Plateforme d'intégration logicielle et matérielle pour la simulation systémique en temps réel

ÉNERGIE ÉLECTRIQUE 4.0

Comité de suivi EE4.0 – axe 3

15 février 2024

Plateforme d'exécution temps réel SPHEREA

Equipement acheté pour l'exécution rapide d'algorithmes et la vérification expérimentale de travaux scientifiques

Positionnement CPER:

* Passer d'un TRL 3 (preuve du concept) à un TRL 6 (démonstration dans un environnement réel simulé)
* Outils de communication pour envisager des transferts industriels

Investissement : OP5600 REAL-TIME TIME SIMULATOR

** OPAL-RTLinux 3.x OS with Real-Time Kernel*

** RT-LAB Host/Workstation License*

** Intel C++ compiler for Linux*

Personnels impliqués:

Bruno FRANCOIS (Centrale Lille), Frédéric COLAS (ENSAM)

PostDoc : Réza RAZI

** 01/03/2023 - 31/08/2024*

** Missions : Mise en oeuvre des matériels*

Développement des applications expérimentales

Autonomous EVs scheduling
Thèse de Haider ALI
(I-Site Appel multidiscplinaire INRIA-L2EP)

ANN based estimator of the power system State
Thèse Mohamad EL IAALI
(50% Centrale Lille + PolyTech Porto)

ANN for Fast Power Reserve Provision
Antonella TANNOUS
(50% ANR IA for engineering + Région HdF)

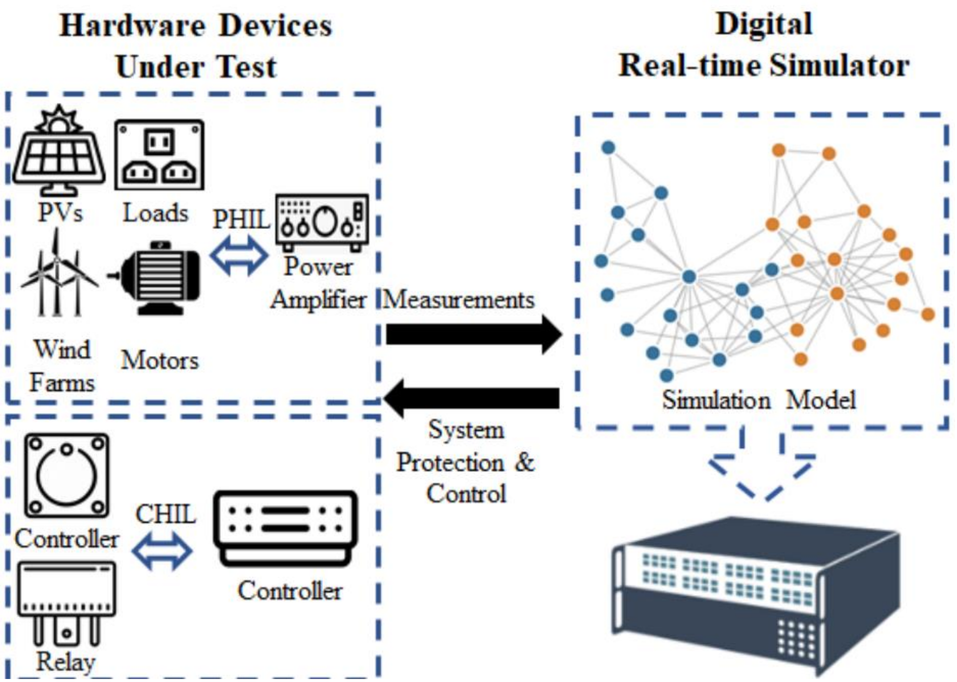
Real-time (RT) simulation (PHIL & Digital Twin)

Why is it essential?

Direct implementation of new approaches into a physical system is **Costly & Risky**

Digital twin technology:

Creation of a virtual replica of the system under examination



Advantages

- Real-time monitoring of the system
- Assessment of technical constraints
- Estimation of environmental impacts
- Generally, explore “what if” questions

Prerequisites:

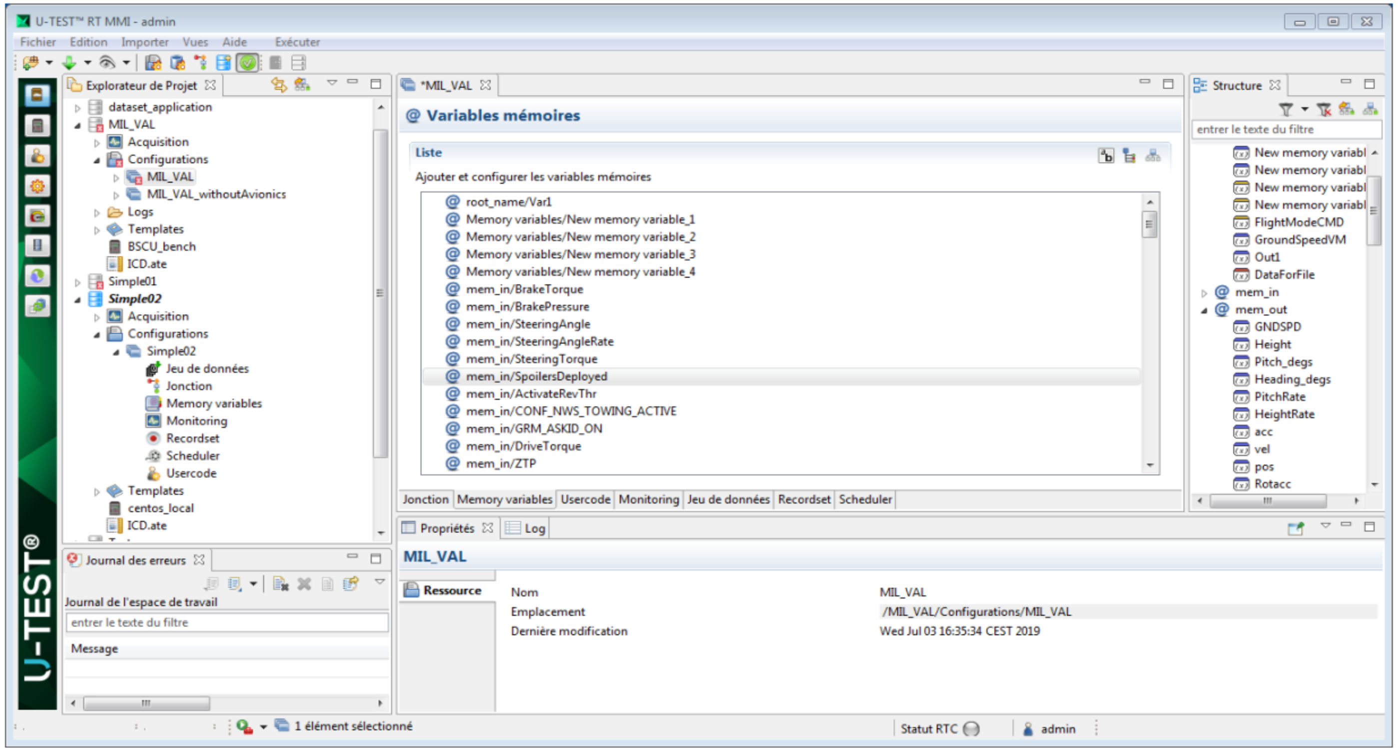
- ➢ Data collection and record archiving
- ➢ Studied system visualization (SCADA)
- ➢ Real-time operational configuration (RT computers)
- ➢ Mastering computing hardware and RT software
- ➢ Interconnections between the replica and physical hardware
- ➢ Accommodation for modifications

SPHEREA (U-TEST software) simulator

What is SPHEREA? Why are we using it?

SPHEREA simulator: fast computational units, accurate data processing, efficient communication systems

U-test software’s key features : user-centric, real-time Linux environment, running Python code



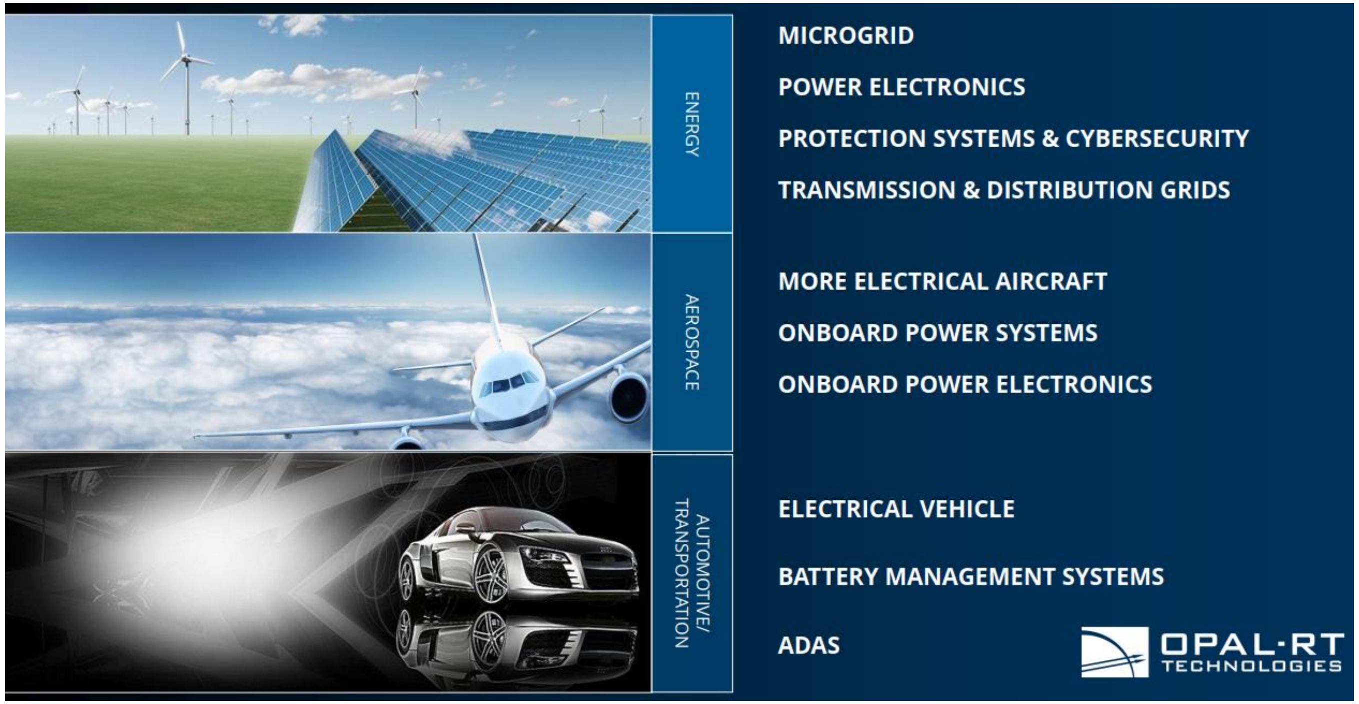
Famous simulator and used in many companies Capgemini AIRBUS ASML

Formation at L2EP-ENSAM du 23/05/2023 au 26/05/2023 U-TEST

Opal-RT simulator

What is Opal-RT ? Benefits of combining two simulators?

OP5600 OPAL-RT simulator: real-time operating system (Linux) and great computation power capability through 12 CPU cores 3.46 GHz.



Suitable for modeling in real time power systems

Both powerful real-time simulators are employed

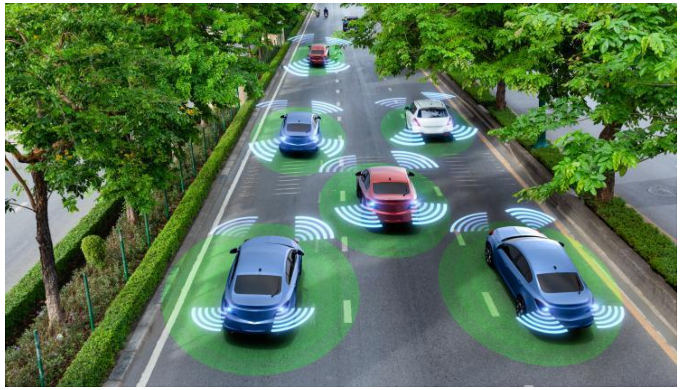
Each simulator is used as an independent entity

They are connected together through suitable communication links

Application 1 : Autonomous EVs one day-ahead scheduling

Electric Vehicles

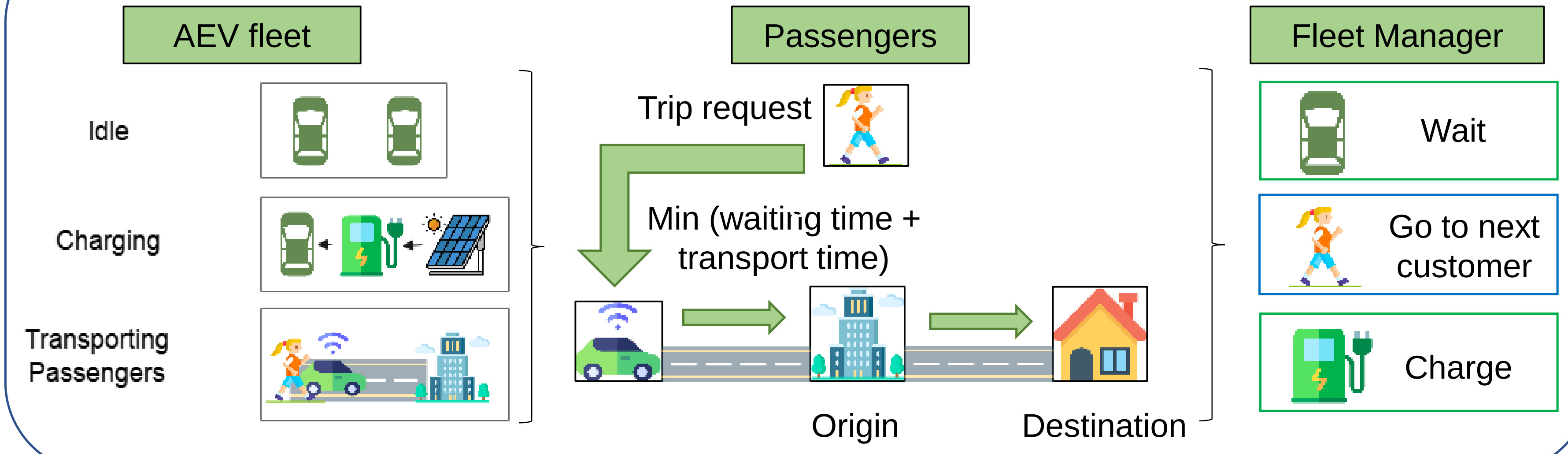
- ✓ Cleaner environment
- ✓ Reduced operating costs
- ✓ Diminished noise pollution



Shared autonomous EV

- ✓ Minimize mobility investments
- ✓ Mitigate accident risks
- ✓ Fortify existing transit systems

General context



Holistic optimization

1. **Transport optimization:** Minimize service time for passengers. research group: INOCS (INRIA)

1. **Charging optimization:** Schedule the charge (location, e-price, constraints in the power system, etc.). research group: RESEAUX (L2EP)

For efficient scheduling (vehicle routing), coordination (overall system performance), and charging of shared AEV fleets (charging infrastructure) ⟹ **Dual Digital twin-based platform**

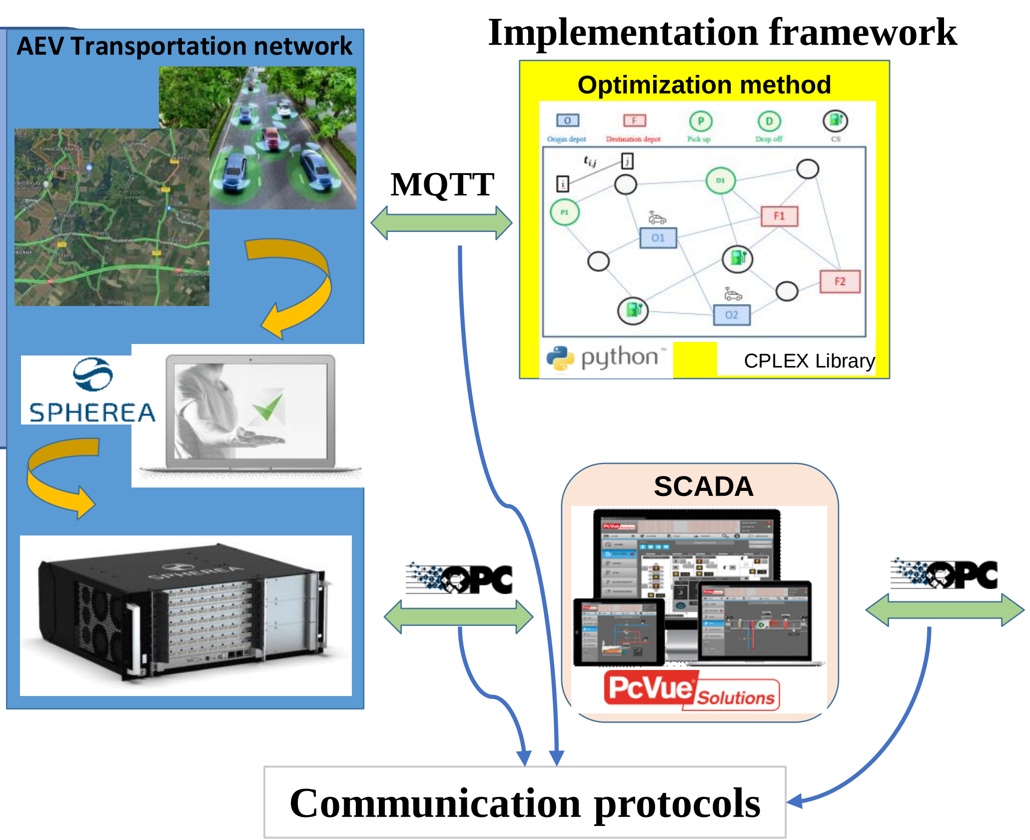
Application 1 : Autonomous EVs scheduling

Dual Digital Twin implementation

Digital twin: creating a virtual replica of a system, enabling real-time monitoring, analysis, and optimization.

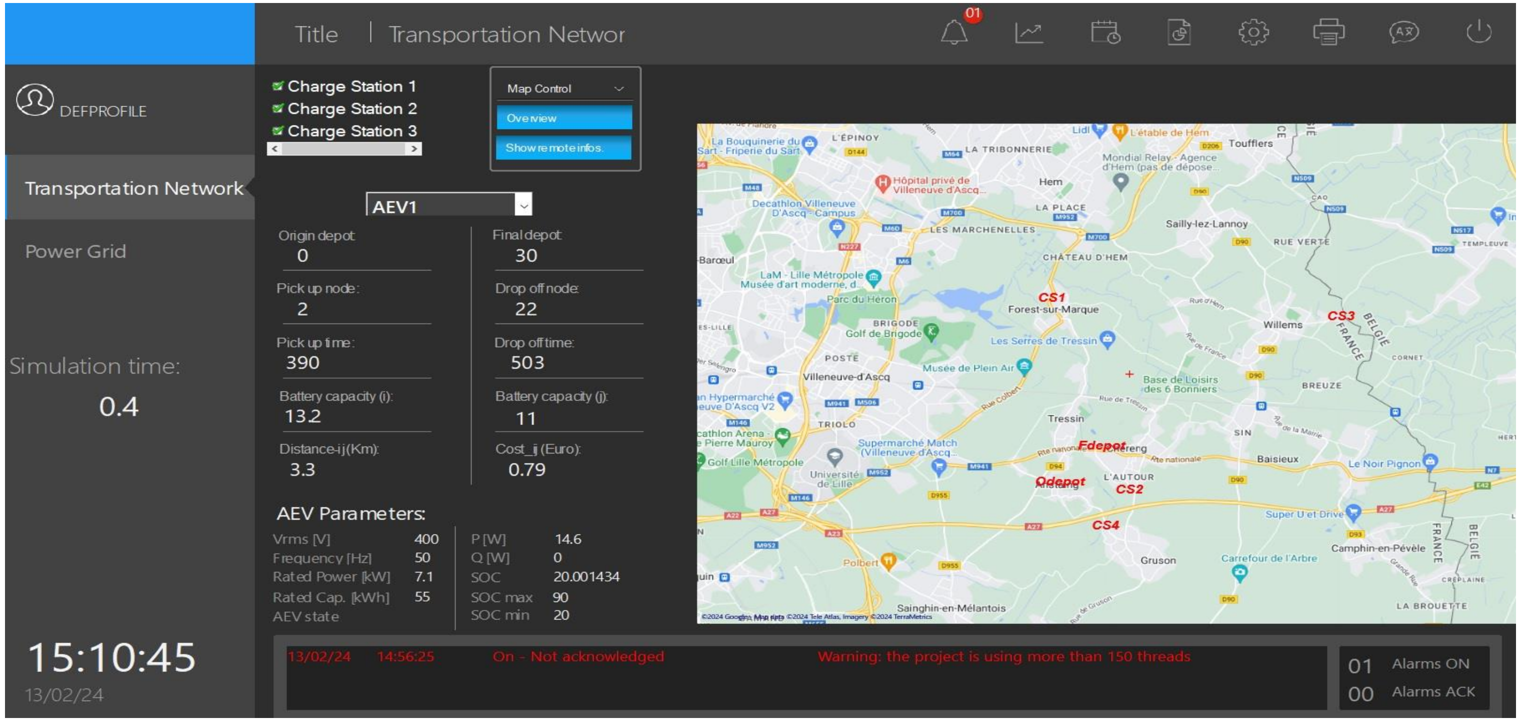
Transportation network

- Traffic flow
- Vehicle characteristics
- Route preferences

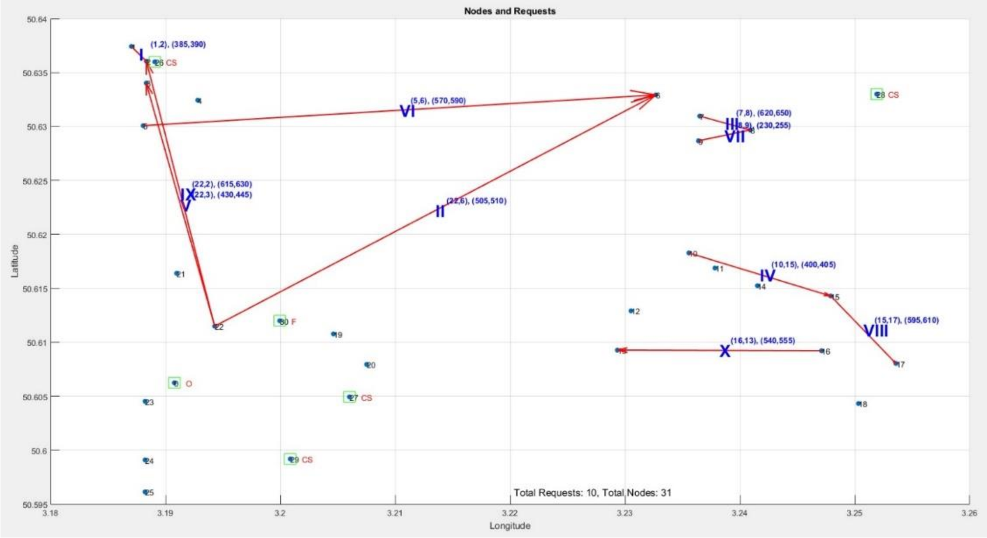


Application 1 : Autonomous EVs scheduling

Geographic mapping of node's location on the SCADA (PCVUE)



Coding of transportation nodes in Python



Day ahead scheduling of AEVs routing

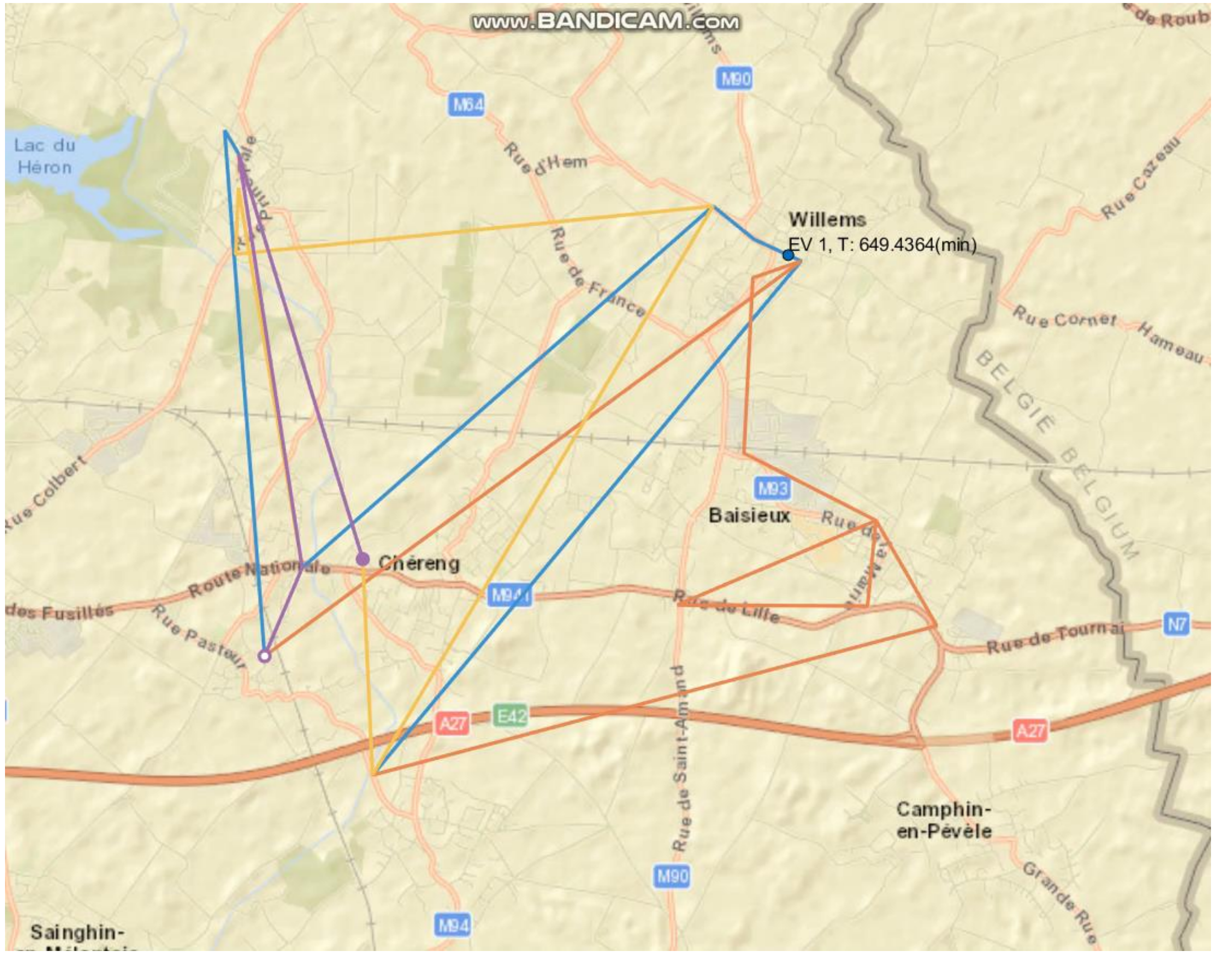
Scenario	Requests	Total AEVs	Utilized AEVs	#Cons	#Vars	Travel Costs (euros)	Charging Costs (euros)
a-10	10	5	5	1492	780	148.8	1.48
a-14	14	5	5	2126	1105	308	12.358
a-18	18	5	-	-	-	-	-
u-18	18	10	10	5875	3050	391.5	6.068
u-24	24	10	-	-	-	-	-
y-24	24	50	15	13876	7155	555	8.066
y-28	28	50	16	58685	30200	720.82	12.649

Transportation optimization

- ❑ Dynamic nature of AEV demand
- ❑ Power grid conditions
- ❑ Charging infrastructure availability

Application 1 : Autonomous EVs scheduling

Transportation digital twin
to play **one day ahead** optimal transportation scenarios



Power system digital twin
to play **one day ahead** impacts on power flows

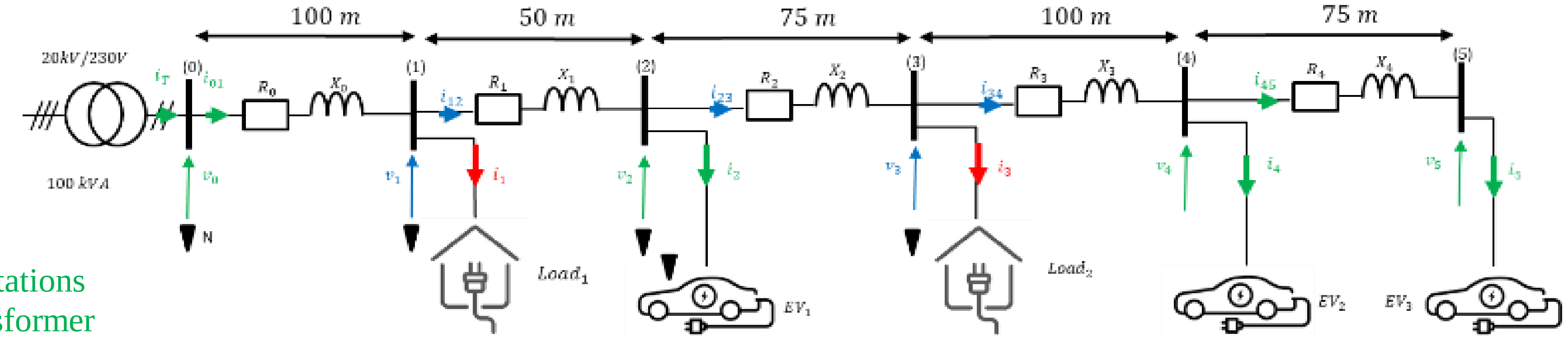
Under construction:

- ❖ Overloaded lines location
- ❖ Voltage
- ❖ Power losses

Application 2: ANN based estimator of the power system state

Integrating EVs is introducing more constraints (undervoltages, overcurents) in the distribution network
How to monitor them **without** additional sensors and communication network ?

→ **Challenge of comprehensive observability and control**



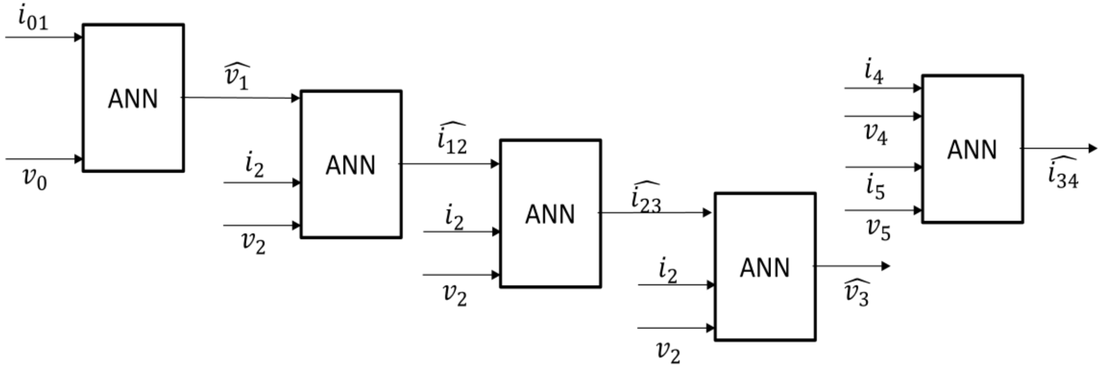
Red color: non-measured quantity
Green color: measured quantity → Charging EV stations
Substation transformer
Blue color: objective quantity

Goal : Real Time monitoring
Develop an adapted state estimation method for electrical quantities that are not measured

Problems:
Unknown line/cable parameters
Nonlinear models (ex Power flow)
Fast computation with enough accuracy

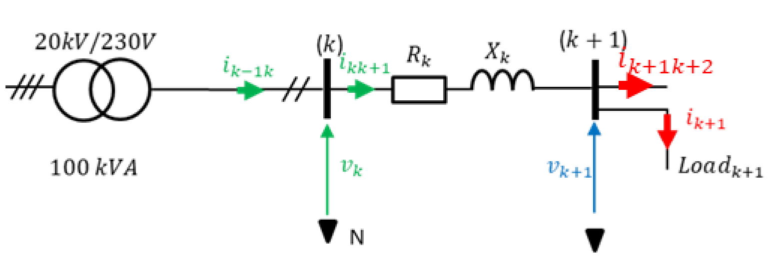
Explored solution :
ANN based state estimator
Physics informed ANN architecture
Python algorithm in Spherea

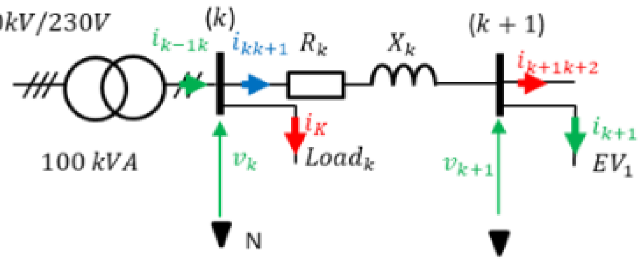
Physics informed cascaded ANN architecture

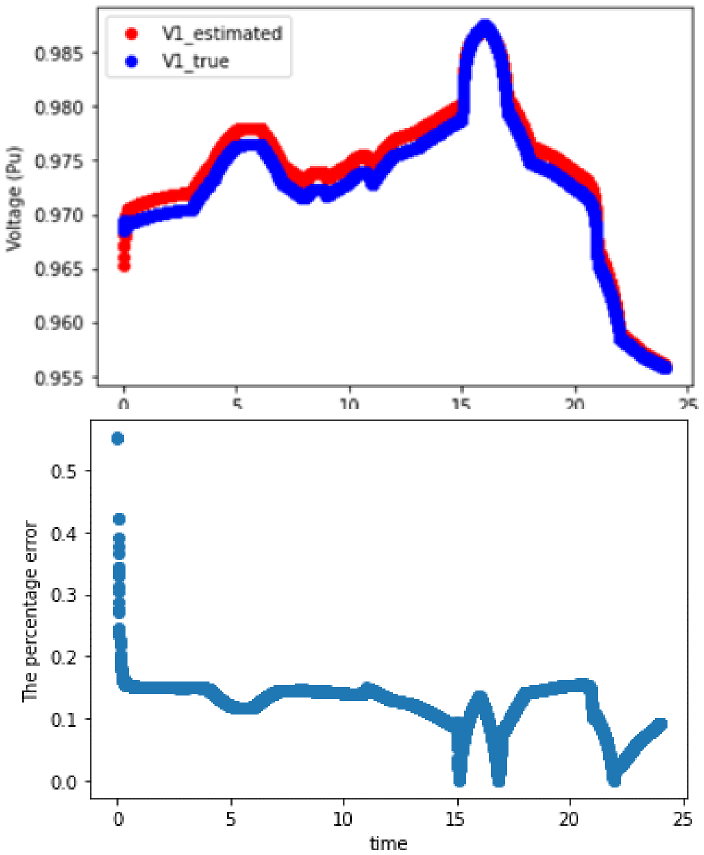


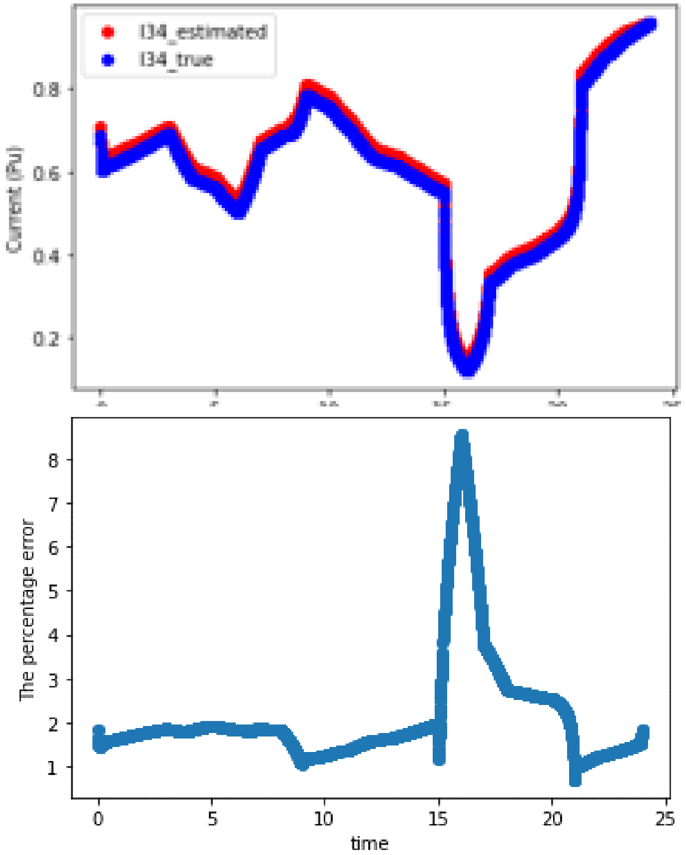
Application 2: ANN based estimator of the power system state

First results in Off-line









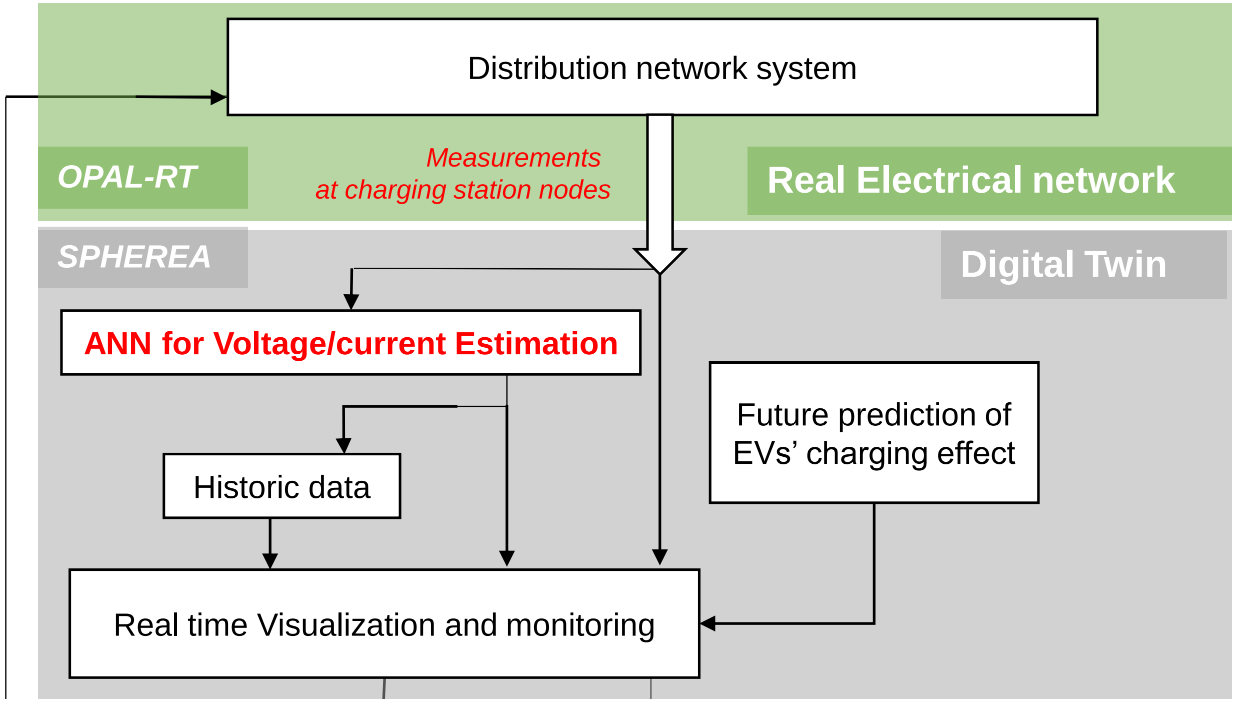
Création des bases de données à partir des mesures

Code Python + Librairie pour l'apprentissage

→ **Implémenté sous Sphéréa**

Application 2: ANN based estimator of the power system state

La suite : Passer en On-line (PolyTech Porto



Application 3 : ANN for Fast Power Reserve Provision

Challenge:

Intermittency and stochastic behaviour of renewable energy sources and load demand

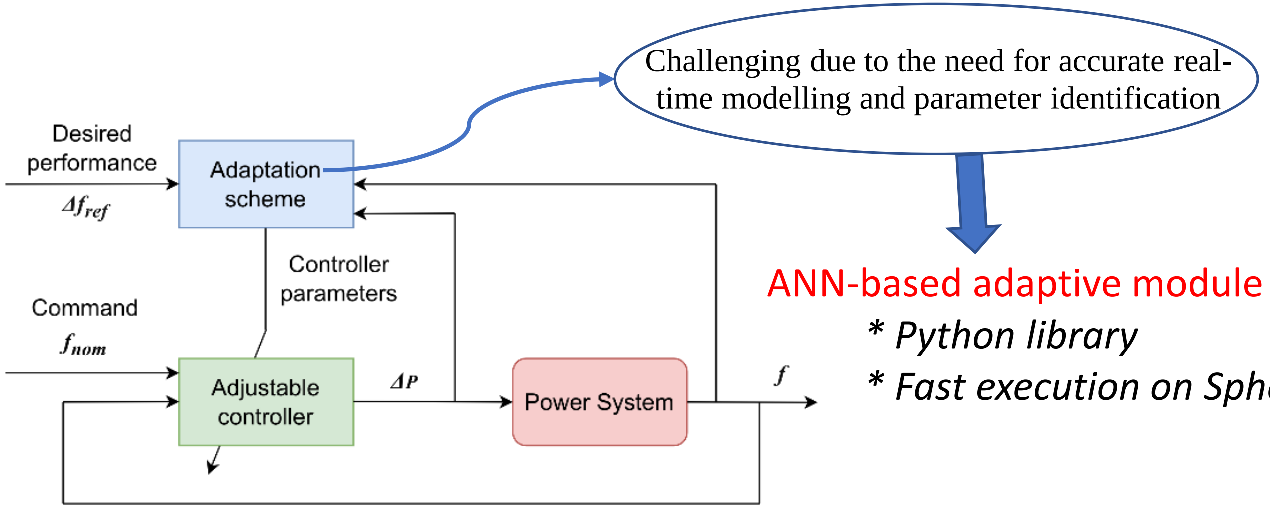
→ Power **reserve** is essential for balancing the power system

Problems:

* **No CO_2 emissions** for this balancing service -> battery storage
* **Anticipation** of unbalancing to prior ESSS in the service provision -> use unbalancing sources as control inputs
* **Adaptation** to variabilities in generation and load demand -> Self learning ANN based controller

Goal :

Developing and testing an adaptive control



ANN-based adaptive module

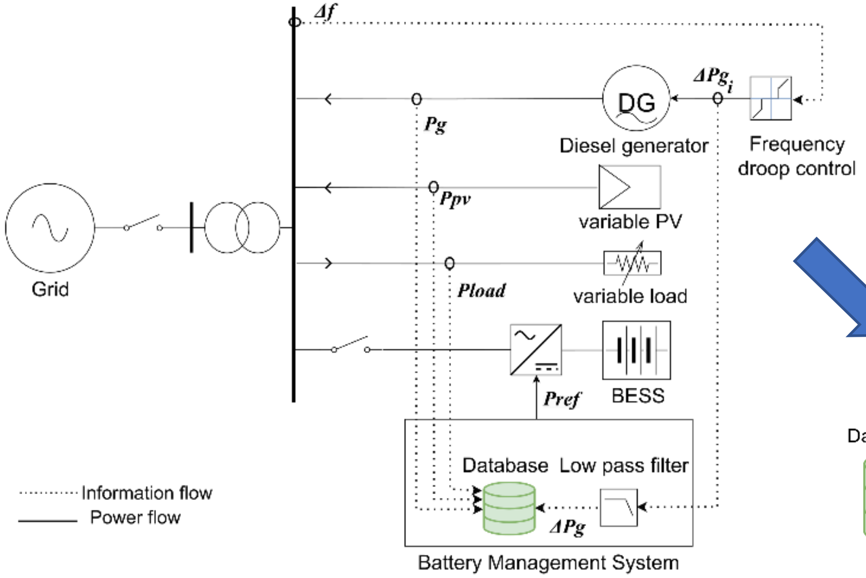
** Python library*

** Fast execution on Spherea*

Battery energy storage systems (BESS)

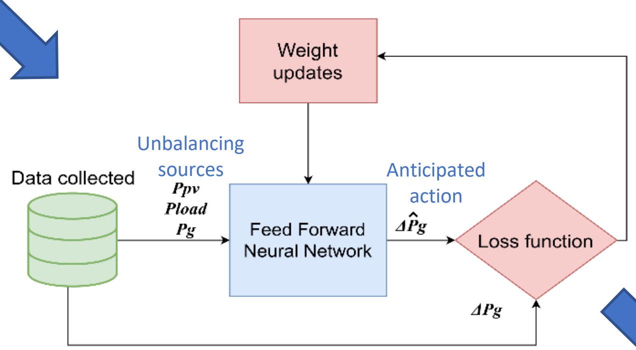
Application 3 : ANN for Fast Power Reserve Provision

Real-time implementation



Data collection **without BESS**

Opal-RT simulator

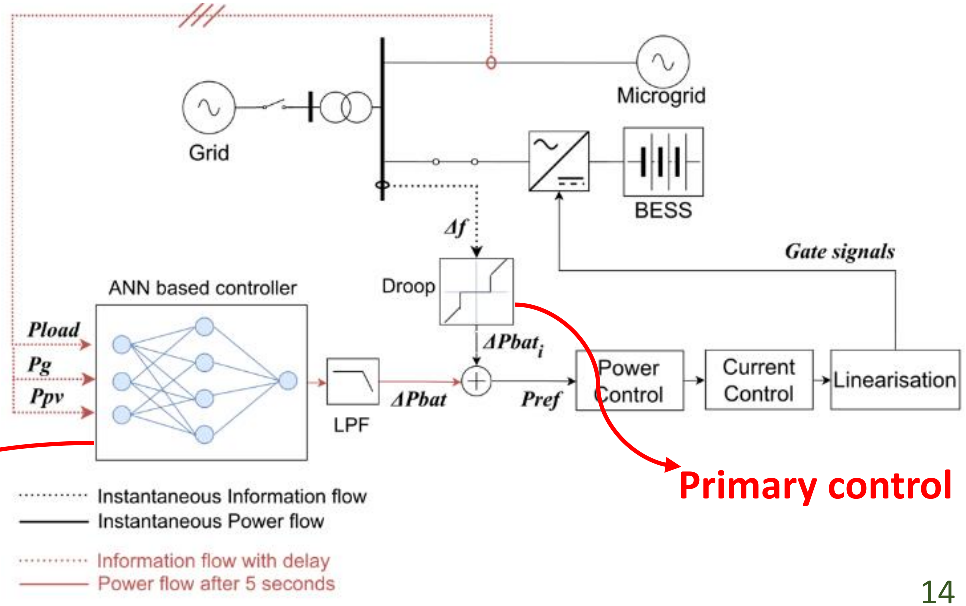


ANN training phase

Spherea simulator

Opal-RT simulator

Proposed ANN-based module



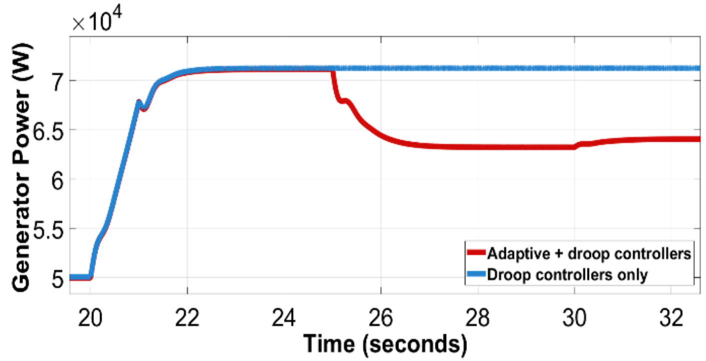
Secondary control

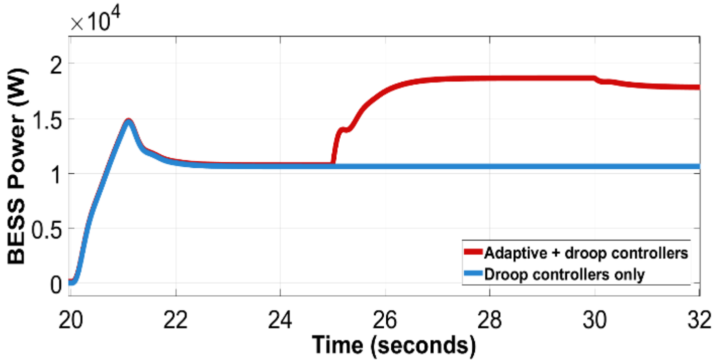
Primary control

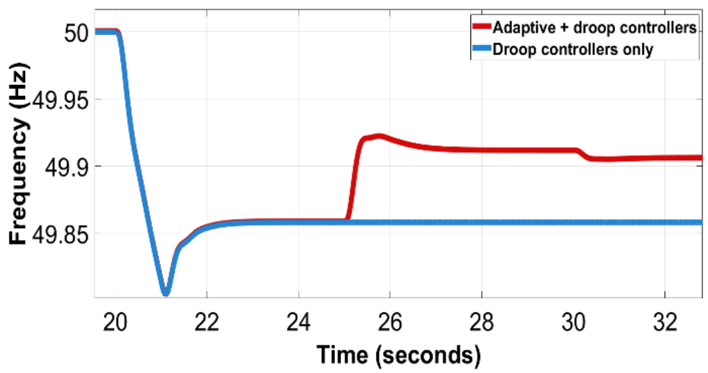
Assuming a 5-second delay for measurement, communication and computation, the ANN predicts

Application 3 : ANN for Fast Power Reserve Provision

30 kW load transient at 20 seconds



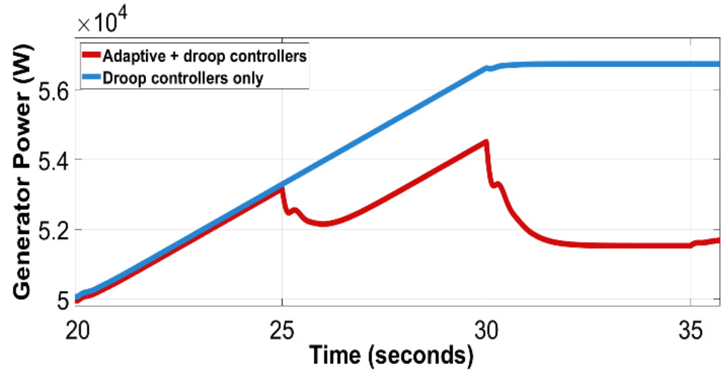


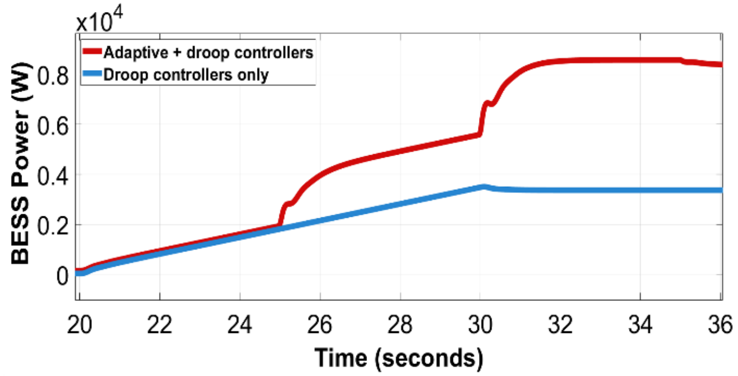


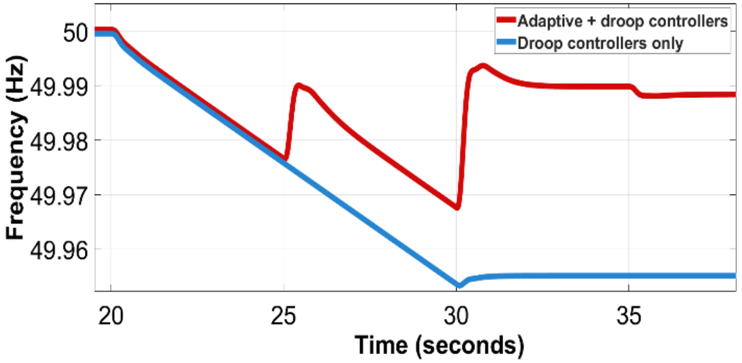
Event	Quantity	Droop controller	With adaptive method
1	Mass of CO_2 [g]	697	679 (-2.6%)
	Cost [euros]	0.52	0.50 (-3.8%)
2	Mass of CO_2 [g]	646	635 (-1.7%)
	Cost [euros]	0.48	0.47 (-2.1%)

Cloud passage

Decreasing PV power gradually from 10 kW to 0 kW over 10 seconds







Conclusion

Merci !

QUESTIONS ?

This work has been achieved within the framework of EE4.0 (Energie Electrique 4.0) project. EE4.0 is co-financed by European Union with the financial support of the European Regional Development Fund (ERDF), French State and the French Region of Hauts-de-France.

Hauts-de-France Contrat de Plan État-Région

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