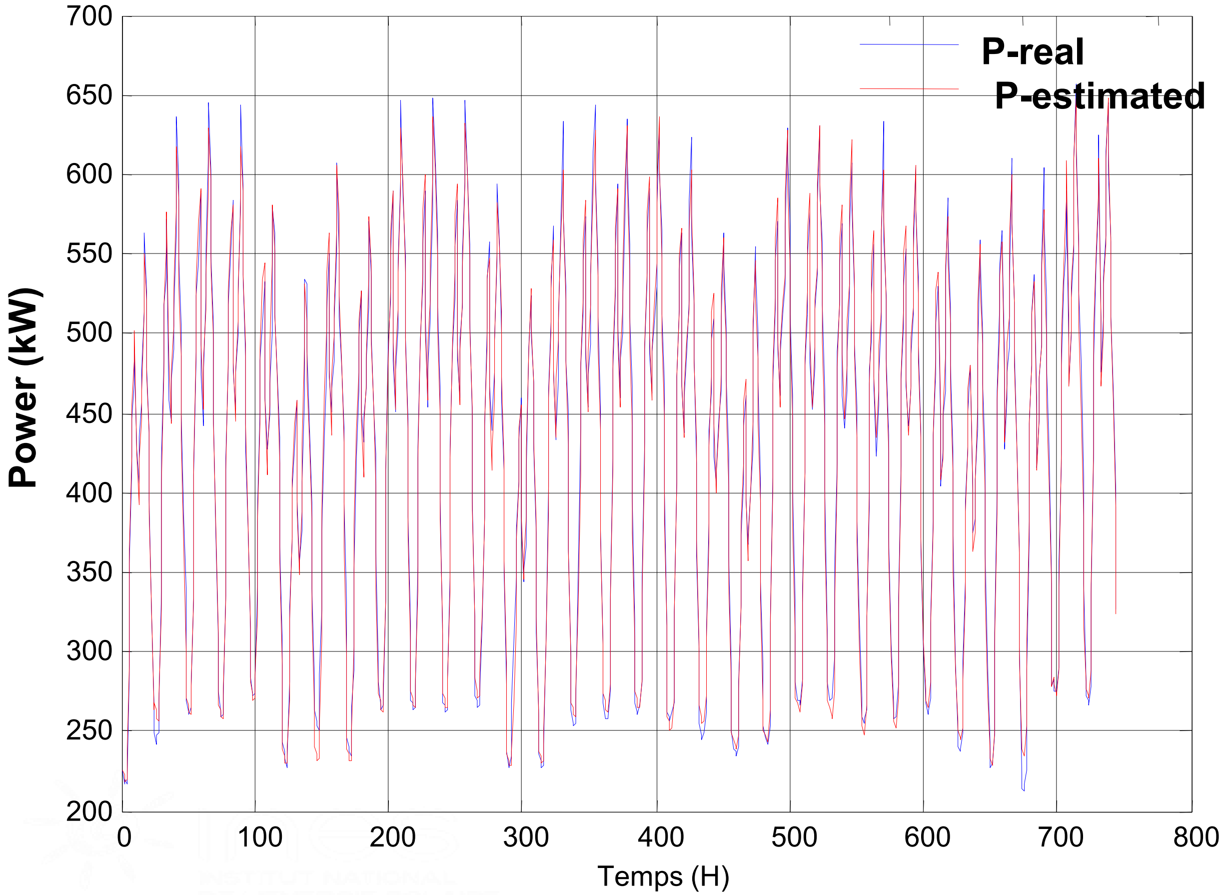
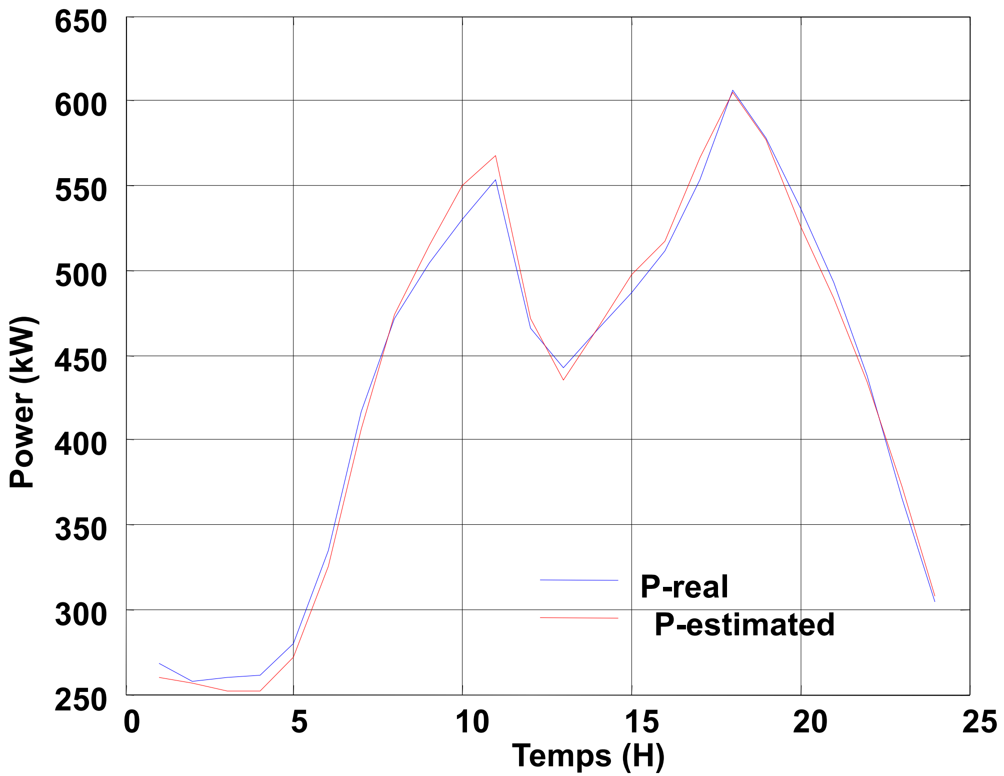
Load forecasting: Neural networks



Quoc Tuan Tran, Thien Phong Tran; **"Short-term Forecasting for load and solar generation in electrical distribution networks";** 23th IEEE International Conference on Environmental and Electrical Engineering – EEEIC, June 2023, Madrid, Spain:
DOI: 10.1109/EEEIC/ICPSEurope57605.2023.10194874

Load forecasting: Neural network

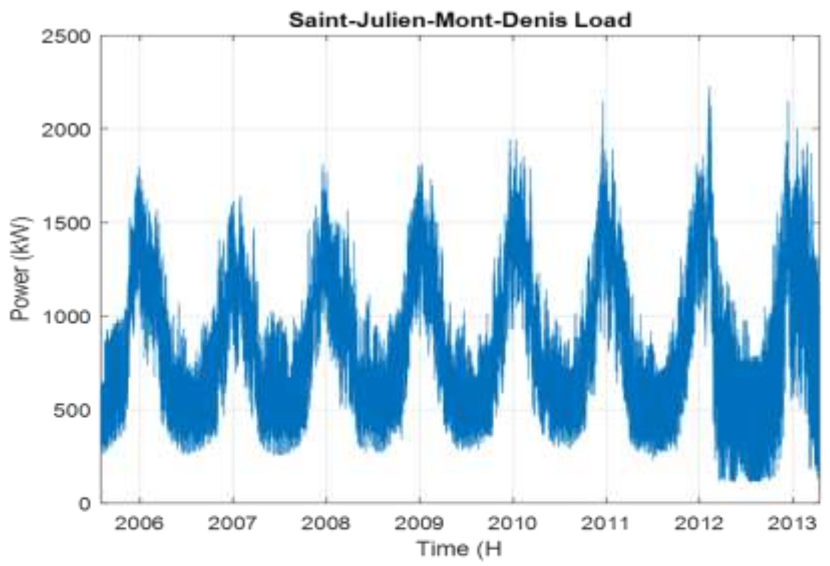


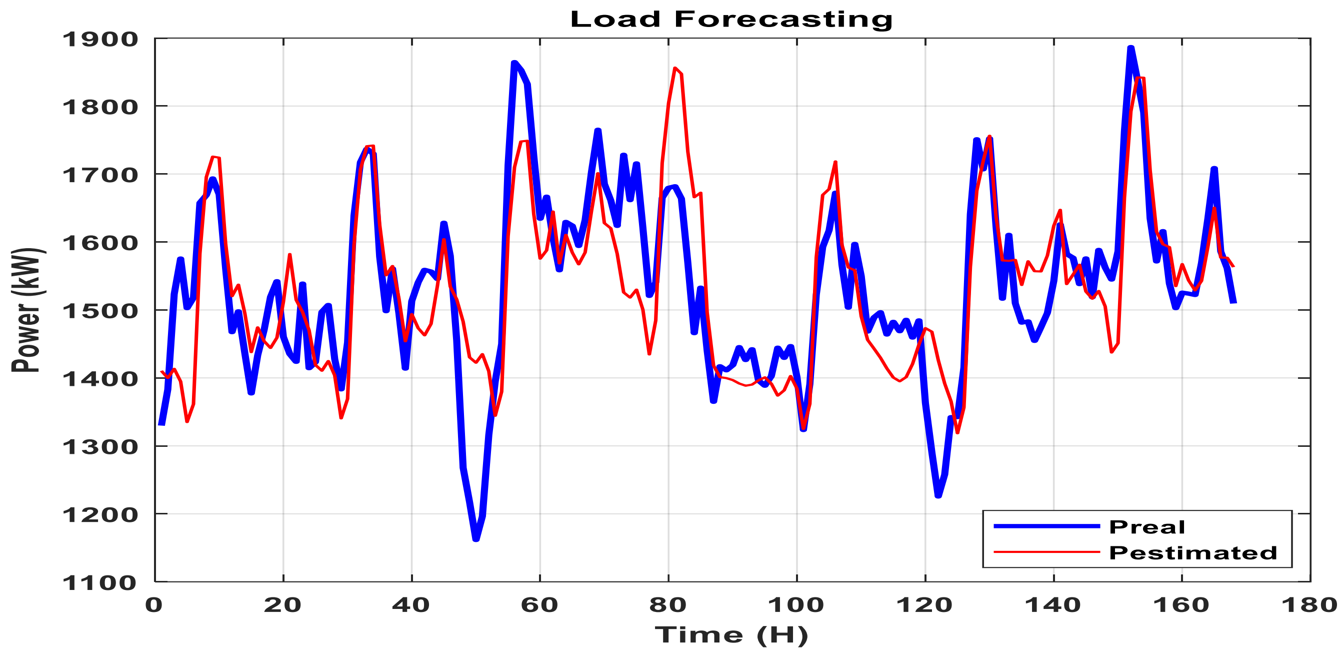


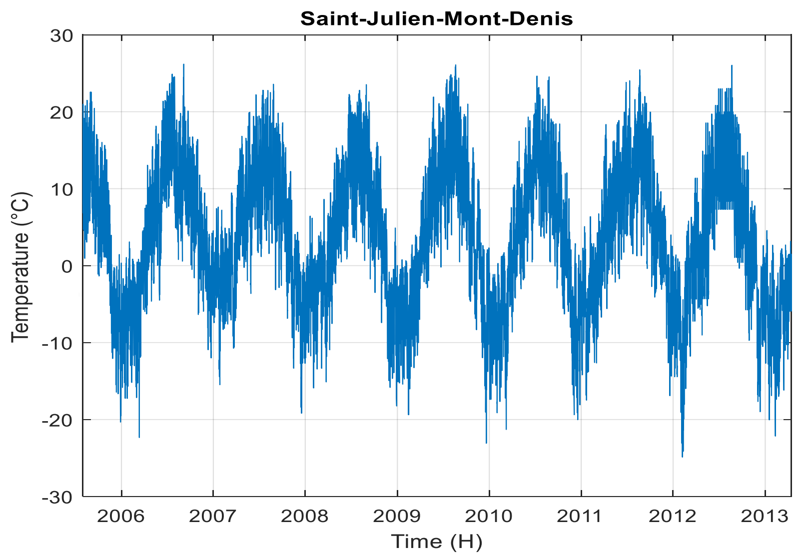
Maximal absolute error = 13%

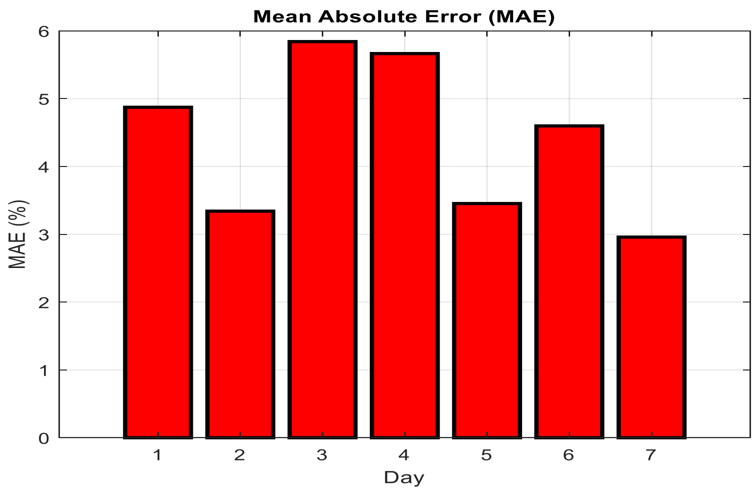
RMSE < 6%.

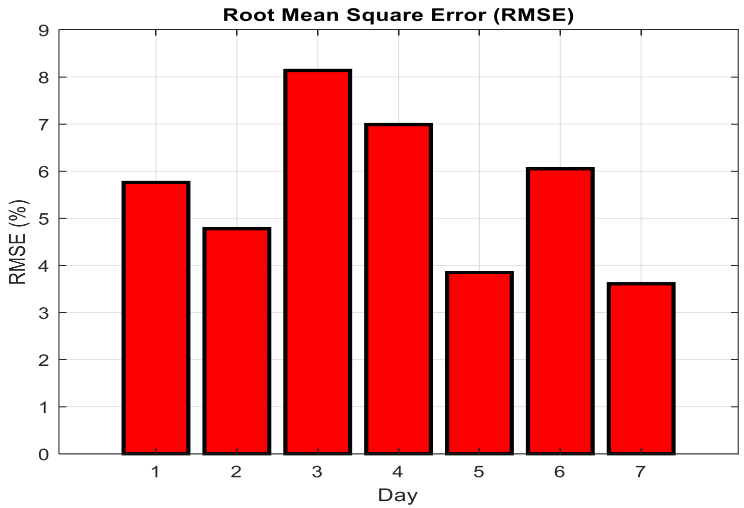
Load forecasting: SOREA







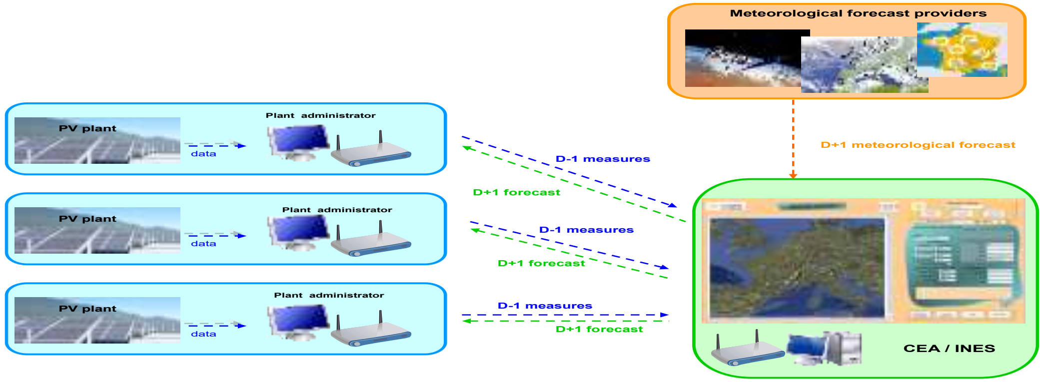




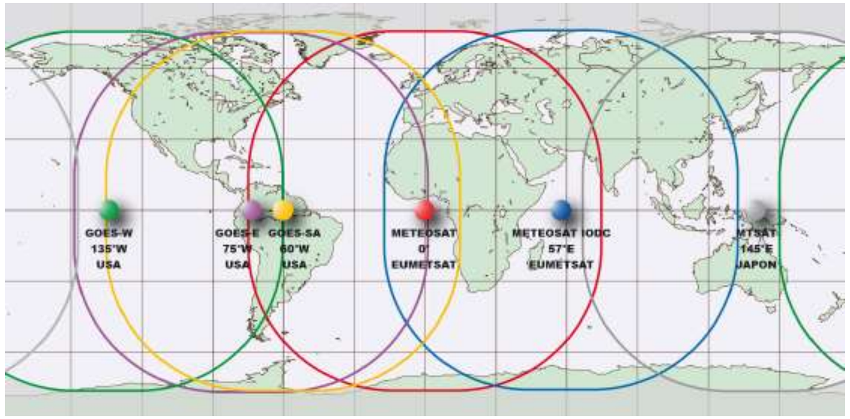
PV forecasting (Developped by CEA INES)

EU project: United grid; No. 773717

1 Day-ahead forecasting based on meteorological data



2 Short-term forecasting based on satellite images (hourly)

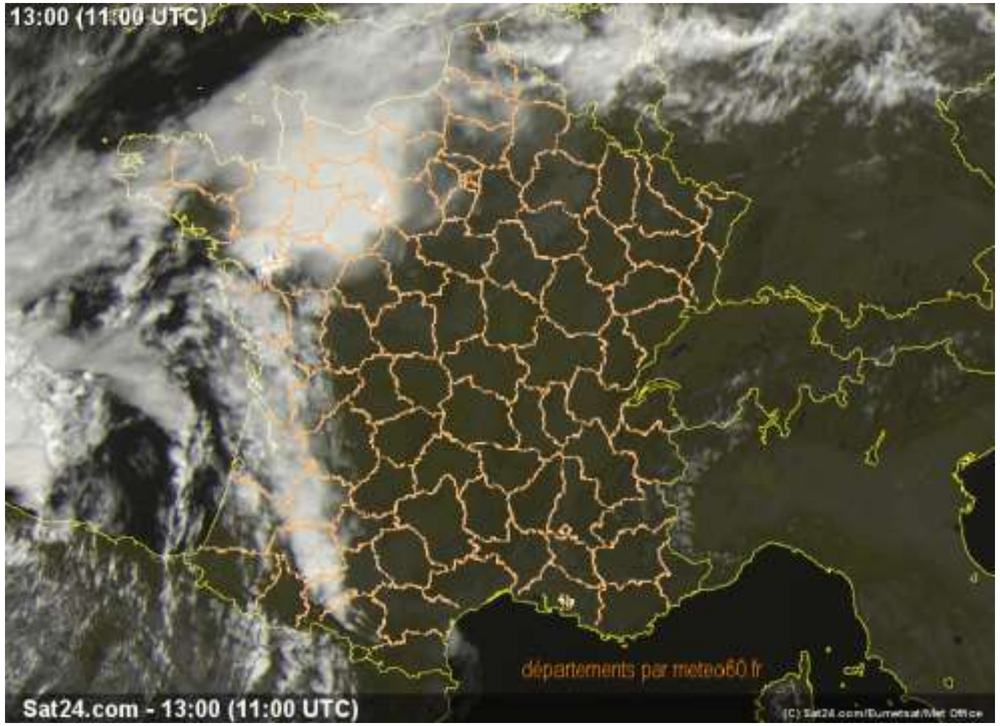


3 Very short-term forecasting based on sky camera (a few minutes)

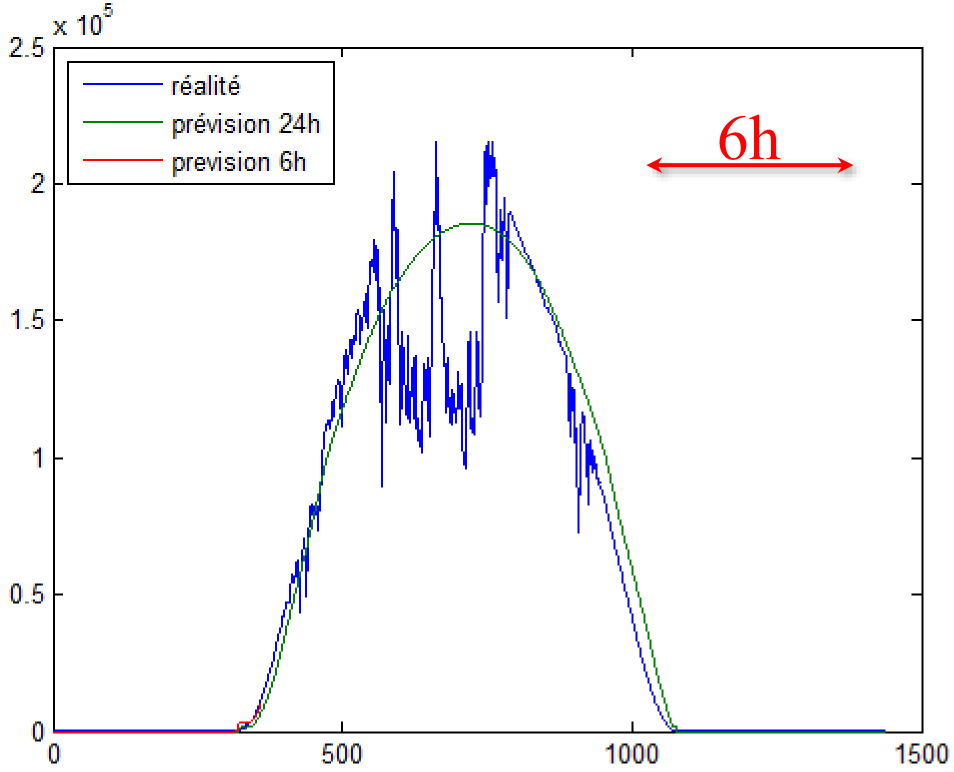
Data needed

Historical Solar Power Generation
Solar Radiation Data
Weather Data
Weather Forecast Data
Numerical Weather Prediction (NWP) Models
PV System Characteristics
Time of Day and Seasonal Data
Sky Imagery data
Satellite Data
Seasonal and Inter-annual Variability
…

Quoc Tuan Tran, Thien Phong Tran; **"Short-term Forecasting for load and solar generation in electrical distribution networks"**; 23th IEEE International Conference on Environmental and Electrical Engineering – EEEIC, June 2023, Madrid, Spain: DOI: 10.1109/EEEIC/ICPSEurope57605.2023.10194874

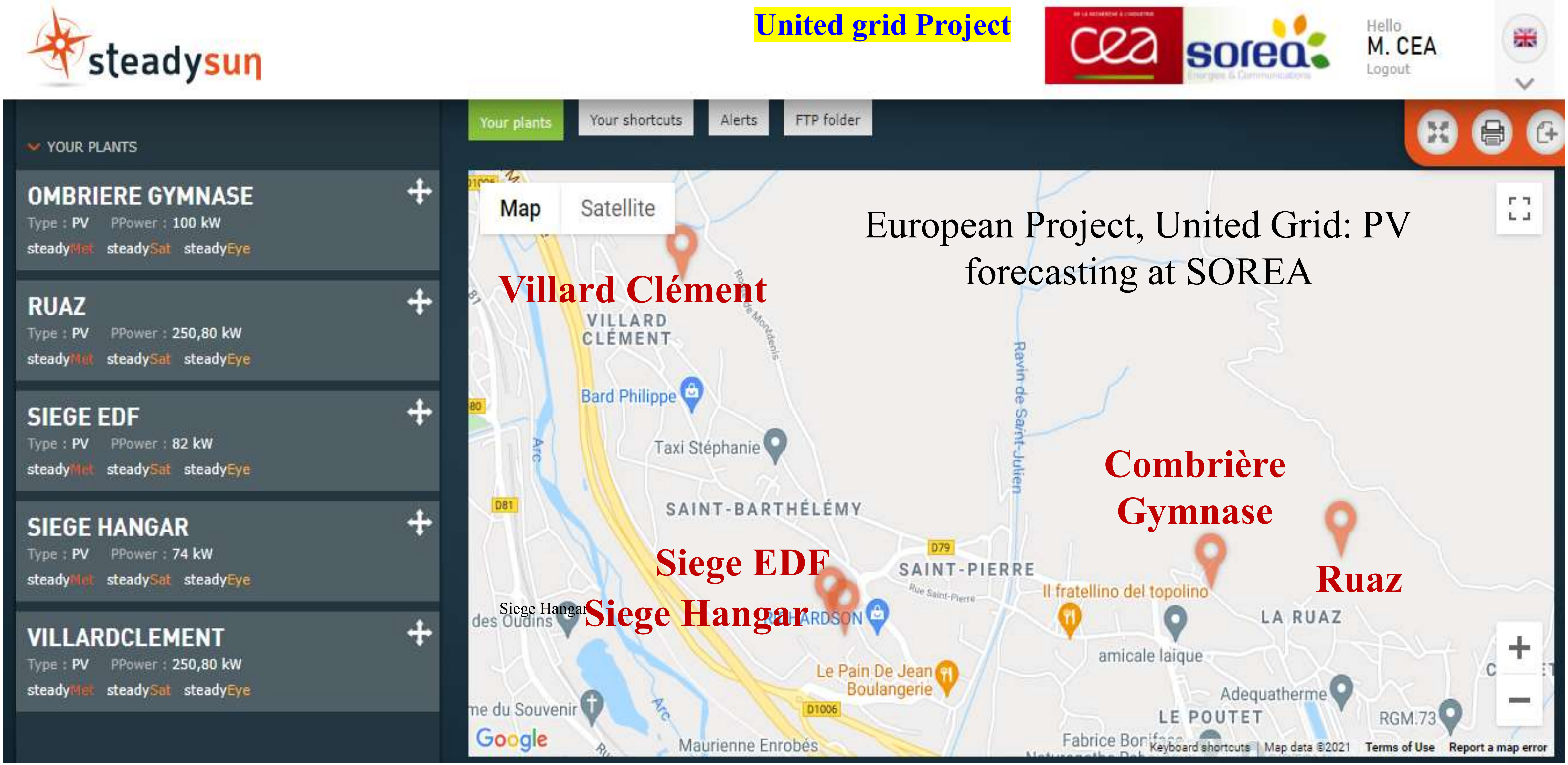


Principle: Use satellite images to predict the evolution of clouds in the short term (<6h) and therefore estimate photovoltaic production



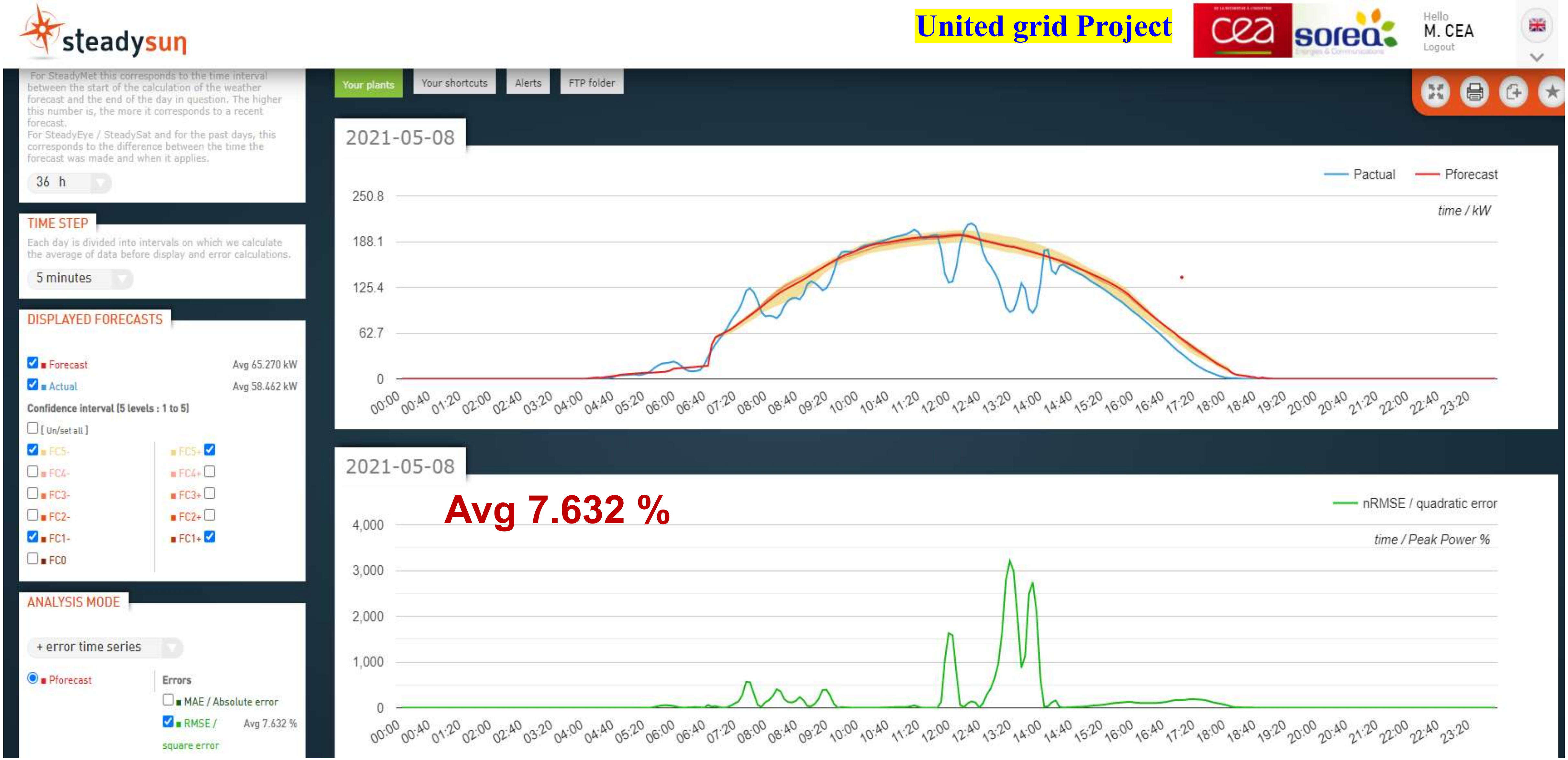
Example of forecasts updated every 15 minutes with a 6-hour horizon

Ex: PV forecasting



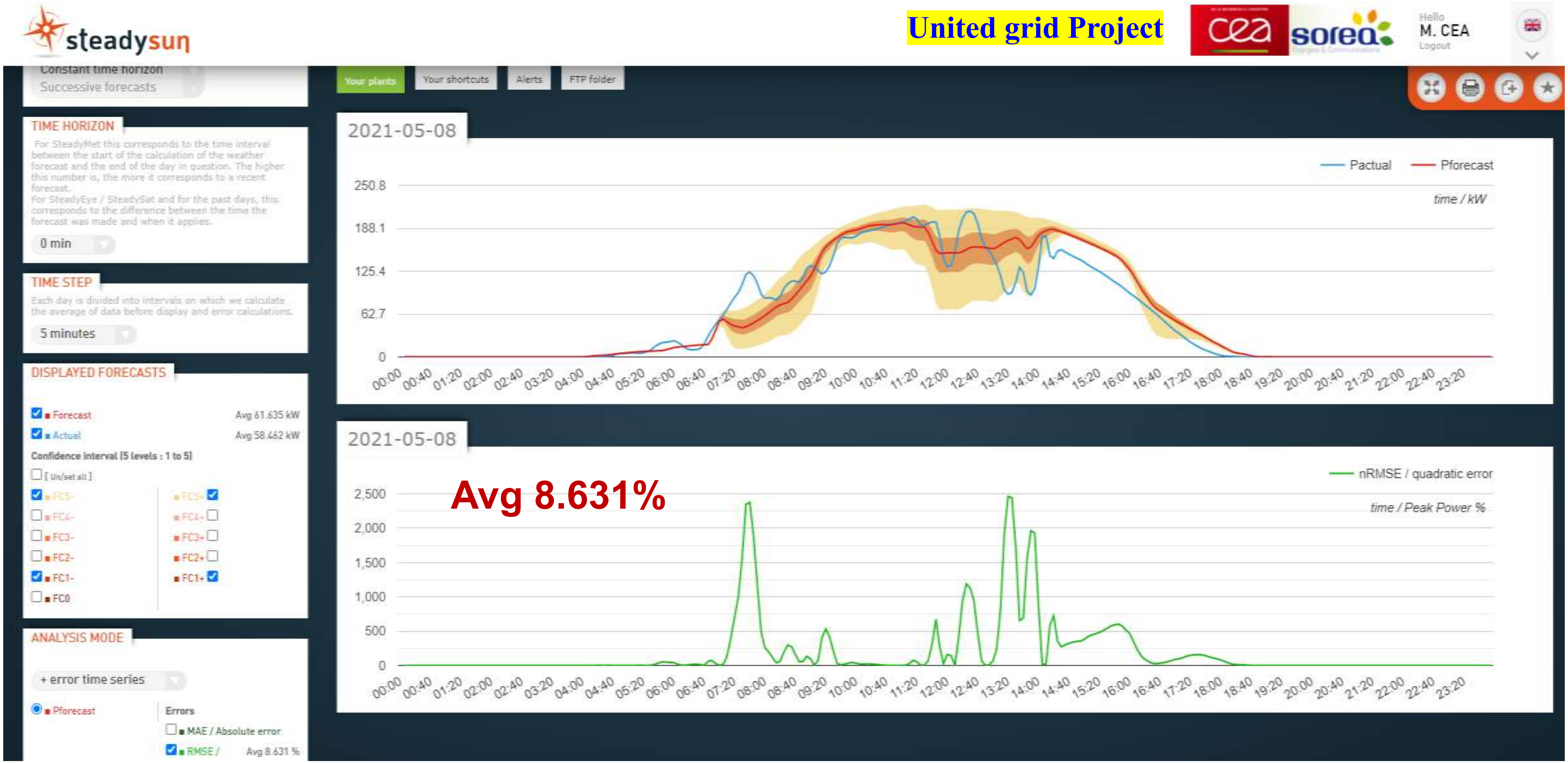
1- PV forecasting based on meteorological data (day)

United grid Project

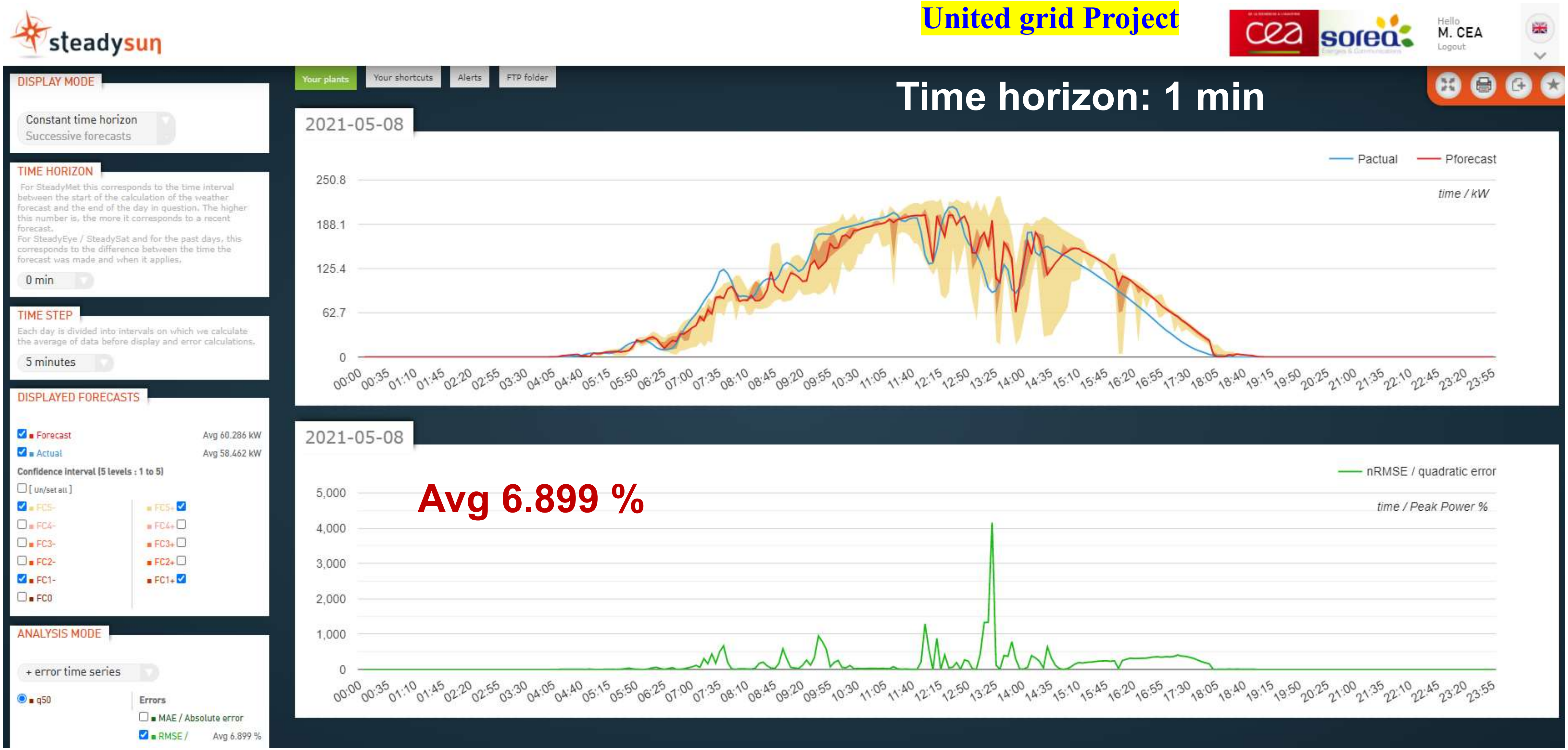


2- PV forecasting based on satellite images (Hour)

United grid Project

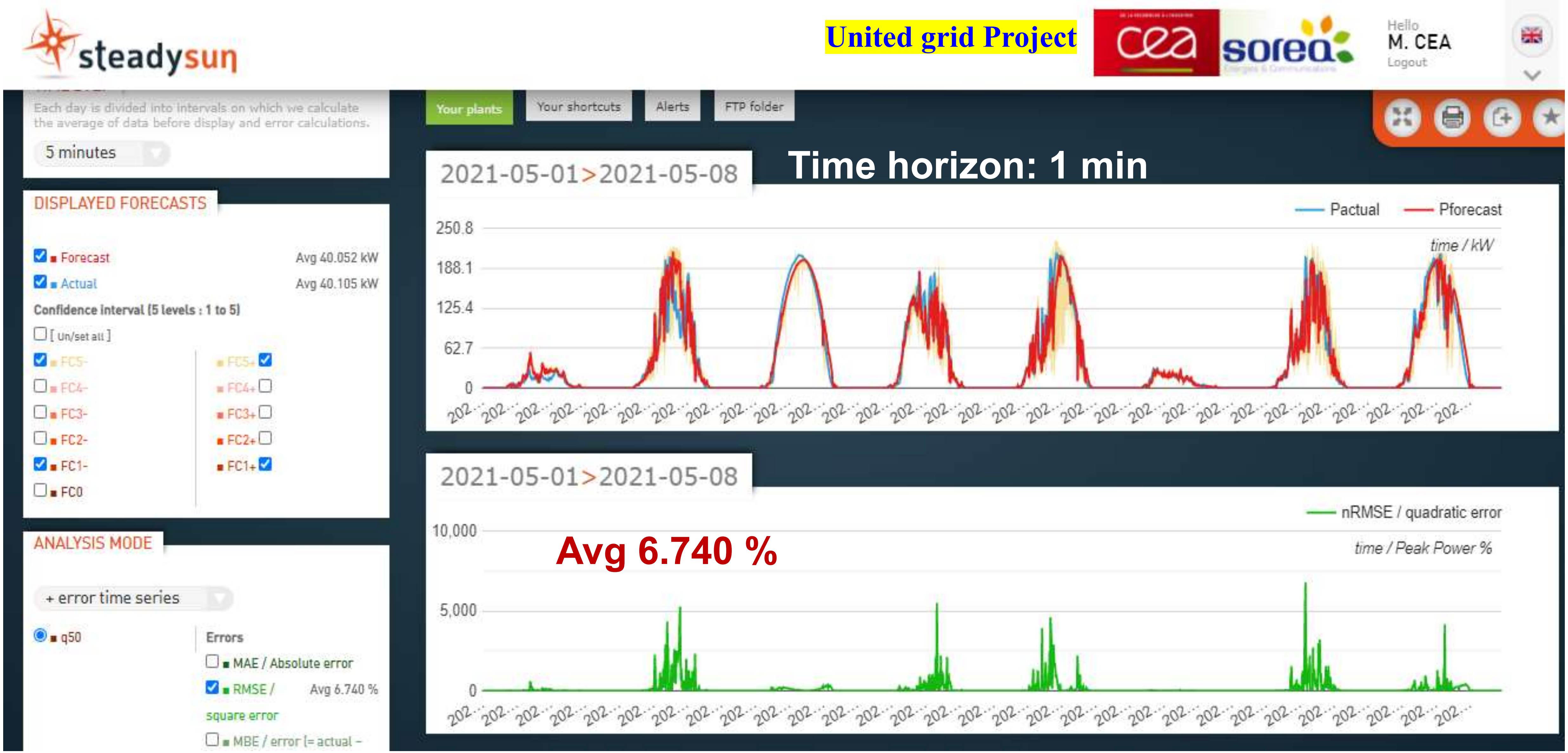


3- PV forecasting based on sky camera (min)

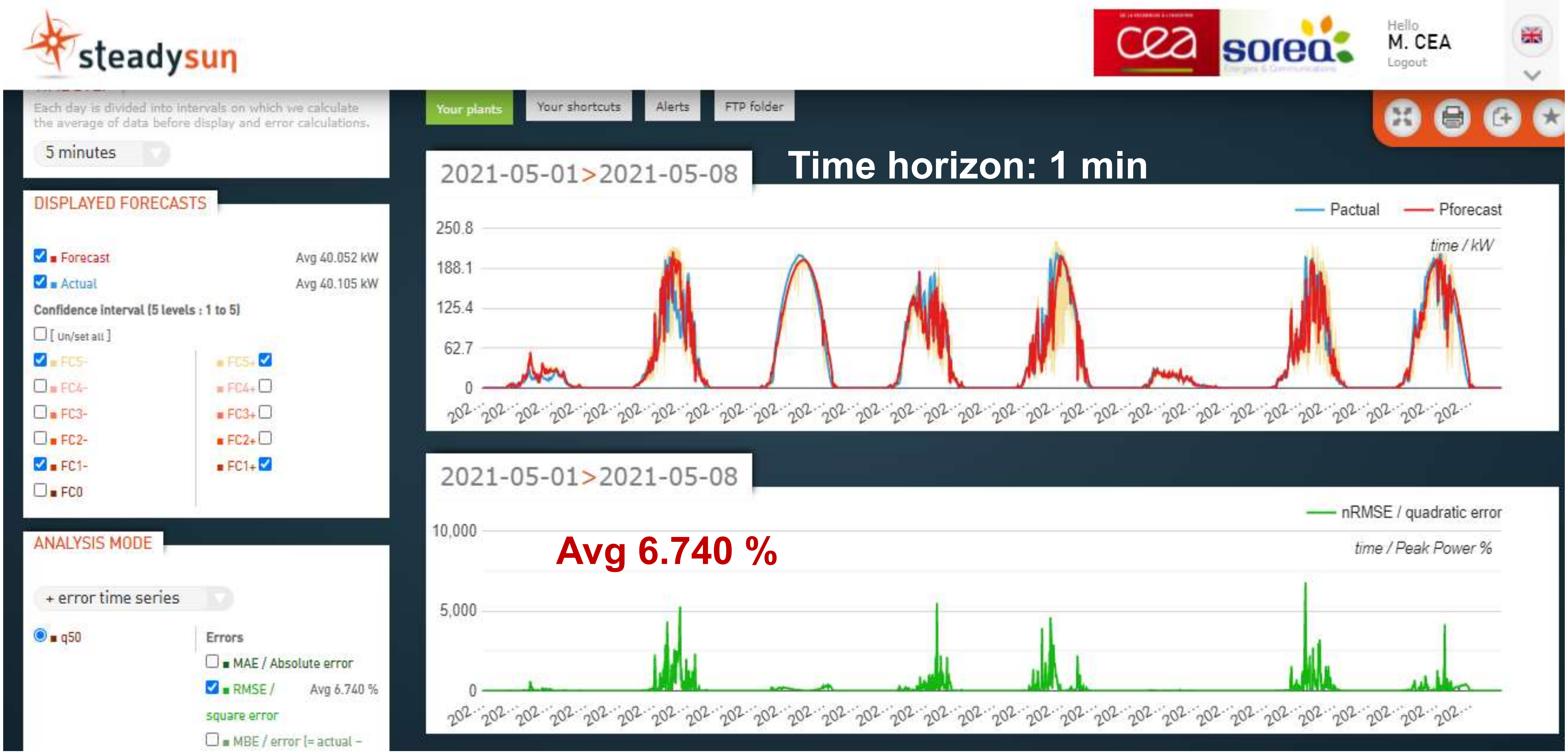


PV forecasting

United grid Project



PV forecasting



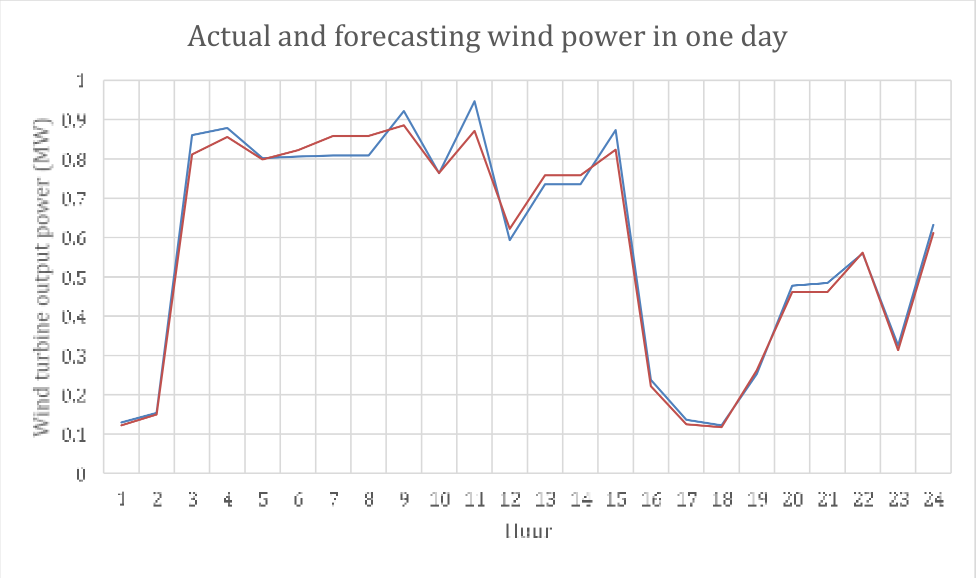
Wind power forecasting

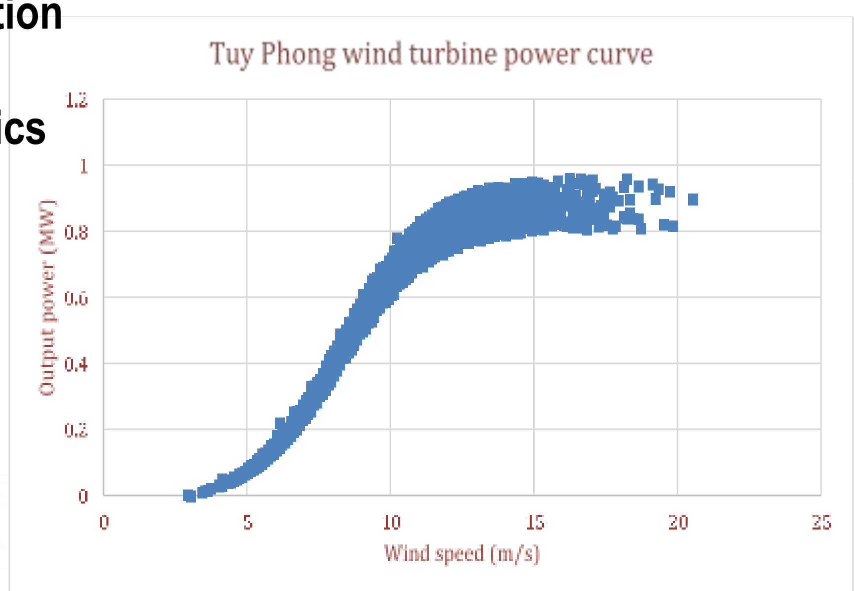
Data needed

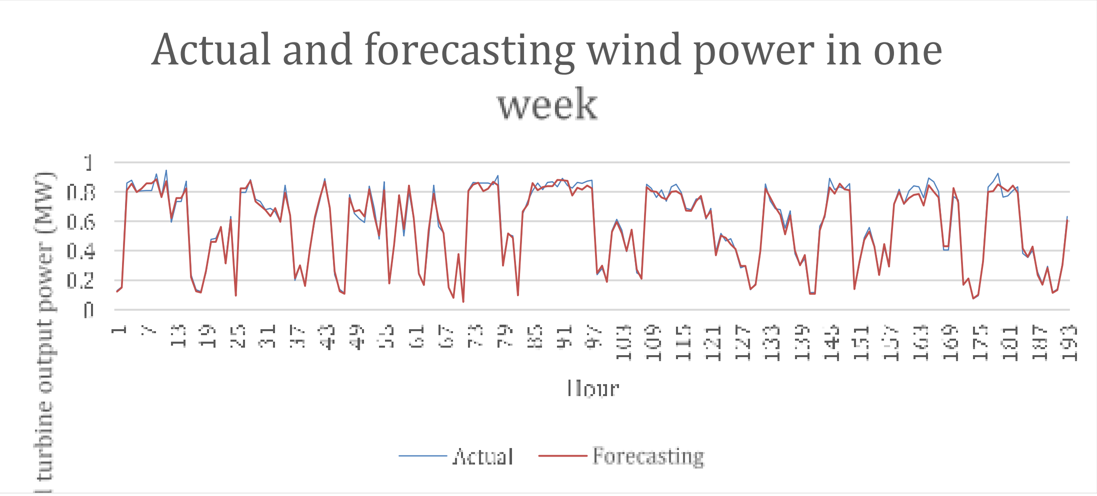
- Historical Wind Power Generation
- Weather Data
- Weather Forecast DataSky
- Imagery data
- Satellite Data
- Numerical Weather Prediction (NWP) Models
- Wind Turbine Characteristics
- Wind Speed and Direction Data
- Wind Farm Layout and Configuration
- …

Methodes

- Artificial Neural Network (ANN)
- Generic Algorithm (GA)
- Hybrid Particle Swarm Optimization (PSO-PSO-ANN)
- Hybrid (GA-PSO-ANN)







PhD thesis: Minh Phuong VO – 2024

"Studying the effects of large capacity wind power sources on the power system and electricity market"

Dinh Thanh Viet, Vo Van Phuong, Minh Quan Duong and Quoc Tuan Tran; "**Models for Short-Term Wind Power Forecasting Based on Improved Artificial Neural Network Using Particle Swarm Optimization and Genetic Algorithms**", Energies 2020, 13(11), 2873; https://doi.org/10.3390/en13112873

PLAN

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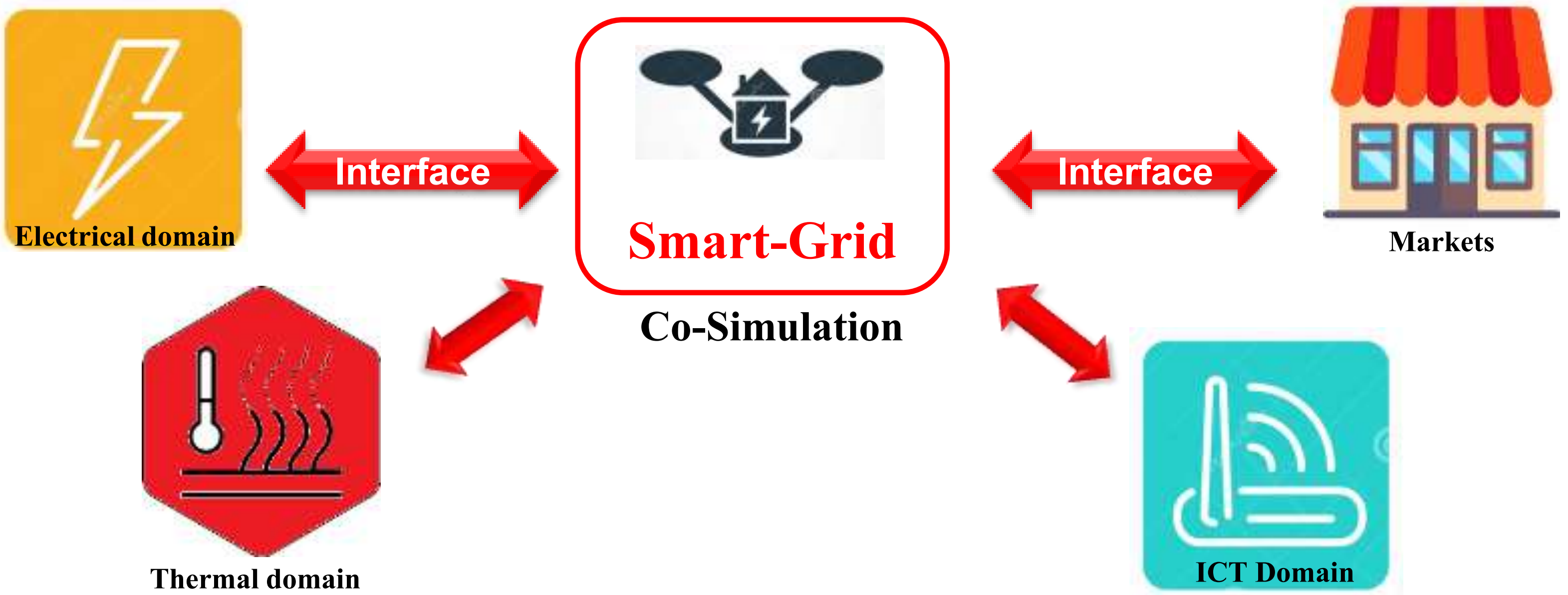
Co-simulation of a cyber-physical system: why?



PhD thesis: Minh Tri LE – 2021

"New approaches to analysis and validation of a smart electricity network using holistic Co-simulation methods"

- Smart grid ➡ energy transition ➡ Intermittent renewable energy and ICT
- Integrated and holistic approach ➡ analyze and evaluate the complex configuration
  ➡ not yet addressed to date.

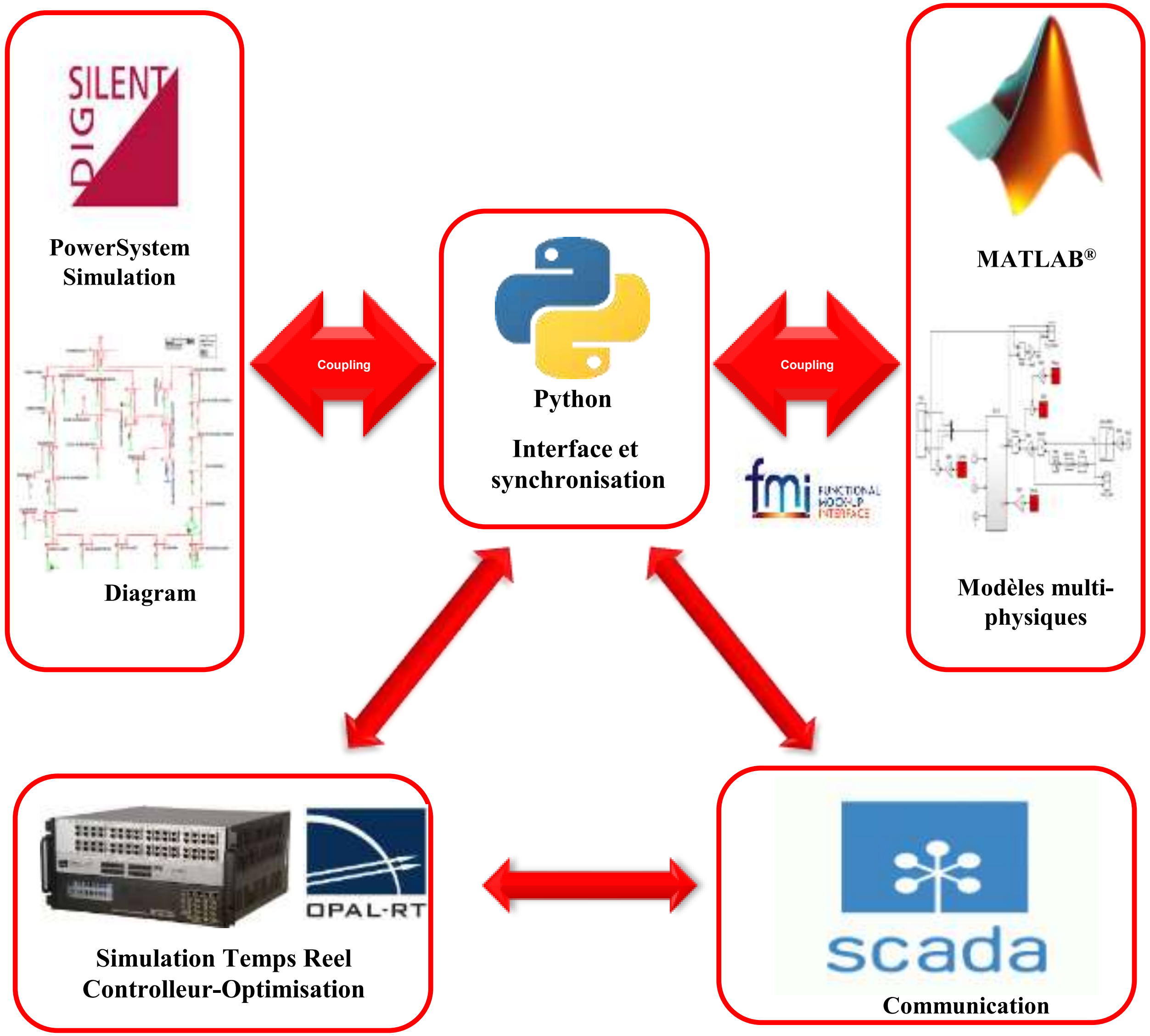
When analyzing and validating a smart grid, the following questions arise:

- How can a multi-physical, multi-domain, and multi-scale smart grid be modeled?
- How can the various available tools and professional software be combined?
- How can these software programs be synchronized with different computational time steps?
- How can the corresponding strategies be validated in a near-real environment with communication?

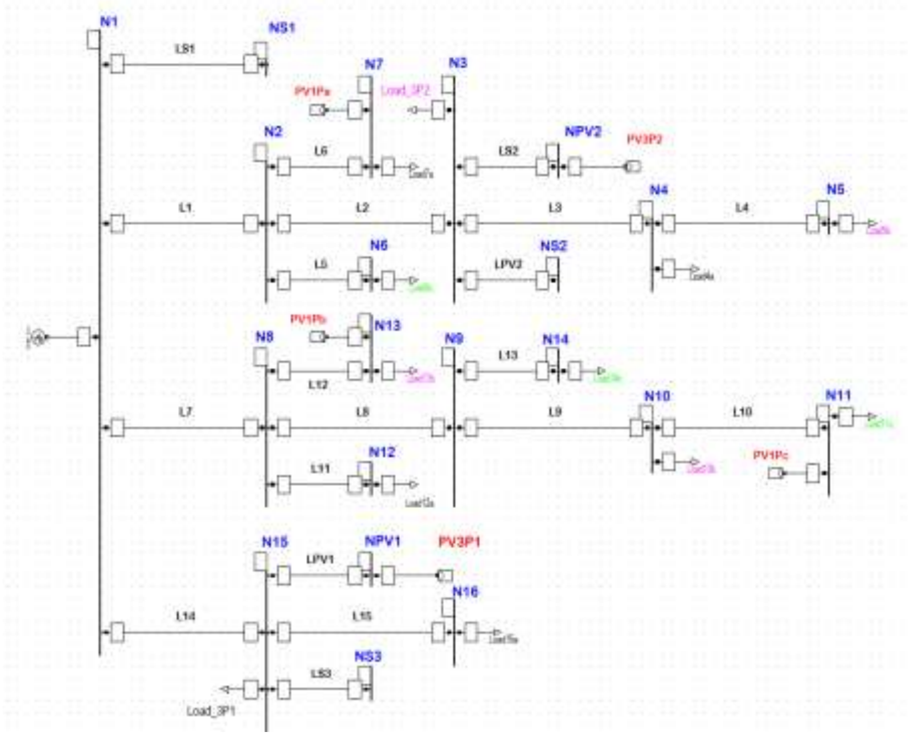
RT co-simulation

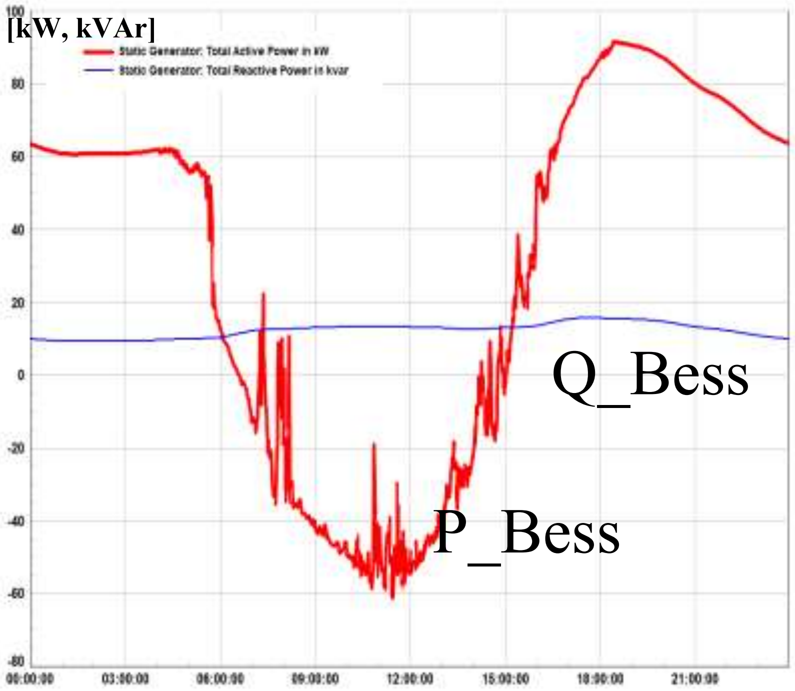
- Develop FMI, FMU interface models
- Study the synchronization of different software
- Develop a Co-simulation platform taking into account communication systems
- Carry out a co-simulation for the different management applications of an electrical network (microgrid) with the interface of different softwares
- Perform co-simulation through real-time simulation (OPAL-RT/RT-LAB) and coupling with different entities (Communications, SCADA, Clouds, Agents, etc.)

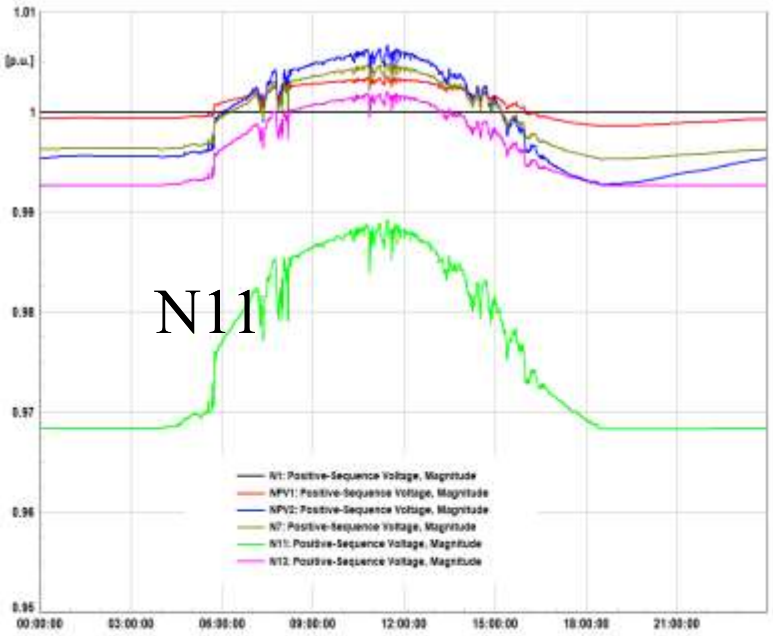
Definitions:
FMI: Functional mock-up interface
FMU: Functional mock-up units
SCADA: Supervisory control and data acquisition
OPAL-RT/RT-LAB *: Real times simulator*



Frequency control: Co-simulation using Mosaik and Python

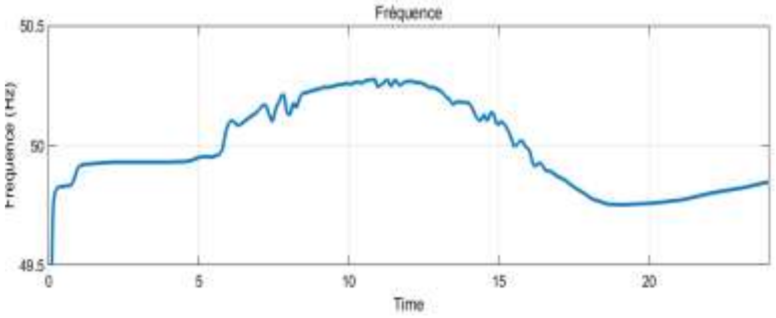






Minh Tri Le, Quoc Tuan Tran, Yvon Besanger; **"Voltage Control of Microgrid using Co-Simulation between Powerfactory and FMUs in Matlab";** 23th IEEE–EEEIC, June 2023, Madrid, Spain; DOI: 10.1109/EEEIC/ICPSEurope57605.2023.10194808

Minh Tri Le, Quoc Tuan Tran, Yvon Besanger; "**Frequency Control of an Islanded Microgrid using co-simulation**"; IEEE– EEE-AM, November 2023, Hanoi, Vietnam; DOI: 10.1109/EEE-AM58328.2023.10395318



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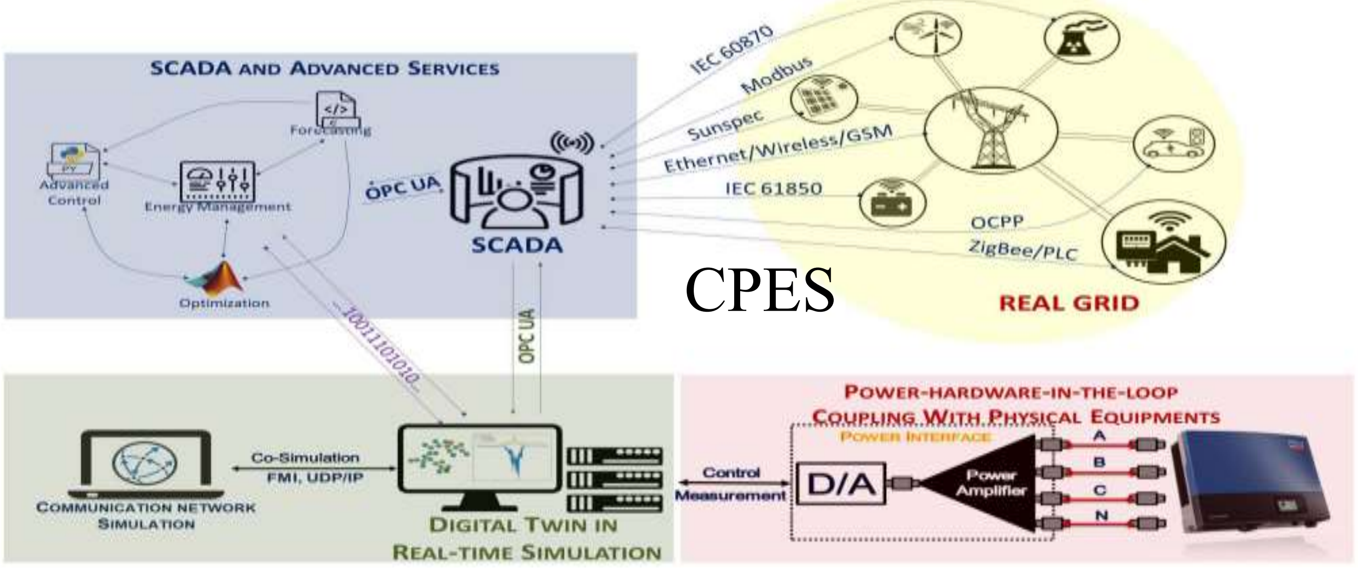
Digital Twin – Proposed Architecture

DT = Virtual replica of a physical object/system/process in real-time

- ✓ Monitor, analyze and simulate the operation of part or all of it
- ✓ Optimize performance and life cycles
- ✓ Plan and implement necessary measures in extreme cases
- ✓ More realistic and less expensive test deployment environment
- ✓ Facilitating enhanced understanding, decision-making, and performance improvements in various domains, including manufacturing, infrastructure, and the Internet of Things (IoT).

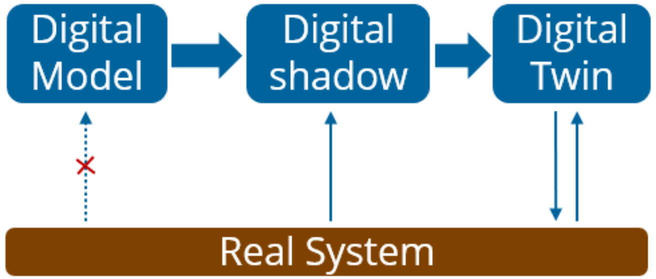
Based on : TIC, IoT, Big Data, IA, Machine Learning, Cloud/Edge Computing

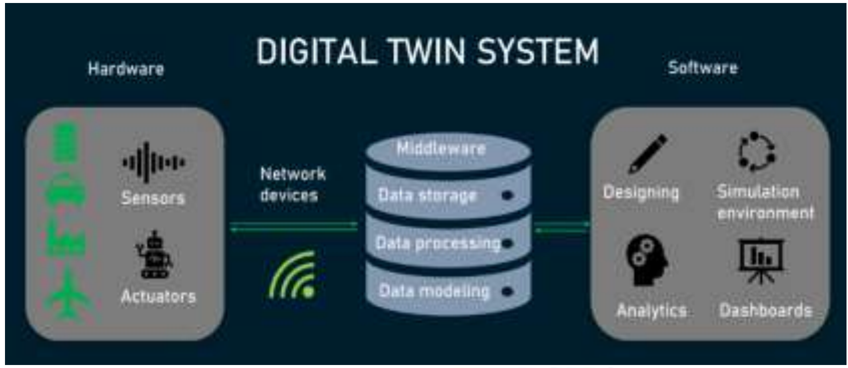


Proposed DT Architecture

PhD thesis: Thien Phong TRAN – 2024

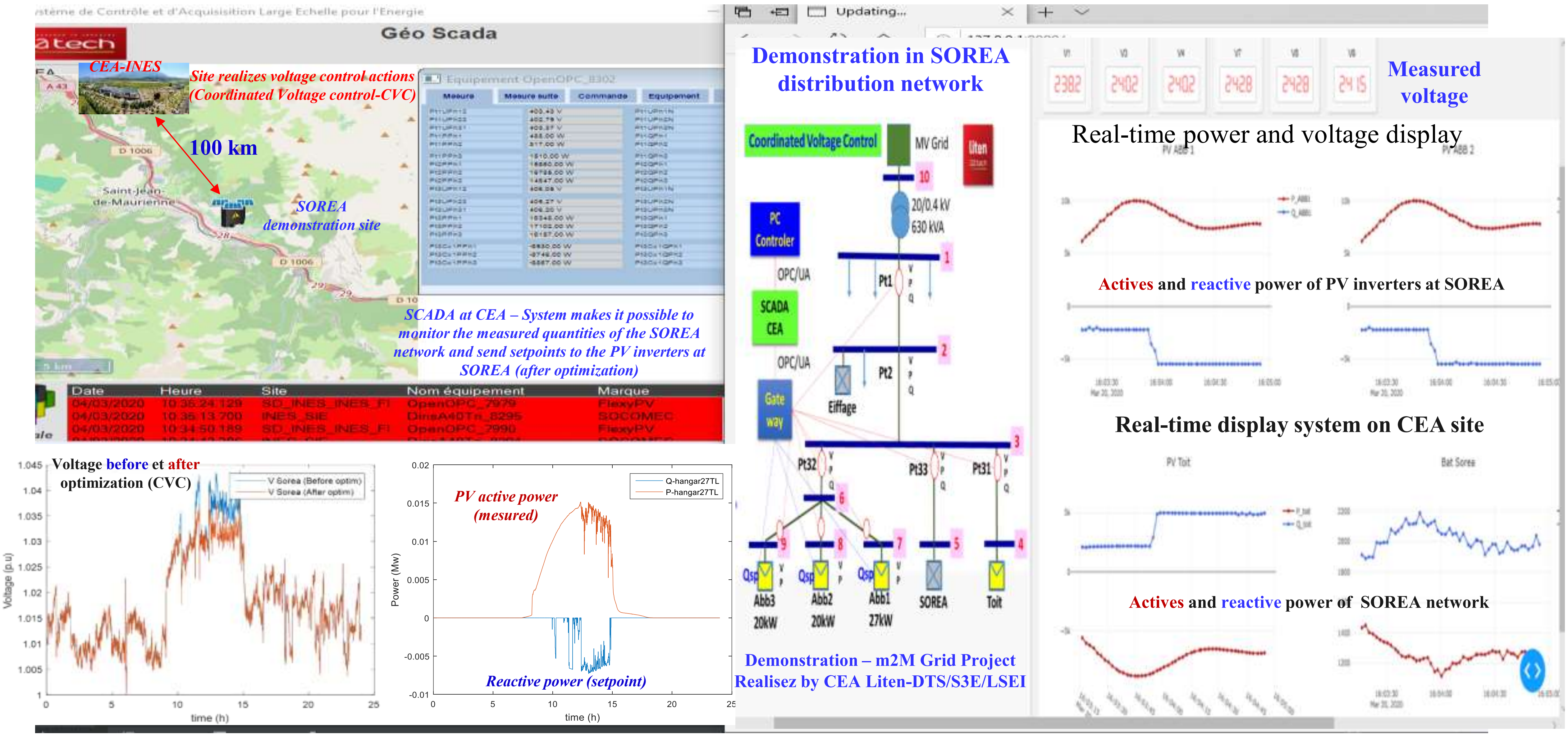
"Digital twin of the smart grid by real-time simulation: methodology and applications"





Digital Twin: Demonstration and validation at SOREA

Erigrid m2M

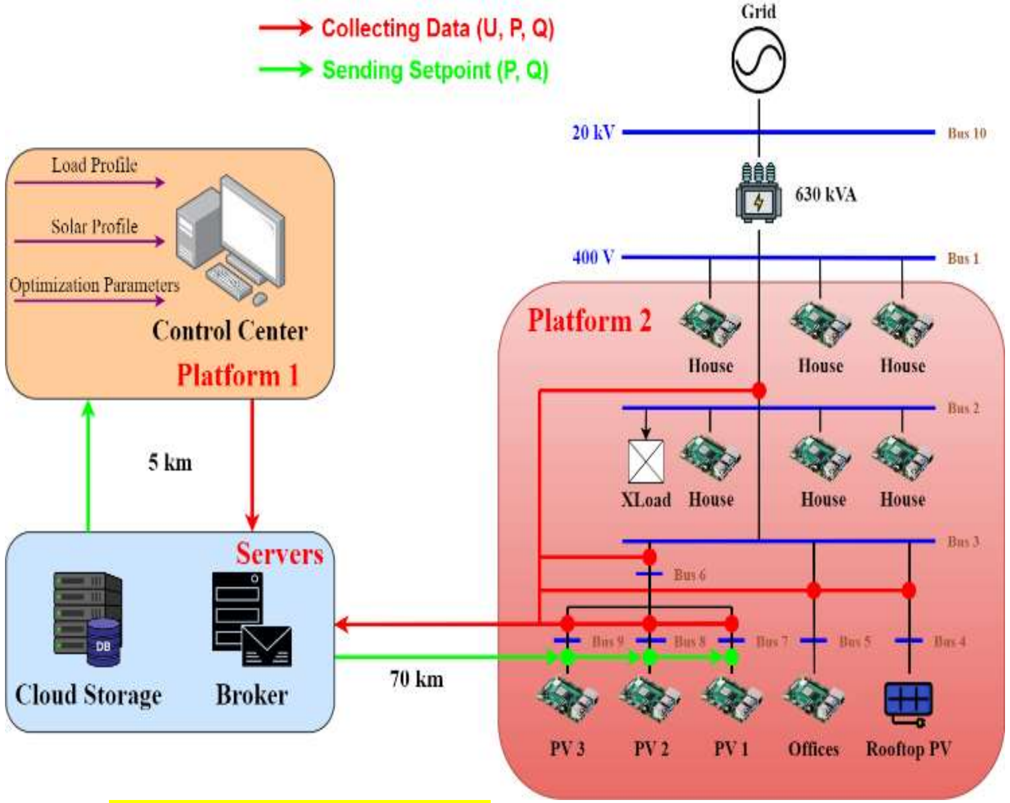


Digital Twin: Optimisation of voltage control

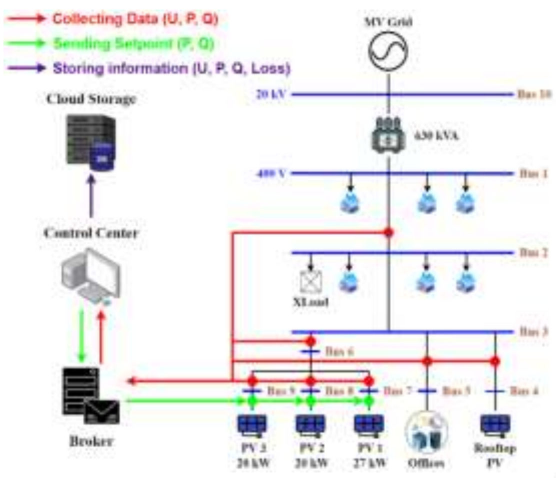
- **Digital Twin for a microgrid: Voltage control with high PV systems on the SOREA network**

- **Objective:** $f = \min_{Var} \left\{ \begin{array}{c} W_V * \sum_1^n \left(V_i - V_i^{sp}\right)^2 + W_Q * \sum_1^m \left(Qpv_j\right)^2 \\ + W_P * \sum_1^m \left(Ppv_j^{sh}\right)^2 + W_L * Loss \end{array} \right\}$

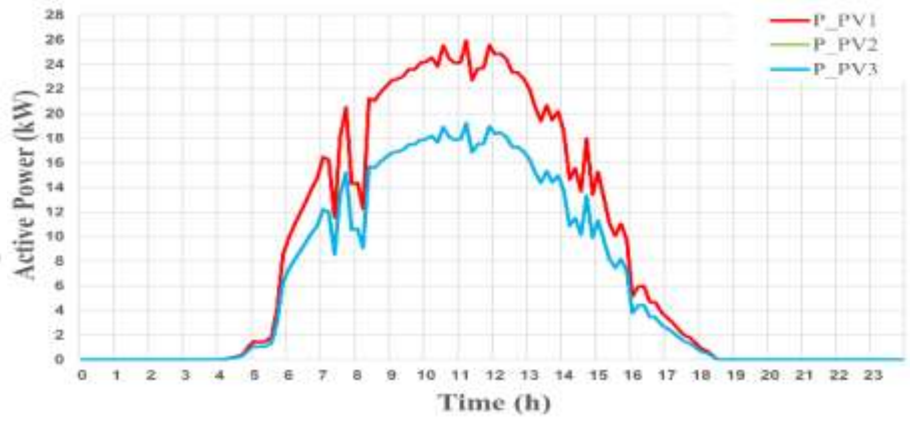
✓ Develop models (PV, network) and implement them in RAS
✓ Communication and data synchronization
✓ Develop different optimization strategies (Genetic Algorithm, Particle Swarm, Monte Carlo, etc.)
✓ Validation for the SOREA distribution network

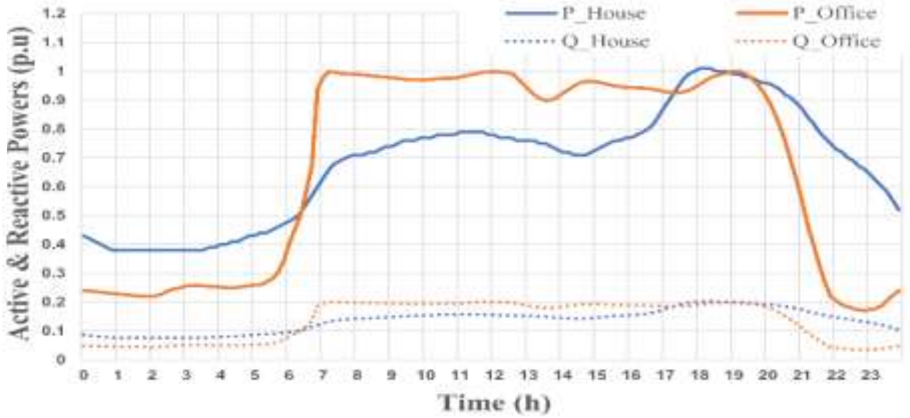


Proposed DT



Réseau SOREA

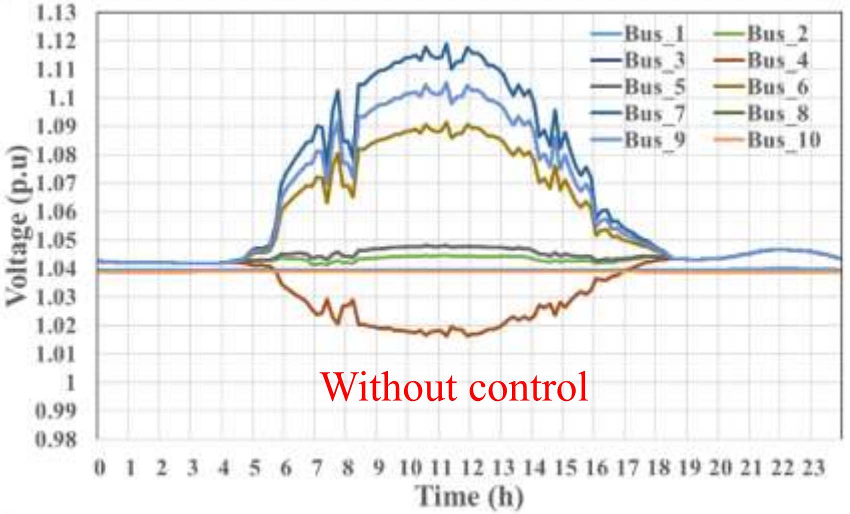


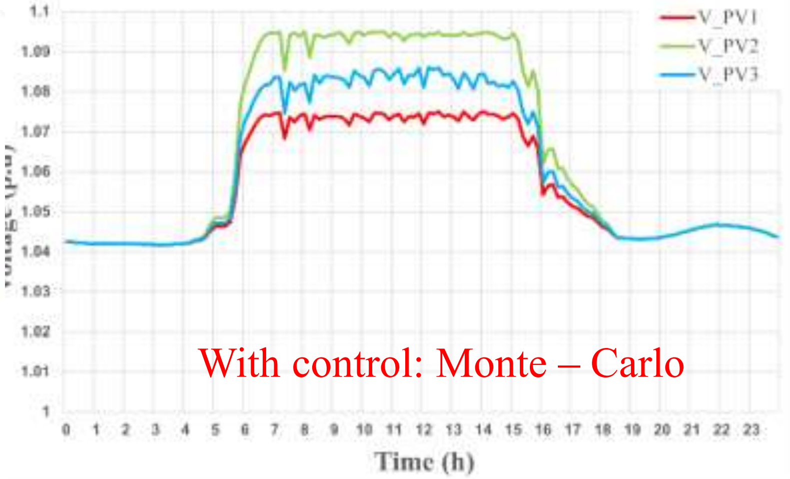


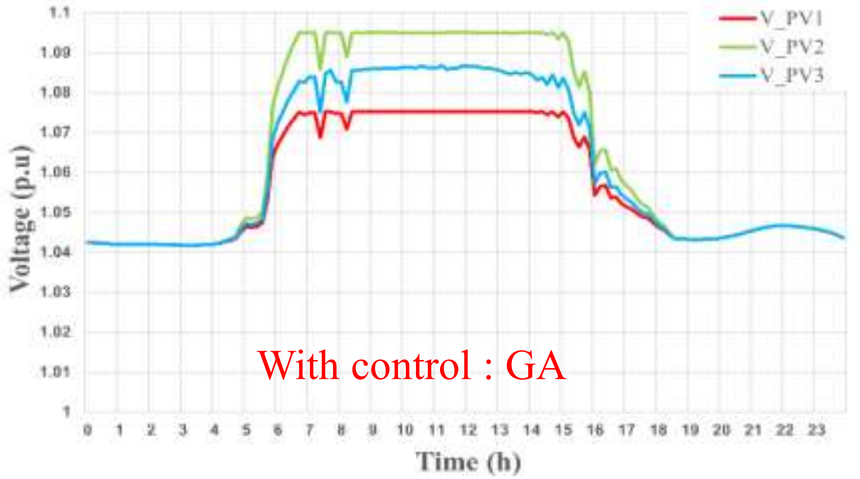
Thien Phong Tran, Quoc Tuan Tran, Minh Tri Le, Raphael Caire; **"Voltage control using digital-twin-based optimization method"**; IEEE Conference – MELECON, June 2024, Porto, Portugal; DOI: 10.1109/MELECON56669.2024.10608689

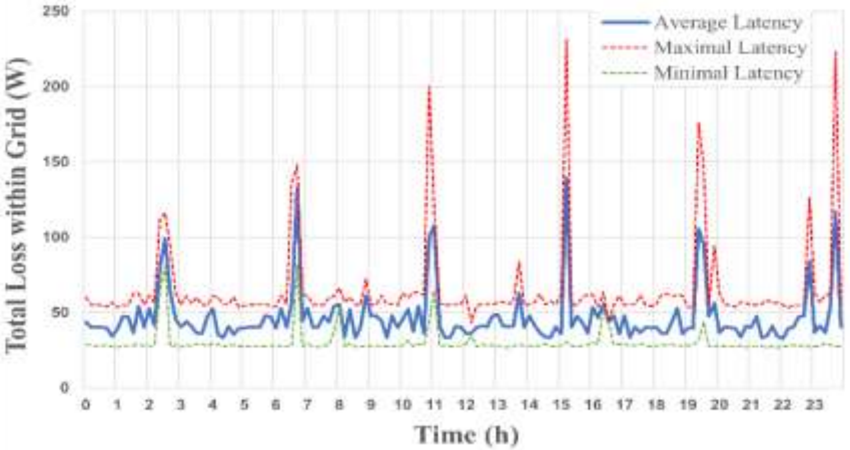
Digital Twin : Optimisation of voltage control

- Validation of proposed DT for optimal voltage control on the SOREA distribution network
- Optimization methods: iterative, Monte – Carlo, Genetic Algorithm, Particle Swarm Optimization

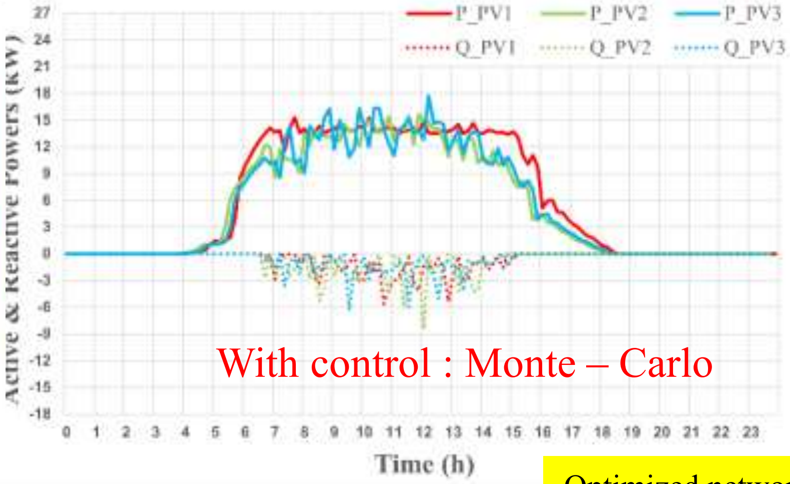


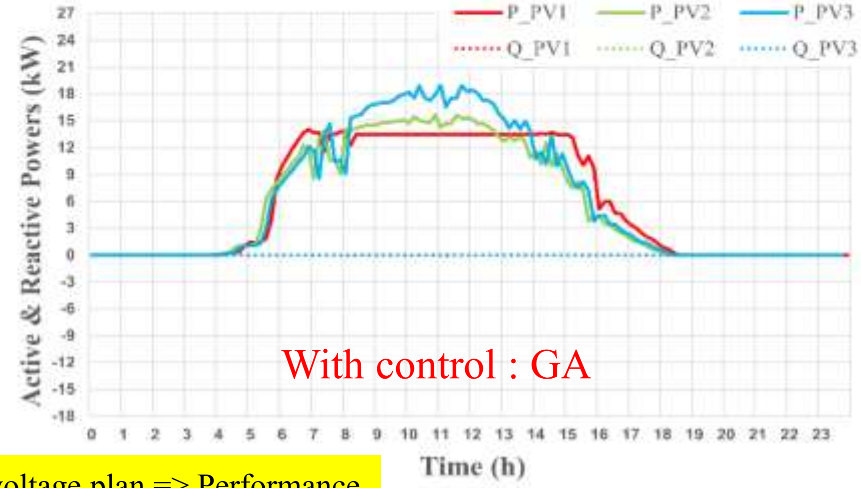






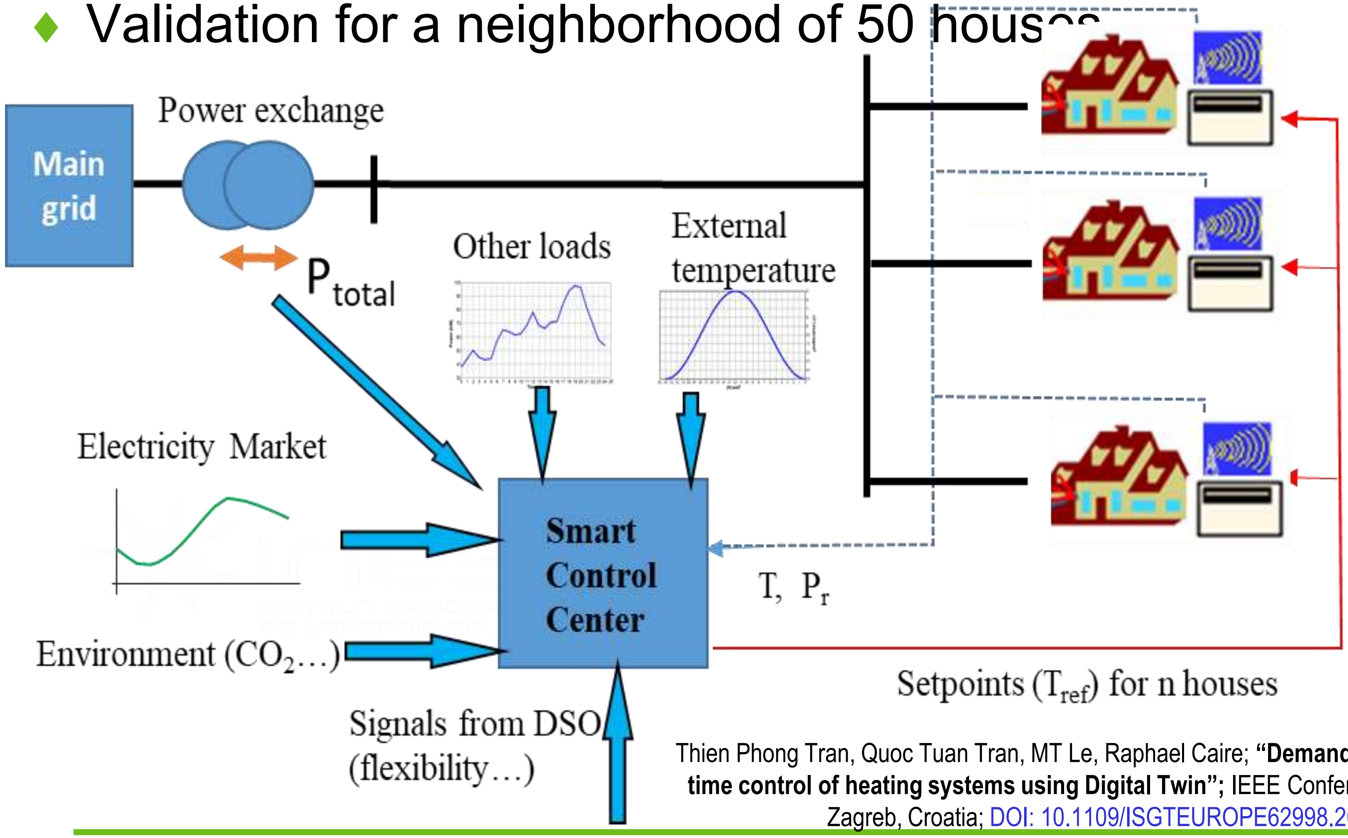
Latence: Moy = 55 ms, max = 242 ms, min = 25 ms

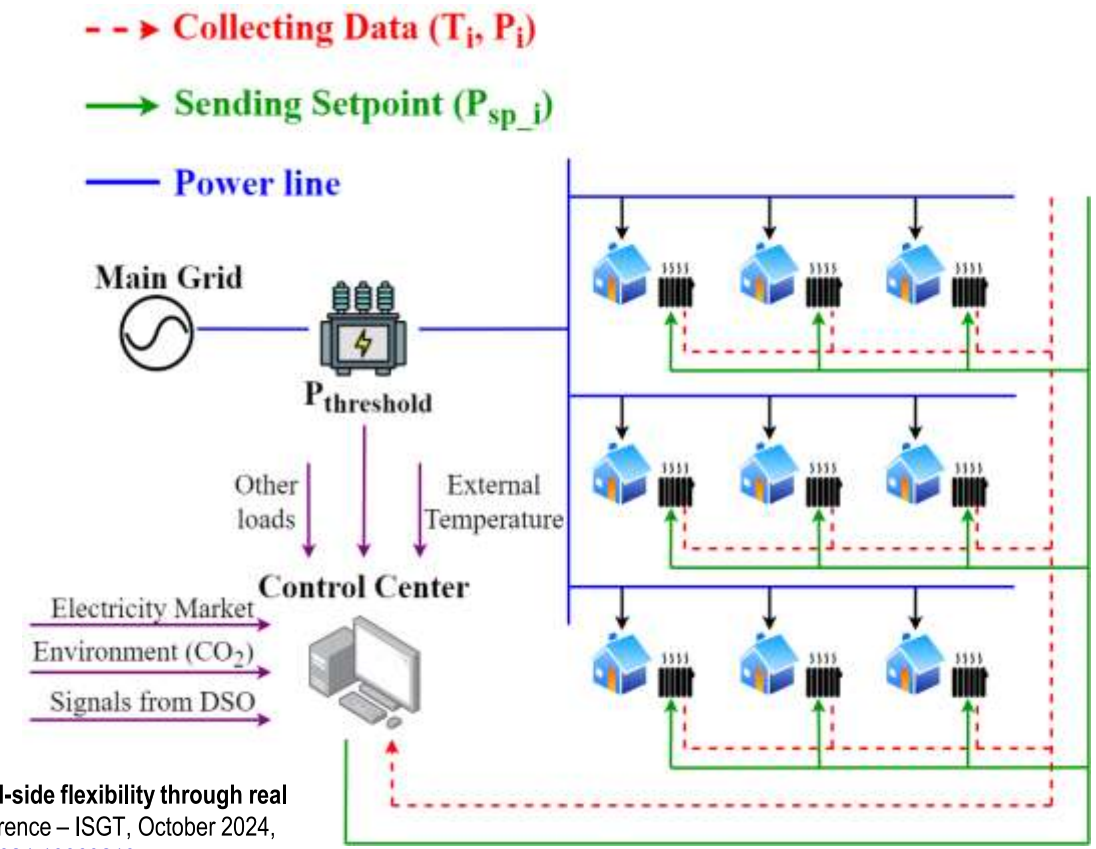




Optimized network voltage plan => Performance of proposals => Confirmed

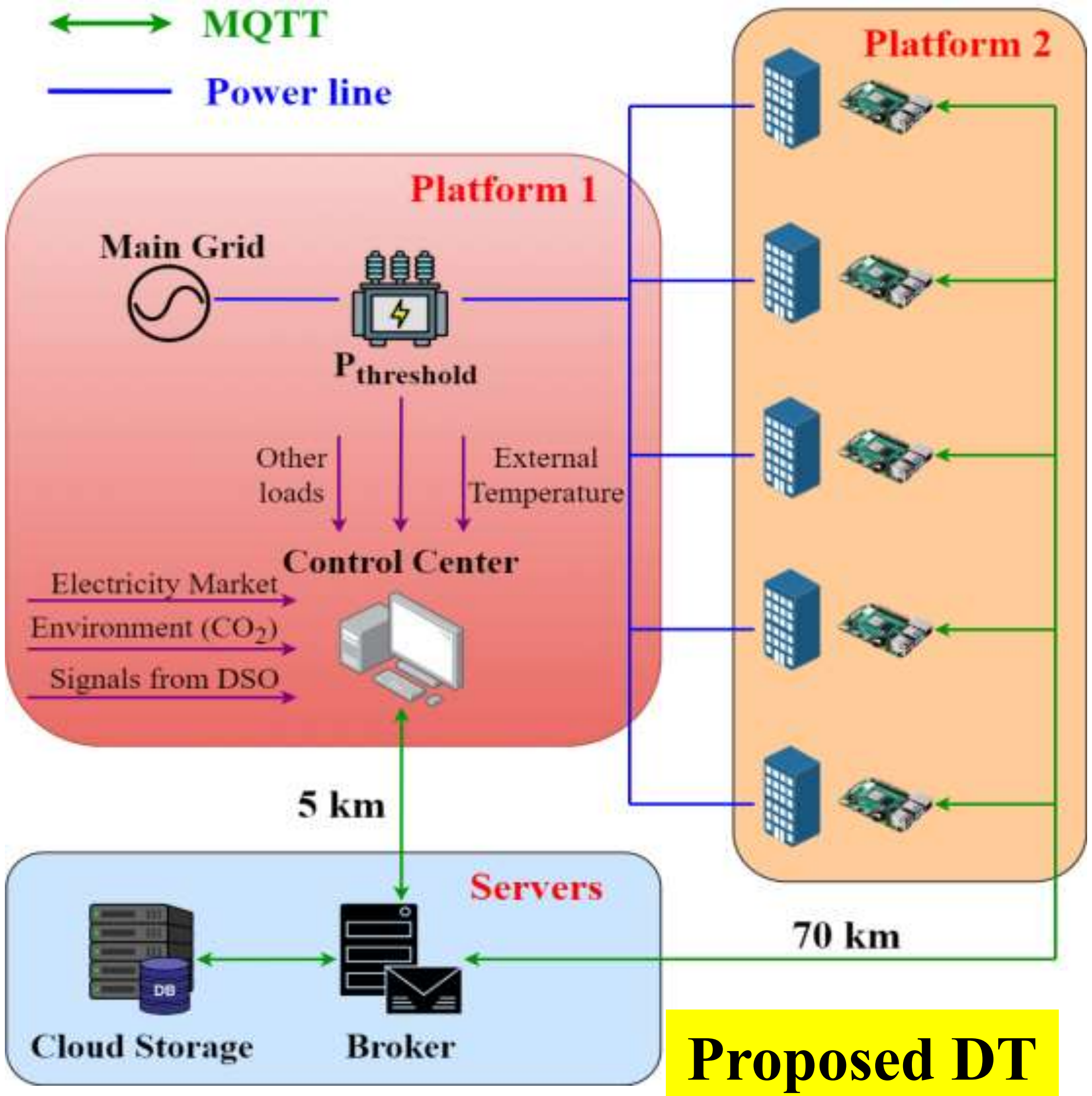
- Proposed DT of a Smart District: Flexibility management on real-time heating control (Buildings)
- Objective: reduce consumption peaks while respecting thermal comfort
  - Develop building models and implement them in RAS Pi
  - Communication and data synchronization
  - Validation for a neighborhood of 50 houses



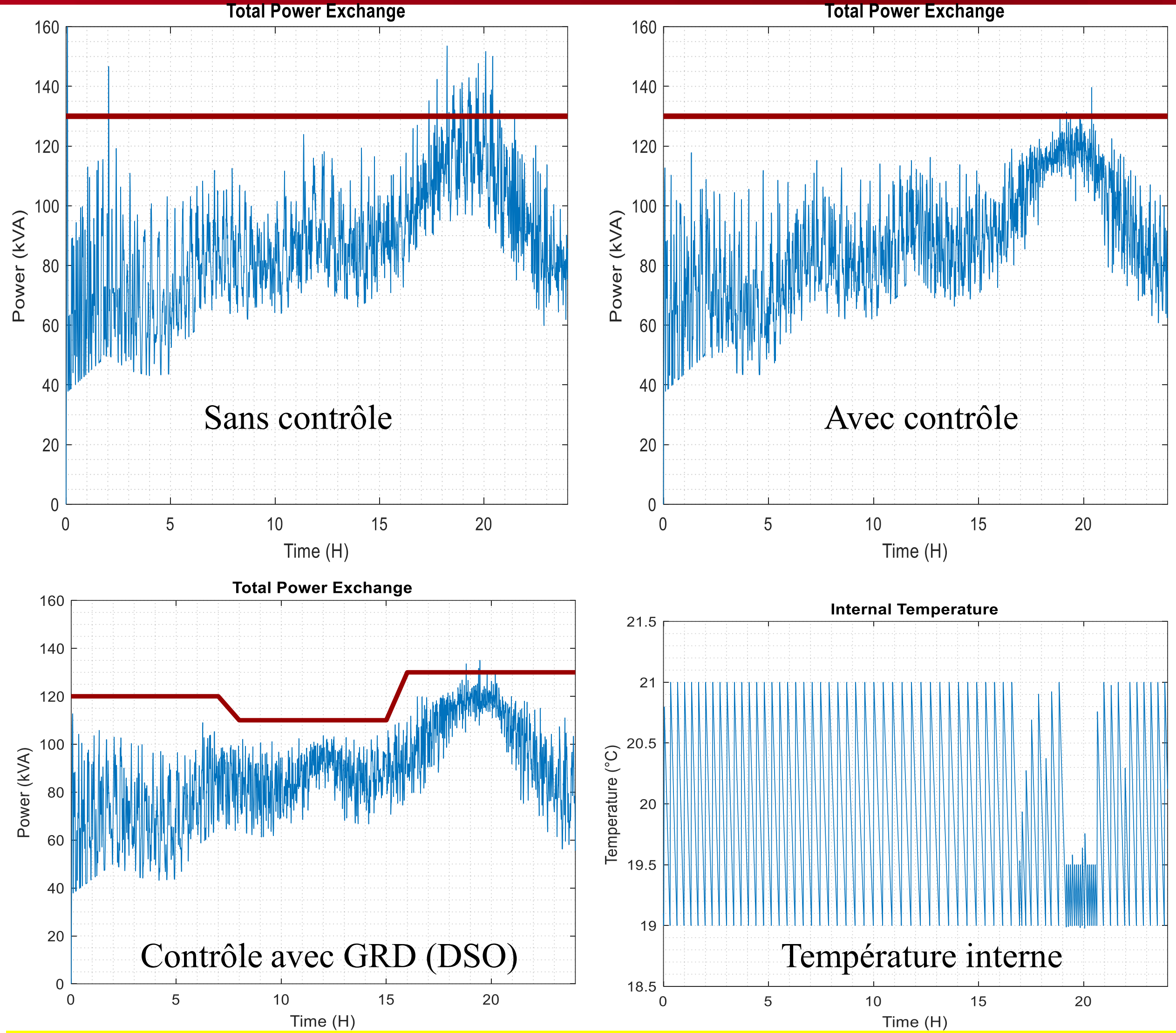


Thien Phong Tran, Quoc Tuan Tran, MT Le, Raphael Caire; **"Demand-side flexibility through real time control of heating systems using Digital Twin";** IEEE Conference – ISGT, October 2024, Zagreb, Croatia; DOI: 10.1109/ISGTEUROPE62998.2024.10863219

Digital Twin: Flexibility Control for Buildings



Proposed DT



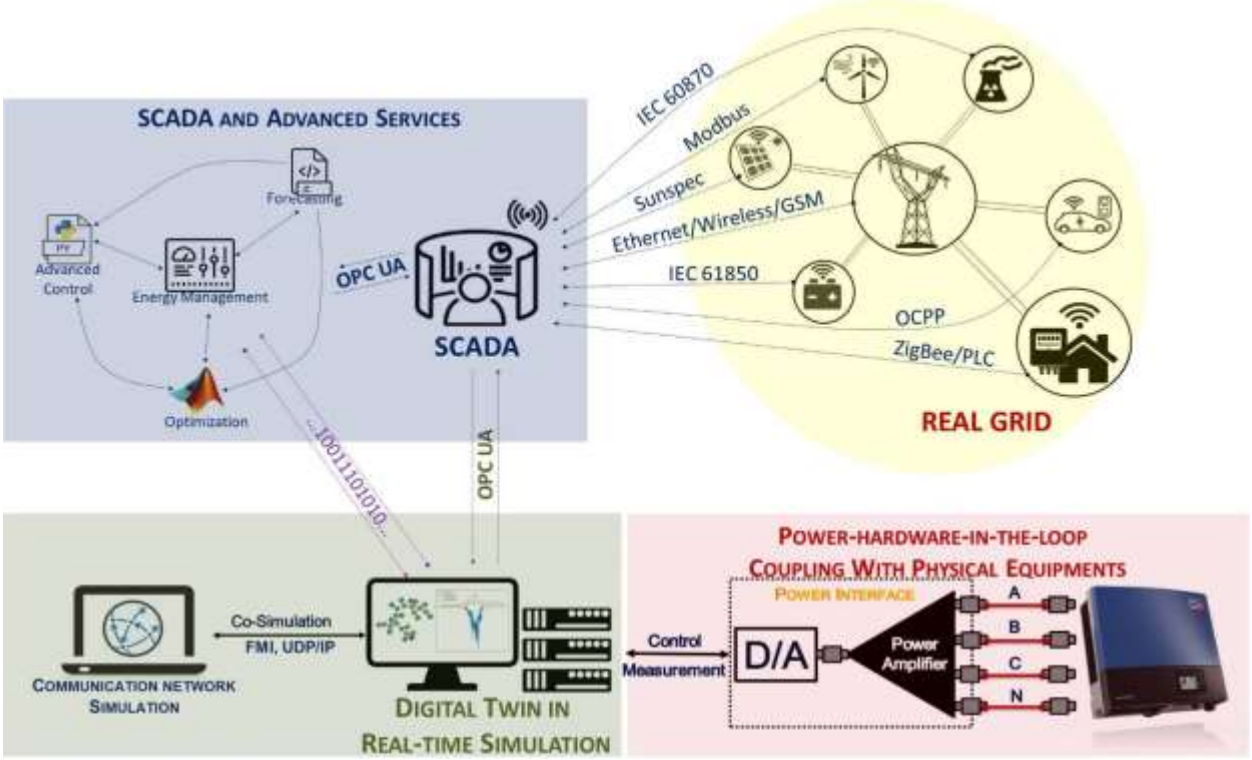
Reduction of consumption peaks while respecting thermal comfort => Validated

RT simulation and PHIL activities at CEA INES

Concept Simulation RTS CHIL Prototype PHIL Co-simulation + PHIL RT Digital Twin + PHIL Full-Hardware

Pre-Deployment Testing sequence

- CEA platform is capable of doing RT simulation and PHIL at LV level (MV incoming).
- Cross-infrastructure researche allows the combination of facilities and expertise
- Integration of SCADA services to RT-simulation to create real-time digital twin of the real environment → Environment that is closest to reality.



V.H. Nguyen, Q.T. Tran, Y. Besanger, M. Jung and T.L. Nguyen, "**Digital Twin integrated Power-hardware-in-the-loop for the assessment of distributed renewable energy resources**". *Upcoming publication on Electrical Engineering, 2021; DOI: 10.1007/s00202-021-01246-0*

PLAN

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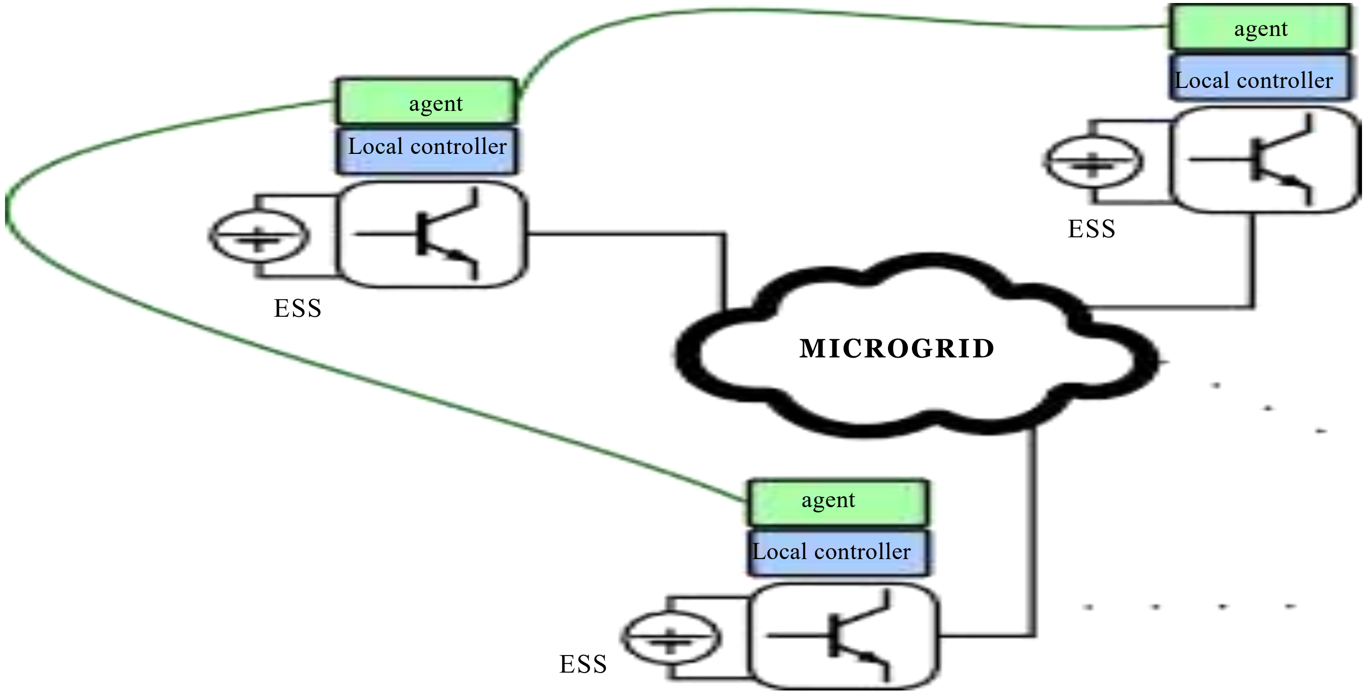
Conclusion

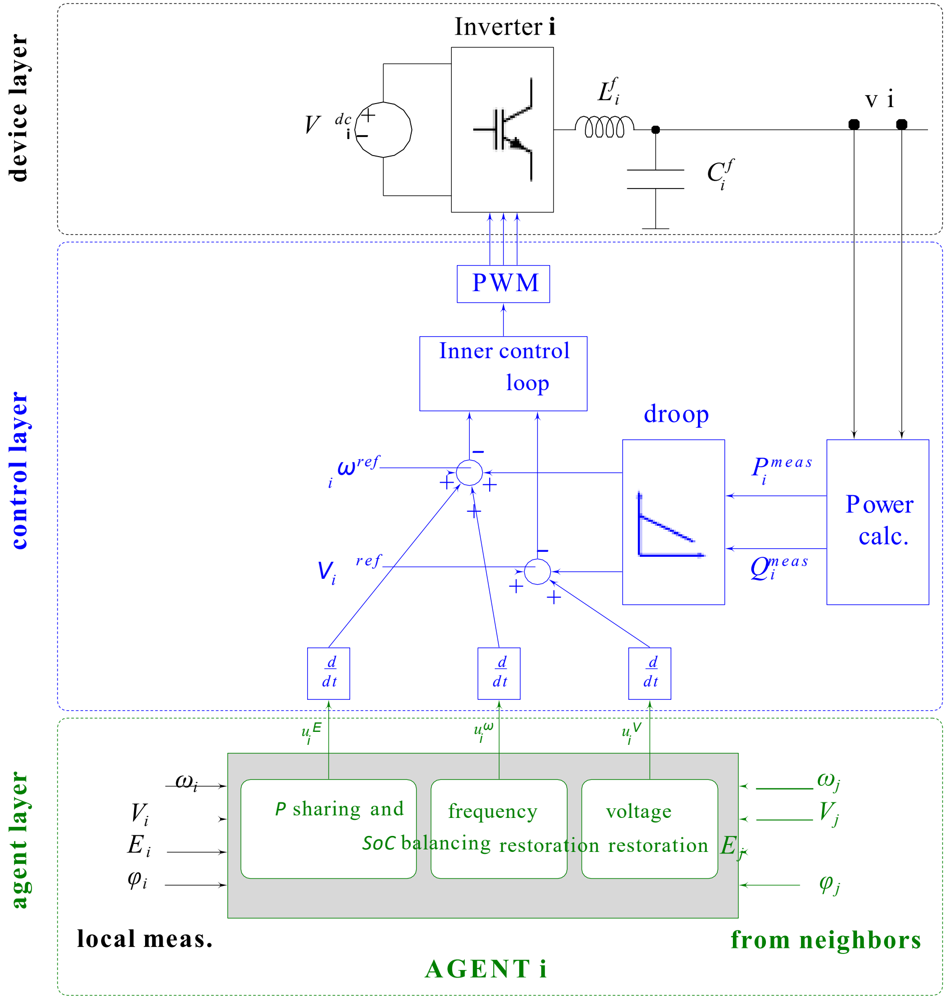
Agent-based Distributed Optimal Power Flow in Islanded Microgrids Using ADMM



Island microgrid with multiple ESSs

PhD thesis: Tung Lam NGUYEN – 2019

"Agent-based distributed control and optimization in microgrids with Hardware-in-the-Loop implementation"



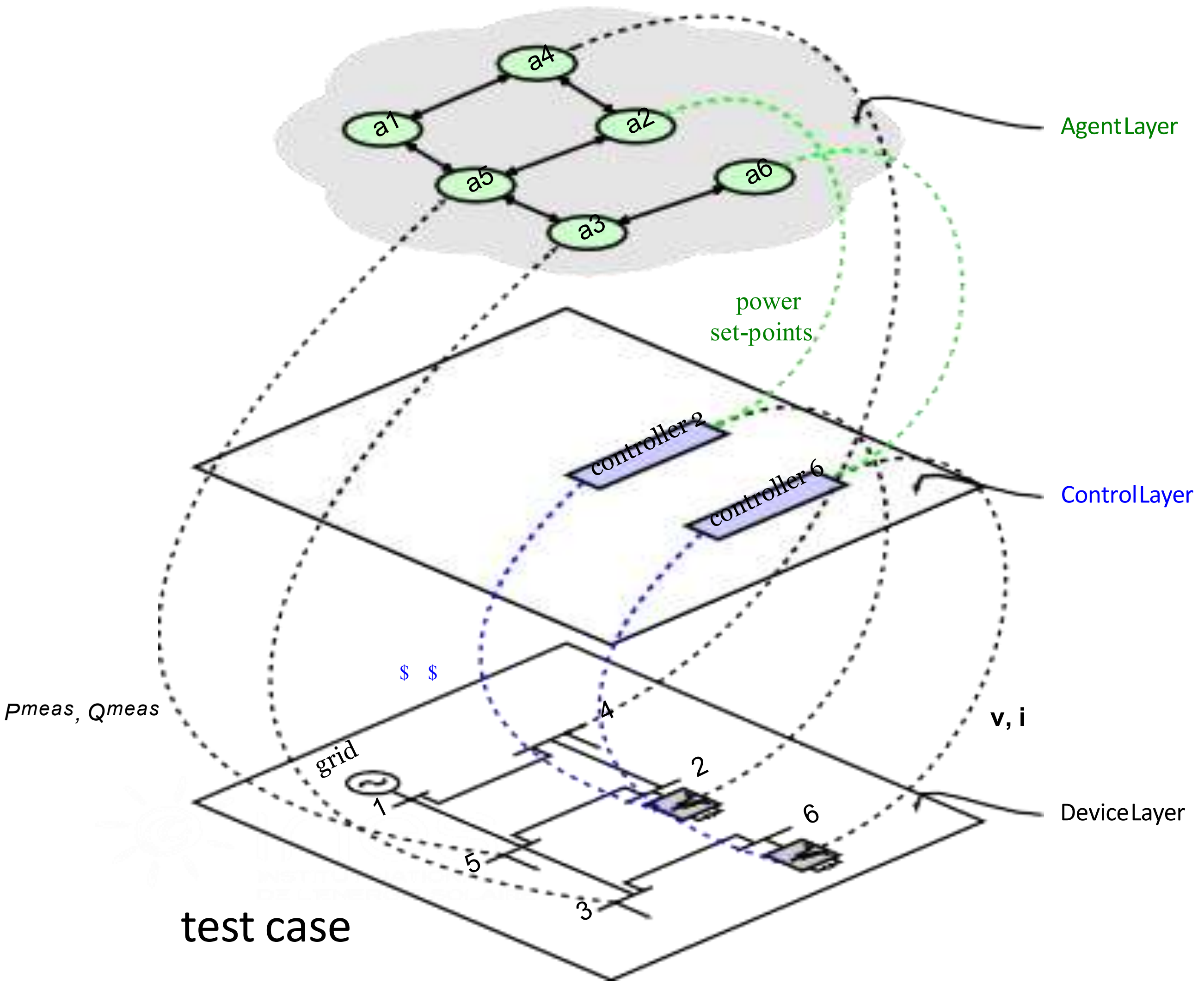
Objectives

1. Fast response (secondary level)
   - recover frequency/voltage
   - proportional power sharing
2. Slow response (tertiary level)
   - minimize total power losses

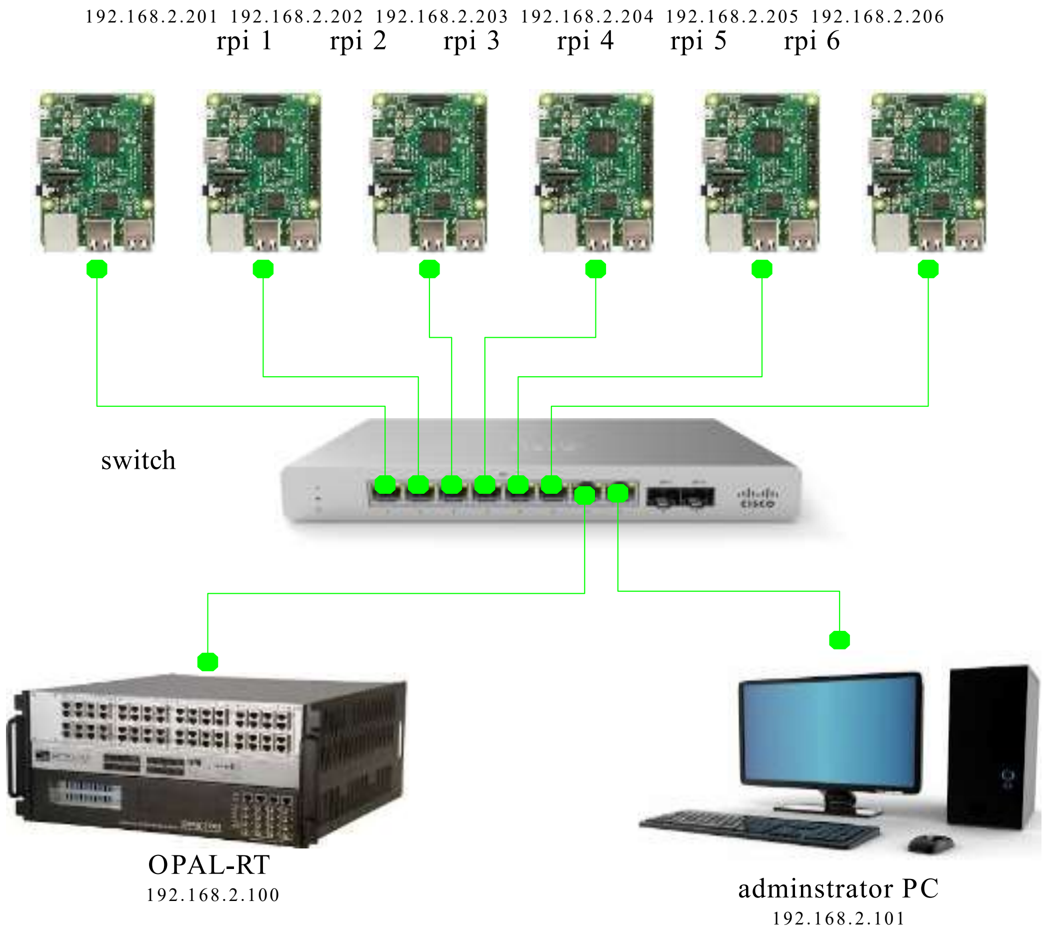
Tung Lam Nguyen; Yu Wang; Quoc Tuan Tran; Raphael Caire; Yan Xu; Catalin Gavriluta "A Distributed Hierarchical Control Framework in Islanded Microgrids and Its Agent-based Design for Cyber-Physical Implementations," IEEE Transactions on Industrial Electronics; September 2020

DOI: 10.1109/TIE.2020.3026267

Controller HIL validation



test case

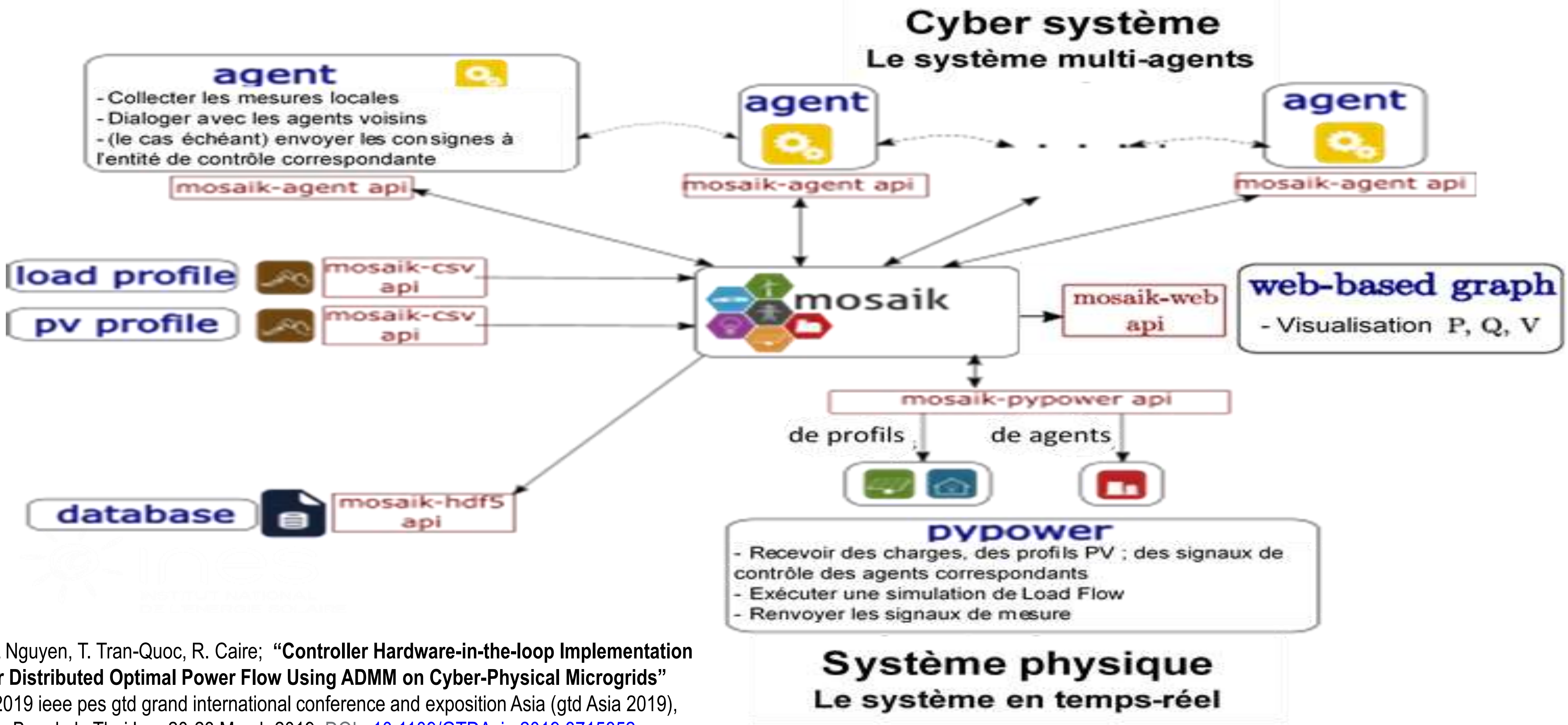


Laboratory platform

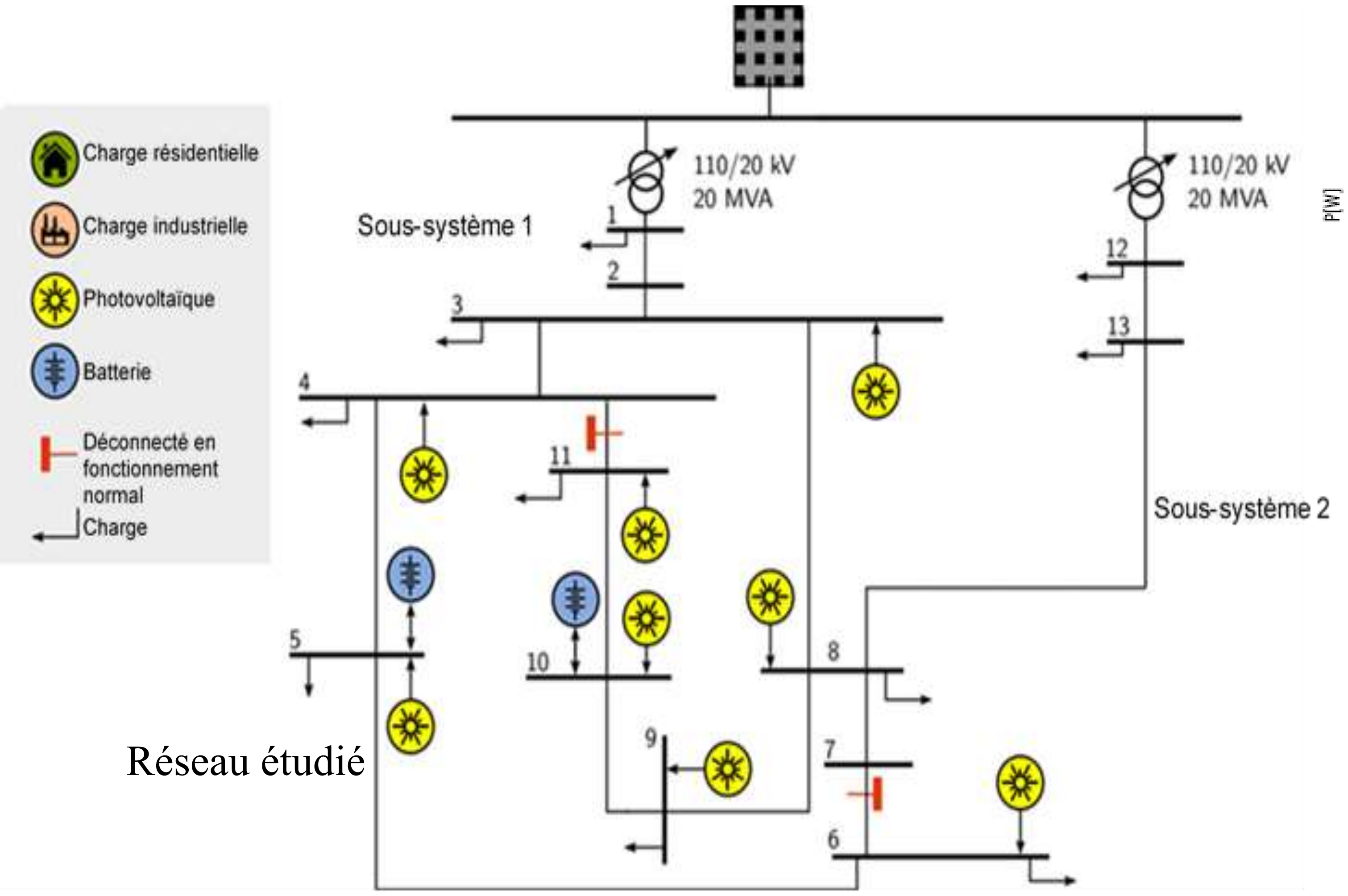
Tung Lam Nguyen, Quoc Tuan Tran, Raphael Caire, Catalin Gavriluta, Van Hoa Nguyen; "**Agent Based Distributed Control in of Islanded Microgrid – Real-Time Cyber-Physical Implementation**"; 7th IEEE International Conference on Innovative Smart Grid Technologies – September 2017, Turin, Italy.: DOI: 10.1109/ISGTEurope.2017.8260275

Multi-Agent System for Distributed Control

Objectif: Minimiser les pertes sur le réseau en utilisant ADMM (Alternating Direction of Multipliers Method)



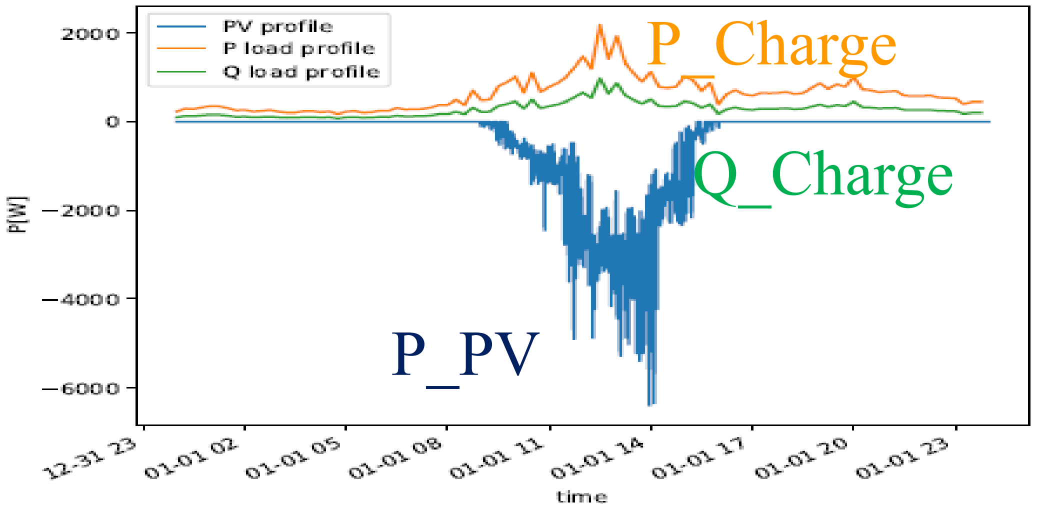
TL Nguyen, T. Tran-Quoc, R. Caire; **"Controller Hardware-in-the-loop Implementation for Distributed Optimal Power Flow Using ADMM on Cyber-Physical Microgrids"** 2019 ieee pes gtd grand international conference and exposition Asia (gtd Asia 2019), Bangkok, Thai Lan 20-23 March 2019; DOI : 10.1109/GTDAsia.2019.8715852



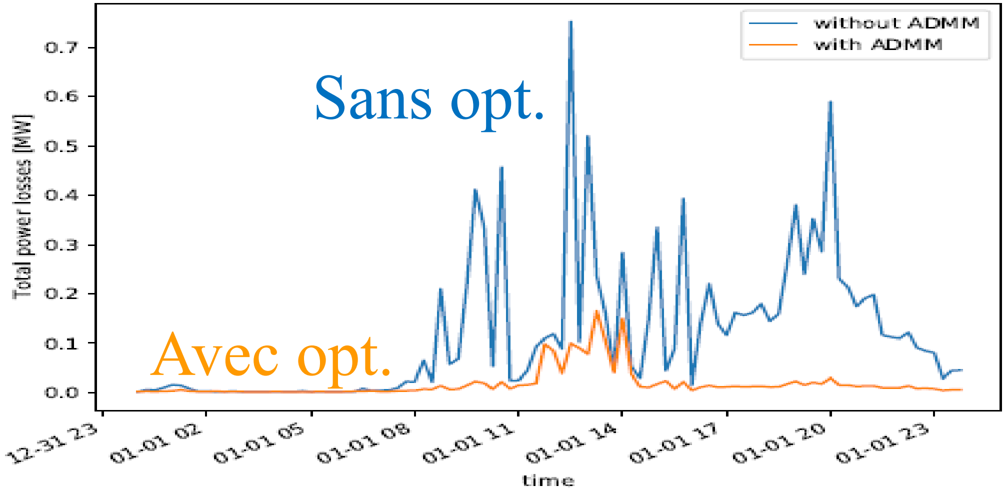
Réseau étudié

Réseau HTA - 20kV :

- 13 agents correspondant aux 13 nœuds



Profils de charges et de production des systèmes PV



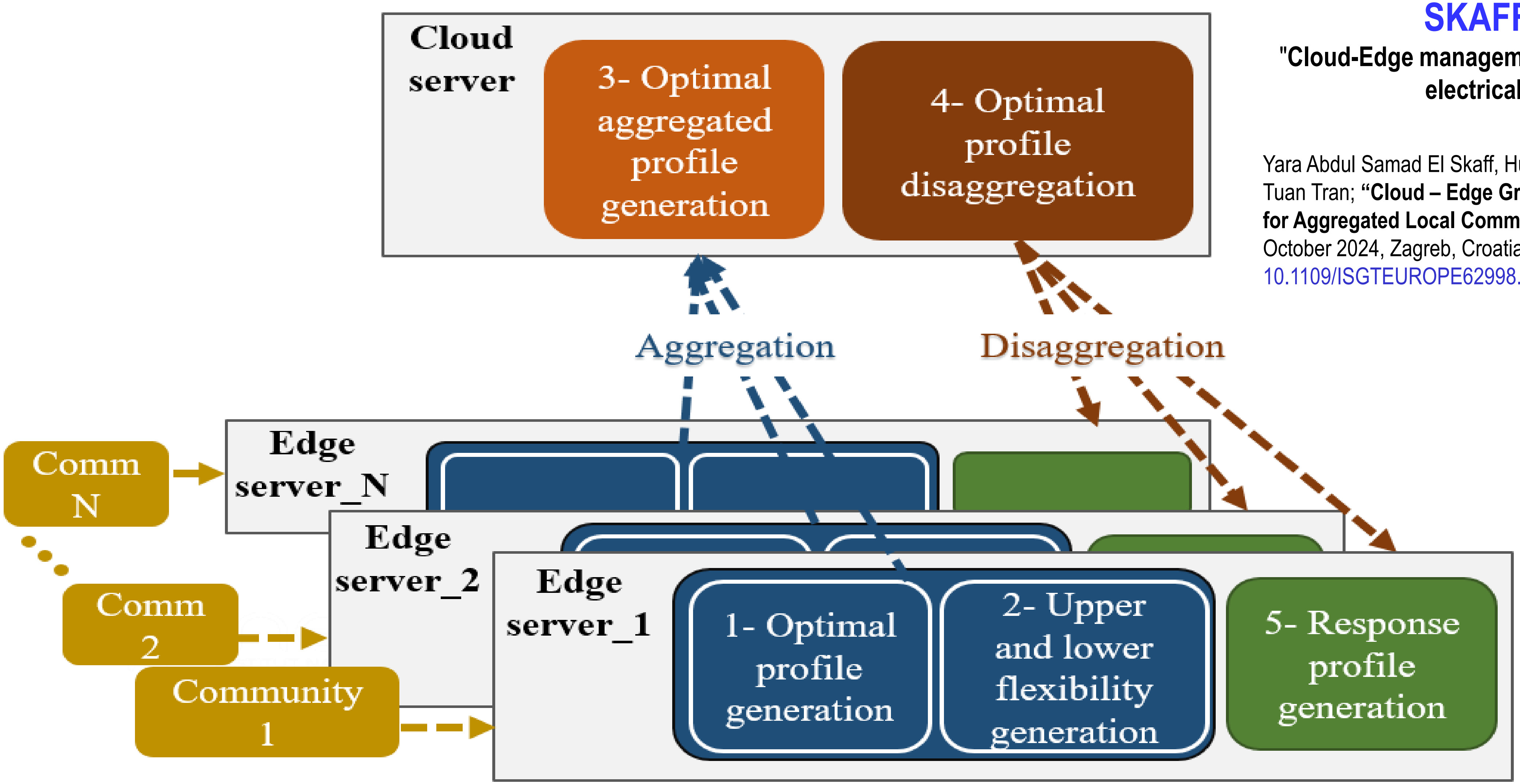
Evolution des pertes sans et avec optimisation ADMM

Cloud-Edge Control

PhD thesis: Yara ABDUL SAMAD EL SKAFF – 2025

"Cloud-Edge management of optimal control of electrical networks"

Yara Abdul Samad El Skaff, Hugo Joudrier, Caire, Raphael, Quoc Tuan Tran; **"Cloud – Edge Grid Control : Advanced Flexibility for Aggregated Local Communities";** IEEE Conference – ISGT, October 2024, Zagreb, Croatia ; DOI: 10.1109/ISGTEUROPE62998.2024.10863166



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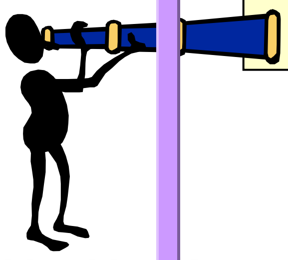

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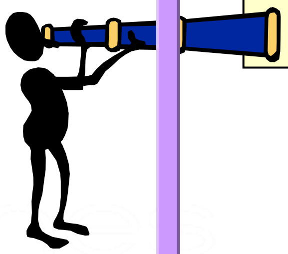
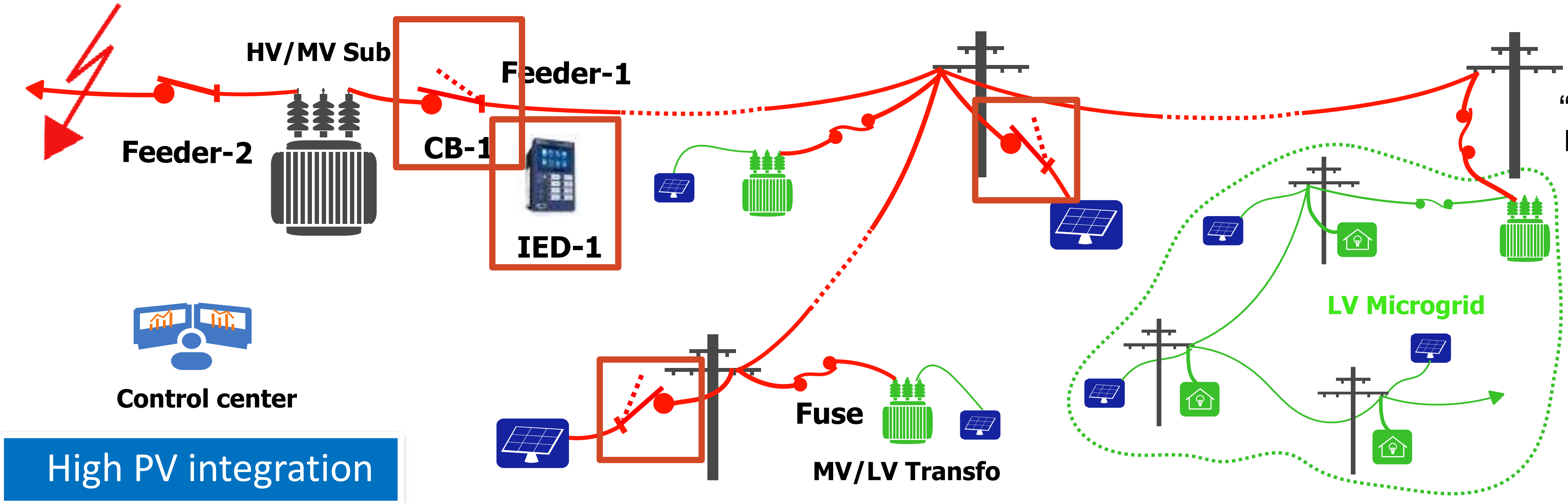


Conclusion

Impacts on MV distribution protection



PhD thesis: Tran The HOANG – 2020
"Protection, Fault Location and Isolation in Active Distribution Networks "

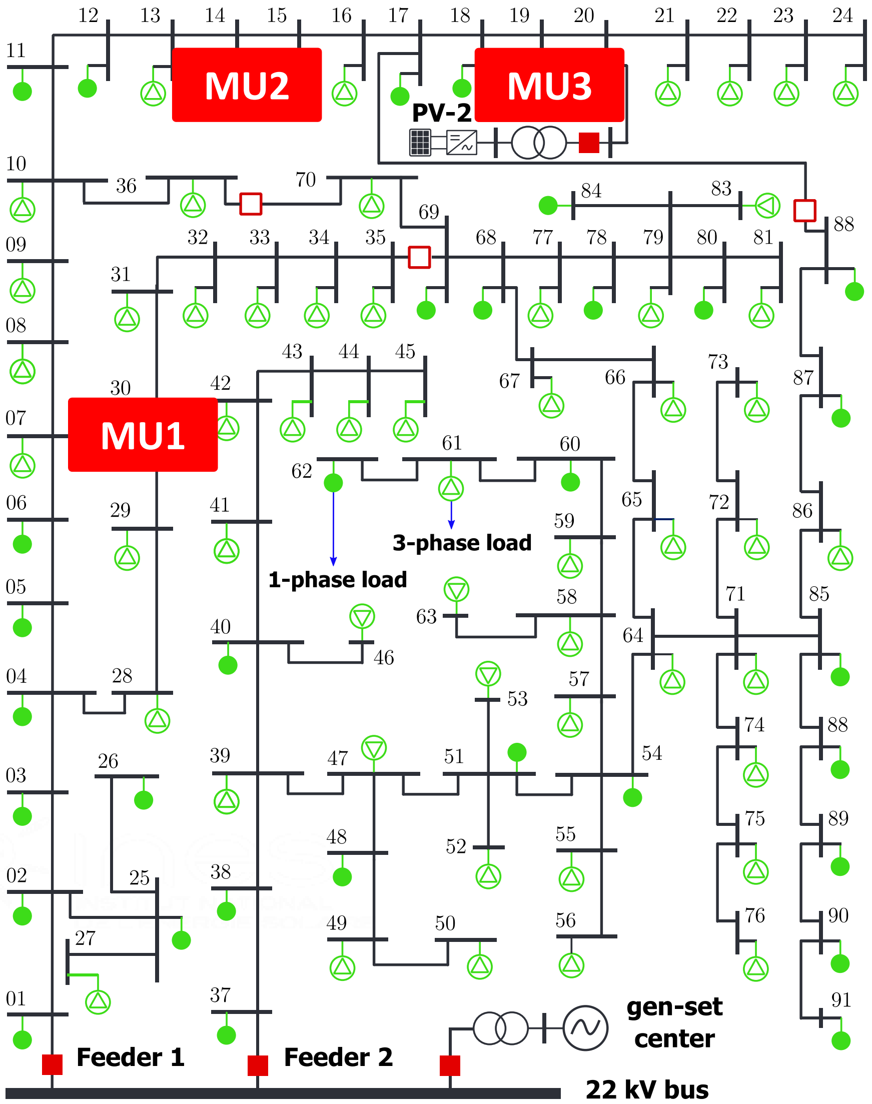
High PV integration

MV protection

- non-directional overcurrent relays (IED: Intelligent Electronic Device)
- time delay: 150 ms for overhead line with recloser & 500 ms for cables

Issues

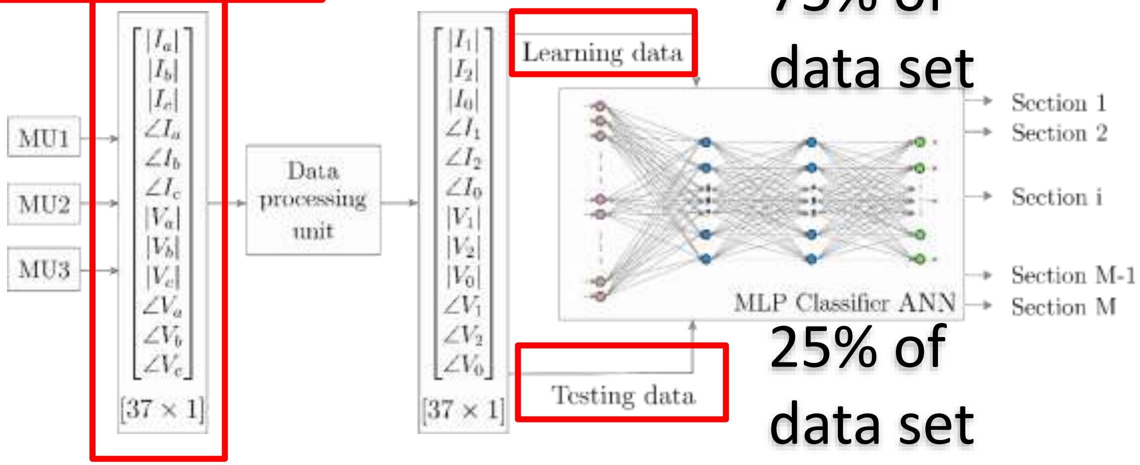
- false tripping
- undesired tripping of PVs (FRT failure) & LV microgrids connected to healthy feeder
- reduced performance of reclosing scheme



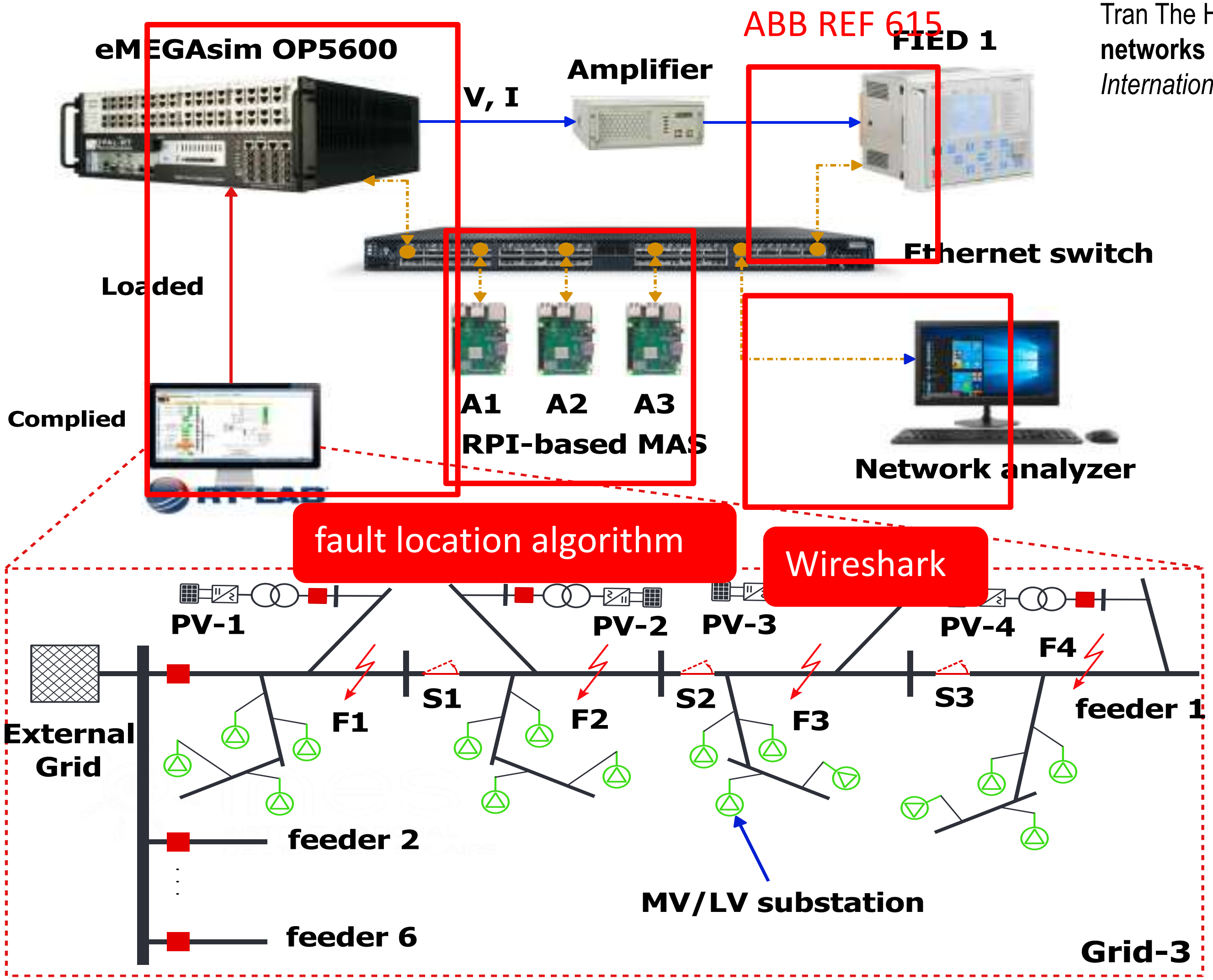
Influencing factors:

- Fault type: three-phase, two-phase, two-phase-to-ground, single-phase-to-ground;
- Fault resistance: from 0 to 60 Ω by a step of 10 Ω;
- Fault location: 19 different sections;
- Simulation hours: from 0 to 20 hour by a step of 4 hours to consider solar variation.

3192 data sets

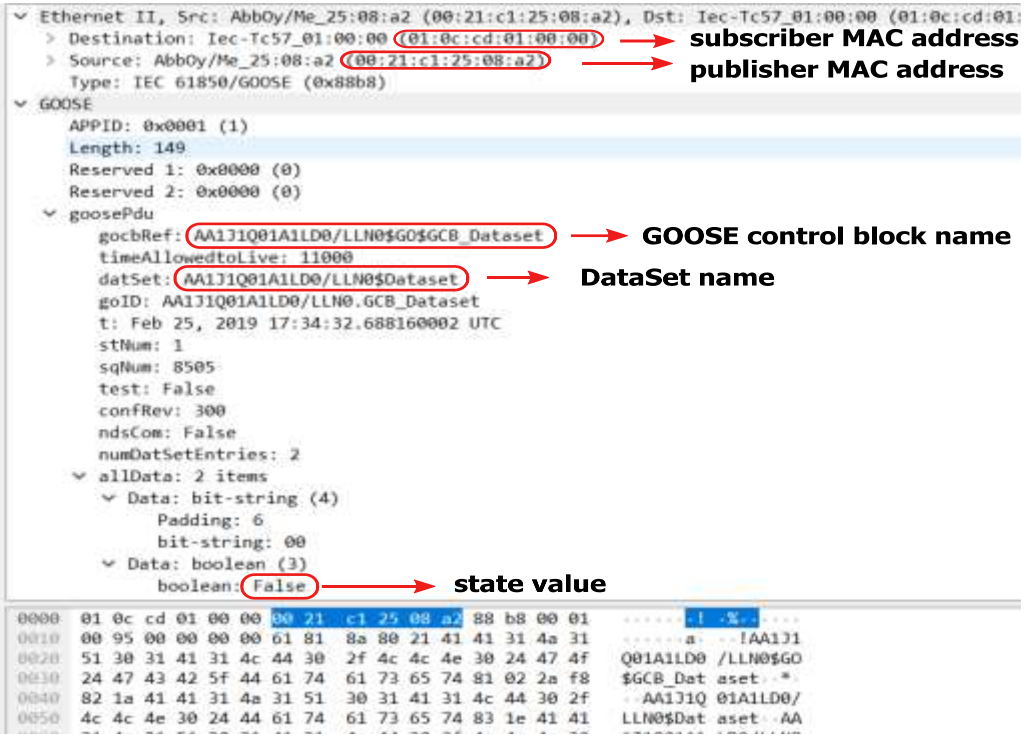


RT validation: Protection, Fault Location and Isolation



Tran The Hoang, Quoc Tuan Tran, **An advanced protection scheme for medium-voltage distribution networks containing low-voltage microgrids with high penetration of photovoltaic systems",** *International Journal of Electrical Power & Energy Systems, Volume 139, July 2022, 107988,*

► **GOOSE package published by REF 615 captured by WireShark**



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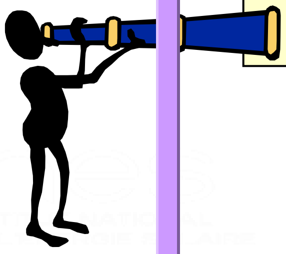


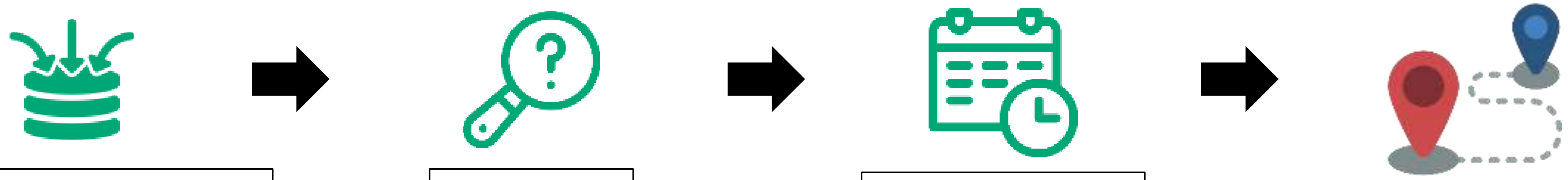
Conclusion

- **Scenario Generation and Reduction**
- **Stochastic Optimization: Searching for Optimal Control**

PhD thesis: Mathieu VALENTIN – 2024

"Advanced management solutions for microgrids with high renewable penetration under uncertainty"

Input → **Representation of uncertainty** → **Planning method** → **Output**



Probabilistic PV forecasting | **Set of scenarios** | **Stochastic optimization** | **Trajectories & planning**

Probabilistic forecasting →

Scenario generation

Definition of a generic method for:
- Estimate marginal distributions
- Characterize a correlation model (dependencies between # random variables)
- Generate a set of scenarios and then reduce them
- Perform data assimilation

Representation of uncertainty

→ **Stochastic**

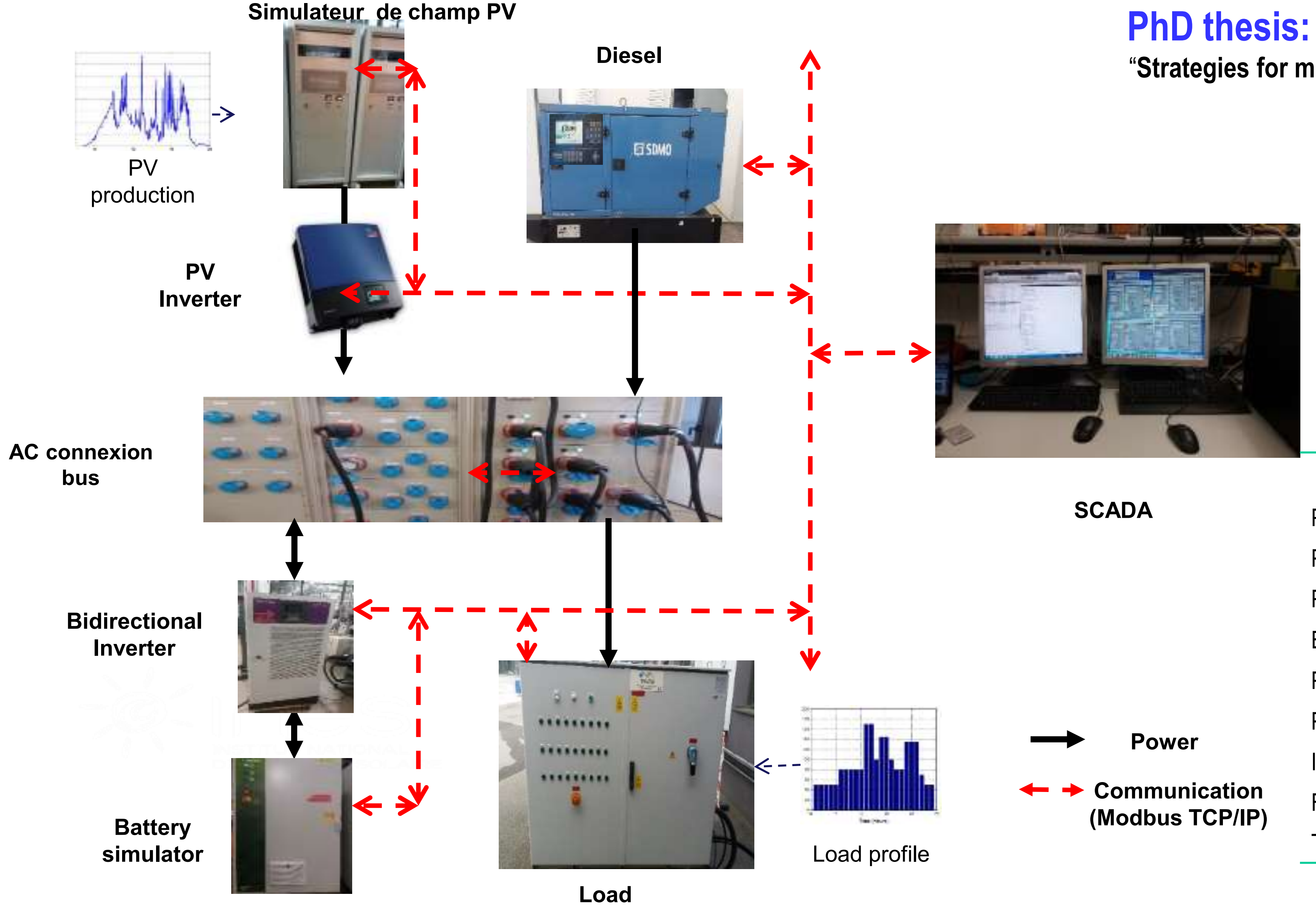
Defining trajectories:
- Anticipating and optimizing costs (risk reduction)
- Providing network service (reducing the amount of demand)

Probabilistic optimization method

→ Optimal control strategies

Mathieu Valentin, Gregoire Pichenot, Quoc Tuan Tran, **"Optimal Management of Microgrid Under PV Forecast Uncertainty Using Stochastic Programming";** 23th IEEE International Conference on Environmental and Electrical Engineering – EEEIC, June 2023, Madrid, Spain
DOI: 10.1109/EEEIC/ICPSEurope57605.2023.10194797

RT Validation: EMS for an islanded microgrid



PhD thesis: Gabin Adantchede KOUCOI– 2017

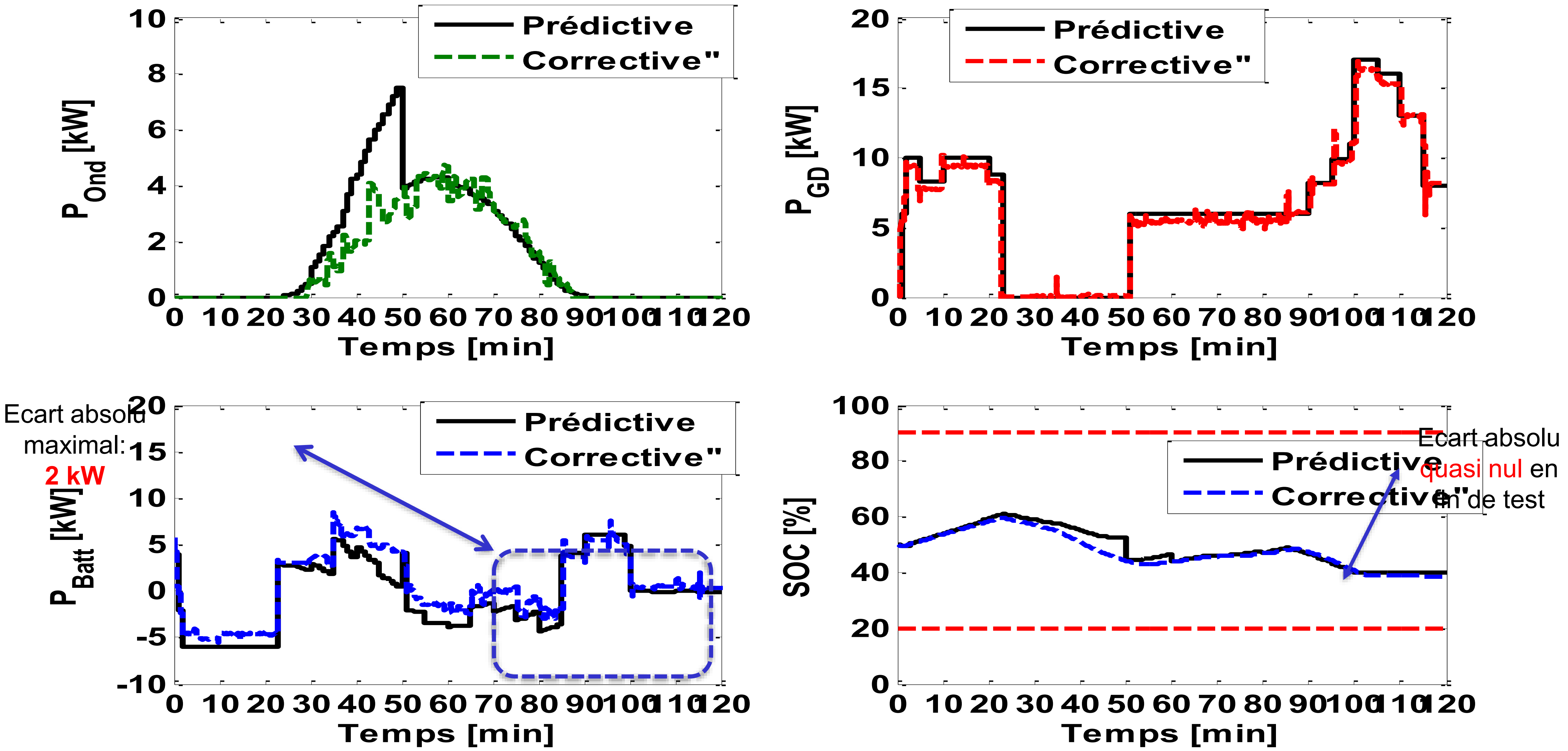
“Strategies for managing a Microgrid on an isolated site in Africa”

Gabin Koucoi, Daniel Yamegueu, Quoc-Tuan Tran, Yézouma Couliblay, Hervé Buttin. “**Energy Management Strategies for Hybrid PV/Diesel Energy Systems: Simulation and Experimental Validation**”, International Journal of Energy and Power Engineering. Vol. 5, No. 1, 2016, pp. 6-14.
doi: 10.11648/j.ijepe.20160501.12

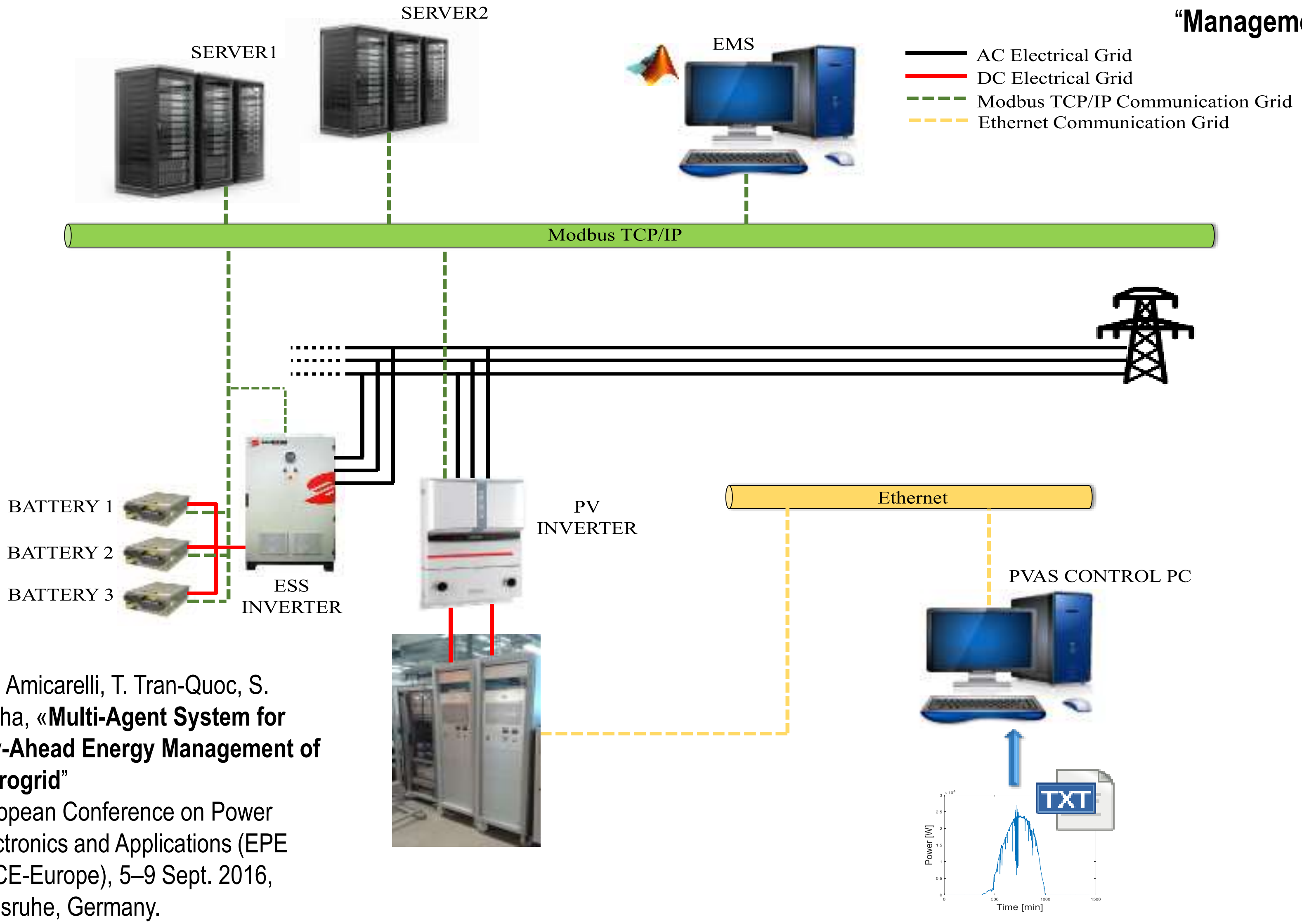
	Value
P_PV	**10 kWc**
P_Diesel	**35 kW**
Pmin_Diesel	**10 kW (30% of P_{GD}^{max})**
E_bat	**15 kWh**
Pmax_Bat (discharge)	6 kW
Pmax_Bat (charge)	-6 kW
Initial SOC (at the start of the day)	50 %
Final SOC (at the end of the day)	40 %
Test time (duration)	**2 H**

RT Validation: EMS for an islanded microgrid

PhD Thesis, Gabin KOUCOI



HIL validation: EMS for local market



1 E. Amicarelli, T. Tran-Quoc, S. Bacha, «**Multi-Agent System for Day-Ahead Energy Management of Microgrid**”
European Conference on Power Electronics and Applications (EPE ECCE-Europe), 5–9 Sept. 2016, Karlsruhe, Germany.

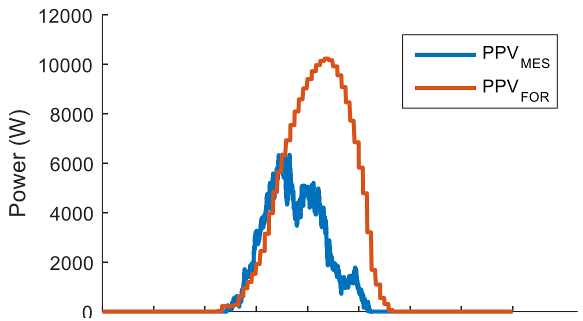
PhD thesis: Elvira AMICARELLI – 2017

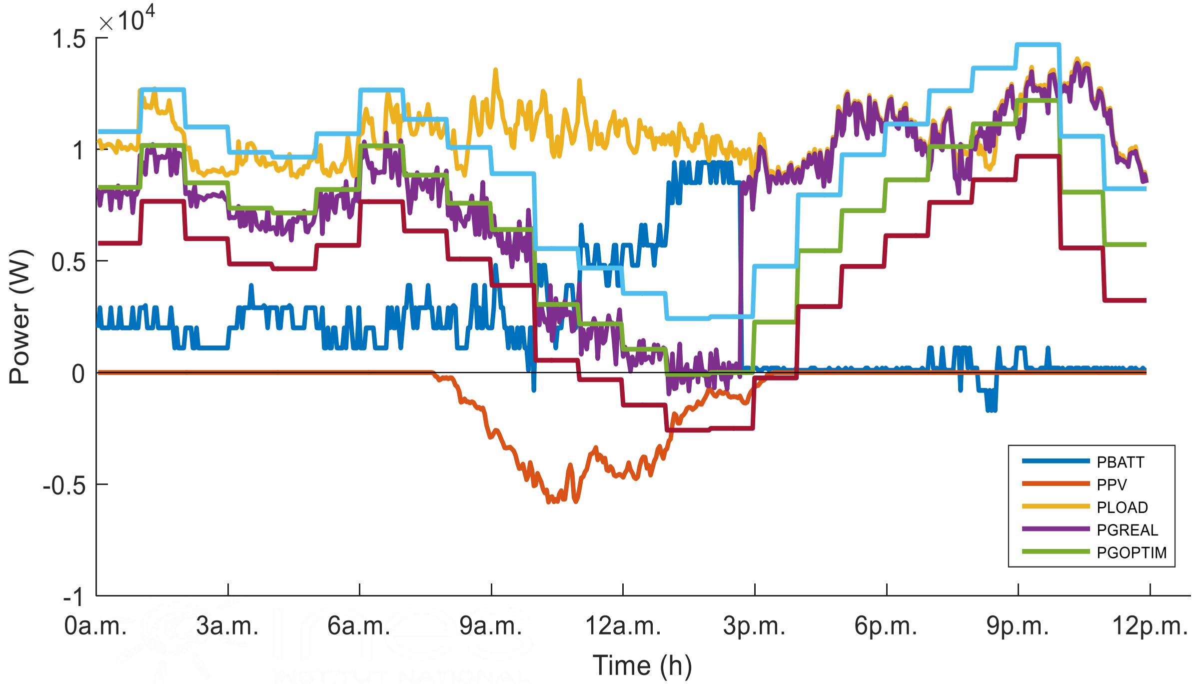
“Management and control strategies for intelligent electricity networks with a high rate of renewable energy”

- **Communication and information exchange**
  - The data acquisition, management and equipment control are applied through the “INES SCADA”
  - The data acquisition uses the Modbus TCP/IP protocol
  - All shared variables in the SCADA can be read and write via OPC UA Protocol
- **Input Data**
  - Consumption real-time profiles comes from a measure campaign in the framework of “IPERD” project funded by ADEME
  - PV production real-time profile comes from a measure campaign on a 40 kW system at INES
  - PV day-ahed forecast profile are computed by a forecast algorithm developed at INES

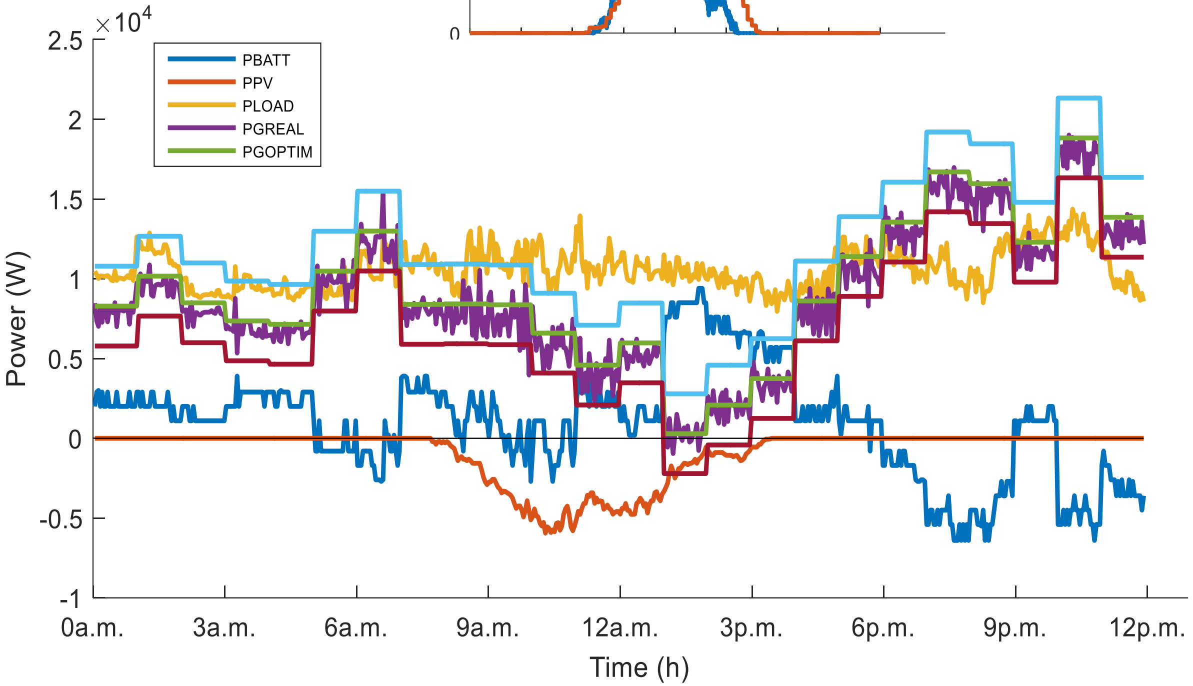
HIL validation: EMS for local market

E. Amicarelli, T. Tran-Quoc, S. Bacha, **“Flexibility Service Market for Active Congestion Management of Distribution Networks using Flexible Energy Resources of Microgrids**”; 7th IEEE International Conference on Innovative Smart Grid Technologies – September 2017, Turin, Italy.
DOI : 10.1109/ISGTEurope.2017.8260198





Mean profiles of photovoltaic, battery, consumption and grid exchange without intra-day optimization



Mean profiles of photovoltaic, battery, consumption and grid exchange with intra-day optimization

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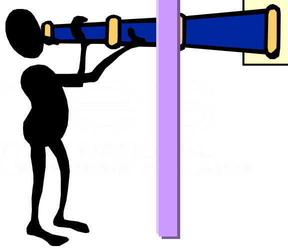


Conclusion

Modelling: Adaptive battery models

PhD thesis: Eiko KRUGER– 2016

"Development of algorithms for optimal management of energy storage systems based on adaptive models"

For Classical approach: Battery model obtained by tests in lab.

Testing
- Open-circuit voltage measurement
- Impedance spectro-scopy

Non-linear model
- OCV characteristic
- Impedance characteristic
- Thermal dependence

Simplified (linear) model

Operation planning
- Linear programming

Control
- Linear control law

Observation/ Measurement
- Physical system

Parameter and state estimation
- Adaptive filter
- Kalman filter

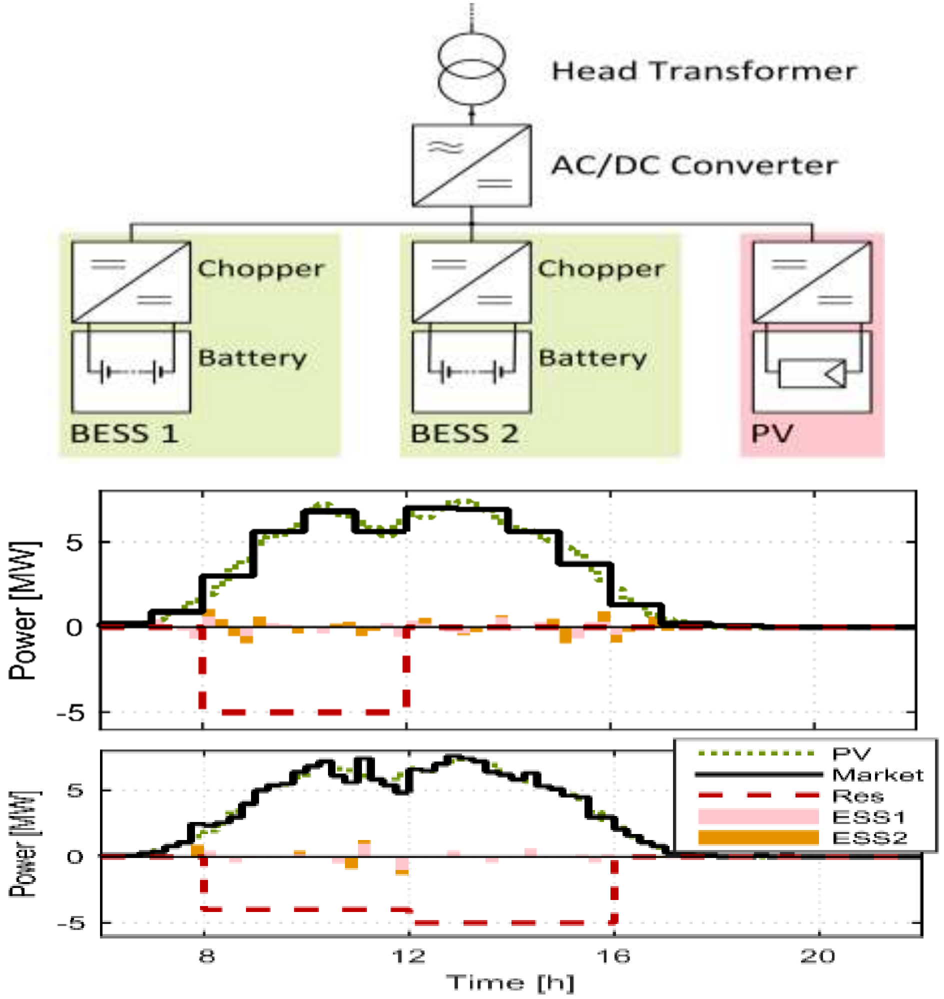
Data Analysis
- Recalibration of OCV
- Learning algorithms

Eiko Krüger, Quoc Tuan TRAN, Franck Al Shakarchi "**Gradient Descent Observer for On-Line Battery Parameter and State Coestimation**"; IEEE, Industrial & Comercial Power Systems conference, I&CPS, Detroit, Michigan, 1-4 May2016.
DOI: 10.1109/ICPS.2016.7490226

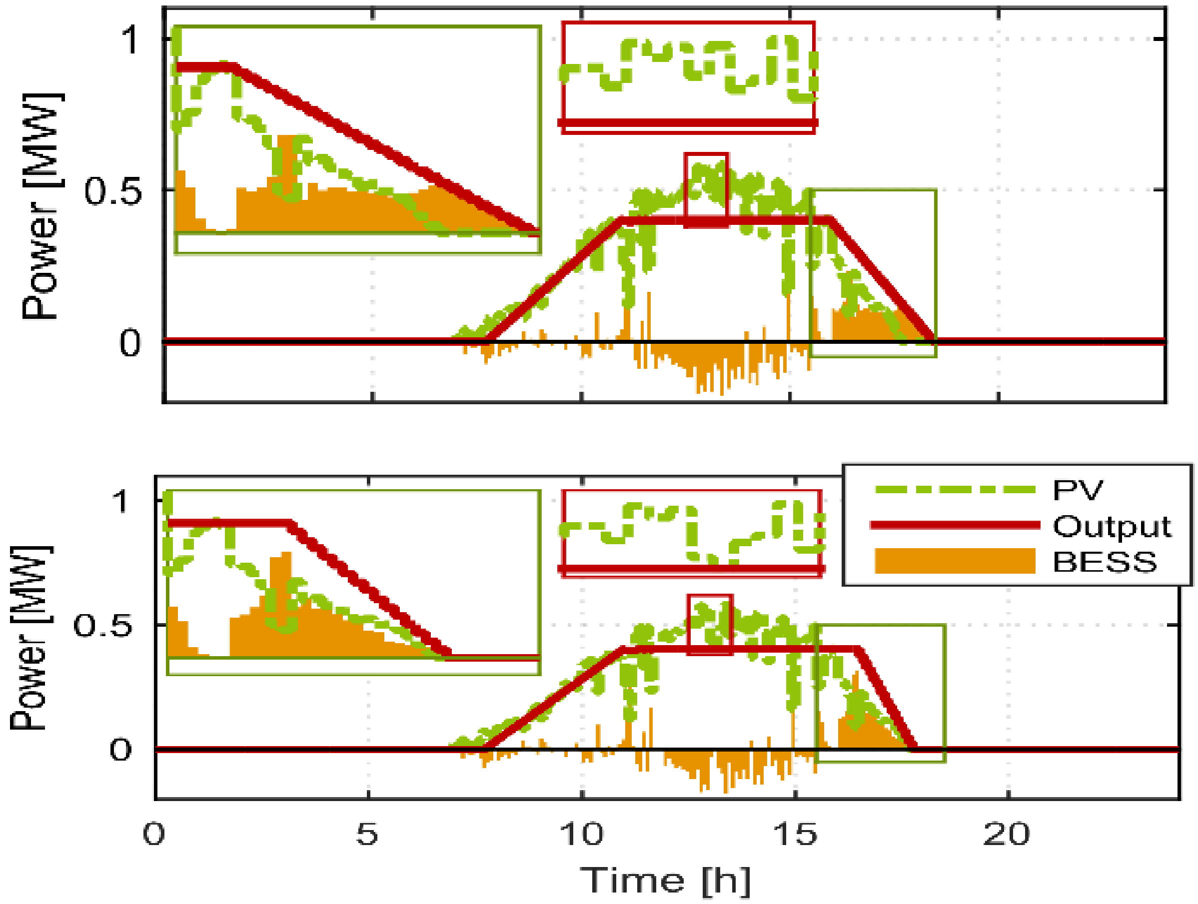
The proposed method is applied for a BESS installed at LECLERC St. Leu (Réunion Island)

Adaptive approach: Battery model obtained by measurements at physical system in operation

STRATEGIES FOR BESS MANAGEMENT IN PHOTOVOLTAIC APPLICATIONS



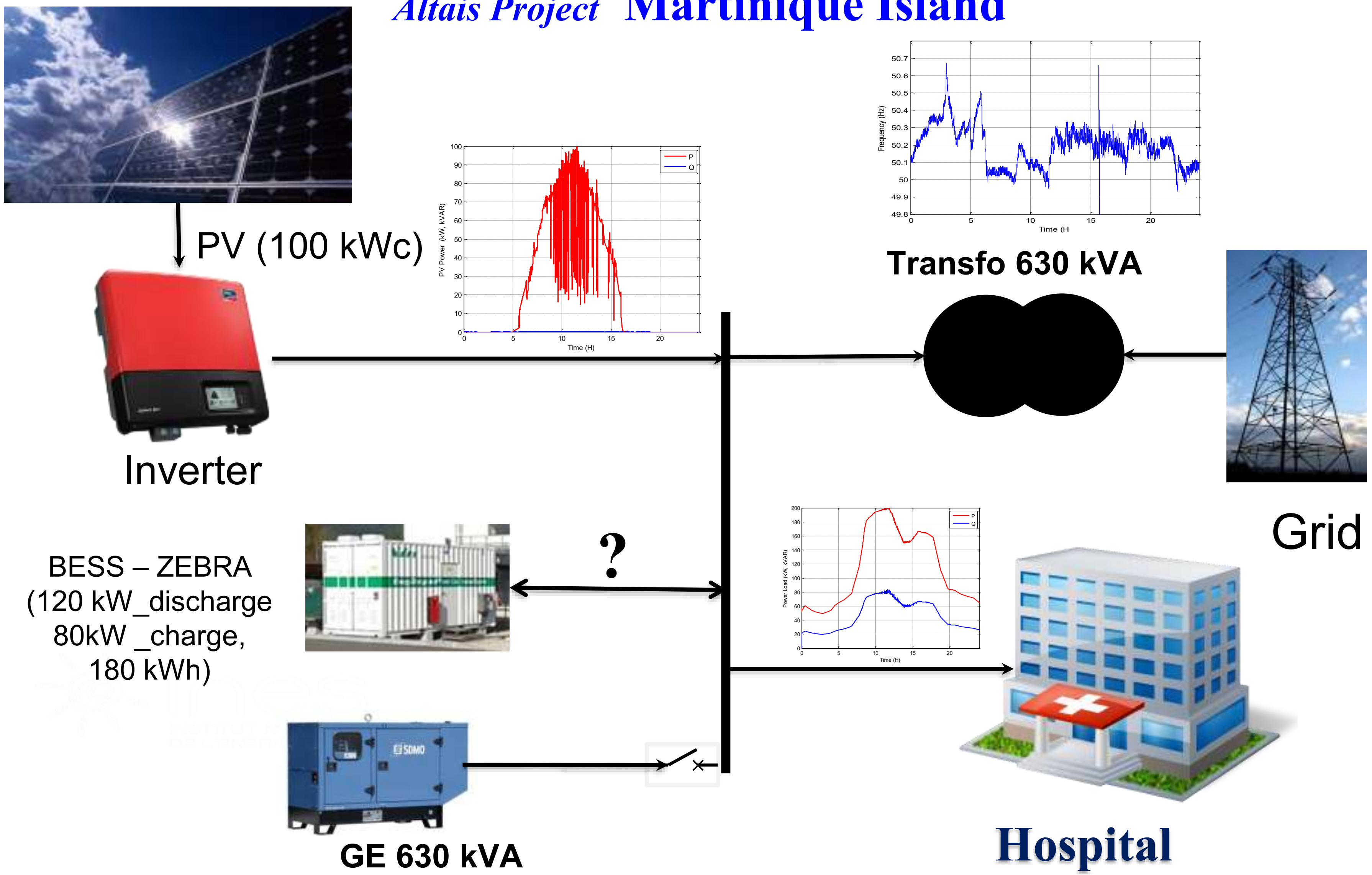
E. Krüger and Q. T. Tran, "**Minimal aging operating strategies for battery energy storage systems in photovoltaic applications**," IEEE-ISGT, Innovative Smart Grid Technologies Conference, 9-12 October 2016, Ljubljana, Slovenia; DOI: 10.1109/ISGTEurope.2016.7856325



Plant production schedule, PV generation and BESS solicitation resulting from optimization. Top: without aging cost, bottom: with aging cost (average aging approach)

Real application - Hospital

Altais Project **Martinique Island**

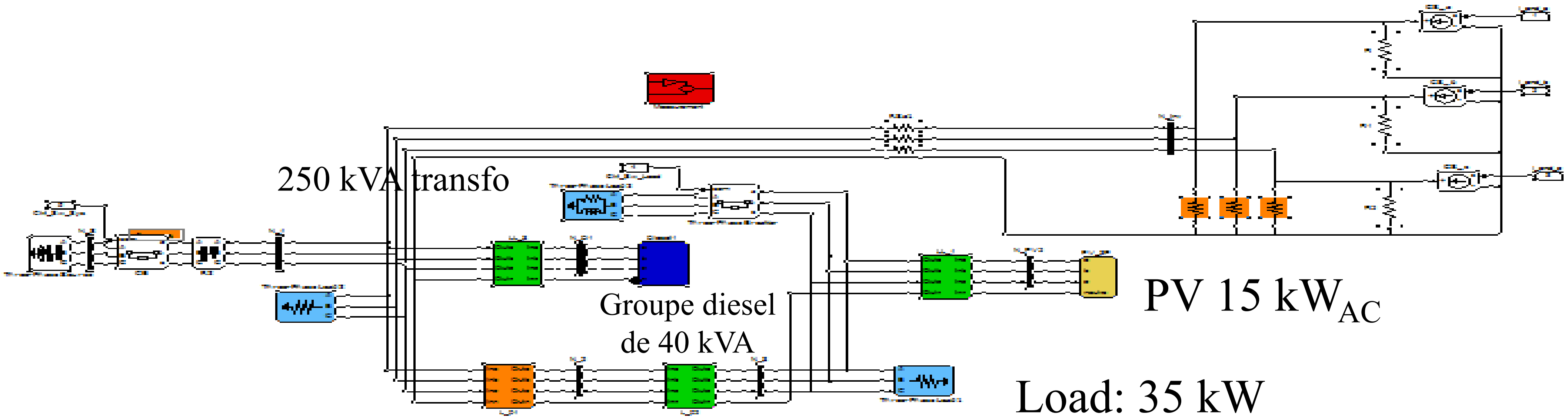


BESS permits to:

1) smooth the intermittency of PV production
2) Reduce peak power
3) Control voltage
4) Control frequency

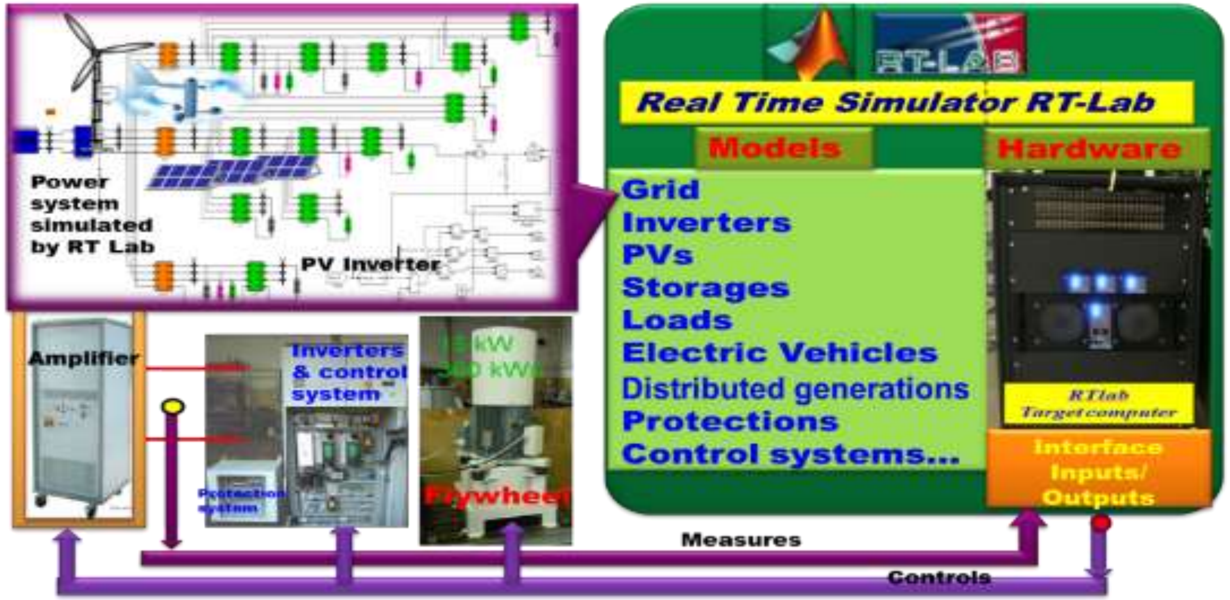
Flywheel: Validation by real time simulation

PhD Thesis: Cedric Abezzot



Test for a island grid

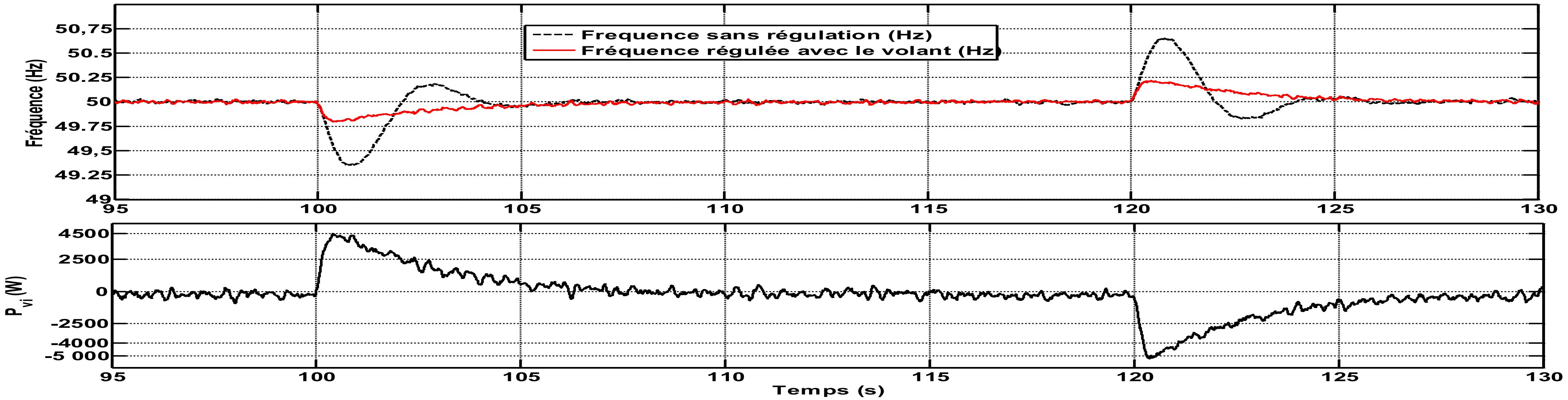
- Frequency setting:
  - Without speed management
  - With speed management
- Testing the impact of PV power smoothing

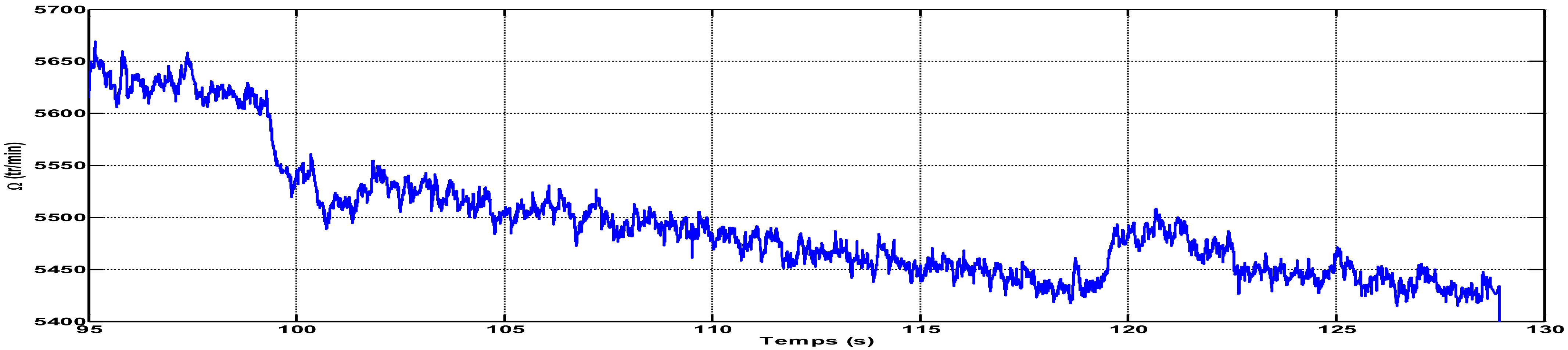


Cédric Abbezzot, Tuan Tran Quoc, Marion Perrin, Philippe Poggi,
"**Flywheel Energy Storage System (FESS) contribution for ancillary services**"
Conference PV-Hybrids and Mini-Microgrids – Berlin, Germany, Avril, 2014

Flywheel: Validation by real time simulation

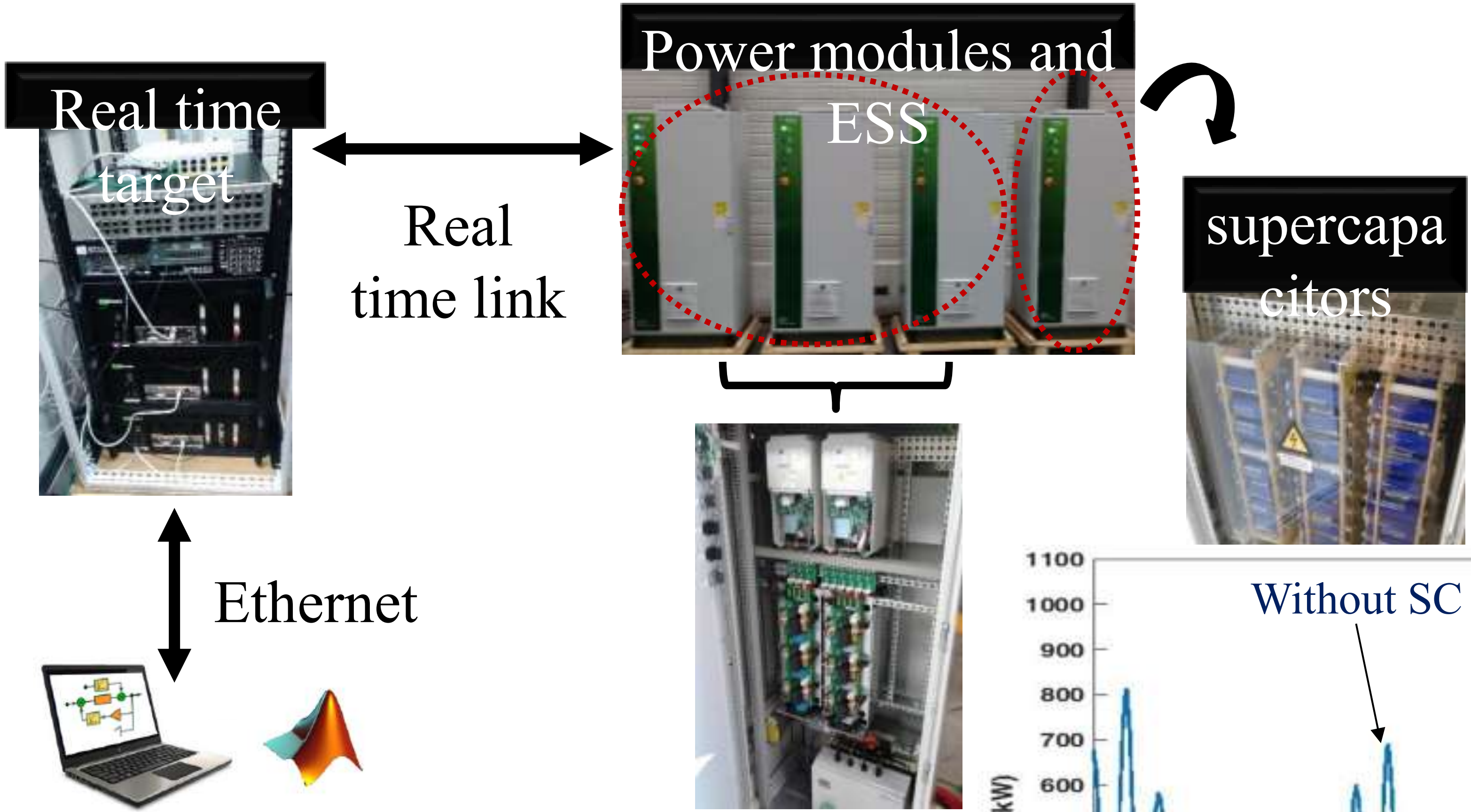
PhD Thesis: Cedric Abezzot



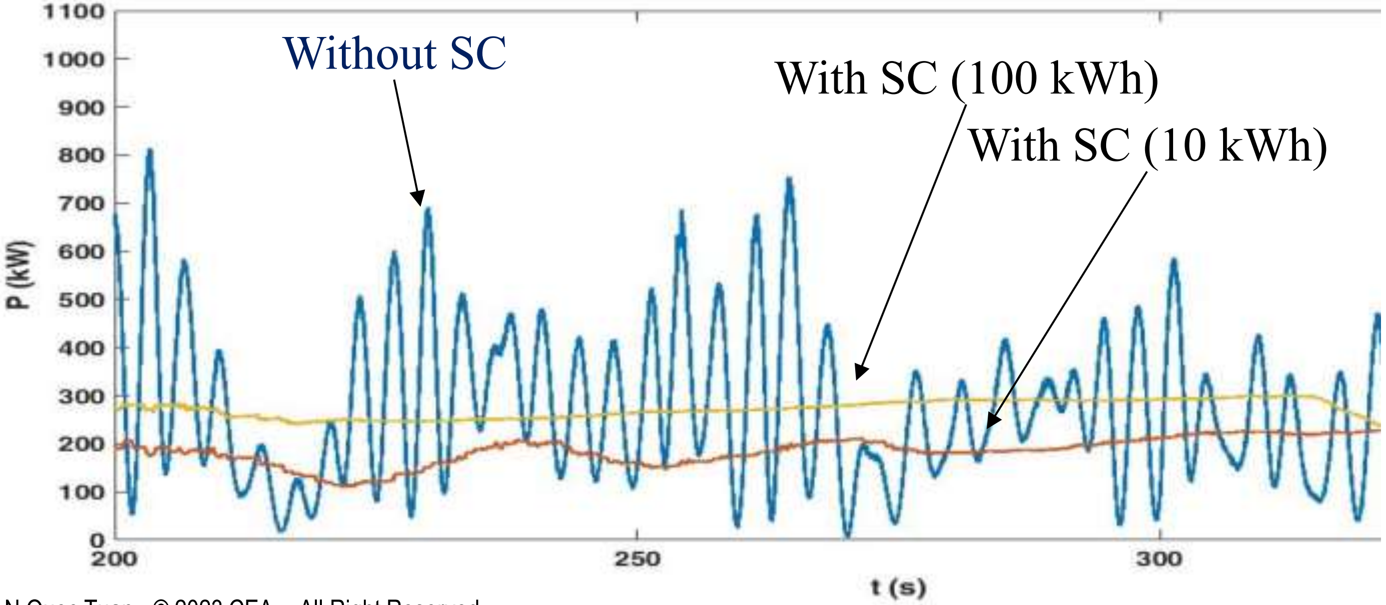


FES participates to control frequency

Supercapacitor: Validation by real time simulation



Hélène Clémot, Florian Dupriez-Robin, Aurélien Babarit, T. Tran-Quoc " **A wave-to-wire chain modeling and command for a direct drive wave energy converter**"; 2017 Twelfth International Conference on Ecological Vehicles and Renewable Energies (EVER), April 11-13, 2017, Monaco, France



PLAN

Introduction

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- Forecasting (Load, PV, Wind)
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- Voltage control
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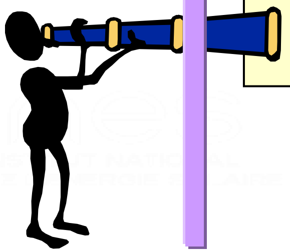
- DC grid
- Demonstrations



Conclusion

Minimize the cost of EV charging

PhD thesis: Van Linh NGUYEN– 2014

"Coupling photovoltaic systems, electric vehicles to the grid - Problems and solutions"

Obj: Interruption of charge

$$Z = \min\left(\sum_{t=1}^{N_T} C_t \sum_{i=1}^{N_{EV}} (P_{EVi} X_{it})\right)$$

Mixed Integer linear programming

Obj: Modulation of charge

$$Z = \min\left(\sum_{t=1}^{N_T} C_t \sum_{i=1}^{N_{EV}} Y_{it}\right)$$

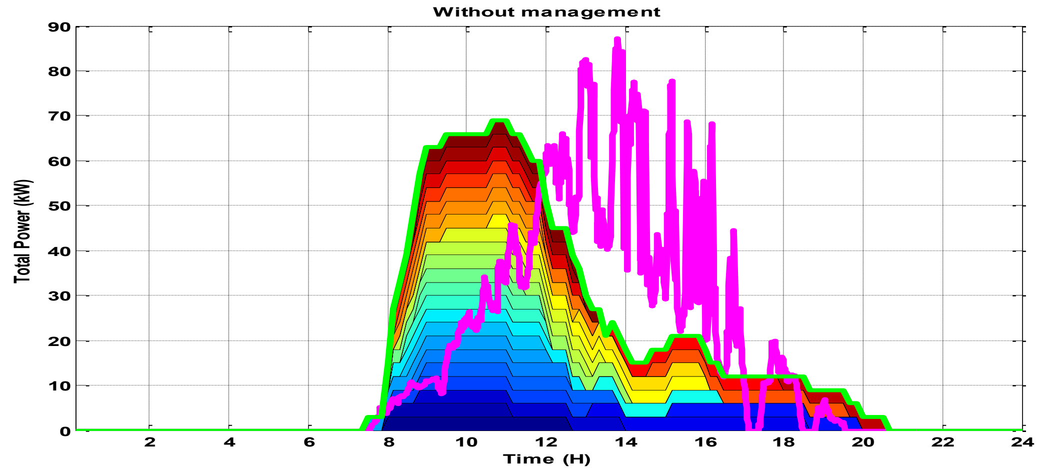
Linear programming

N_{EV} is the number of vehicles
P_{EVi} the rated power of vehicle i
X_{it} is an *integer variable* (0 or 1) at the interval t.
Y_{it} *real variable* presents the charging power of the EV_i at the interval t.
C_t is electricity price purchased from the grid at interval t (Euros/kWh)

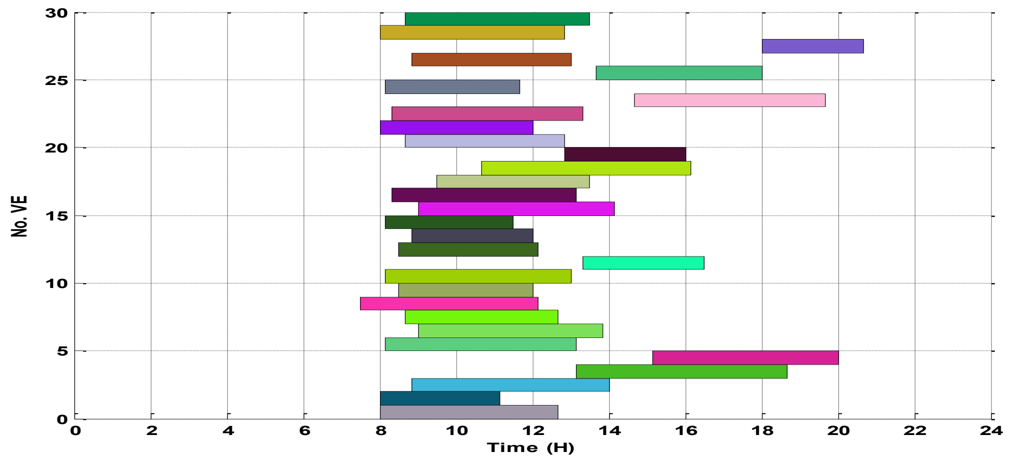
Constraints

- $\sum_{i=1}^{N_{EV}} P_{EVi} X_{it} - PV_t \leq P_{DSOt}$ $\qquad$ $\sum_{i=1}^{N_{EV}} Y_{it} - PV_t \leq P_{DSOt}$
- SOC => 100% for all EV before the departure time

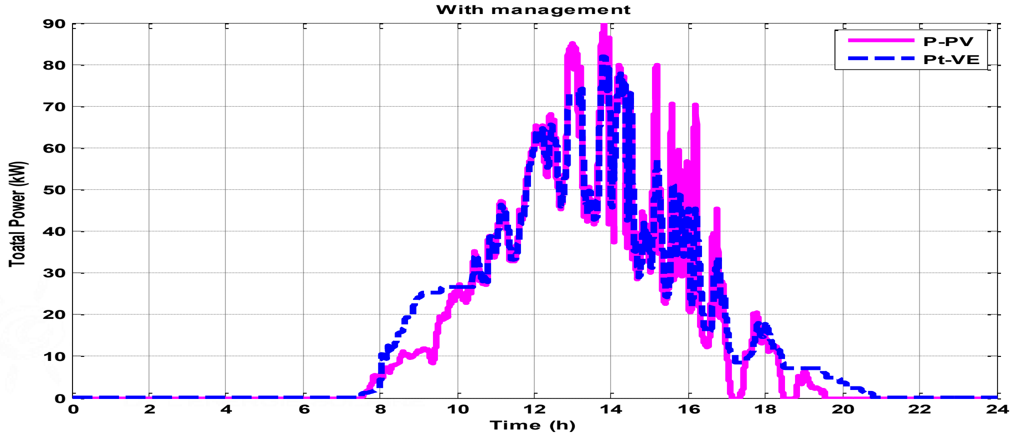
Results, modulation of charge



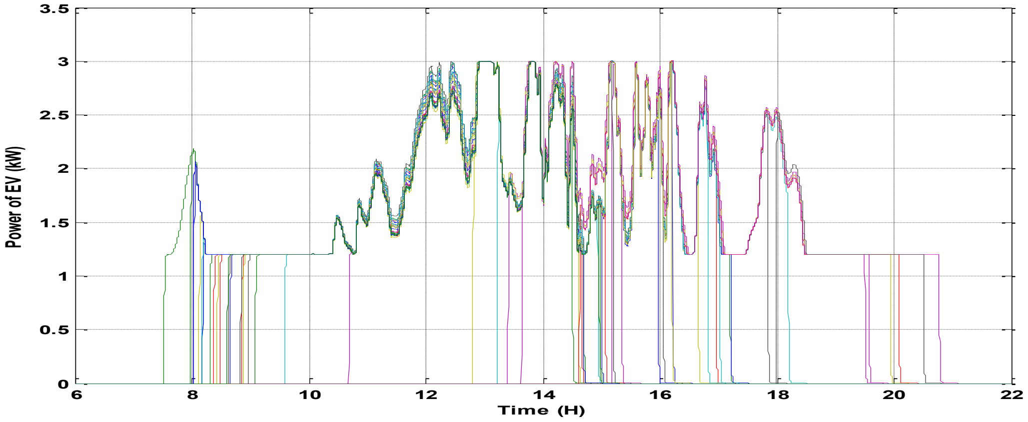
Without management, Solar coverage rate: 57.81%



Time charging of EVs without management



With management, Solar coverage rate: 93.16%

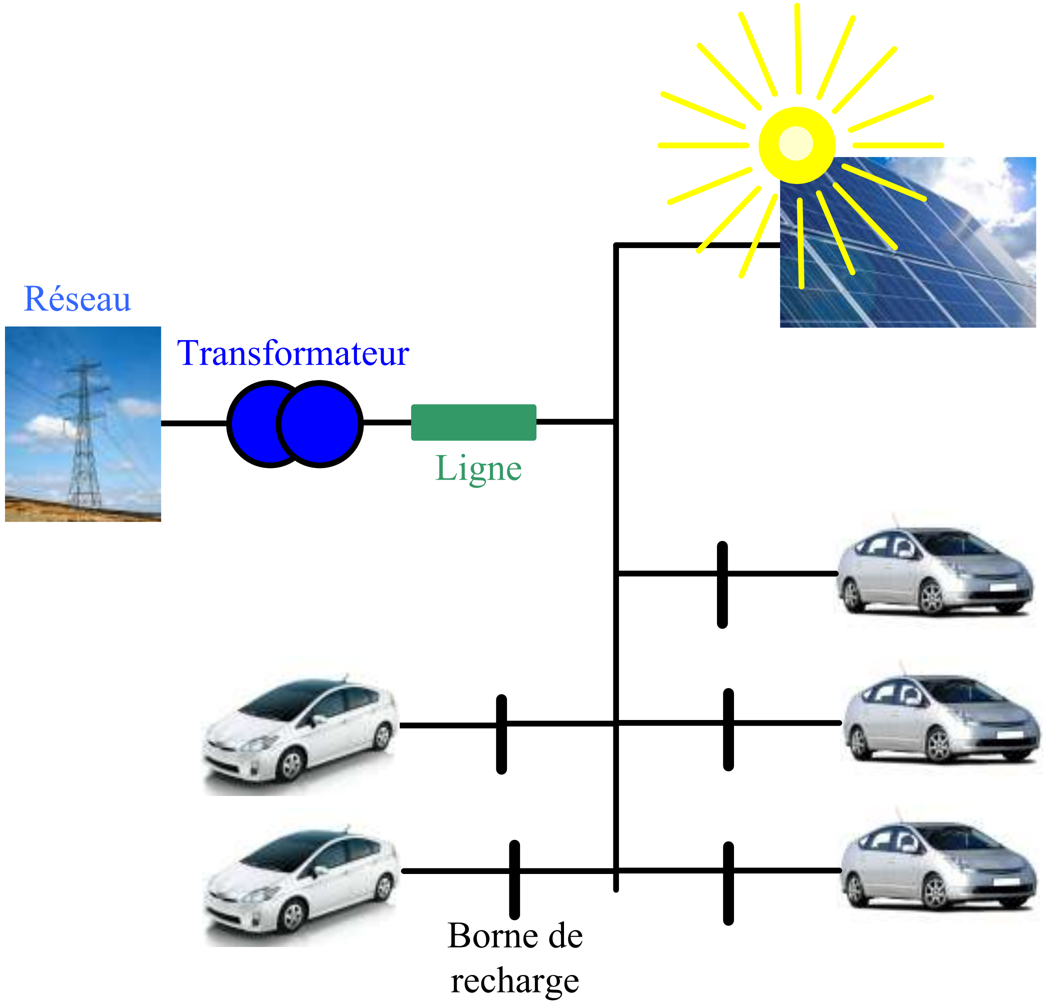


Power variation of EVs

Real time control of EV

Objectif: development of real time control strategies of EV charging in parking :

- Miminise power exchange with grid
- Maximise the use of PV energy to charge EV
- Possibility to inject power to grid (V2G)

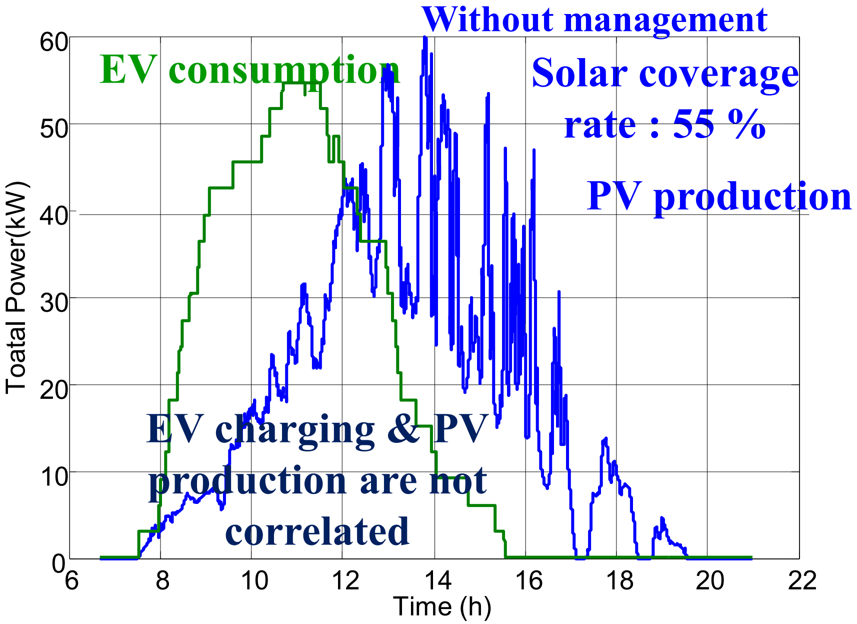


Hypothesis

- Modulated charging
- Communication system in parking

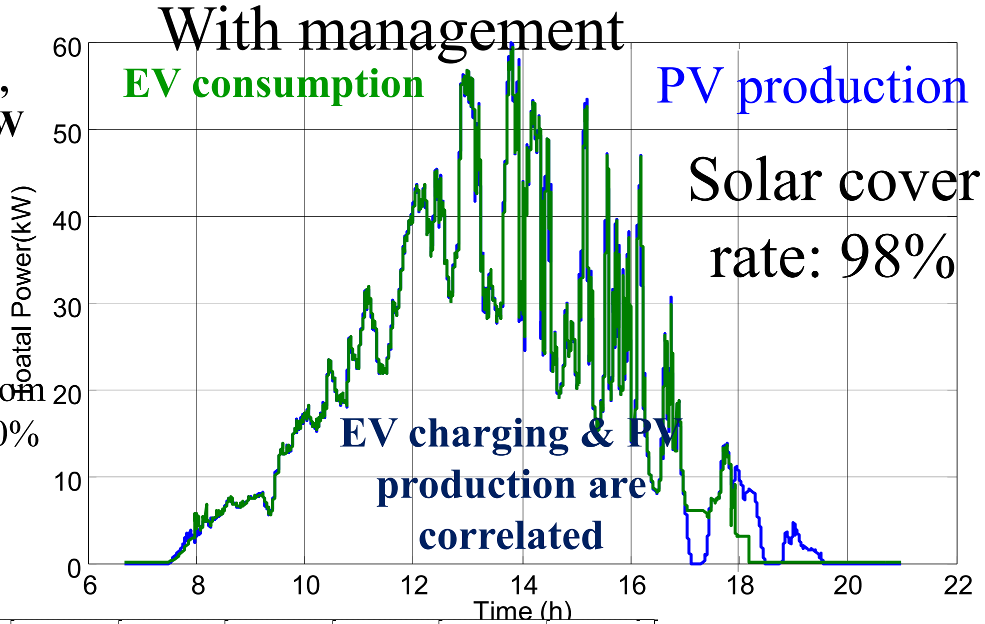
Adaptation of load consumption with PV production => Self-consumption

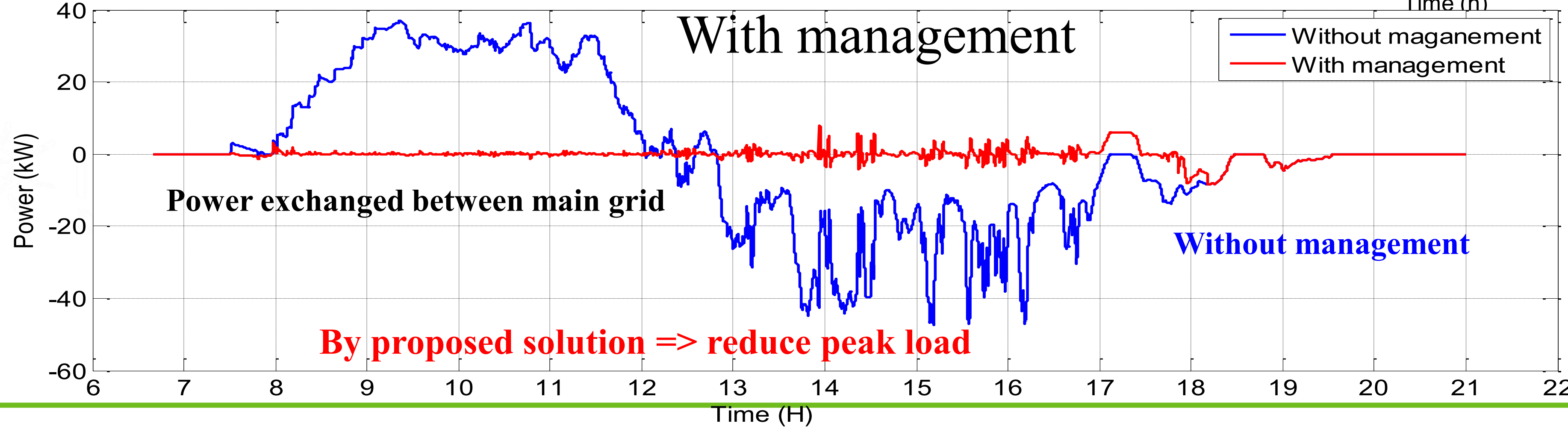
Maximize the use of solar energy for charging EV (20 EVs)



Parking with 20 EVs, PV sys: 70 kW

Init. SOC: random
Final SOC: 100%

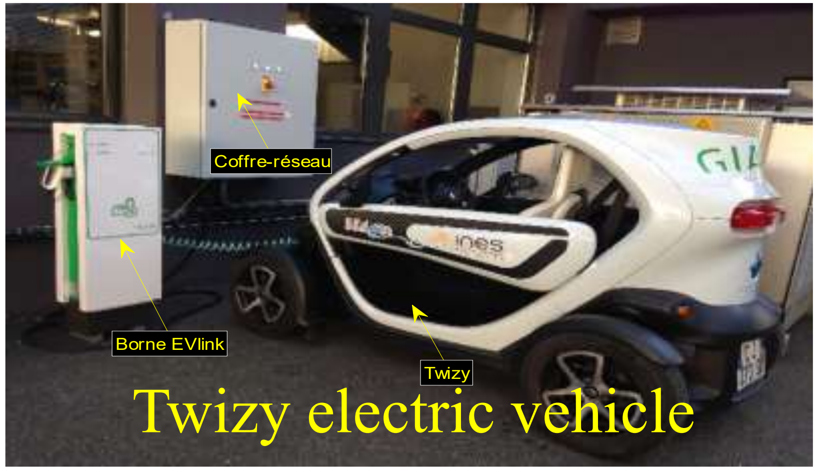


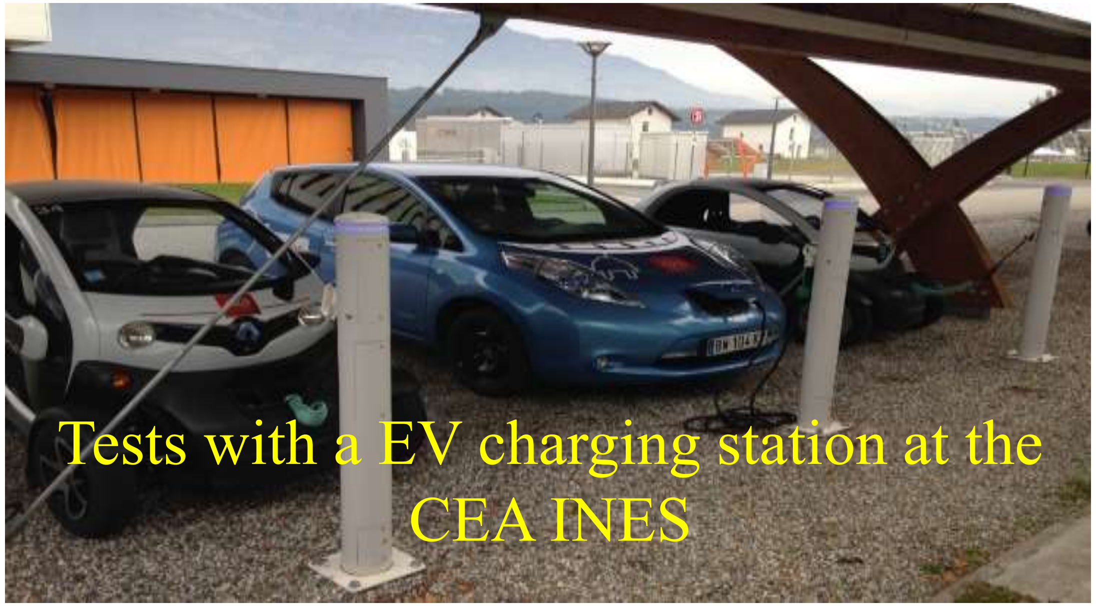


Validation by demonstration

Post Doc Van Linh Nguyen

Greenlys project

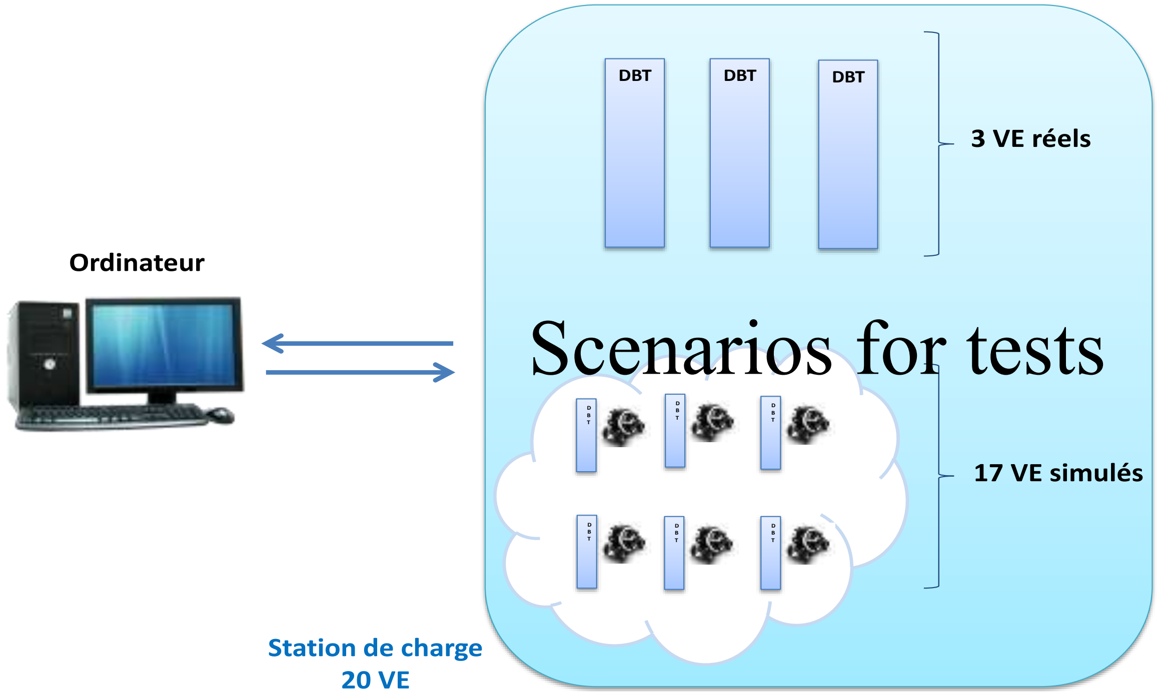


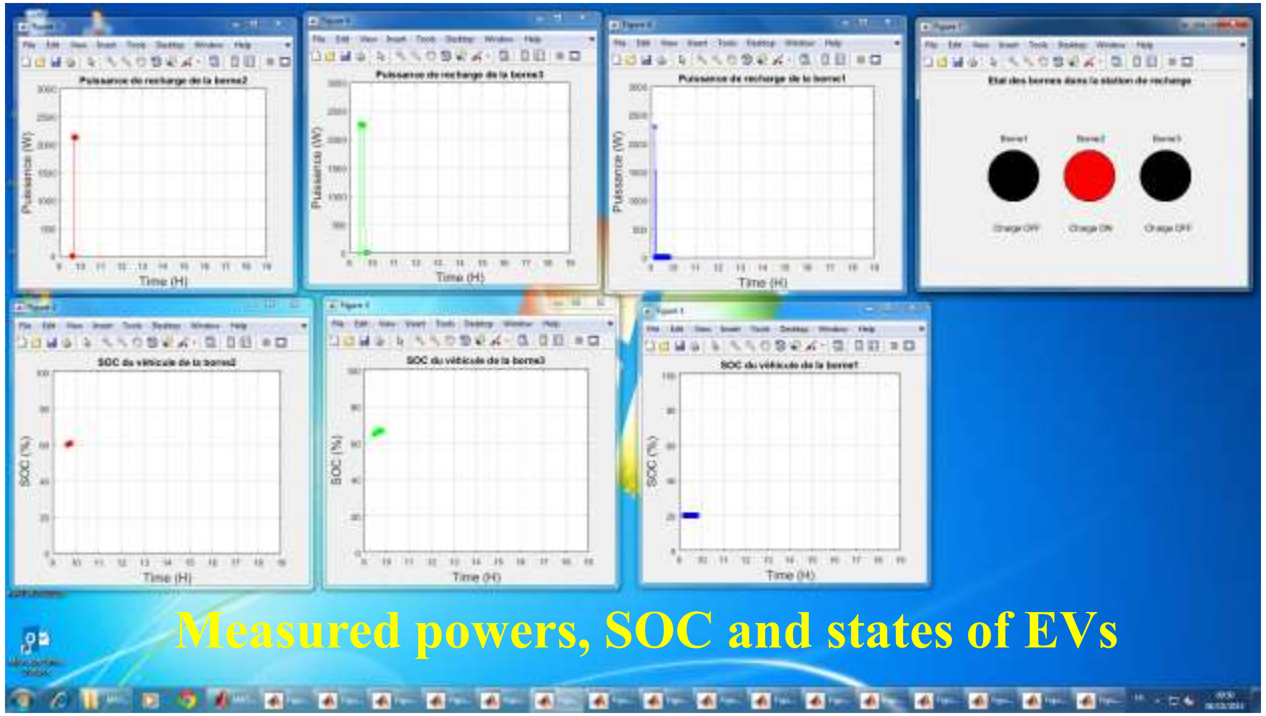


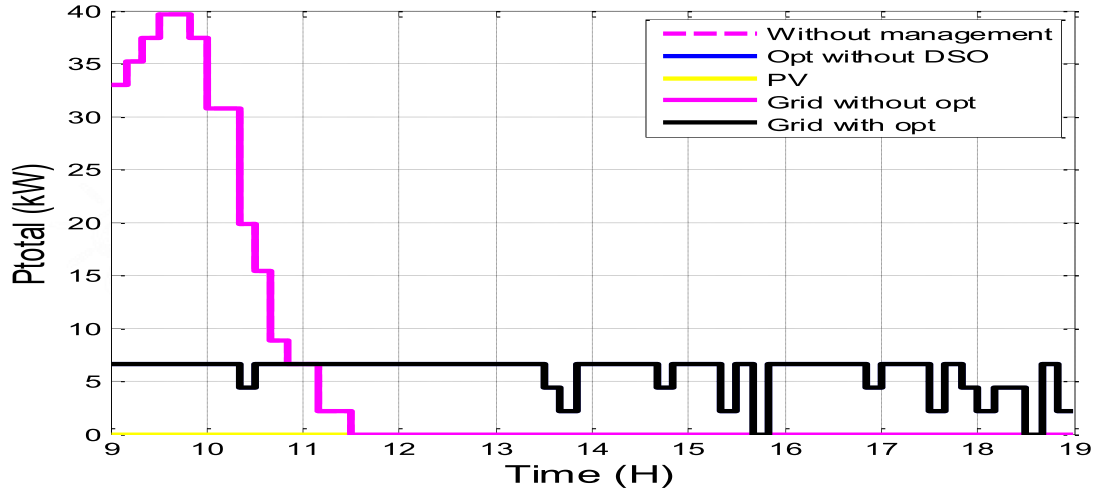
Validation by demonstration

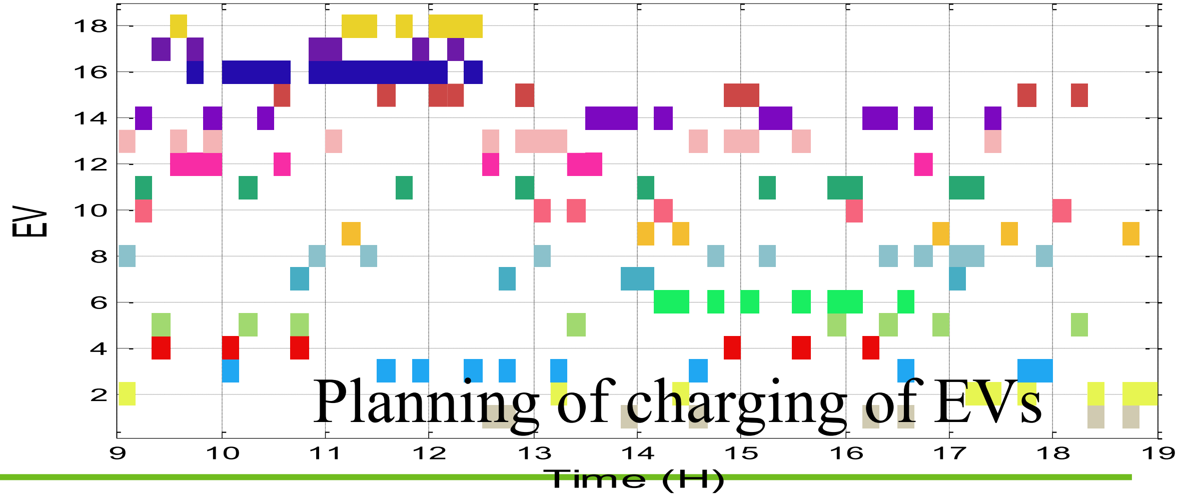
Post Doc Van Linh Nguyen

Greenlys project



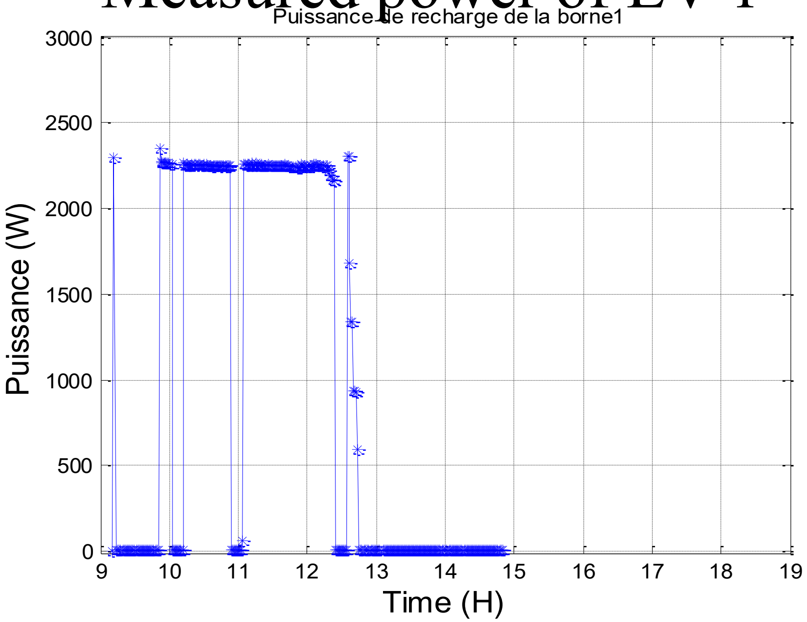




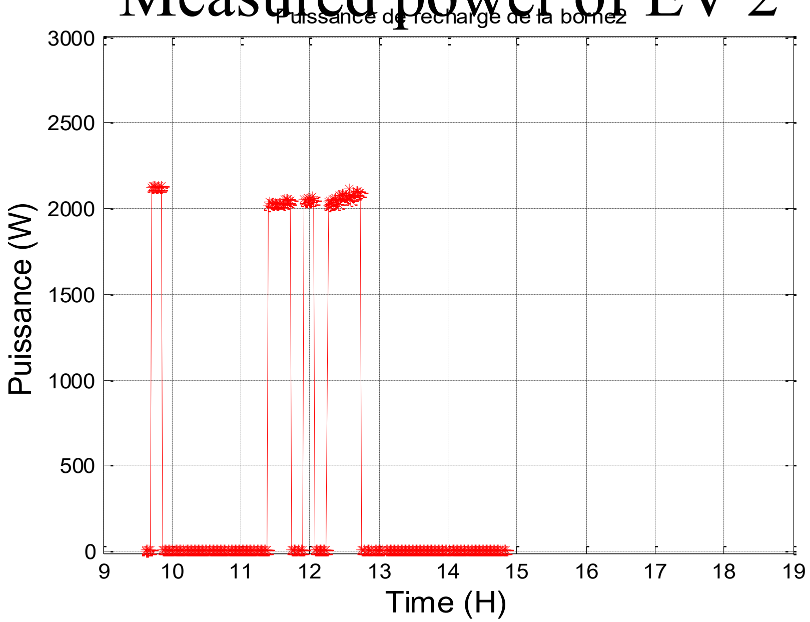


Validation by demonstration

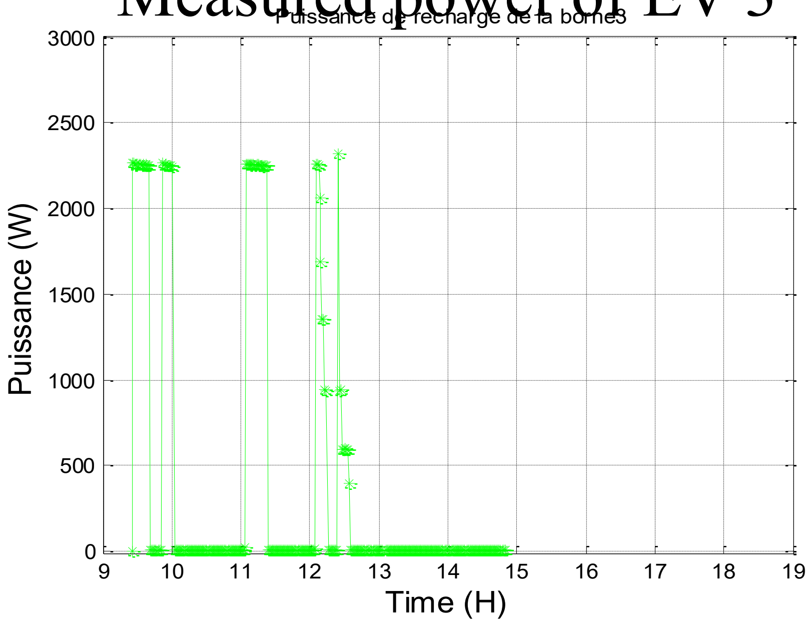
Measured power of EV 1

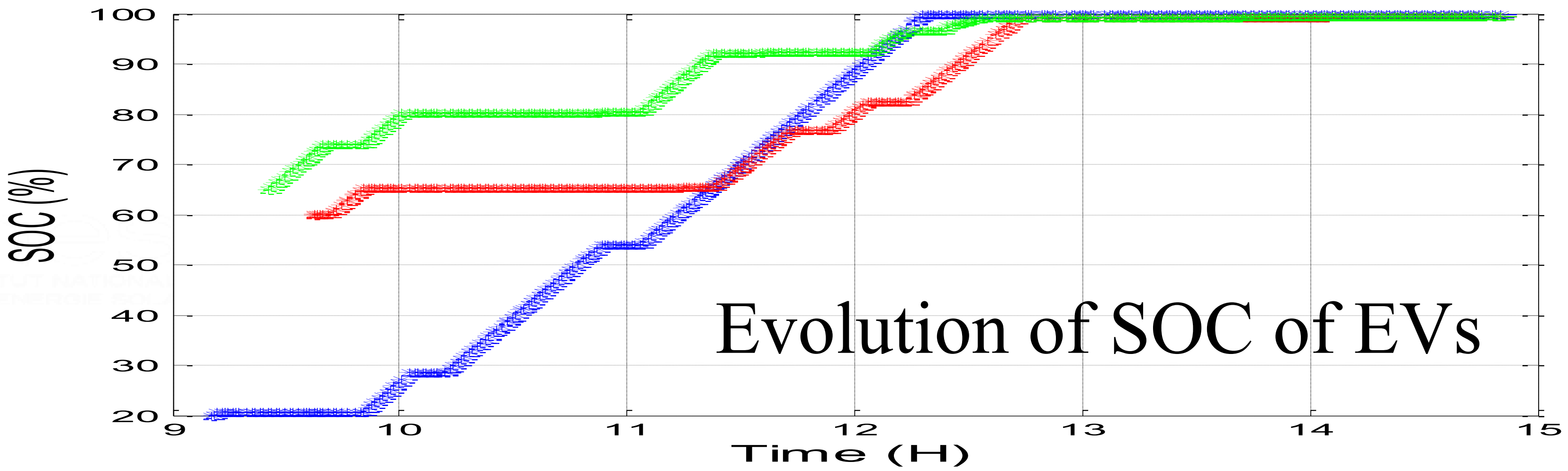


Measured power of EV 2



Measured power of EV 3





Evolution of SOC of EVs

Demonstration in CEA-INES and real applications

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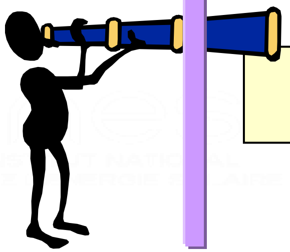
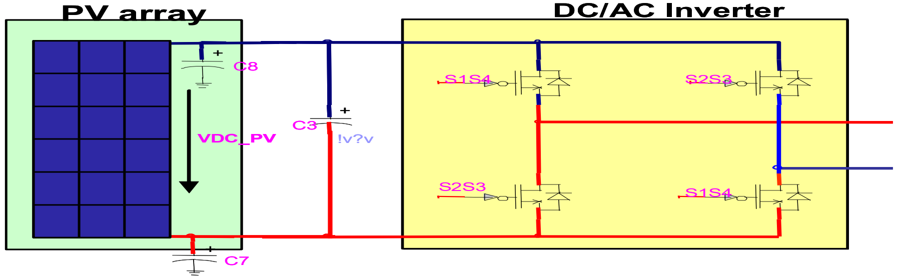


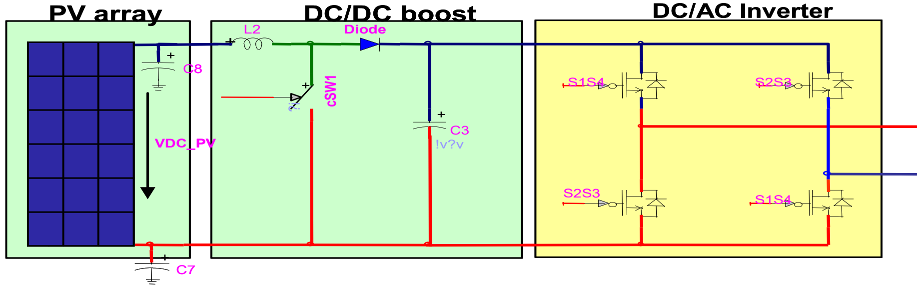
Conclusion

Inverter modelling

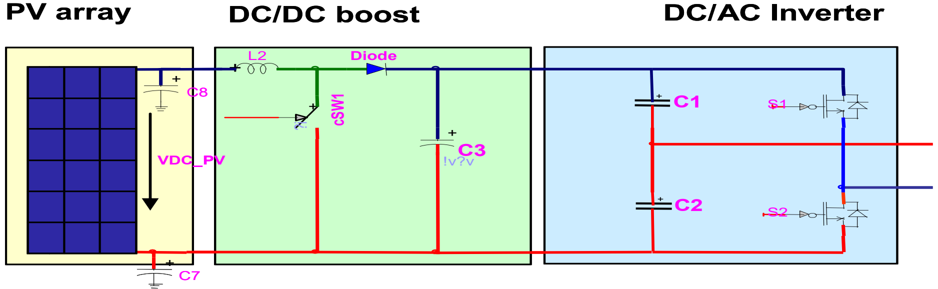
T1 : Full-bridge inverter – no DC/DC converter- transformerless



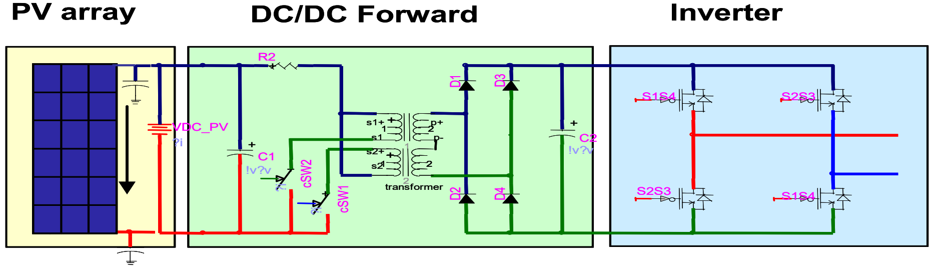
T2 : Full-bridge inverter – DC/DC boost converter – transformerless



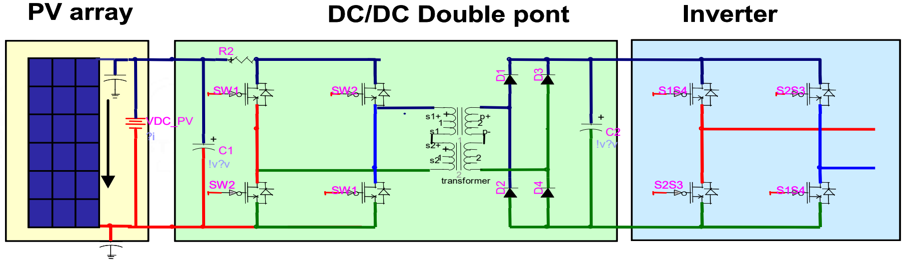
T3 : Half bridge inverter – DC/DC boost converter – transformerless



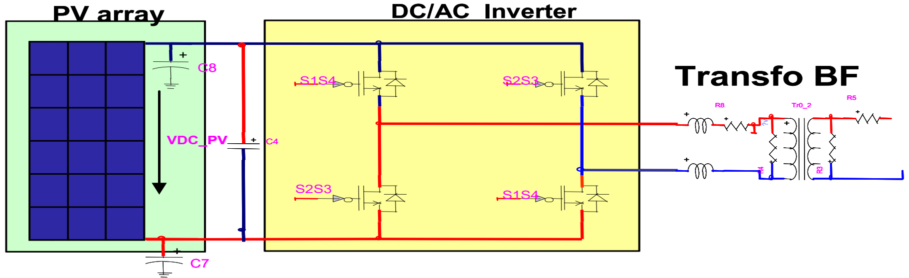
T4 : Full-bridge inverter – DC/DC Forward converter –HF transformer



T5 : Full-bridge inverter – DC/DC full-bridge converter –HF transformer

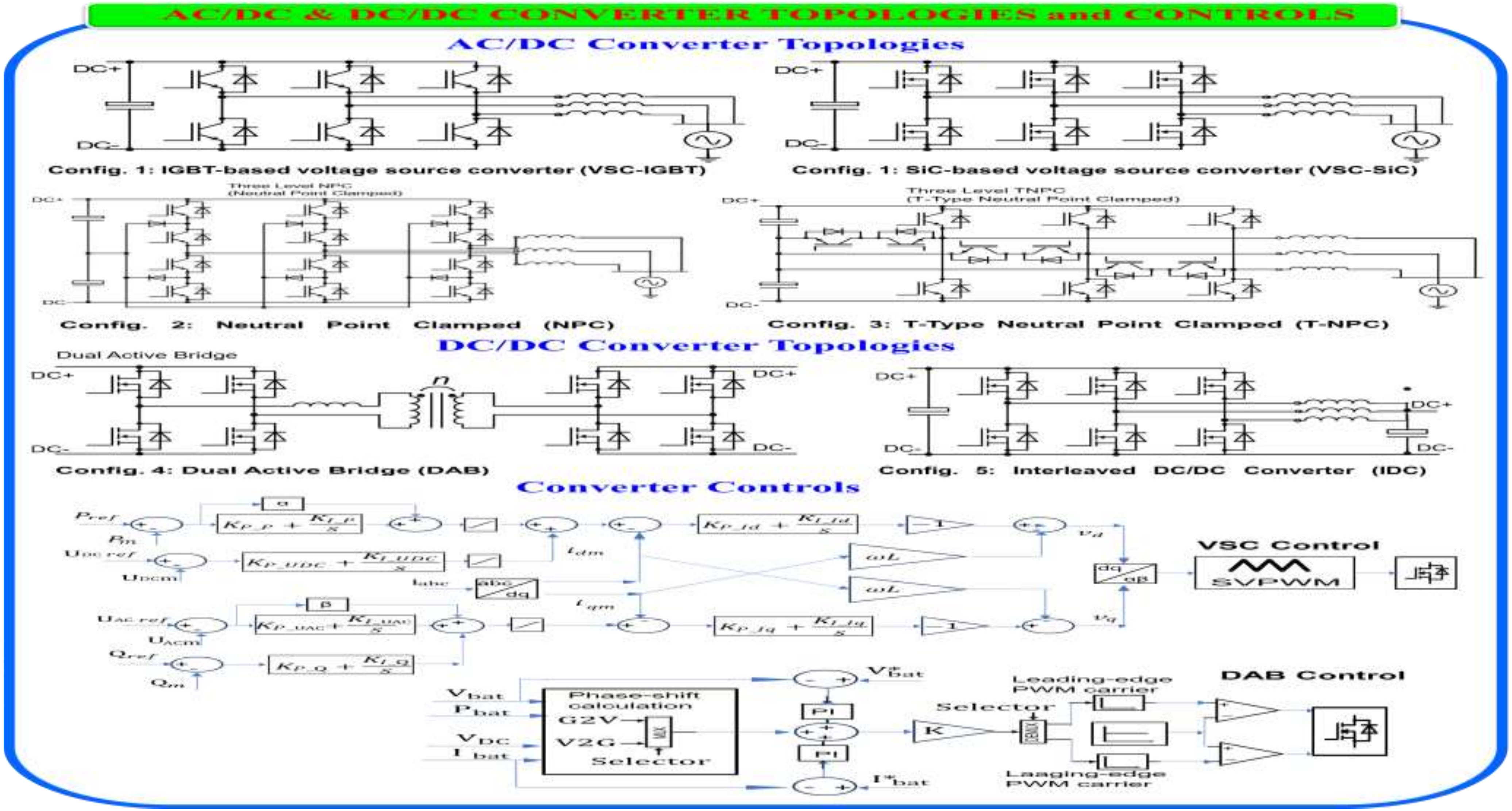


T6 : Full-bridge inverter – no DC/DC converter – BF transformer



Model EMTP-RV

[TRAN.Q.Tuan_2010_25th EU PVSEC et WCPEC-5;
Chapitre6; La distribution d'énergie électrique en présence de production décentralisée, Lavoisier]



TRAN Quoc Tuan: EUROSOI-ULIS conference

PLAN

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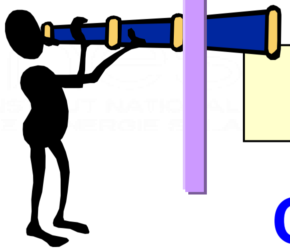
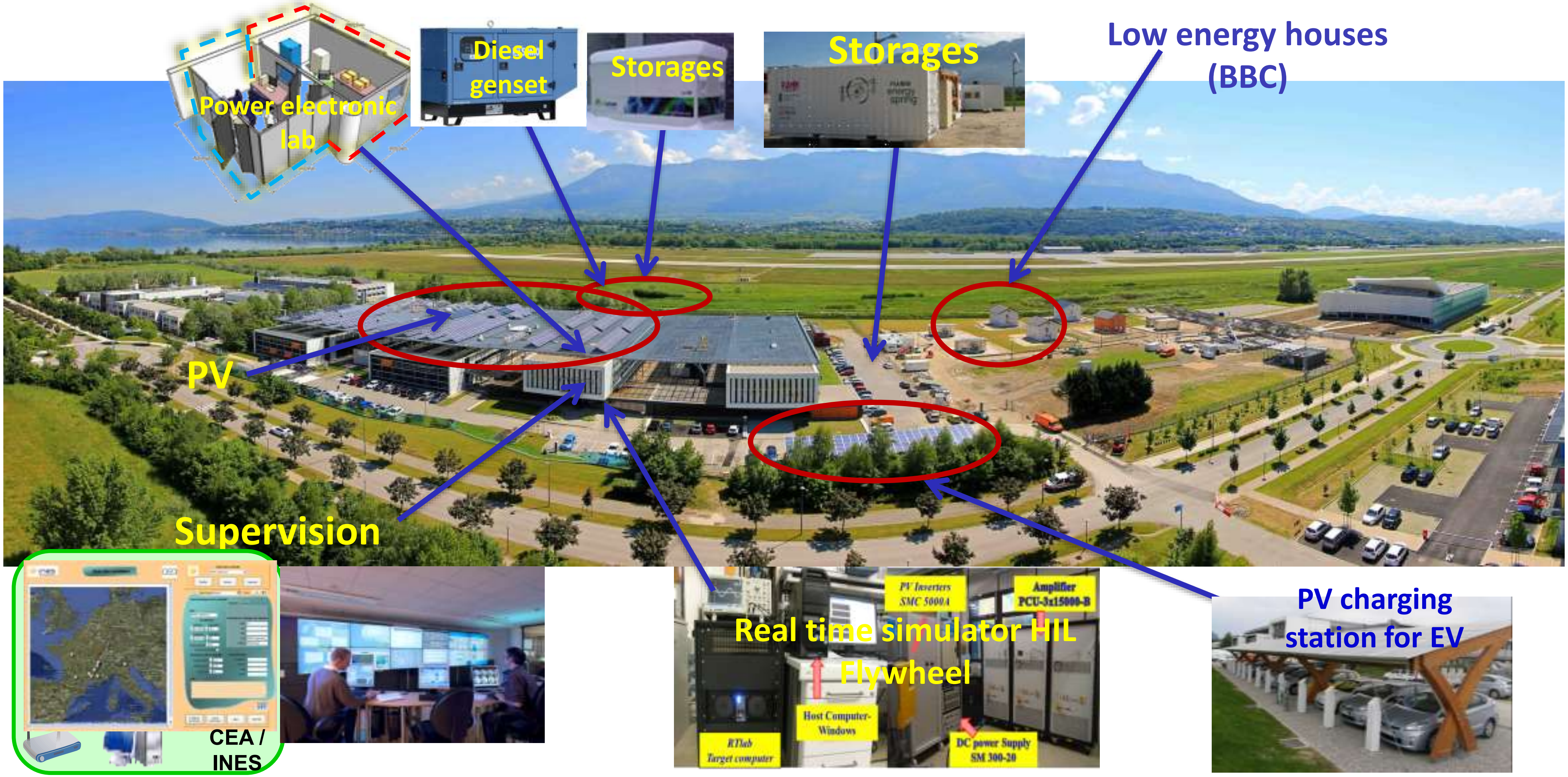
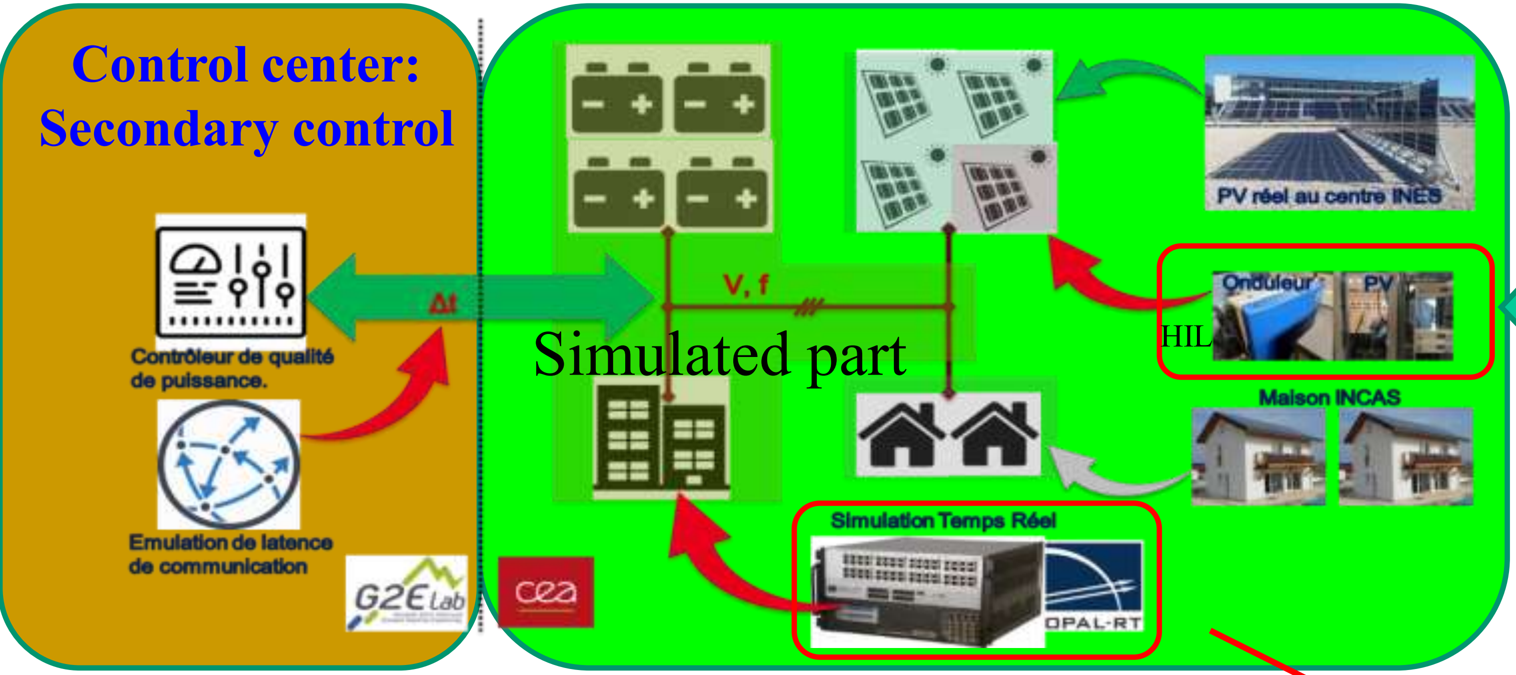


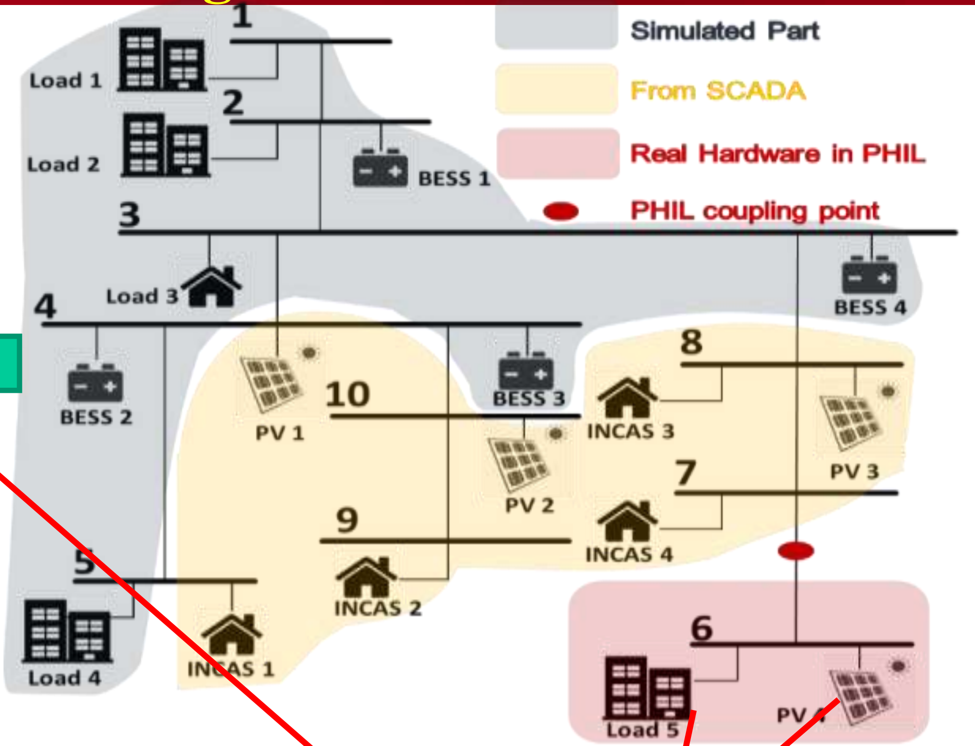
Conclusion

Demonstrations: Micro Grid at CEA-INES



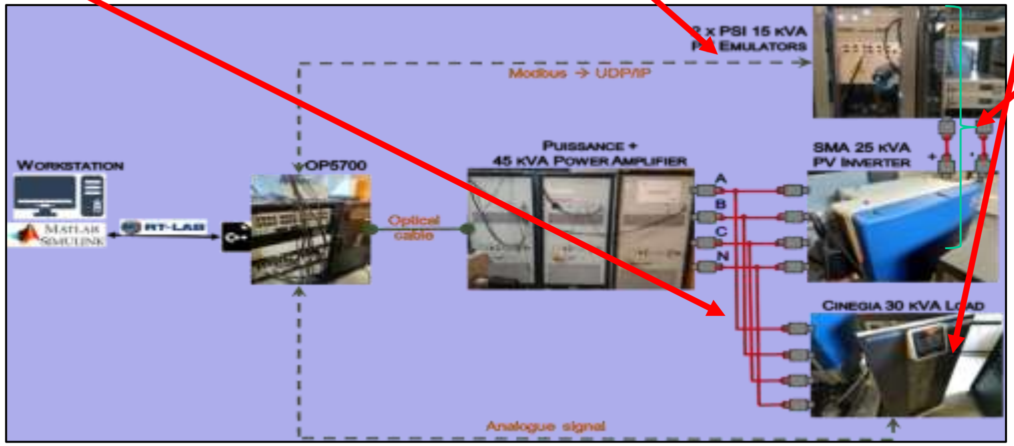
Impact of communication network (latency) on performance of centralized frequency control of an isolated microgrid





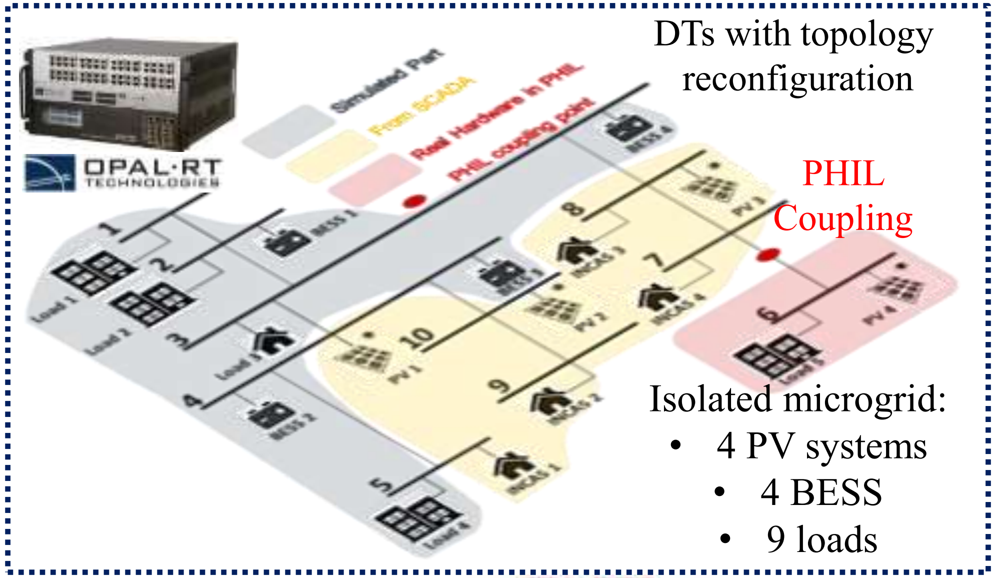
Exchange of infos between CEA-INES & G2elab

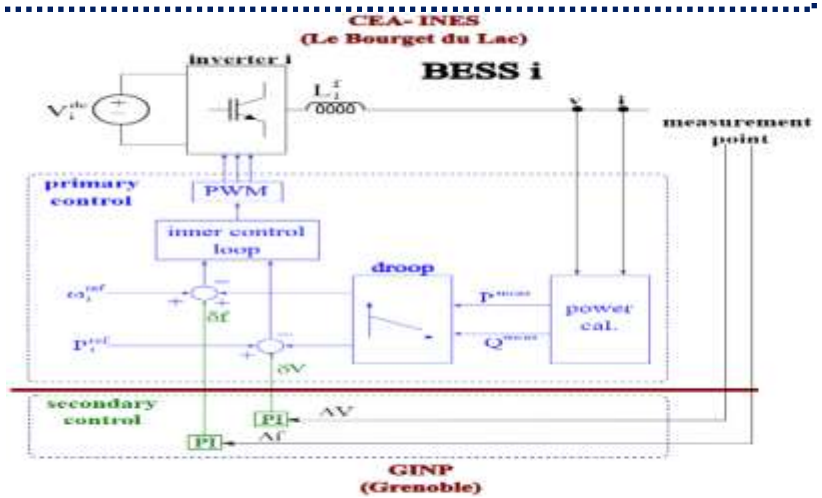
- **4 PV packs: 1 hardware PV, 3 PVs from SCADA**
- **4 battery energy storage systems (BESS): real-time simulation**
- **9 loads: 1 hardware load, 4 loads from SCADA, 4 loads form RT**



"Integration of SCADA services and Power-hardware-in-the-loop technique in cross-infrastructure holistic tests of cyber-physical energy systems" – *IEEE Transactions on Industrial Applications*.

- Distributed Control Testing on a mixed virtuo-physical microgrid.
- Impact of communication on control performance
- DER integration via PHIL cluster



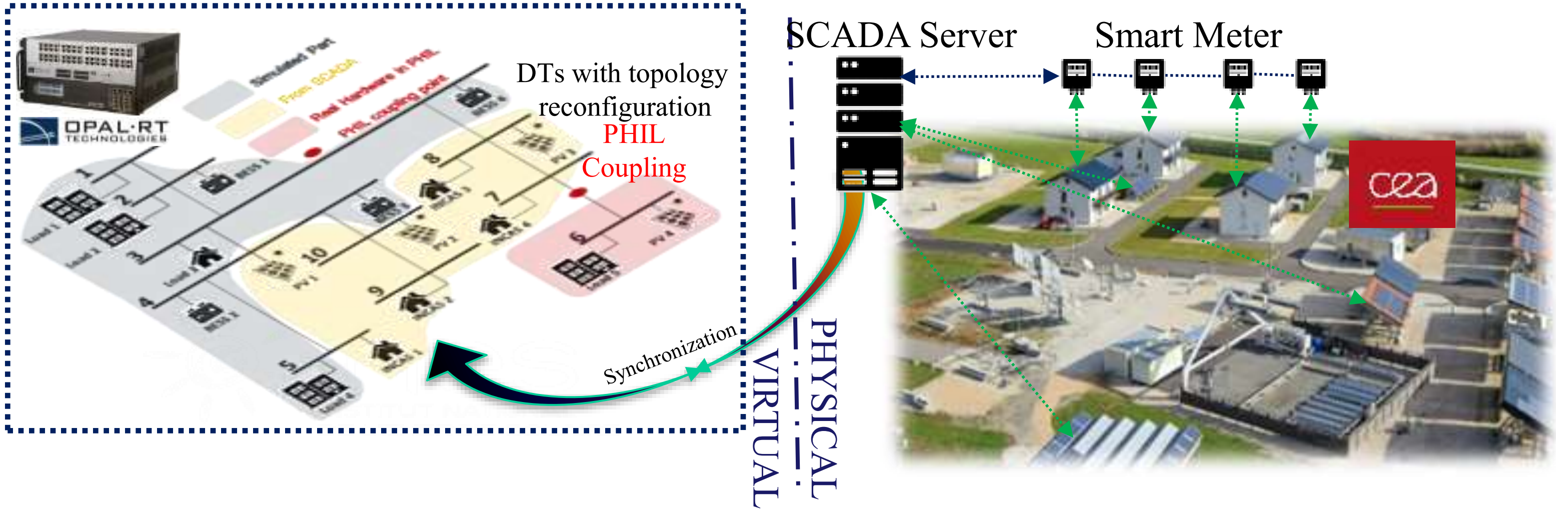


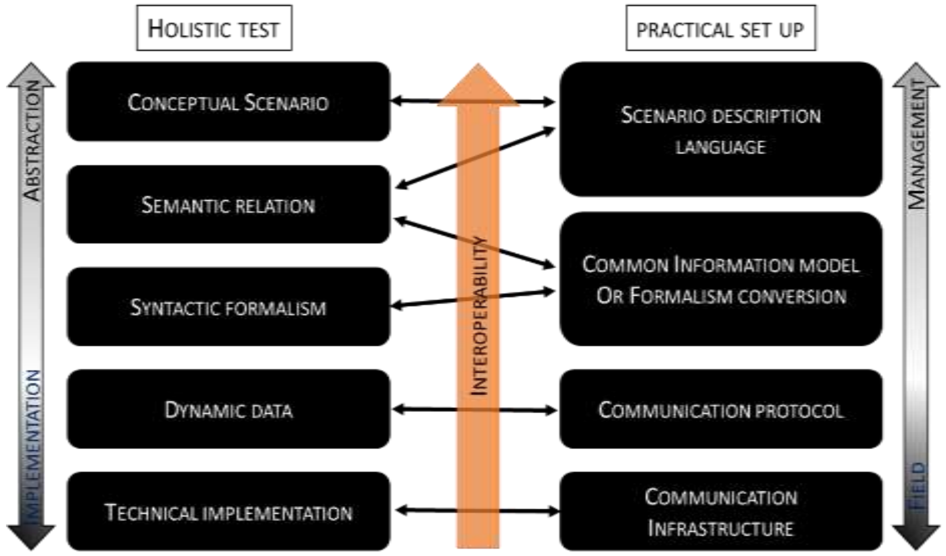
V.H. Nguyen, T.L. Nguyen, Q.T. Tran, Y. Besanger and R. Caire, "Integration of SCADA services and Power-hardware-in-the-loop technique in cross-infrastructure holistic tests of cyber-physical energy systems". *IEEE Transaction on Industry Applications, 2020.*

OPC UA SCADA System

Different integration methods for different layers of interoperability.

Test-case configuration

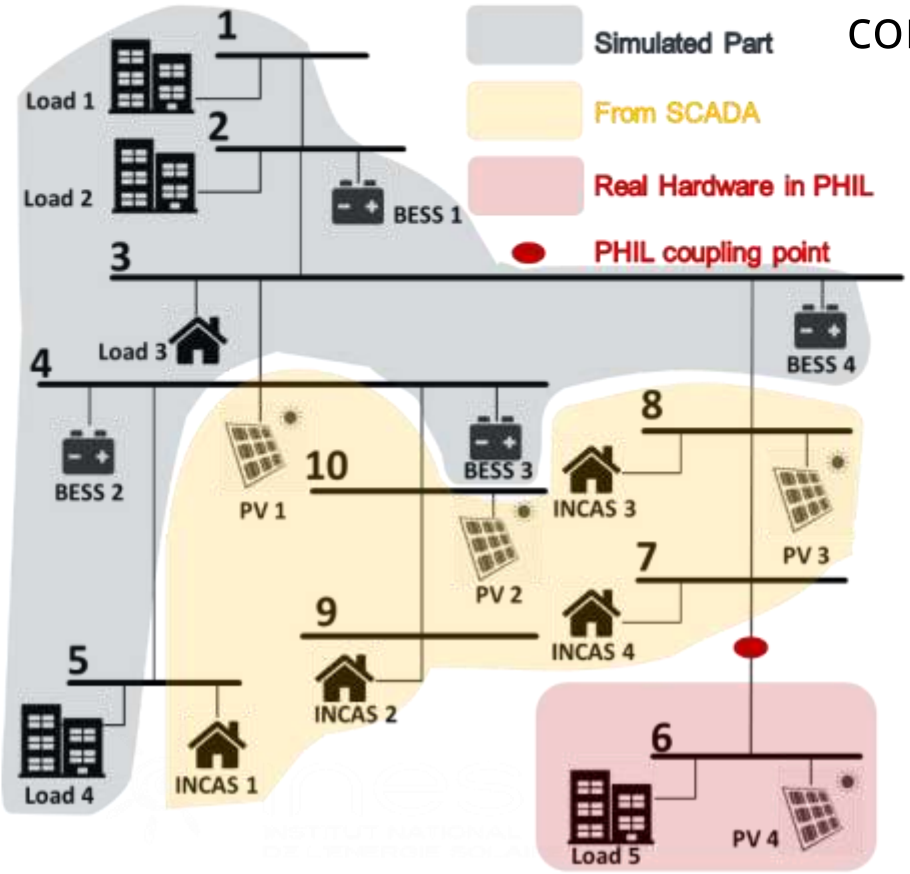


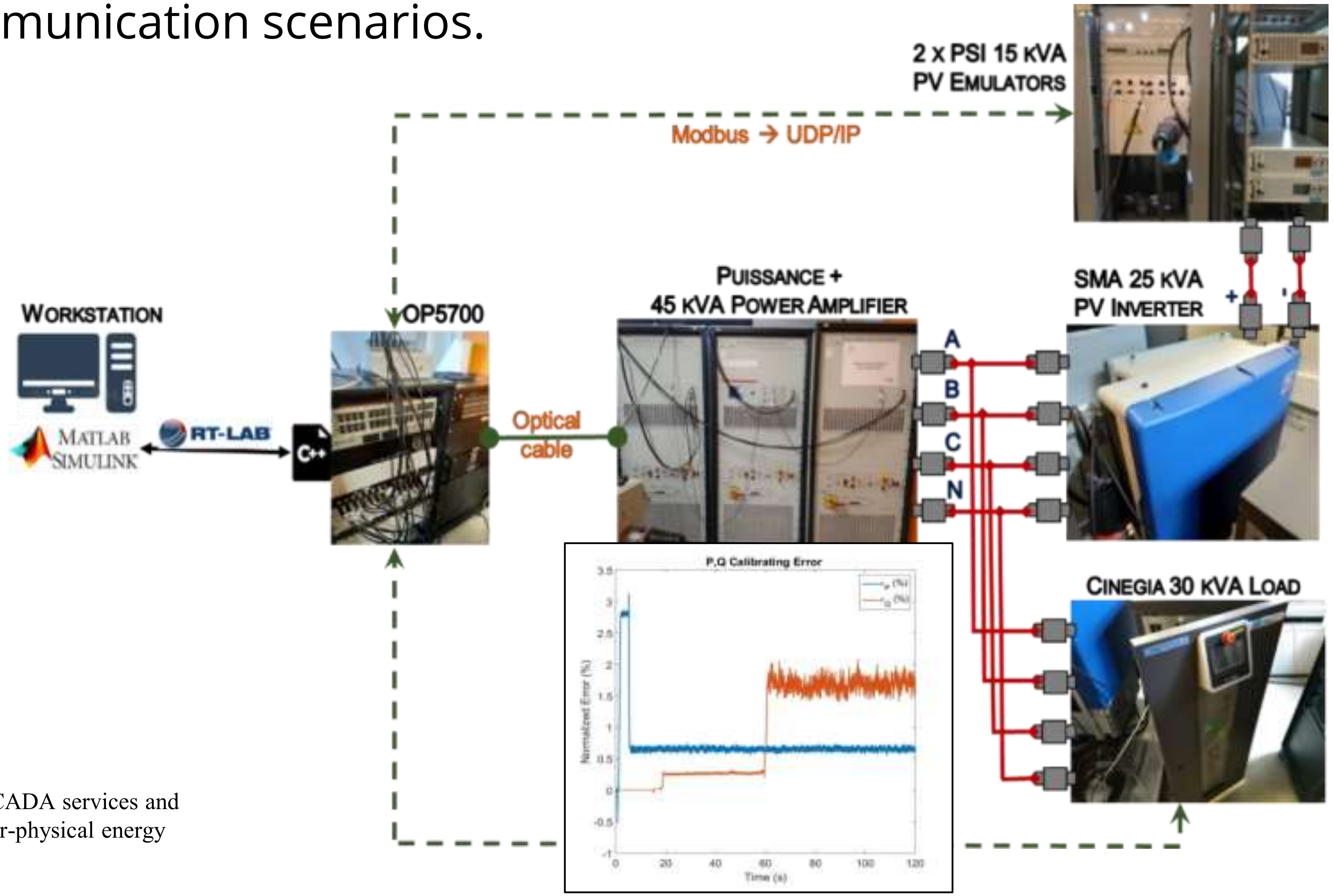


V.H. Nguyen, T.L. Nguyen, Q.T. Tran, Y. Besanger and R. Caire, "Integration of SCADA services and Power-hardware-in-the-loop technique in cross-infrastructure holistic tests of cyber-physical energy systems". *IEEE Transaction on Industry Applications, 2020.*

Impacts of communication to distributed control in isolated microgrid

Investigation of the DER integration at bus 6 and its response to the disturbance caused by the communication scenarios.



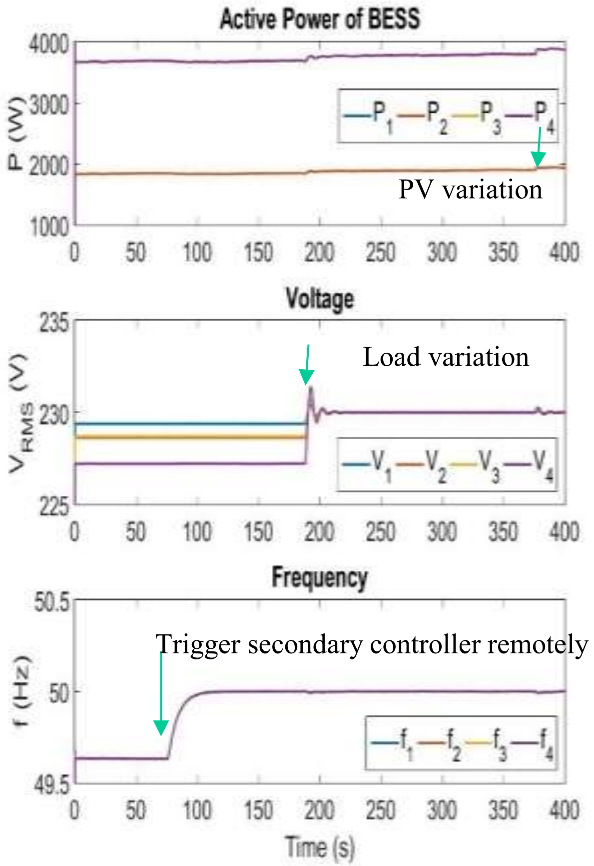


V.H. Nguyen, T.L. Nguyen, Q.T. Tran, Y. Besanger and R. Caire, "Integration of SCADA services and Power-hardware-in-the-loop technique in cross-infrastructure holistic tests of cyber-physical energy systems". *IEEE Transaction on Industry Applications, 2020.*

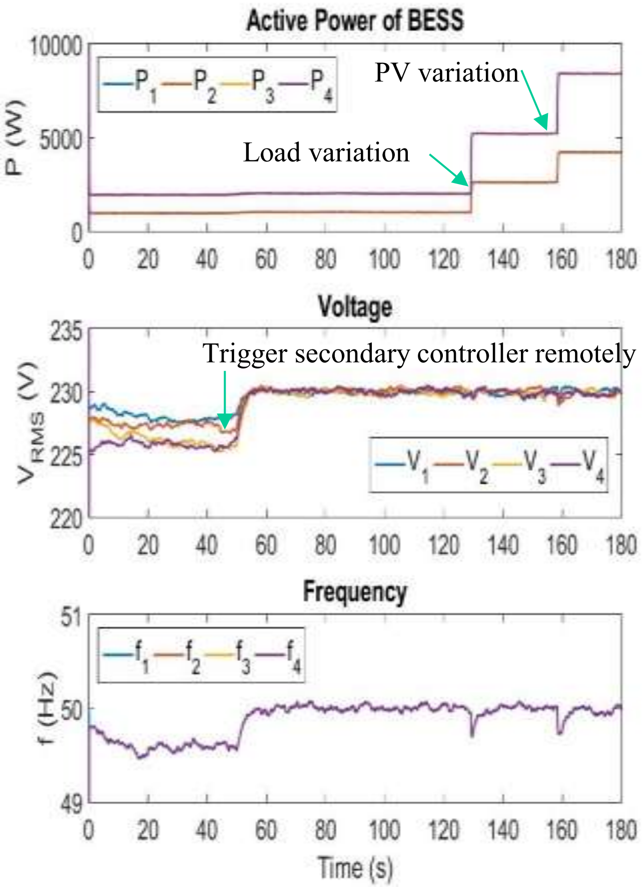
Holistic consideration: Latency is emulated to study impact of communication (latency + noise) to control performance and the responding behaviours of the physical equipments (i.e. destablize the system and trigger anti-islanding protection on PHIL cluster)

Case 1: Normal operation

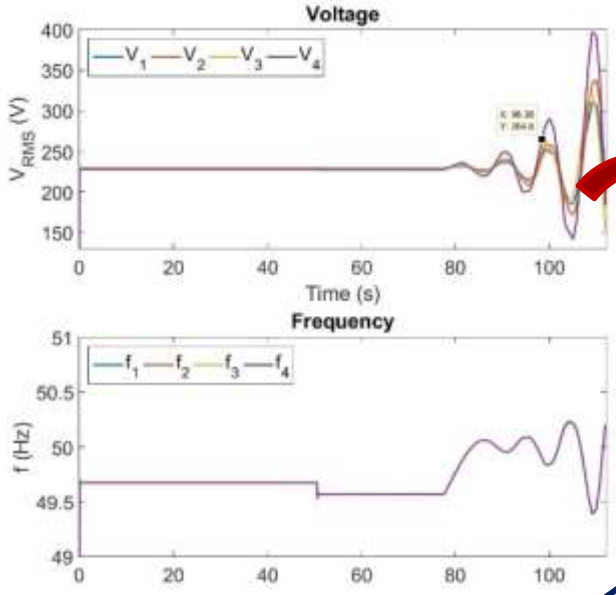
Latency=32 ms



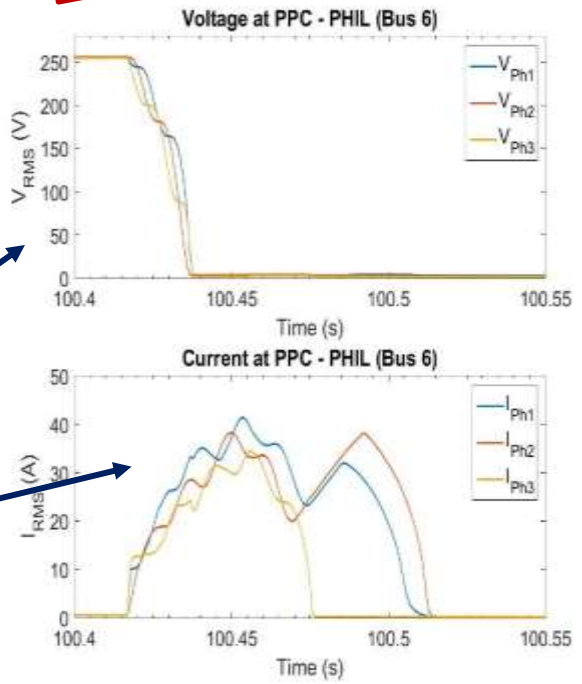
Case 2: Communication with Gaussian Additive Noise

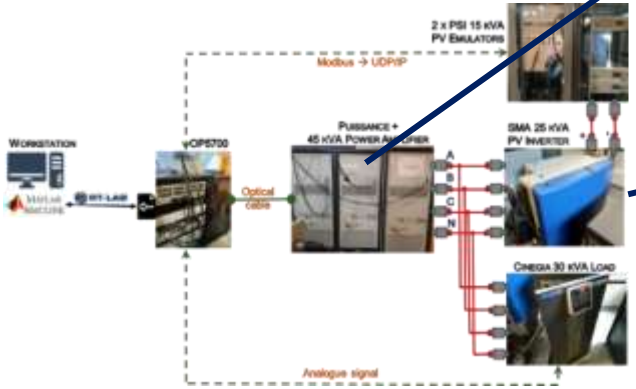


Case 3: Under important latency



Trigger Anti-islanding protection of PV inverter

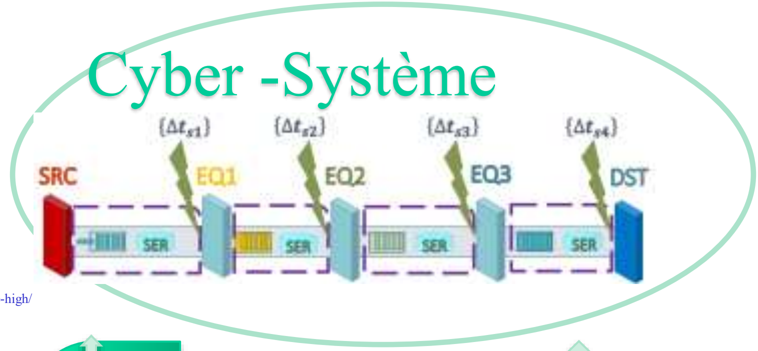




Test-case 5 : Method LSTM

Contrôle + Supervision

https://www.information-age.com/risks-facing-industrial-control-systems-reach-all-time-high/



Smart Grid

https://iot-analytics.com/the-leading-5g-iot-use-cases-2019/

Smart Grid et fiabilité

Retards de communication impacts sur la stabilité, le pilotage et la supervision des réseaux électriques.

ADAGIO considère l'évaluation de la tendance et de la variabilité du retard à travers les canaux de communication contenant différents protocoles et technologies (*i.e.* Wi-Fi, Internet, Ethernet, *etc.*).

Modélisation guidée par les données

Canal de Communication

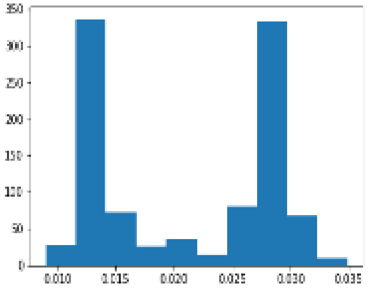
Contrôle Prédictif
Régulateur de Smith

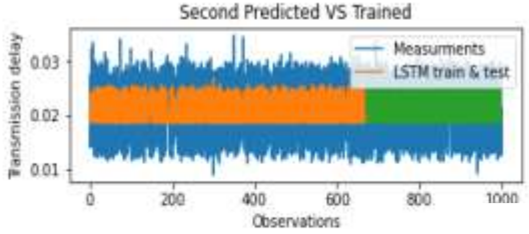
Compensation
Fourier Compensation

SRC: Source
DST: Destination
EQ: Equipement
SER: Service

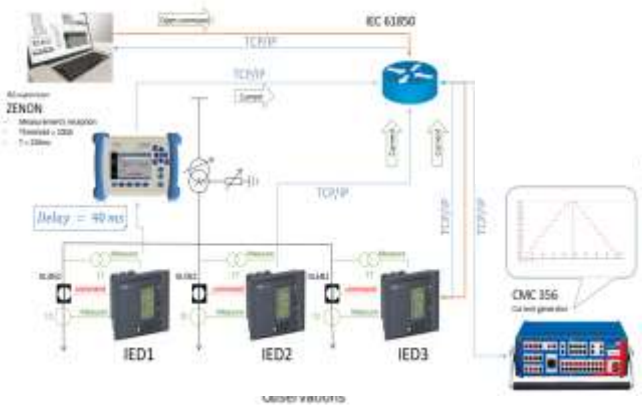
Long Short-Term Memory (LSTM)

Prévision Y (t+1)





Set de données: 1000 valeurs/0,5s mesurées par Wireshark (bleu)
LSTM: données entraînement (orange), données test (vert)



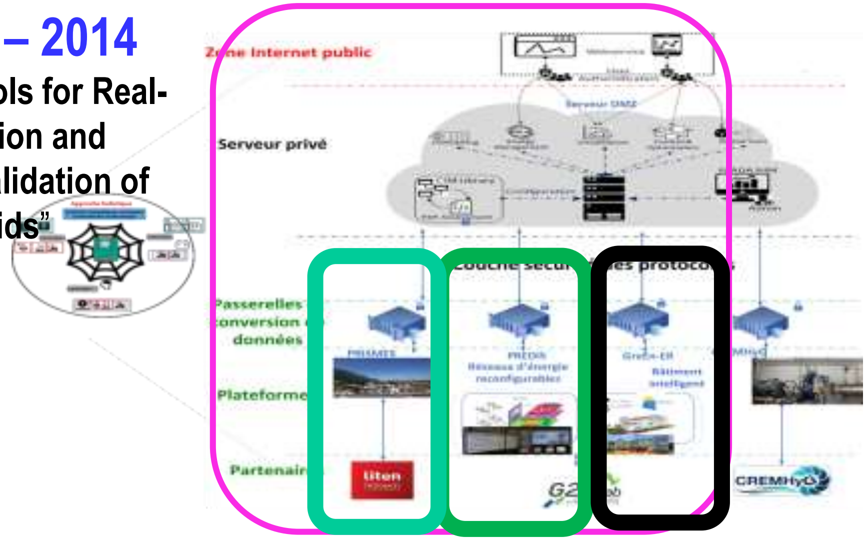
*LSTM: Long Short-Term Memory, **ARIMA**: Auto Regressive Integrated Moveing Average
IA: Intelligence Artificielle

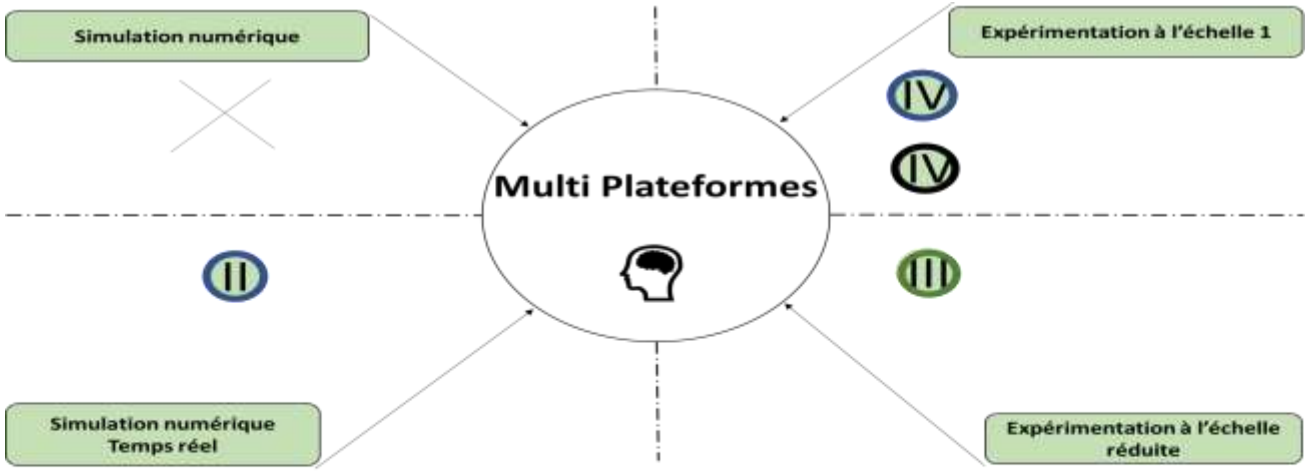
Déterminer une méthode de compensation de retard pour garantir la cohérence des expérimentations couplées en temps-réel et à distance (*ex.* entre les plateformes PREDIS (Grenoble INP) et PRISMES (CEA INES Chambéry).

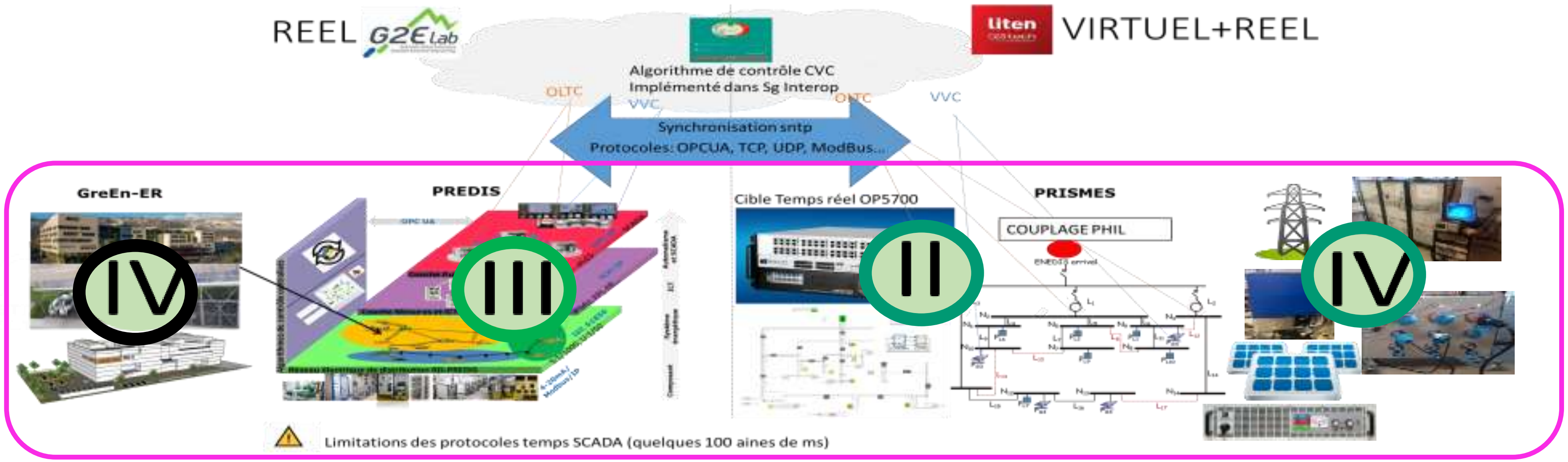
R. Feizimirkhani, Y. Besanger, Q.T Tran, A. Bratcu, VH Nguyen, A. Labonne, T. Braconnier, "Application of Long Short-Term Memory (LSTM) NeuralNetwork for the estimation of communication network delay in smart grid applications", 21th IEEE International Conference on Environmental and Electrical Engineering – EEEIC, September 2021, Bari, Italy

PhD thesis: Antoine LABONNE – 2014

"Methods and Tools for Real-Time Simulation and Experimental Validation of Smart Grids"







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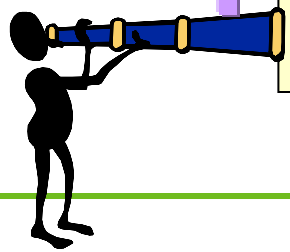

Conclusion

Conclusion

•**Digitalization is transforming** traditional power grids into smart, adaptive, and efficient energy systems.
•It **enables real-time monitoring, automation**, and **integration of renewables and distributed energy resources**.
•Supports **greater efficiency, resilience, safety**, and **consumer empowerment**.
•A key enabler in the **transition to low-carbon and net-zero energy systems**.
•Success requires **collaboration between technology, policy, and industry stakeholders**.

THANK YOU FOR YOUR ATTENTION

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