

# SESSION 2

Chairman Florence OSSART, GeePs, Sorbonne Université

1. Reliable reserve balancing in a DC microgrid system under uncertainties, C. Kiebler, I. Prodan, F. Petzke, S. Streif, F. Stoican, Technische Universität Chemnitz Automatic Control and System Dynamics Lab, LCIS INP Univ. Grenoble Alpes, UPB Department of Automatic Control and Systems Engineering Bucharest Romania
2. Local self-protection function for power line communication node in DC micro grid, T. K. Tran, H. Yahoui, D. Genon-Catalot, N. Siauve, N. Fourty, T. H. T. Ma, AMPERE Université Lyon 1, LCIS Grenoble Institute of Technology, Valence
3. DC Microgrids, H. Morel, P. Bevilacqua, G. Clerc, R. Delpoux, E. Dumitrescu, J.-Y. Gauthier, X. Lin-Shi, E. Niel, L. Pietrac, J.-F. Trégouët, AMPERE Lyon
4. Optimal real time management of droop-controlled microgrids, M. Legry, F. Colas, J.Y. Dieulot, C. Saudemont, L2EP Lille, CRISTAL Lille
5. Robust energy management optimization of a smart microgrid in day ahead markets, R. Bourbon, B. Sareni, X. Roboam, S.U. Ngueveu, LAPLACE CNRS Univ. Toulouse
6. Flatness-based hierarchical control of a meshed DC microgrid, I. Zafeiratou, D. V. A. Nguyen, I. Prodan, L. Lefèvre, L. Piétrac, LCIS INP Univ. Grenoble Alpes, AMPERE CNRS INSA Université de Lyon
7. Social acceptability of microgrids dedicated to electric vehicle charging stations, M. Sechilariu, F. Locment, N. Darene, AVENUES EA 7284 et COSTECH EA 2223 UTC

9 Juillet 2018 – Université de Technologie de Compiègne, France

# Reliable reserve balancing in a microgrid system under uncertainties

Clemens Kiebler, TU Chemnitz

Ionela Prodan, LCIS INP Grenoble

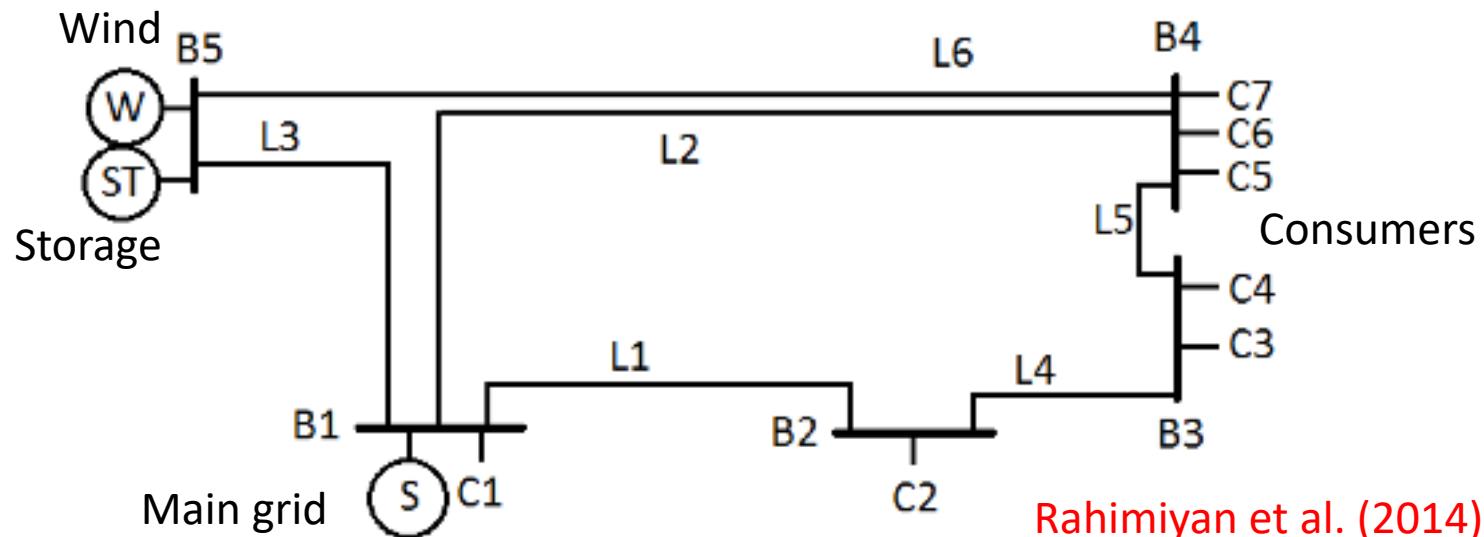
Felix Petzke, ACSD TU Chemnitz

Stefan Streif, ACSD TU Chemnitz

Florin Stoican, ACSE UPB



# Outline



## Goal

- Energy management system (EMS):
  - Maximize utility, minimize energy cost
  - Model predictive control with shrinking prediction horizon
- Robust power balancing under forecast uncertainties
- Using the storage to meet the minimum demand under line faults

# EMS

Optimization problem:  $e$  – energy,  $P$  – power,  $\lambda$  – energy price

$$\min_{\mathbf{P}^B} \quad J = \lambda_t^S e_t^S - \mathbf{u}_t^T \mathbf{e}_t^C + \lambda^W e_t^W + \sum_{h=1}^{24-t} \lambda_{t+h}^S e_{t+h}^S - \mathbf{u}_{t+h}^T \mathbf{e}_{t+h}^C + \lambda_{t+h}^W e_{t+h}^W$$

s.t. balancing problem  $\mathbf{P}_{t+h+1}^L = \mathbf{M}_L \mathbf{M}_B^{-1} \mathbf{P}_{t+h+1}^B, \quad \sum_b P_{b,t+h+1}^B = 0$

bus injections  $\mathbf{P}_{t+h+1}^B = \Omega_b^W P_{t+h+1}^W - \Omega_b^C \mathbf{P}_{t+h+1}^C + \Omega_b^{ST} (P_{t+h+1}^{ST,-} - P_{t+h+1}^{ST,+}) + \Omega_b^S P_{t+h+1}^S$

storage state-space-equation and capacity constraints

trapezoidal rule  $\mathbf{e}_{t+h} = \frac{\mathbf{P}_{t+h} + \mathbf{P}_{t+h+1}}{2}$

main grid min/max and variation constraints

main grid mixed integer cond.  $0 \leq P_{t+h+1}^{ST,-} \leq \alpha_{t+h+1} P^{ST,max}$

$$0 \leq P_{t+h+1}^{ST,+} \leq (1 - \alpha_{t+h+1}) P^{ST,max}$$

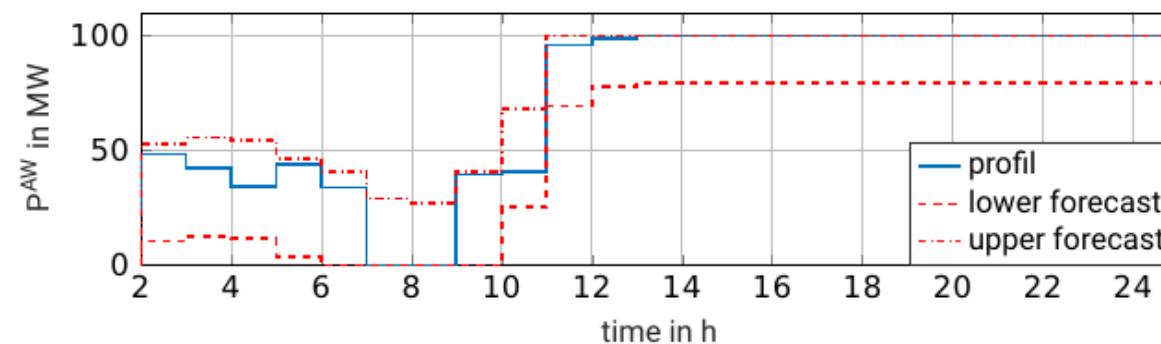
consumer min/max and variation constraints

minimum consumption  $\sum_{h=1}^{t-1} \mathbf{e}_h^C + \sum_{h=0}^{24-t} \mathbf{e}_{t+h}^C \geq \mathbf{e}^{day}$

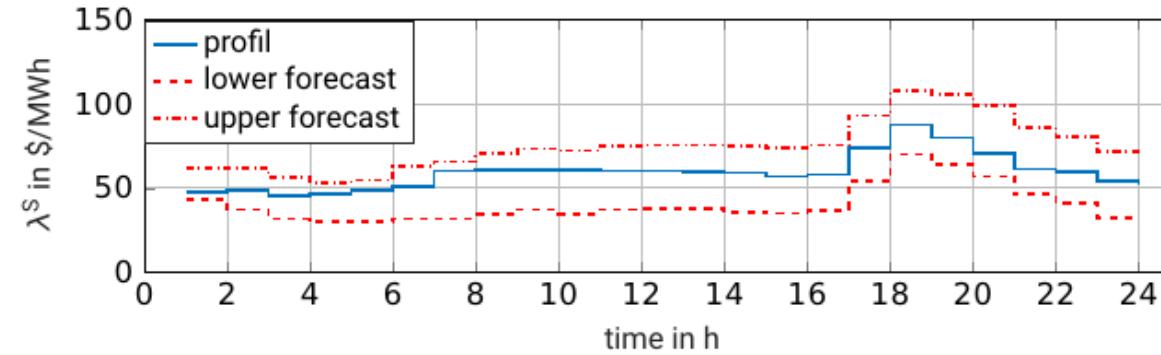
line capacity constraints; wind power generator constraints

# EMS – forecast profils

Wind generator power with wind energy price:  $\lambda^W = 50 \text{ \$/MWh}$



Energy cost profile: Rahimiyan et al. (2014)



- EMS is infeasible under forecast disturbances, thus the need for robust approach

# Robust EMS

$$\min_{\mathbf{p}^S} J_{\text{REMS}} = \sum_{h=0}^{24-t} \lambda_{t+h}^S e_{t+h}^S - \mathbf{u}_{t+h}^T \mathbf{e}_{t+h}^C + \lambda_{t+h}^W e_{t+h}^W + \beta^S \Gamma^S + \sum_{h=1}^{24-t} \xi_{t+h}^S$$

s.t. previous model

$$\beta^S + \xi_{t+h}^S \geq (\lambda_{t+h}^{S,\max} - \lambda_{t+h}^{S,\min}) y_{t+h}^S$$

$$-y_{t+h}^S \leq e_{t+h}^S \leq y_{t+h}^S$$

$$P_{t+h+1}^W - 0.5(P_{t+h+1}^{\text{AW},\max} + P_{t+h+1}^{\text{AW},\min}) + \beta_{t+h+1}^W \Gamma_{t+h+1}^W + \xi_{t+h+1}^W \leq 0$$

$$\beta_{t+h+1}^W + \xi_{t+h+1}^W \geq 0.5(P_{t+h+1}^{\text{AW},\max} - P_{t+h+1}^{\text{AW},\min}) y_{t+h+1}^W$$

$$1 \leq y_{t+h+1}^W$$

$$\beta_{t+h+1}^W, y_{t+h+1}^W, \xi_{t+h+1}^W, \xi_{t+h}^S, y_{t+h}^S, \beta^S \geq 0$$

$$h = 1, \dots, 24-t$$

Rahimiyan et al. (2014)

- Set degree of robustness by  $\Gamma^S$  and  $\Gamma^W$
- Less conservative than minimax MPC

# Robust MPC approach for EMS

## Minimax EMS

$$\min_{P^B} \max_{w^S, w^{AW}} J$$

s.t. previous model

$$P_{t+h+1}^{AW} = \frac{P_{t+h+1}^{AW,\max} + P_{t+h+1}^{AW,\min}}{2} + w^{AW} \frac{P_{t+h+1}^{AW,\max} - P_{t+h+1}^{AW,\min}}{2}$$

$$-1 \leq w_{t+h+1}^{AW} \leq 1$$

$$\lambda_{t+h+1}^S = \frac{\lambda_{t+h+1}^{S,\max} + \lambda_{t+h+1}^{S,\min}}{2} + w^S \frac{\lambda_{t+h+1}^{S,\max} - \lambda_{t+h+1}^{S,\min}}{2}$$

$$-1 \leq w_{t+h+1}^S \leq 1$$

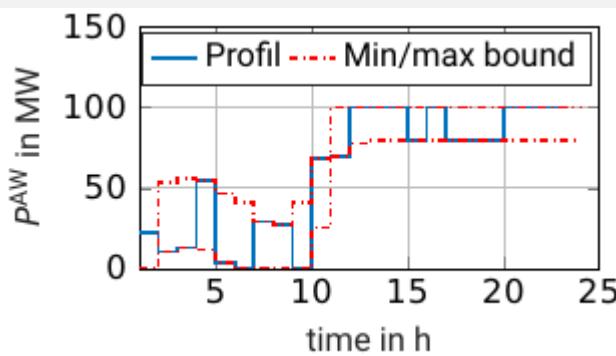
- Consider worst-case scenario for disturbance
- Solved with YALMIP Löfberg 2012

# Performance under disturbances

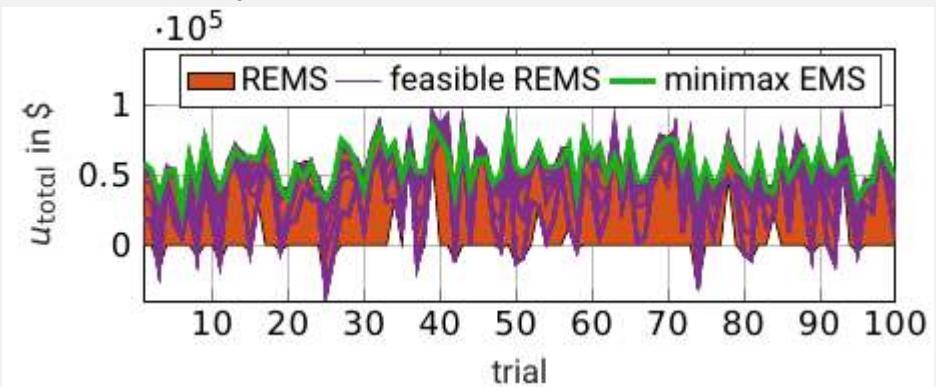
Total utility of consumers:

$$u_{\text{total}} = - \sum_{t=1}^{24} \lambda_t^S e_t^S - \mathbf{u}_t^T \mathbf{e}_t^C + \lambda^W e_t^W$$

Available wind power



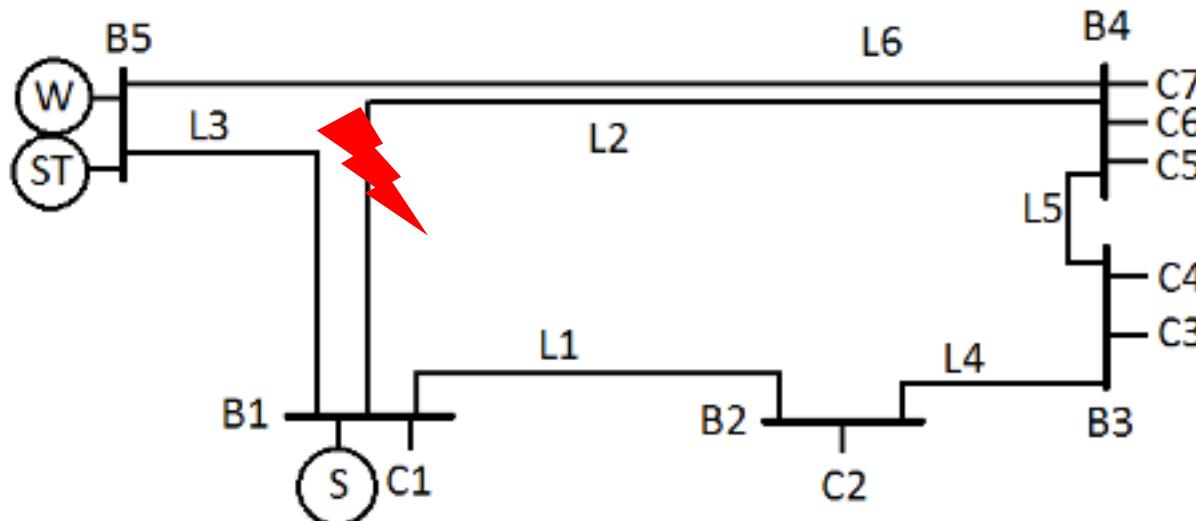
Total utility for 100 trials



- Minimax provides good and feasible results
- Good performance independent of parameter

- Robust EMS depends on parameter choice
- No unique optimal parameter choice

# Line faults



- Unknown duration
- Unknown event time

Fault

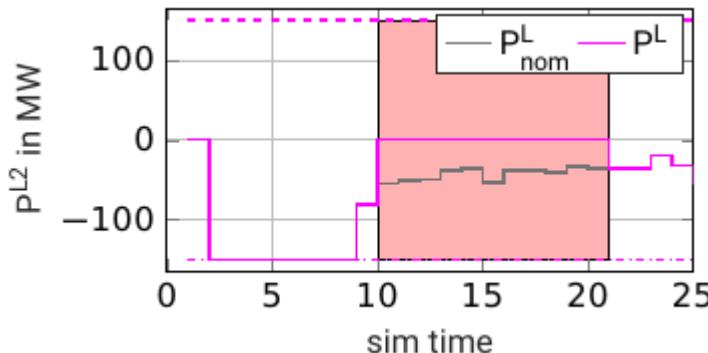
**Healthy controller**  
Healthy model

**Faulty controller**  
Faulty model

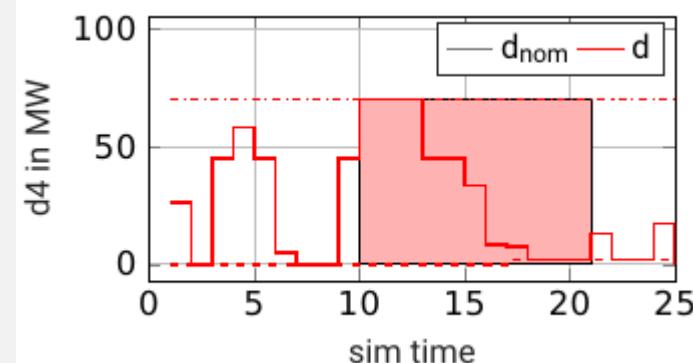
Fixed

# Performance under line faults

Faulty Line 2

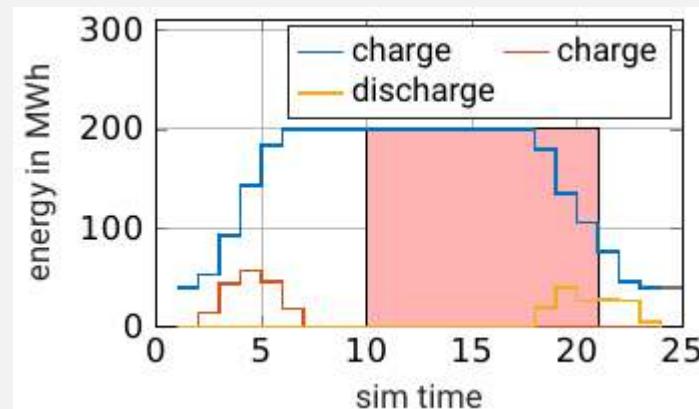


Consumer 4



- Feasibility for every line fault
- Storage is not required
- Meeting the minimum demand
- Same performance
- Same utility under faults

Storage



# Conclusion

## Forecast Disturbances

- Minimax EMS feasible for every trail
- Feasible Robust EMS can achieve better performance

## Line faults

- EMS can handle faults without forecast information
- Same performance as the nominal case
- Feasibility depends on the workload
- No energy reserve required
- Faults causes infeasibility if system is underdesigned
  - Line capacity
  - Power flow

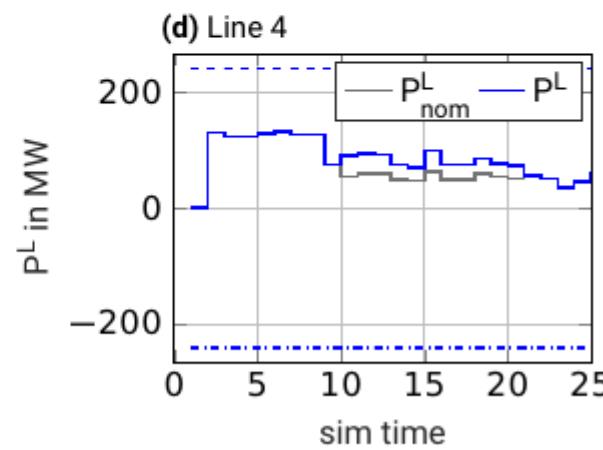
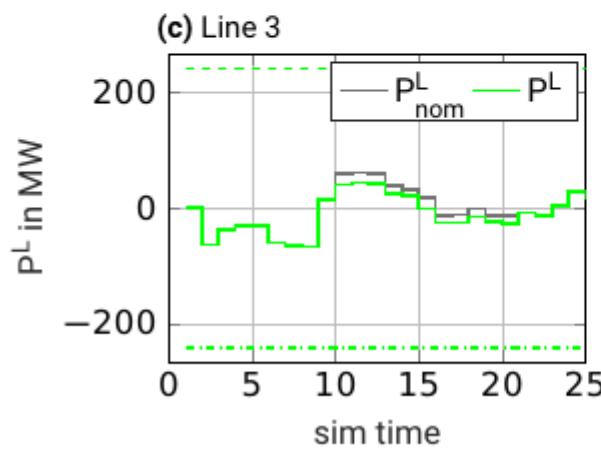
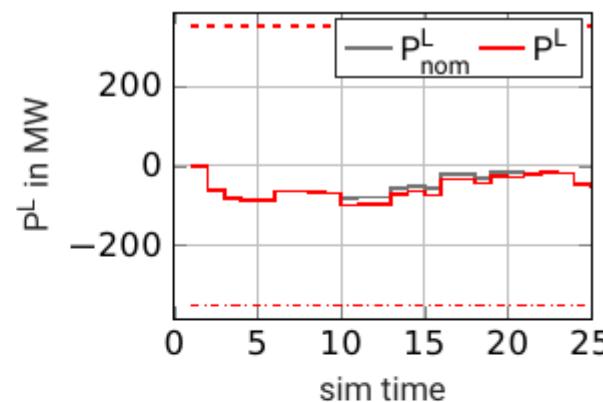
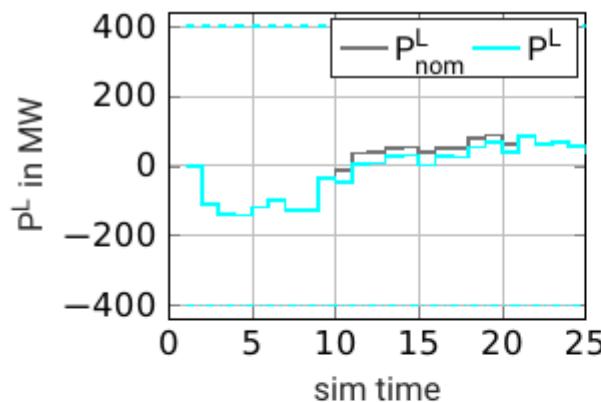
## Undergoing work:

- Analysing different architecture

# Bibliography

- M. Rahimiyan, L. Baringo, and A. J. Conejo, “Energy management of a cluster of interconnected price-responsive demands,” *IEEE Transactions on Power Systems*, vol. 29, no. 2, pp. 645–655, 2014
- Johan Löfberg. “Automatic robust convex programming”. In: *Optimization methods and software* 27.1 (2012), pp. 115–129
- Sechilariu , M., Wang, B., Locment, F., and Jouplet, A. (2014). DC microgrid power flow optimization by multi-layer supervision control. Design and experimental validation. *Energy Conversion and Management*, 82.1-10.10,163

# Line fault



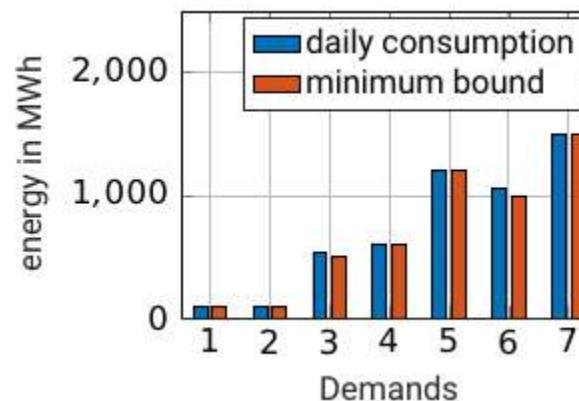
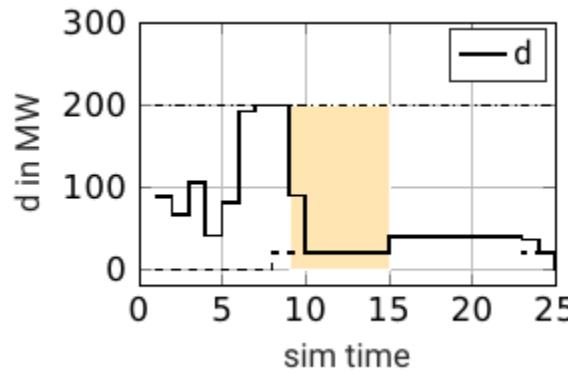
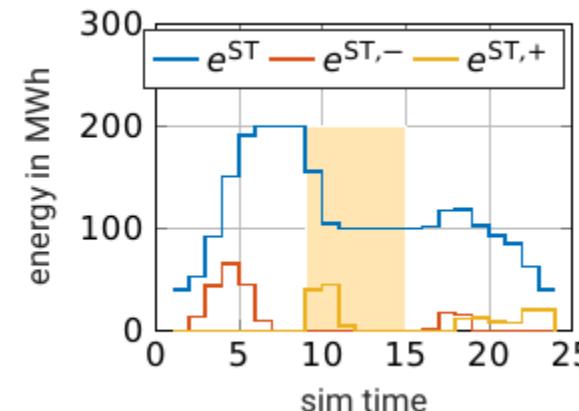
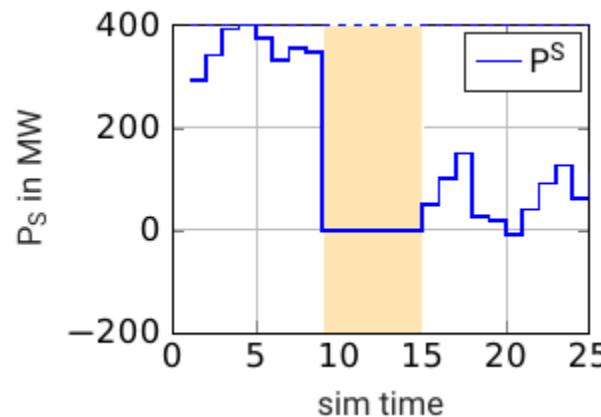
(e) Line 5

(f) Line 6

**Table 4.1:** Comparison between nominal EMS, robust EMS and minimax EMS

<b>Approach</b>	$u_{\text{total}} [\$]$	$e_{\text{total}} [\text{GWh}]$	$V_0$	$N^{\circ}_+$	$N^{\circ}_-$	$V_1 [\$/\text{MWh}]$	Built time (healthy/faulty) [s]	Sim time [s]
no Fault	$3.92 \cdot 10^4$	5.11	0.035	1	1	7.66	9.77/0	3.2
Line fault 1	$3.92 \cdot 10^4$	5.11	0.035	1	1	7.68	9.84/6.36	2.68
Line fault 2	$3.92 \cdot 10^4$	5.11	0.035	1	1	7.68	9.88/6.32	2.65
Line fault 3	$3.92 \cdot 10^4$	5.11	0.035	1	1	7.68	9.89/6.35	2.70
Line fault 4	$3.92 \cdot 10^4$	5.09	0.035	1	1	7.70	9.85/6.35	2.70
Line fault 5	$3.92 \cdot 10^4$	5.09	0.035	1	1	7.70	9.89/6.37	2.68
Line fault 6	$3.92 \cdot 10^4$	5.11	0.035	1	1	7.68	9.84/6.35	2.68

# Grid fault



- Feasibility until minimum demand cannot be met
- Storage is required
- Meeting the minimum demand

# Local self-protection function for power line communication node in DC micro grid,

T. K. Tran, H. Yahoui, D. Genon-Catalot, N. Siauve, N. Fourty, T. H. T. Ma

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LCIS Grenoble Institute of Technology, Valence

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# Toward Robust DC Microgrids

Hervé Morel, Pascal Bevilacqua, Guy Clerc,  
Romain Delpoux, Emil Dumitrescu, Jean-Yves Gauthier, Xuefang Lin-Shi, Eric Niel,  
Laurent Pietrac, Jean-François Trégouët.



**INSA**



## Context of grid, μgrid and DC μgrid

μgrids → <b>building</b> or district scale	DC μgrid,
Integration of <b>renewable</b> (PV) and smart loads	<b>Efficiency</b> (25 % ↑)
Smart Cities	MVDC
Integration of renewable & <b>e-mobility</b>	<b>Efficiency</b> , better control
Supergrids	HVDC
Source areas to consumer areas, reduce intermittency effect	<b>Efficiency</b> , better control

# 1- Meshed DC µgrids

## Motivations

Hervé Morel, Pascal  
Bevilacqua, Guy Clerc,

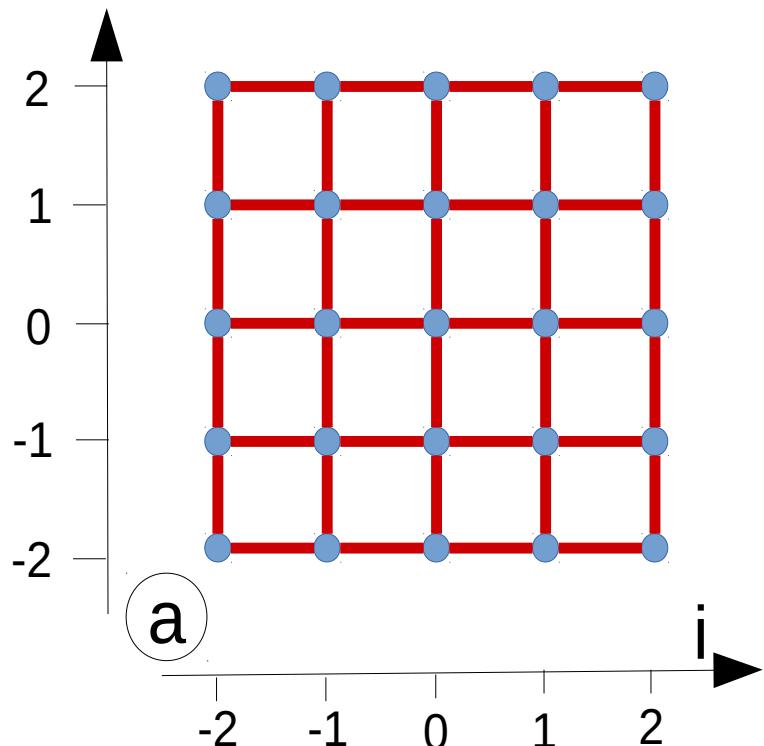
- A project to the ANR Call ! → innovation+feasibility
- Reduction (radial grid) of the **amount of conductor**
- Smart-Cities → **complex** → meshed MVDC
- Meshed DC µgrids are low cost vs. meshed MVDC
- **Redundancy** → better **availability**
- Better flexibility (to insert a new node)

## Drawbacks

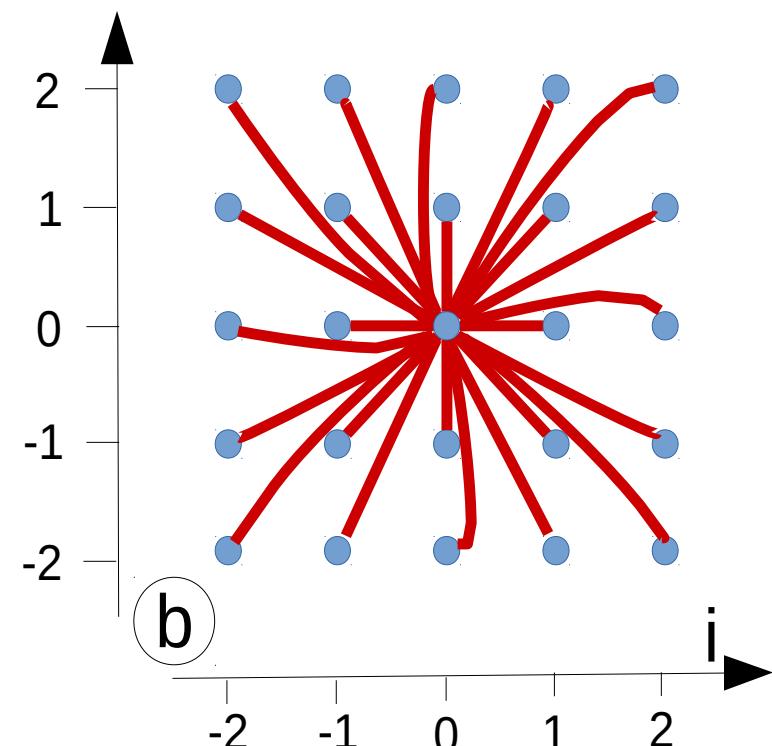
- **Control flow** (line limits)
- Existing AC grids ...

# Meshting Buildings

Building → regular structure



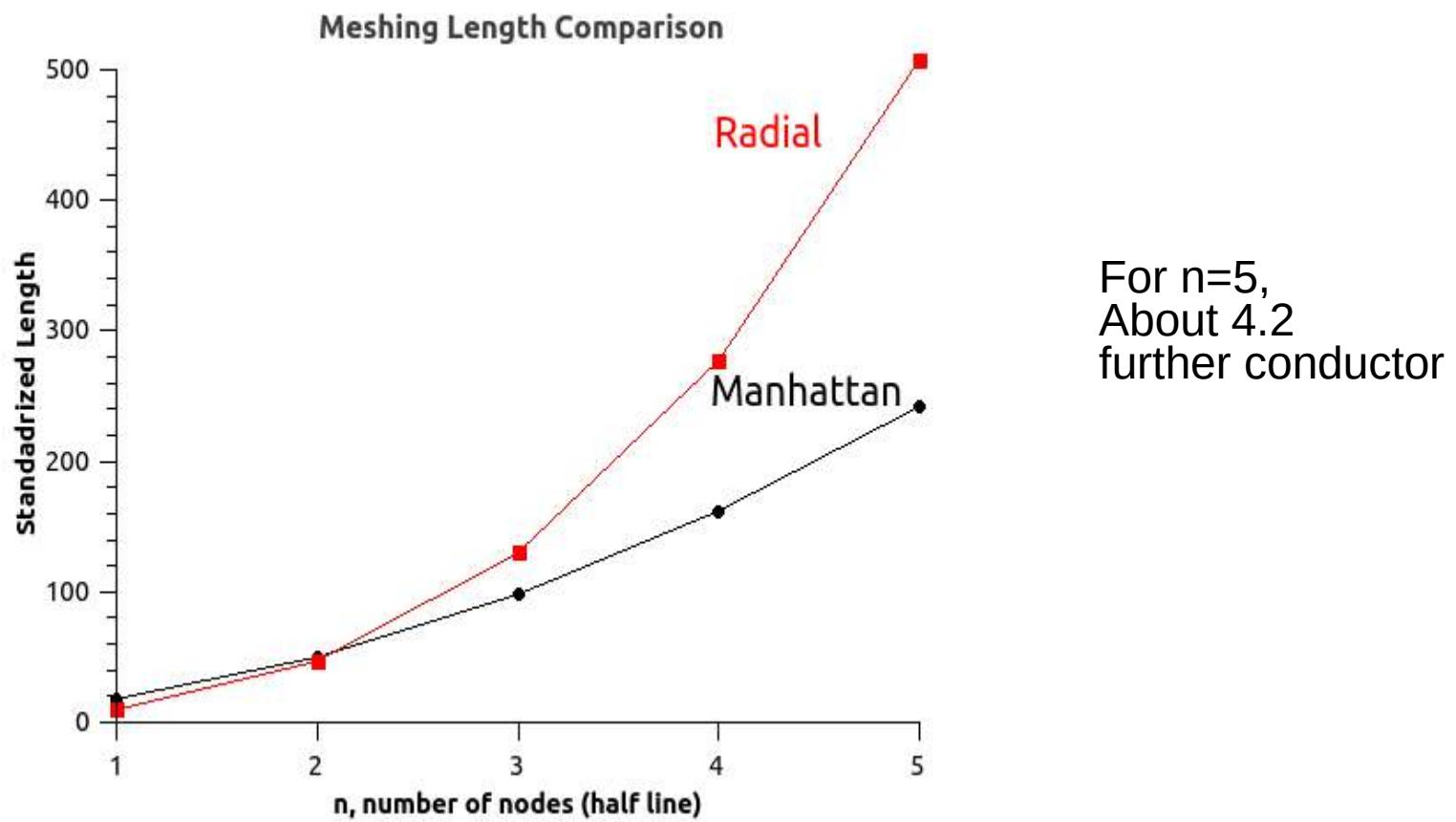
Manhattan



Radial

Powering from the central node

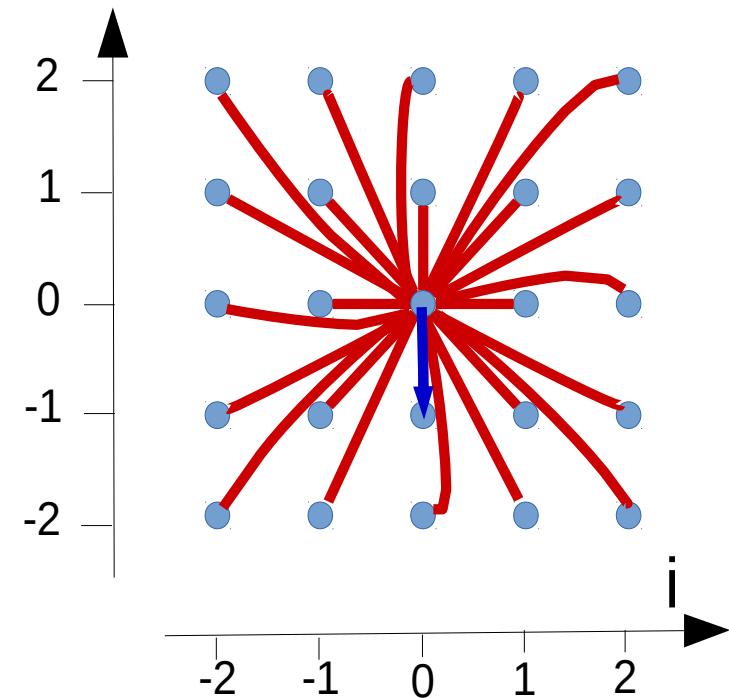
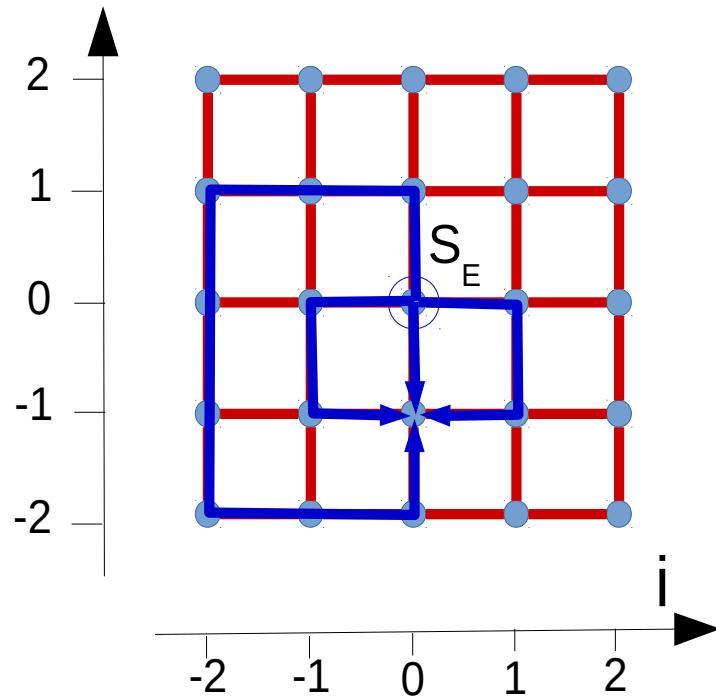
## Meshing Buildings (2)



Radial/Manhattan

## Meshing Buildings (3)

Powering from the central node



Manhattan/radial = 4 x maximal power.

Average power is very low in such  $\mu$ grid !

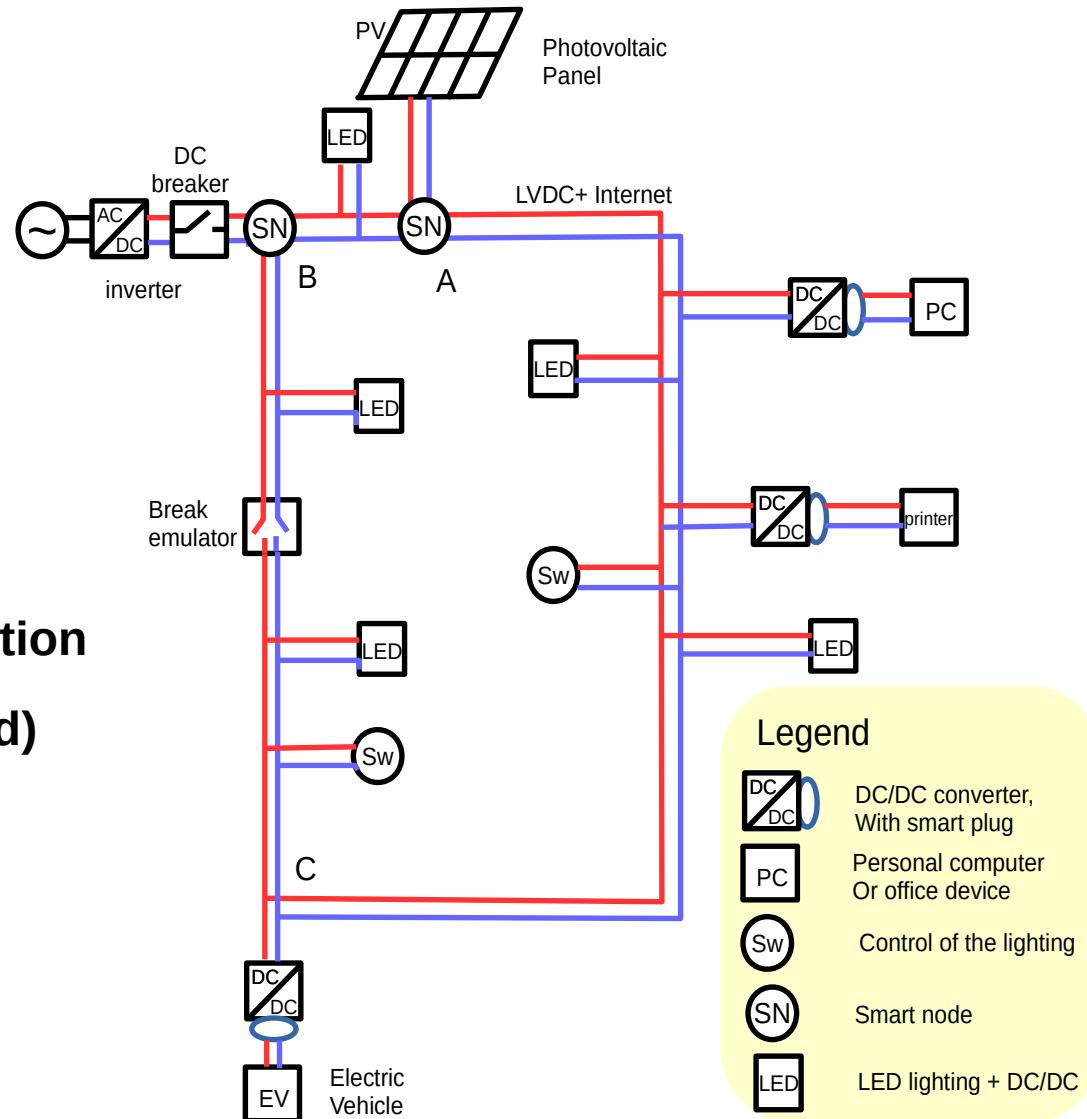
For n=5 and the  
Same power  
 $\times 16.8$  conductor

# Targeted Meshed DC µgrid (ANR/C3µ)

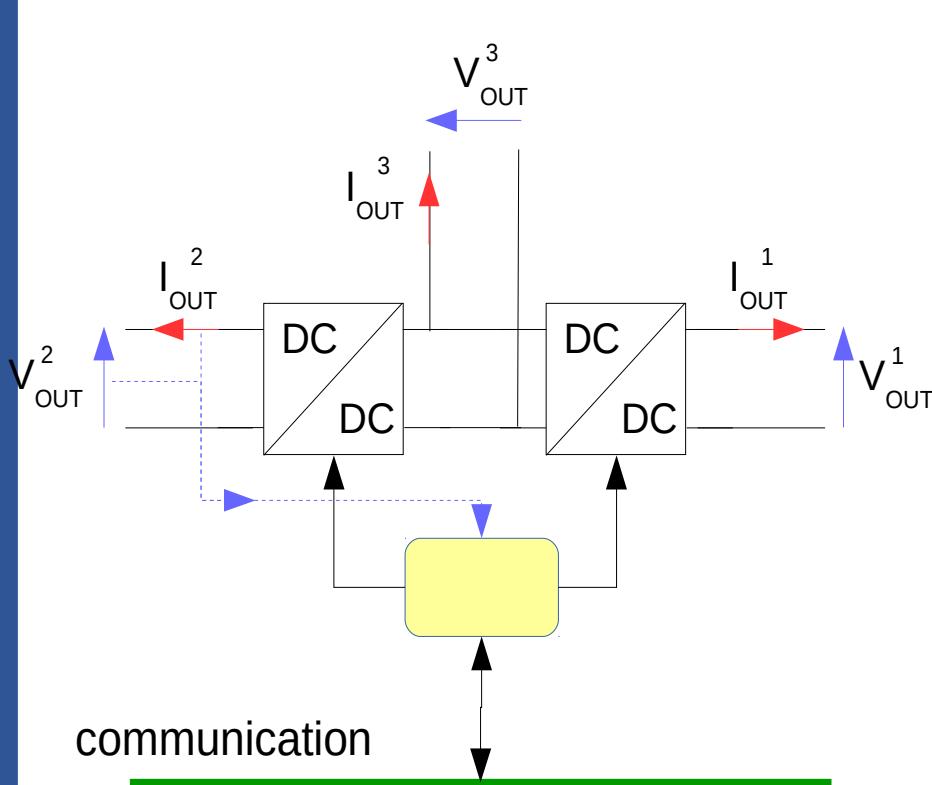
Completed by  
CPER/GD3E project

Control Flow Converters:  
→ Smart Nodes !

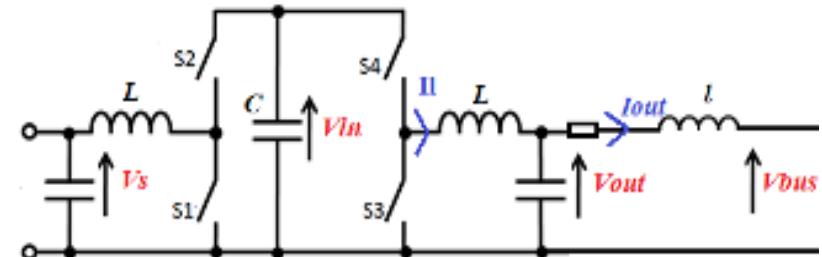
- Not Addressed issues :
- DC Breaker, Protection, Insulation
  - Bus Voltage → 400 V
  - Only emulation (PV, EV, AC-grid)
  - Smart plug



# Smart Nodes



## Split-Pi Converters<sup>SN</sup>



Split-Pi  
Converters from  
CATS,  
20 kW x 6



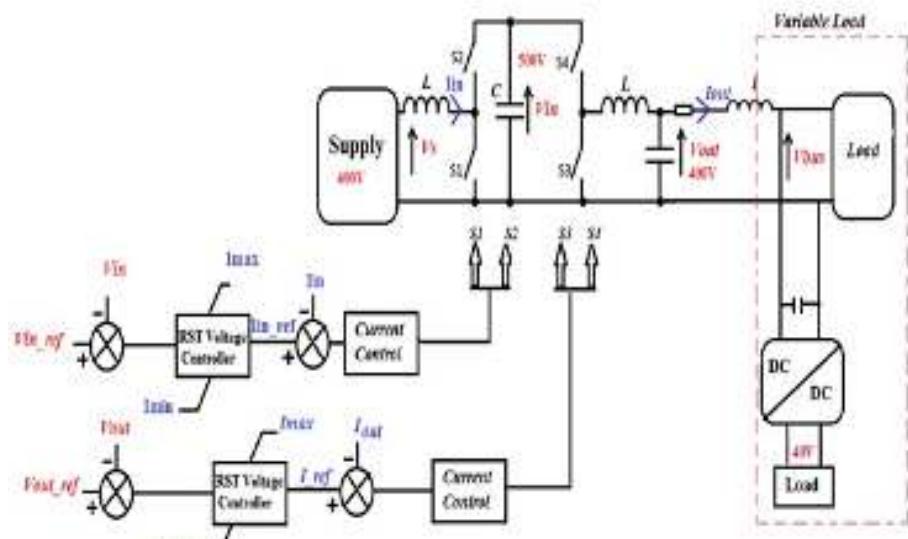
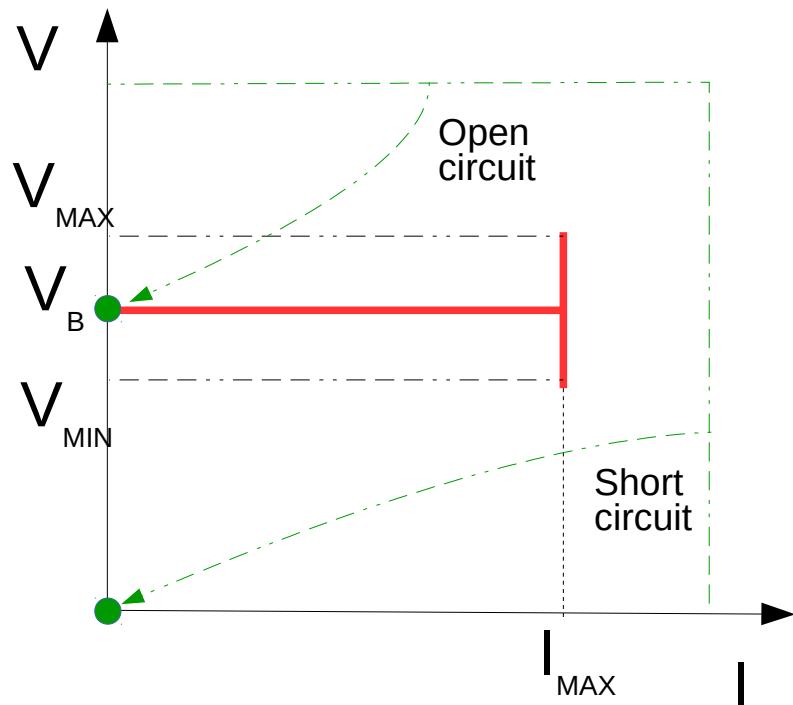
**Communication:** carrier current technology on power twisted pair  
→ Ethernet + Power

**Smart:** Power management protocol (starting, protection,  
optimization, user control...)

# Control Flow Control

- No configuration → robust control,
- At least one branch control the voltage,
- Capability to control Power (current)

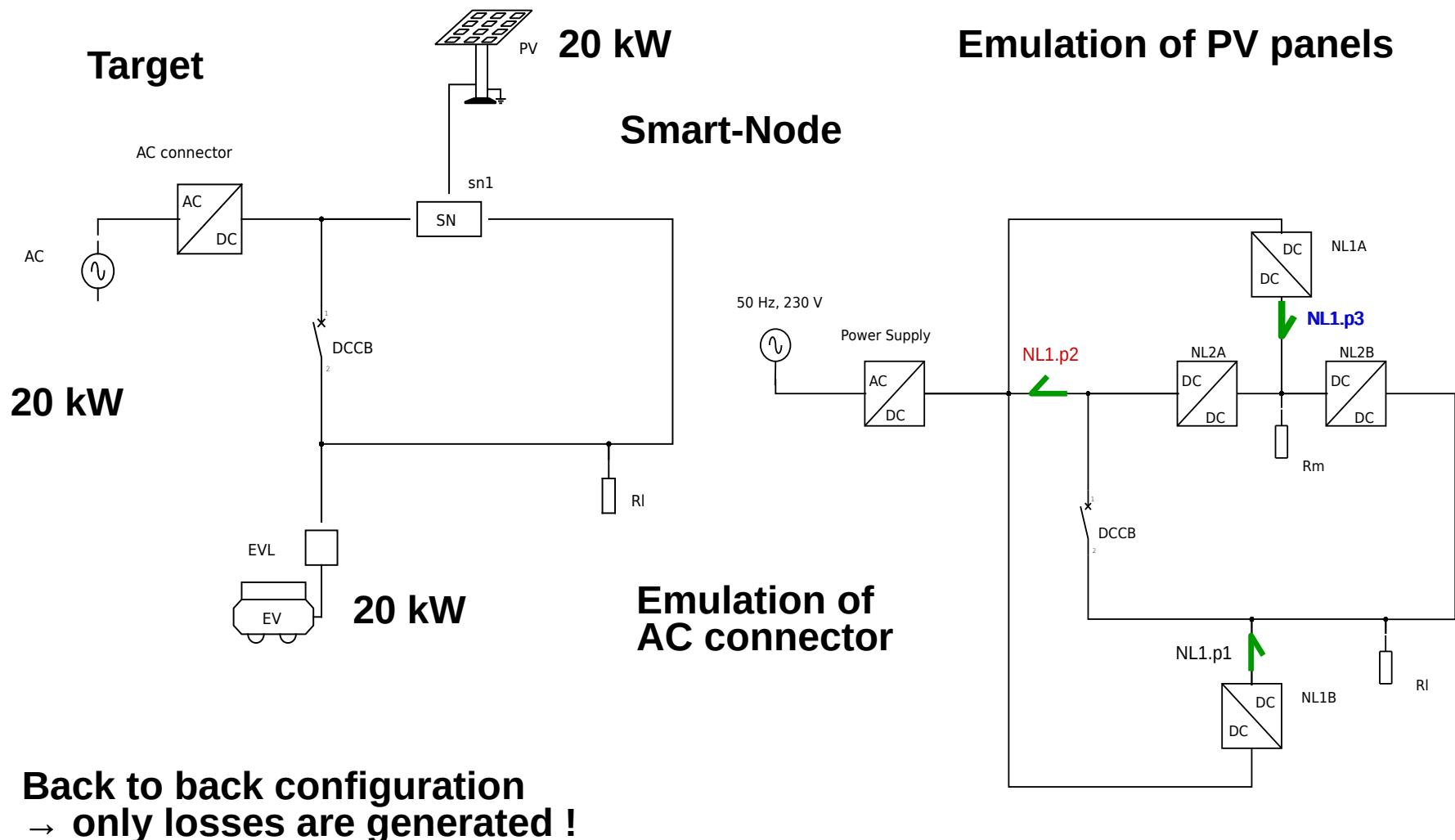
Inspired from the  
**voltage margin method**



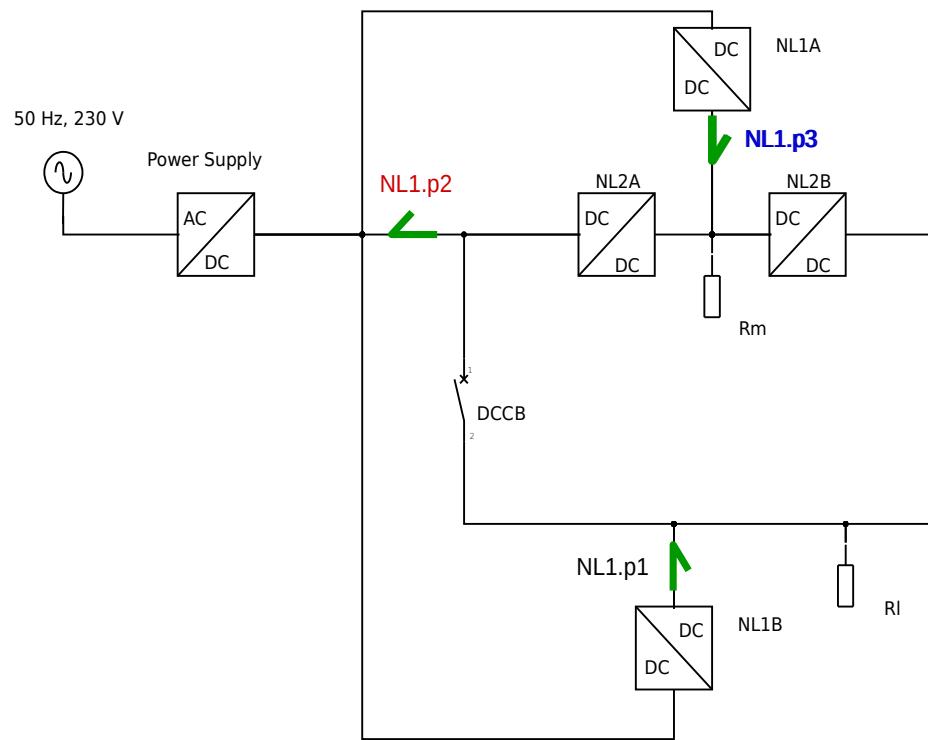
Validated by simulation and reduced scale mock-up.

M. Barara et al. Control Strategy Scheme for Consistent Power Flow Control in Meshed DC Microgrids, CoSys-DC, Grenoble, 2017

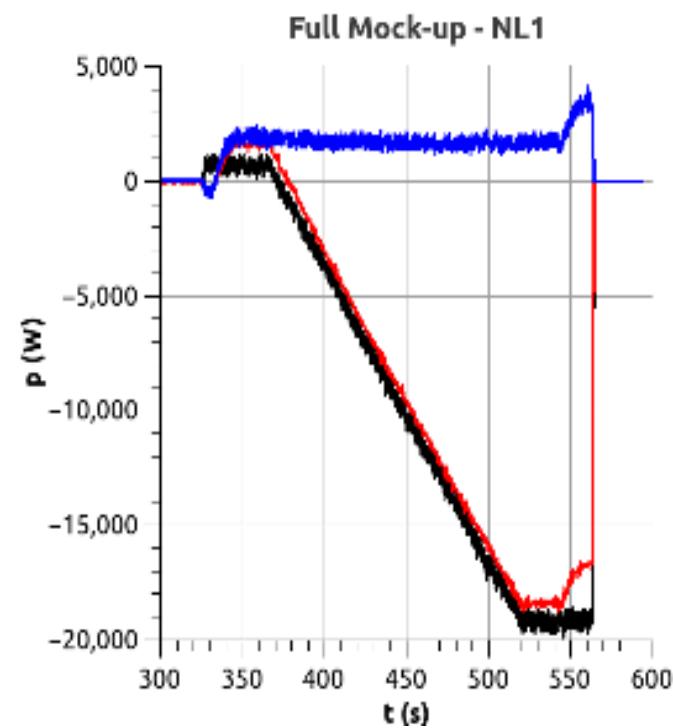
# Targeted Mock-up



# First Tests



Full test at 20 kW

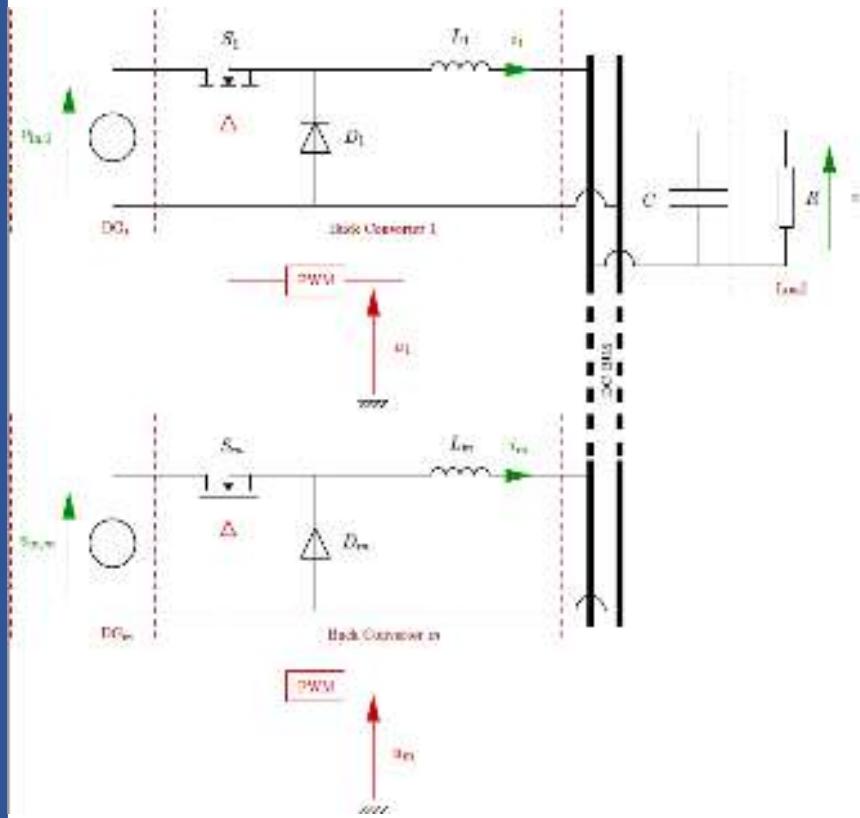


Full Test: controlling NL1.p<sub>1</sub>

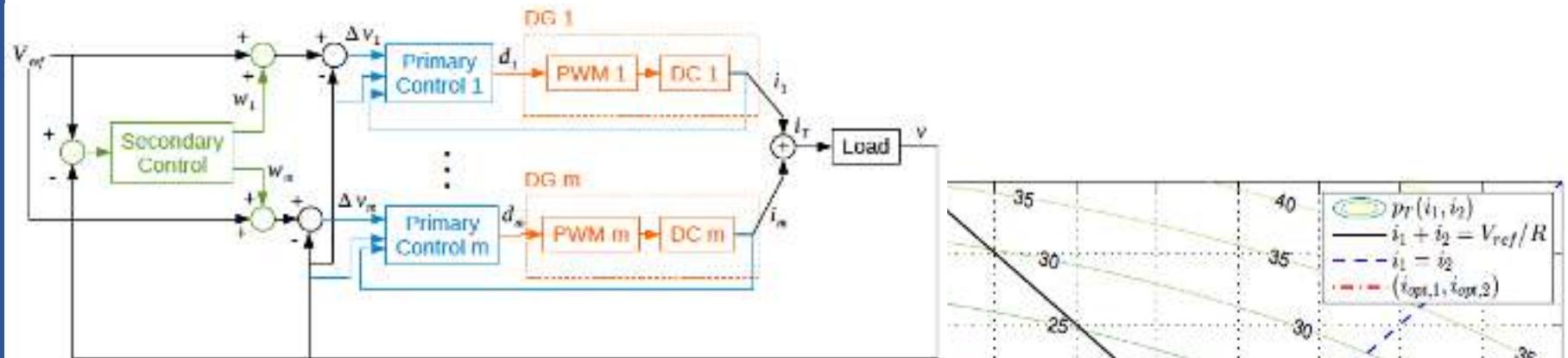
## 2 - DC Microgrid Control

J. - F. Trégouët, R. Delpoux,  
J.-Y. Gauthier, X. Lin-Shi

Parallel interconnection of DC/DC converters  
– Simplified Microgrid



# Optimal current sharring

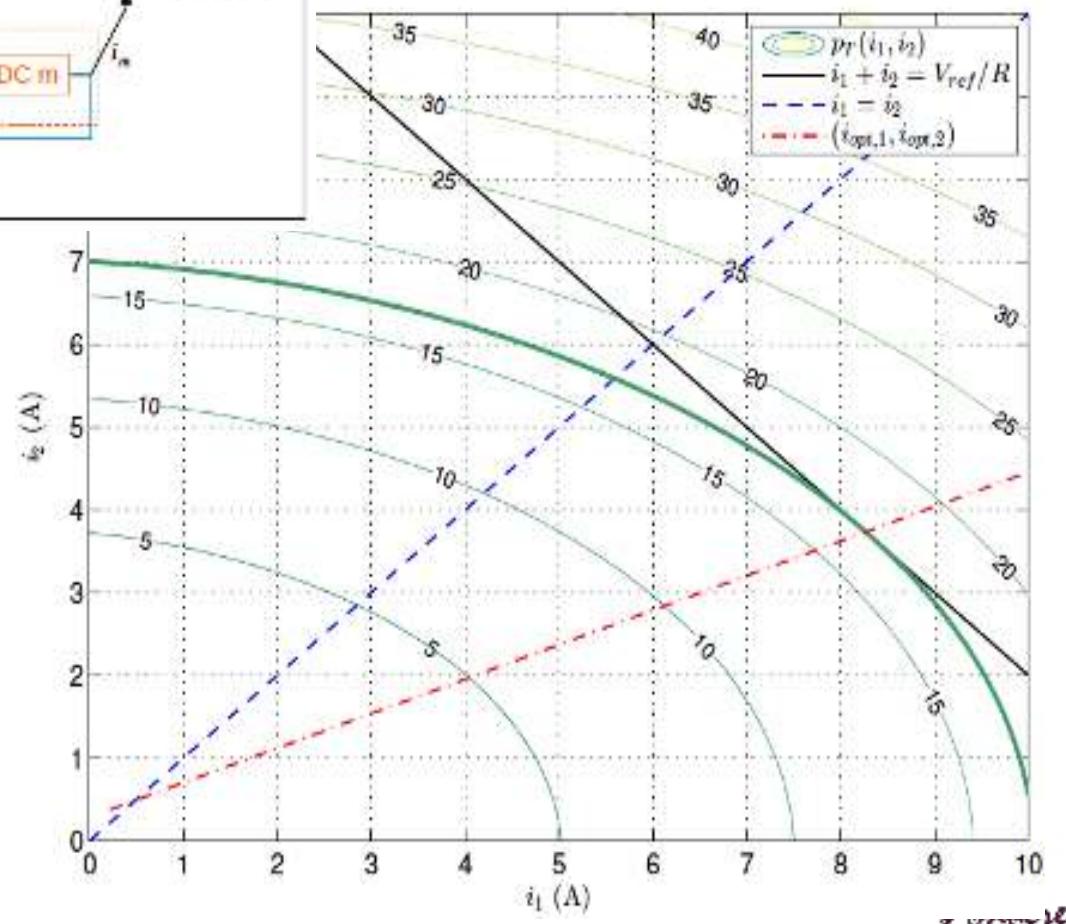


## Primary control :

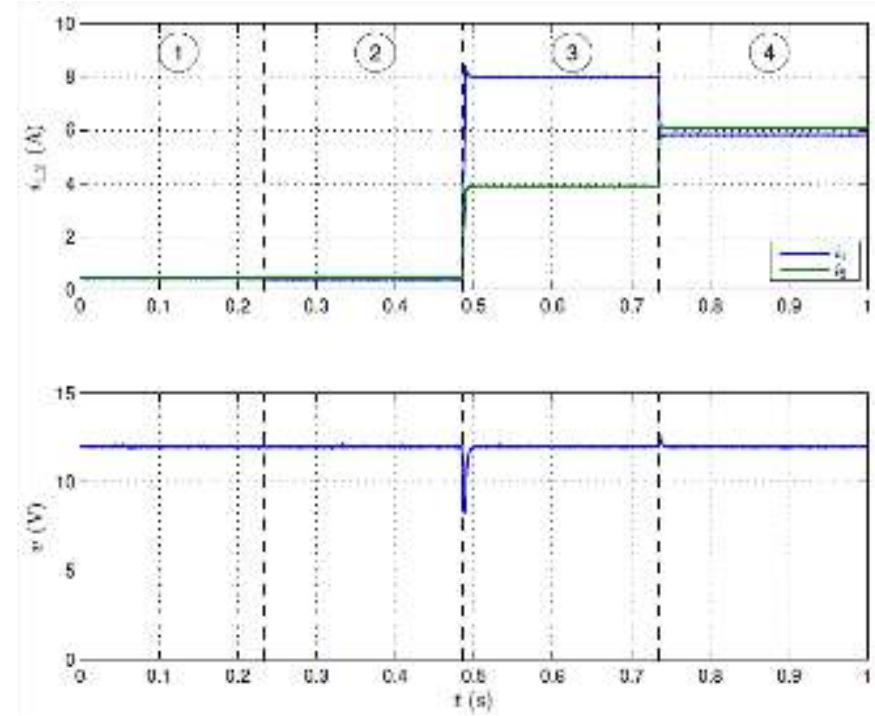
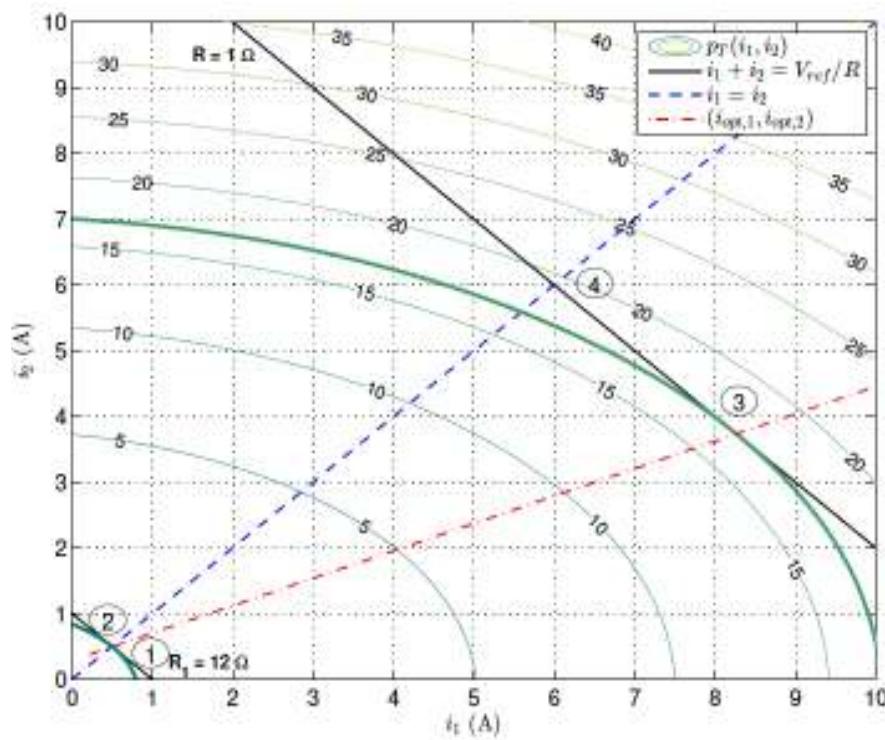
- Ensure stability for all  $R$
- Rely on  $v$  and  $i_k$

## Secondary Control :

- Correct voltage deviation :  
 $v(t) \rightarrow V_{ref}$
- Define current-sharing policy



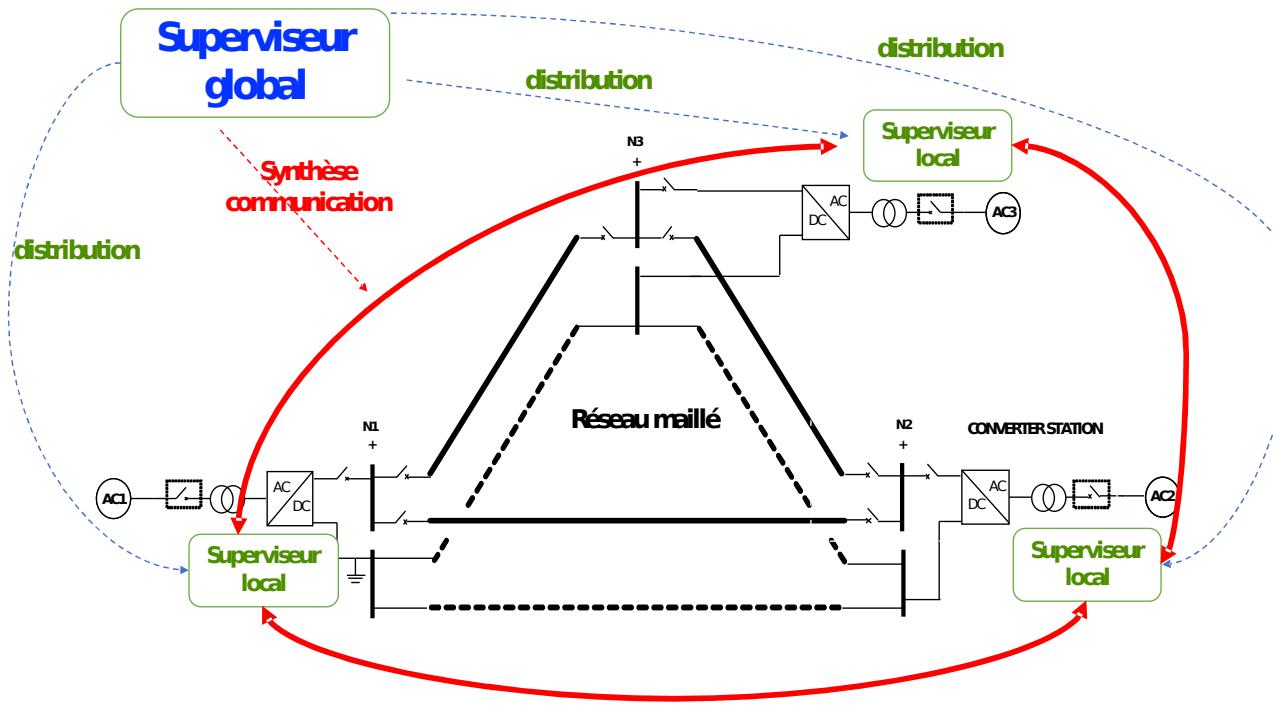
# Experimental result



### 3- Discrete Events and Grids

Emil Dumitrescu, Eric Niel,  
Laurent Pietrac

- Power Converters + Power Protection Systems
- **Event management protocols** (start, open, short circuit, failure...)



- Reconfiguration sequences → global logic (coherence)
- Decentralized nature of the grid → local implementation of each global reconfiguration logic.
- Reconfiguration strategy → supervisor + model (behavior of the nodes).
- Synthesis by supervision, but obtaining a locally distributed control logic remains an important **scientific lock** today.

# Conclusion

## Meshed DC μGrids

- Meshed DC μgrids may reduce the amount of conductor needed in a building.
- Meshed DC μgrids need a robust control flow strategy (Smart-nodes)
- Our strategy has been validated as robust by simulation
- Our mock-up has been tested up to 20 kW.
- Further robust control of split-pi converters is needed.

# Conclusion (2)

## DC Microgrid Control

- new primary control layer
- new **secondary control layer** (optimal steady-state current-sharing policy)
- arbitrary number of converters

## Discrete events and networks

- Global supervisor → distributed Supervisor

# To Continue ...

- Power Hardware In the Loop (**PHIL**)
- Protection Scheme → **Smart Nodes** (Full SiC Converter)
- Low-cost technologies (Smart Nodes)
- **Advanced and robust control** for (Meshed) DC µgrids
- **Decentralized Supervision**
- **Power Control Protocol → Smart Node Level**  
(starting, stopping, protection, user control and optimization) : randomization

9 Juillet 2018 – Université de Technologie de Compiègne, France

# Optimal real time management of droop- controlled microgrids

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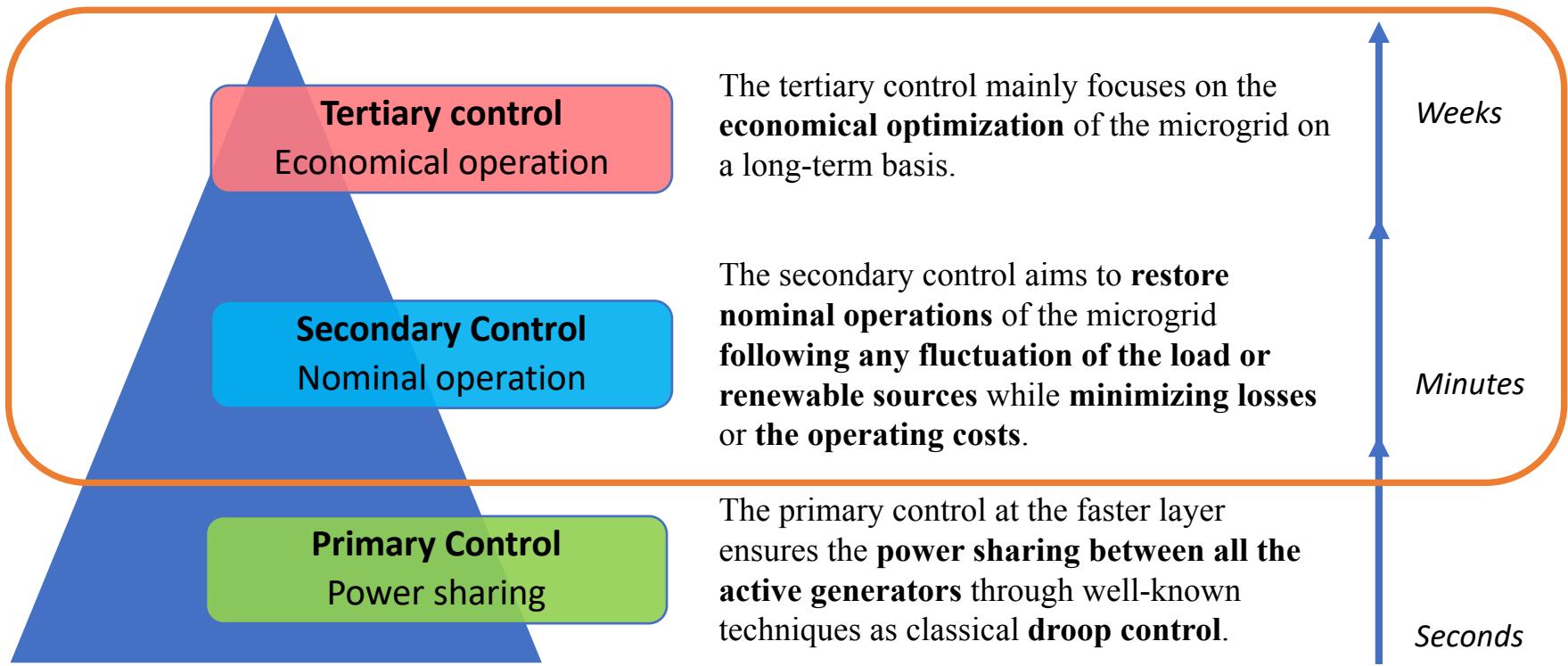
# Contents

- I. Introduction of microgrid control structure
- II. Model Predictive Control applied to microgrids
- III. Simulation results
- IV. Conclusion

# Contents

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# Microgrid control structure



Time scale

# Supervisor specifications

- The supervisor must be able:

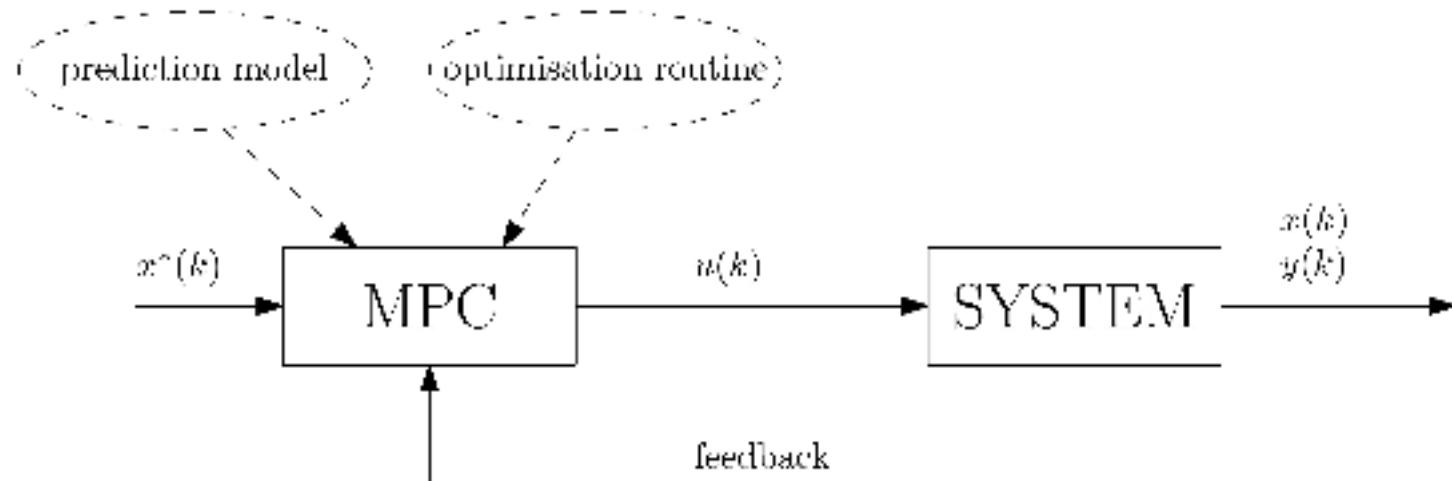
- To handle reference tracking, and direct/indirect indexes,
- To handle multiple variables, multiple states,
- To consider dynamics of the system,
- To consider control/prediction horizon,
- To deal with two time scale control/optimization.

## MULTI-LAYER MODEL PREDICTIVE CONTROL

# Contents

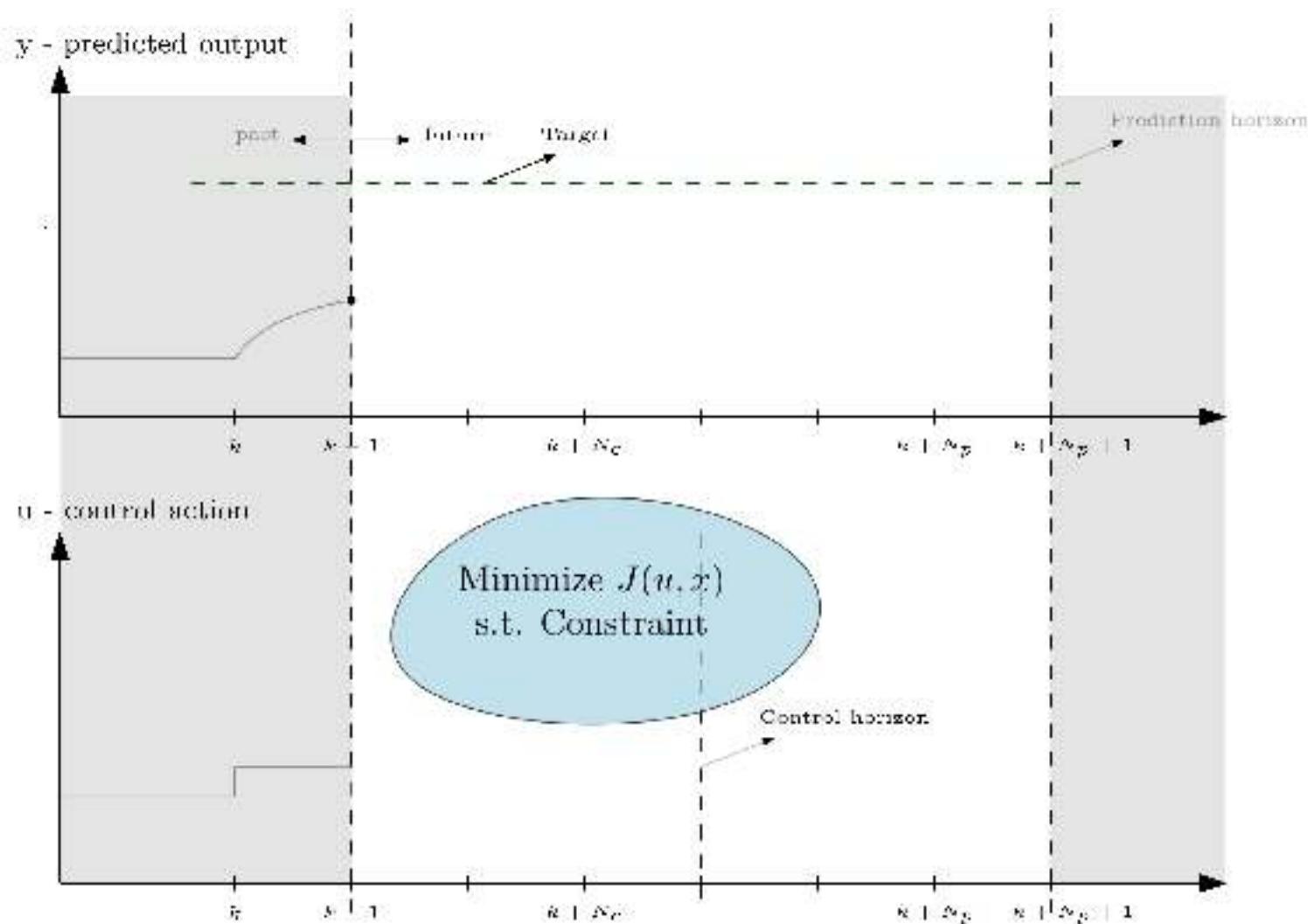
- I. Introduction of microgrid control structure
- II. Model Predictive Control applied to microgrids
- III. Simulation results
- IV. Conclusion

# Model Predictive Control (1)



An **embedded model of the system** predicts the **future behavior** to define an **optimal control sequence**

# Model Predictive Control (2)



# Model Predictive Control (3)

Mixed Integer Quadratic Problem

Quadratic objective function:

$$\min_{\Delta u} J = \sum_{k=1}^{N_c} \left[ \alpha (\tilde{x}(k) - x^*(k))^2 + \beta (\Delta u(k))^2 + \lambda (P_{losses})^2 \right]$$

Linear Constraints:

$$X(k+1) = \mathbf{A}.X(k) + \mathbf{B}.\Delta U(k) + \mathbf{C}.\Delta D(k)$$

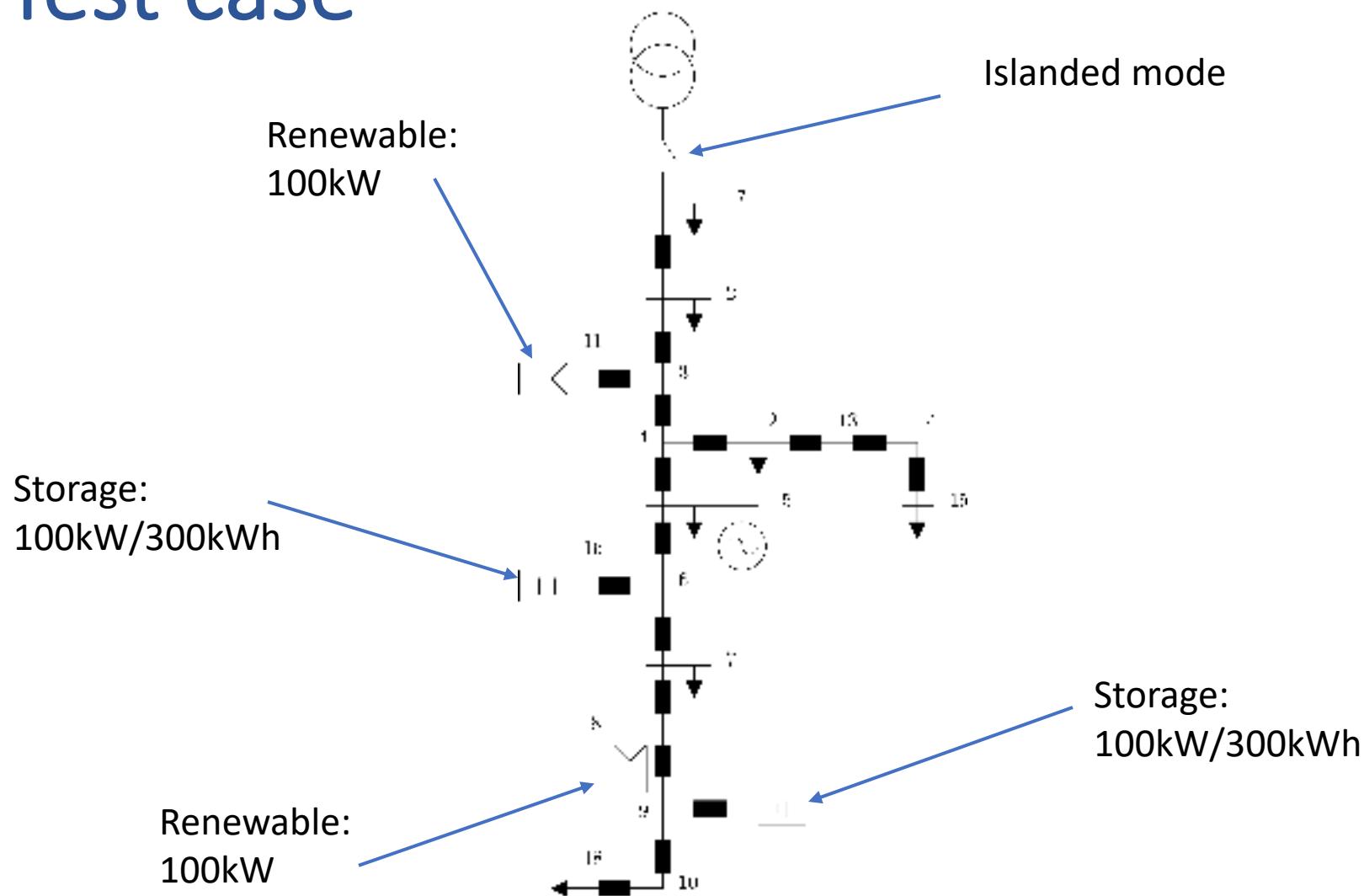
$$X_{min} < X(k+1) < X_{max}$$

$$\Delta U_{min} < \Delta U(k+1) < \Delta U_{max}$$

# Contents

- I. Introduction of microgrid control structure
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- III. Simulation results
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# Test case

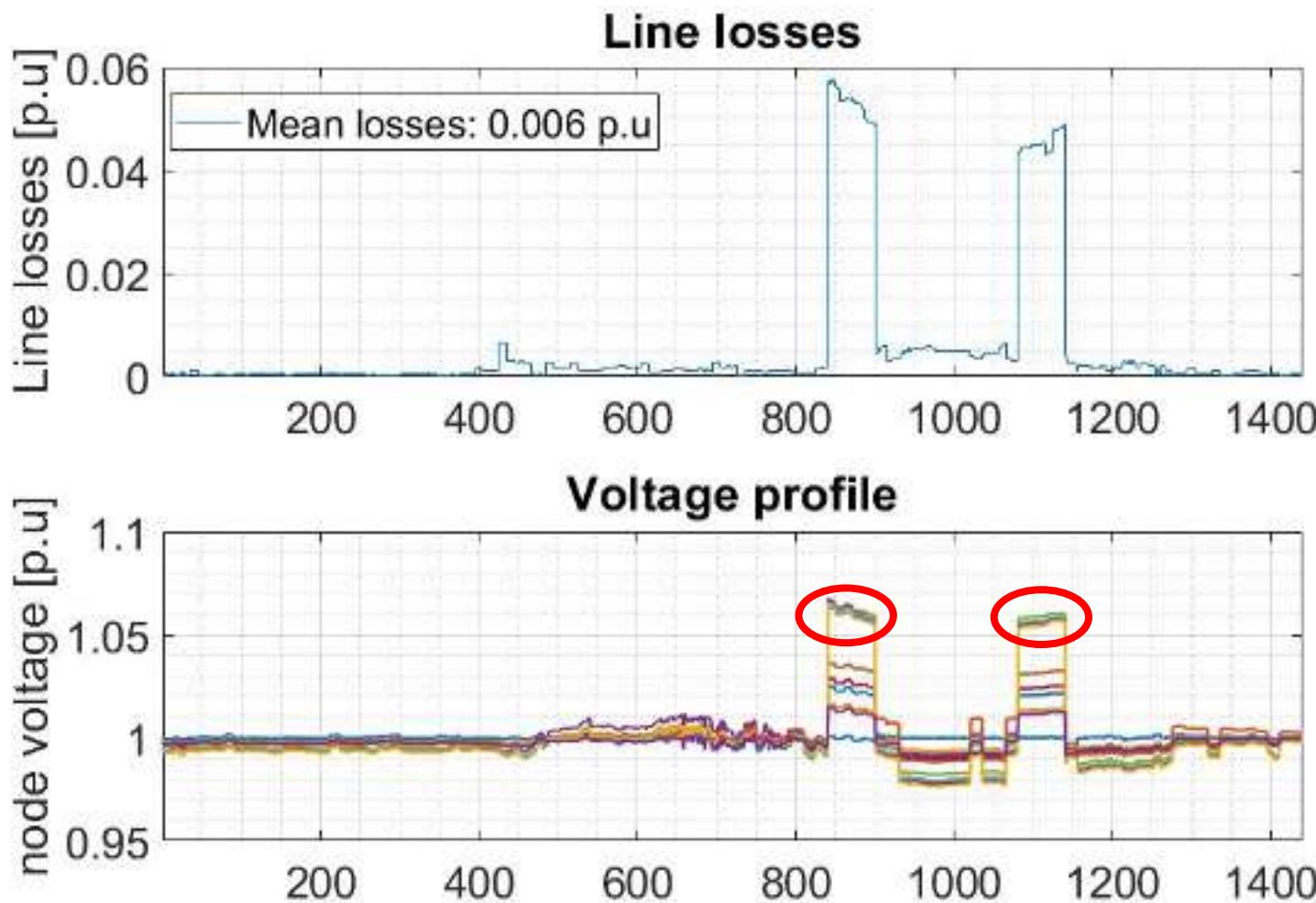


Modified CIGRE European LV network testbench

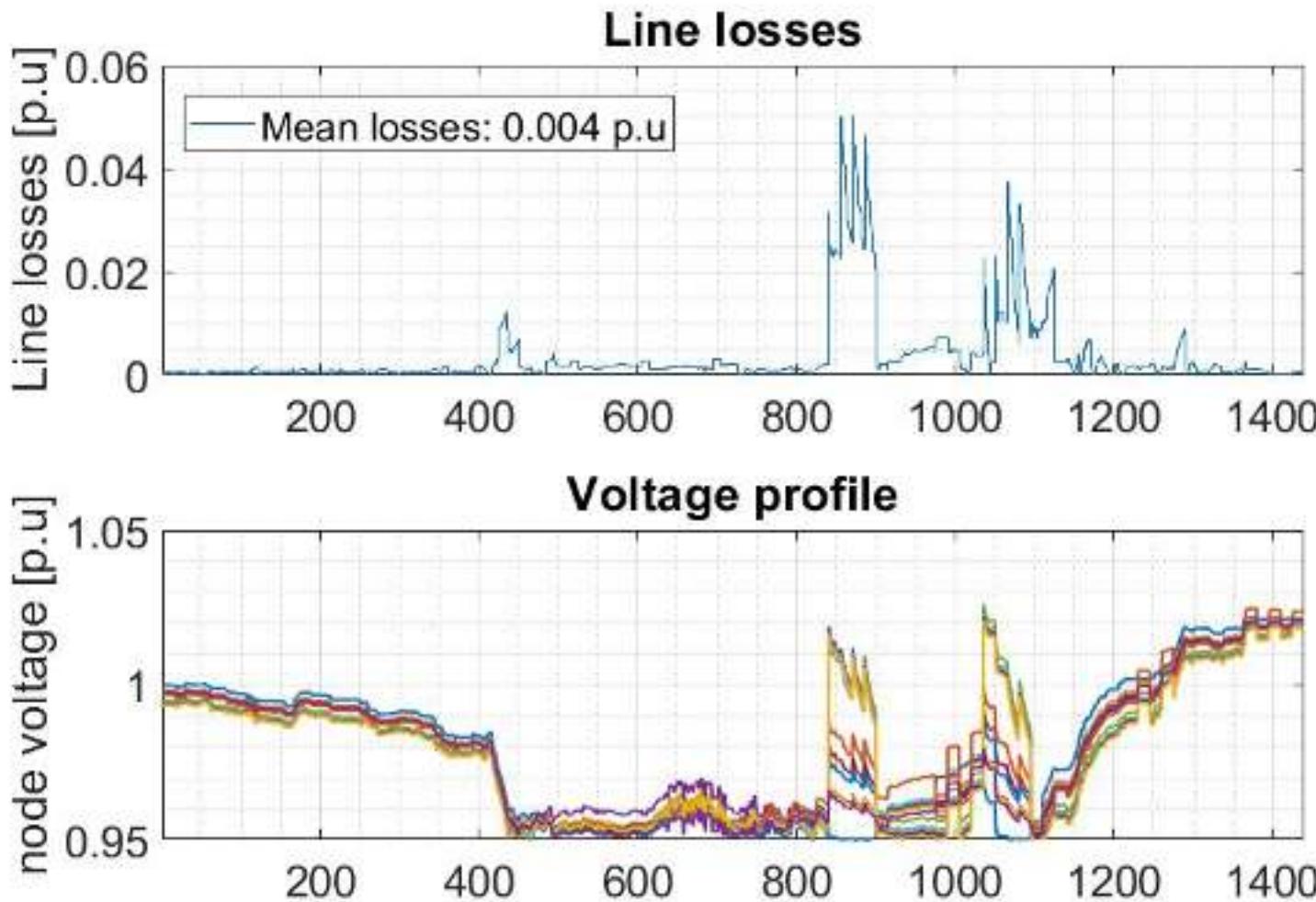
# Simulation cases

- Case 1:  
The economical references are the only references for the droops.
- Case 2:  
The supervisor minimizes the losses and track the references.

# Case 1



# Case 2



# Contents

- I. Introduction of microgrid control structure
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# Conclusion

In general:

- MPC is able to predict the future behavior,
- MPC is able to tackle constraints,
- MPC to define optimal actions.

Applied to microgrids:

- MPC is able to tracks economical references,
- MPC ensure multi-objective operation.

Thank you for your attention

Martin LEGRY  
[Martin.legry@ensam.eu](mailto:Martin.legry@ensam.eu)

9 Juillet 2018 – Université de Technologie de Compiègne, France

# Towards a robust energy management optimization of a smart wind powerplant in day ahead markets

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# Plan

- I. Problem setting
- II. MILP
- III. Robust Optimization:  
problem formulation
- IV. Conclusion

# I.1 Problem setting: power commitment with smart wind powerplant



Renewable  
energy  
sources  
(R.E.S.)

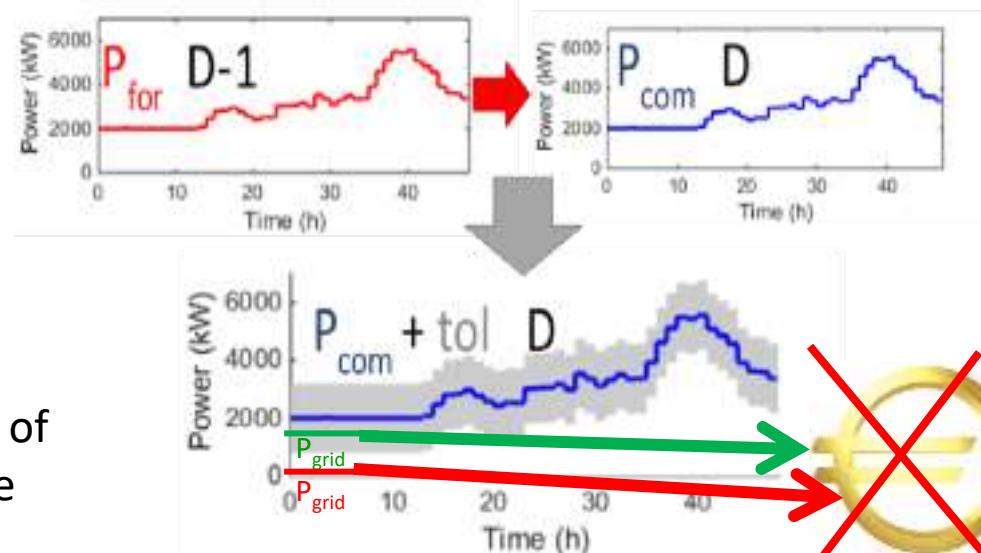


Sizing and  
management of  
storage device



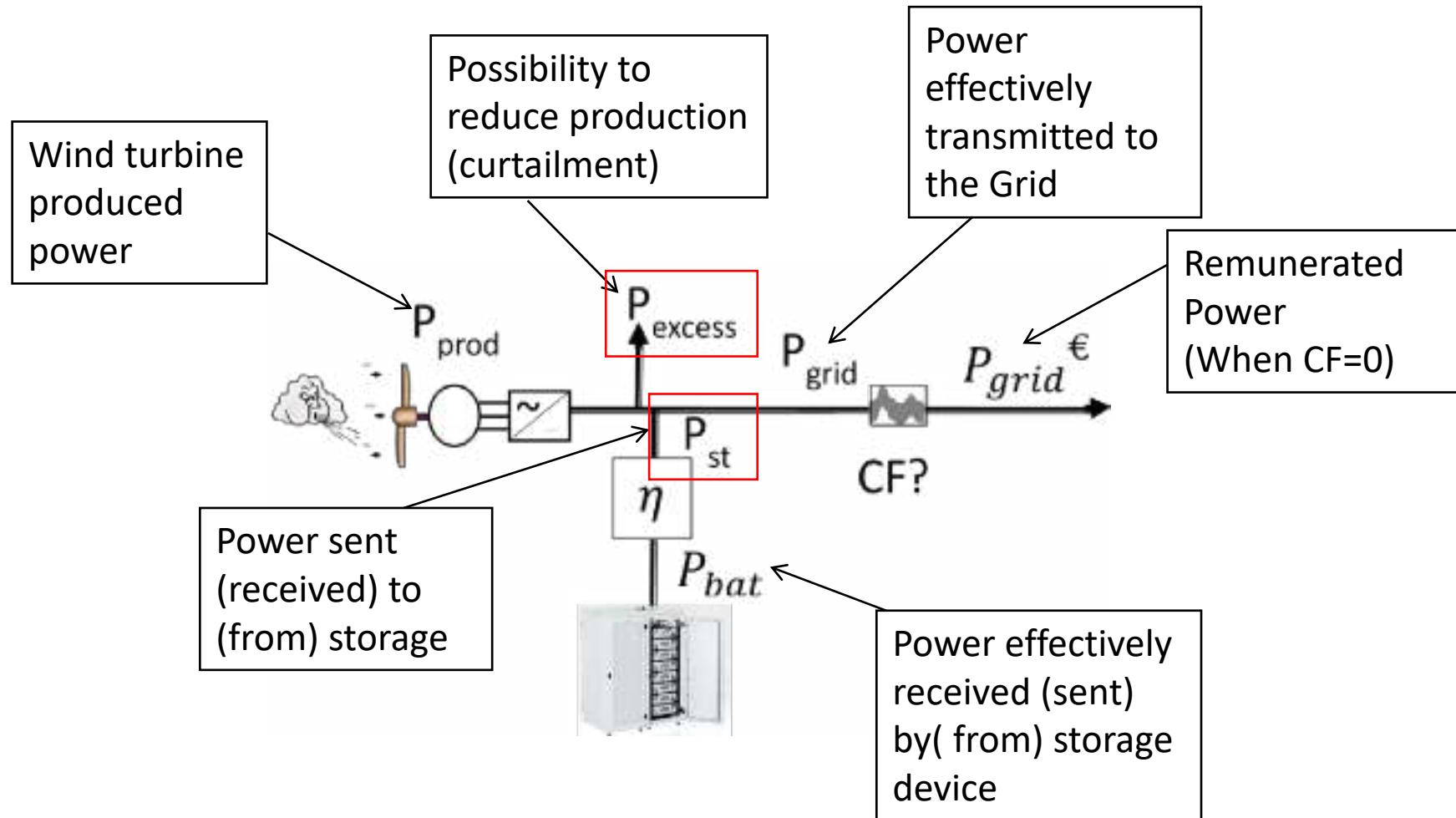
Increasing the participation  
rate of R.E.S. in islanded  
electric grids

Participation to grid services



- «  $P_{\text{com}}$  » : Committed power
- «  $P_{\text{for}}$  » : Forecast power
- «  $P_{\text{grid}}$  » : Power sent to the grid
- « CF » : Commitment Failure

## I.2 Power flow simplified (to be linearized) model:



2 degrees of freedom

## II. 1 MILP

- Linearization

$$P_{bat}[k] = \eta_{ch} \cdot P_{st}^{-}[k] + \frac{P_{st}^{+}[k]}{\eta_{dis}}$$

$$SOC[k+1] = SOC[k] + \frac{P_{bat}[k]\Delta t}{E_{nom}}$$

- Problem implementation

### 7 Variables

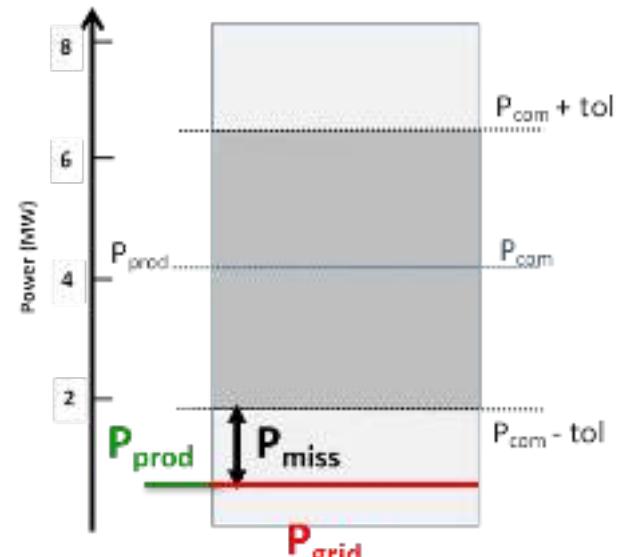
Time horizon: 24h

Time step  $\Delta t=10\text{min}$

1008 ( $7*24*6$ ) decision variables

$$P_{grid}[k] \geq P_{eng}[k] - tol - P_{miss}[k]$$

**Big M method:**  $M \times CF[k] \geq P_{miss}[k]$



## II. 2 Objective function:

**Sum all costs due to penalty and use of the storage device**

Battery life cost:

$$\text{Cost}_{lifelion}[k] = \text{Cost}_{LiIon} \cdot \frac{\left( \frac{P_{st}^+[k]}{\eta_{dis}} - \eta_{ch} \cdot P_{st}^-[k] \right) \cdot \Delta t}{E_{bat,tot}}$$

Penalty due to efficiency:

$$\text{Cost}_{\eta LiIon}[k] = FIT \cdot \left[ (\eta_{ch} - 1) \cdot P_{st}^-[k] + \frac{1 - \eta_{dis}}{\eta_{dis}} P_{st}^+[k] \right] \cdot \Delta t$$

FIT: Feed in Tarif

Power excess penalty:

$$\text{Cost}_{exc}[k] = FIT \cdot P_{excess}[k] \cdot \Delta t$$

Penalty due to CF:

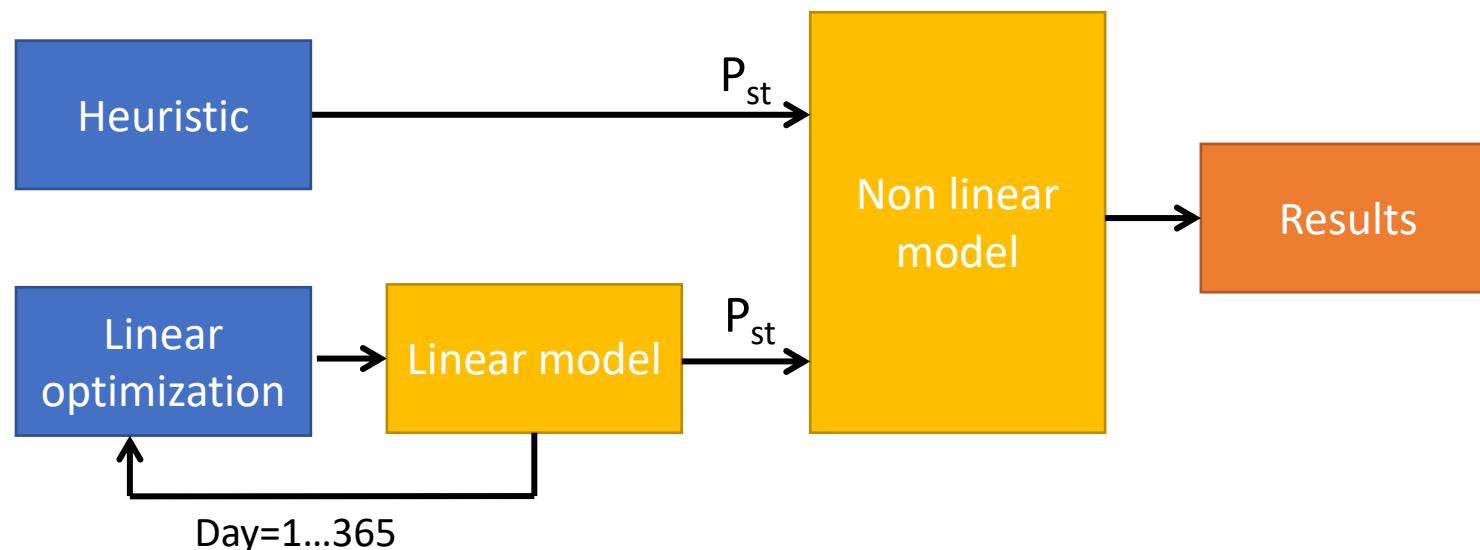
$$\text{Cost}_{pen}[k] = FIT \cdot CF[k] \cdot P_{prod}[k] \cdot \Delta t$$

$$\text{Cost}_{Tot}[k] = \text{Cost}_{lifelion}[k] + \text{Cost}_{\eta LiIon}[k] + \text{Cost}_{dev}[k] + \text{Cost}_{was}[k]$$

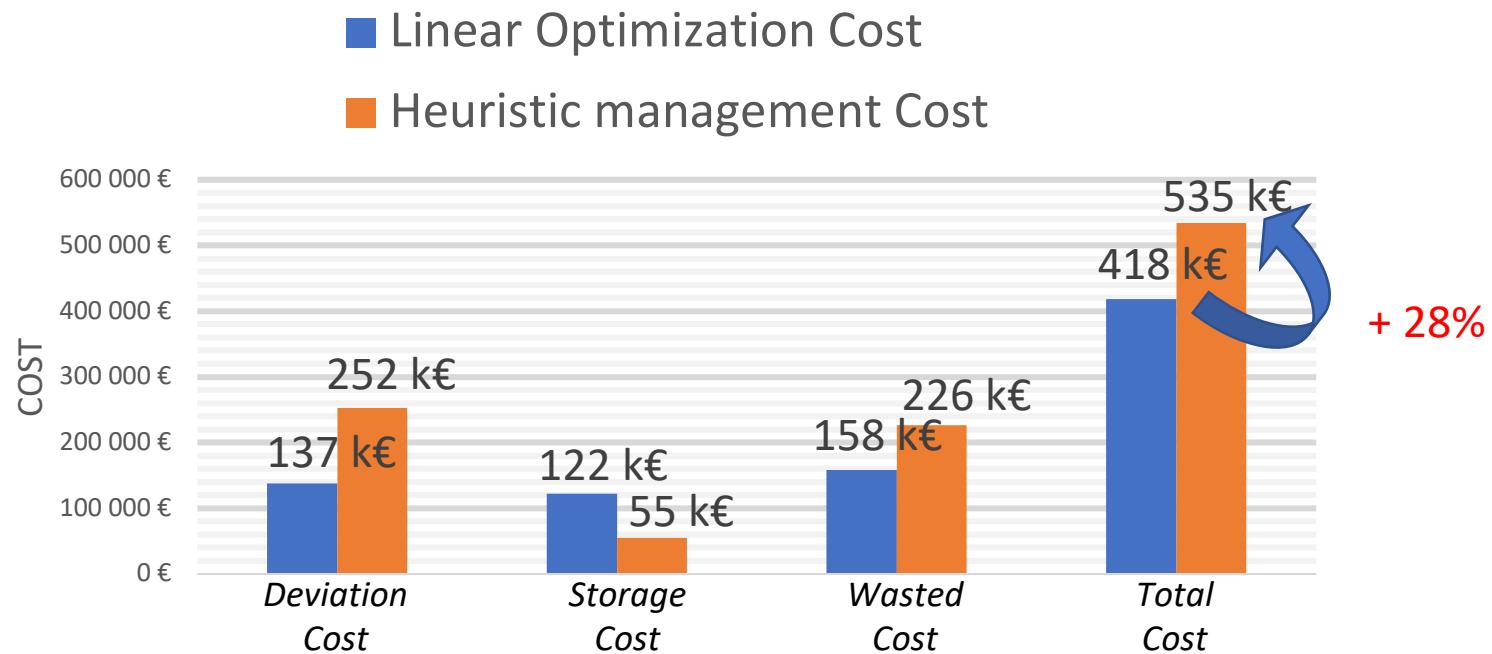
## II. 3 power management comparative analysis

:

- Heuristic strategy directly run on non linear model for 1 year
- Days optimized 1 by 1 on linear model then assembled for 1 year simulation on non linear model:



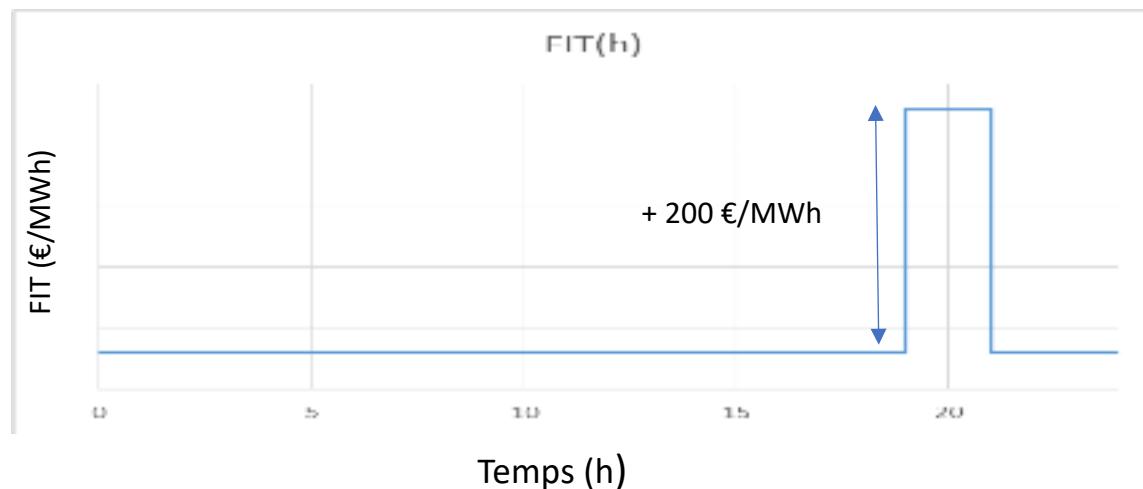
## II. 4 Comparative results between Heuristic and Optimization:



	Heuristic management	Linear optimization	Relative difference
Cost	534.6 k€	418.2 k€	27.83%
CF	8.32%	5.78%	2.87%

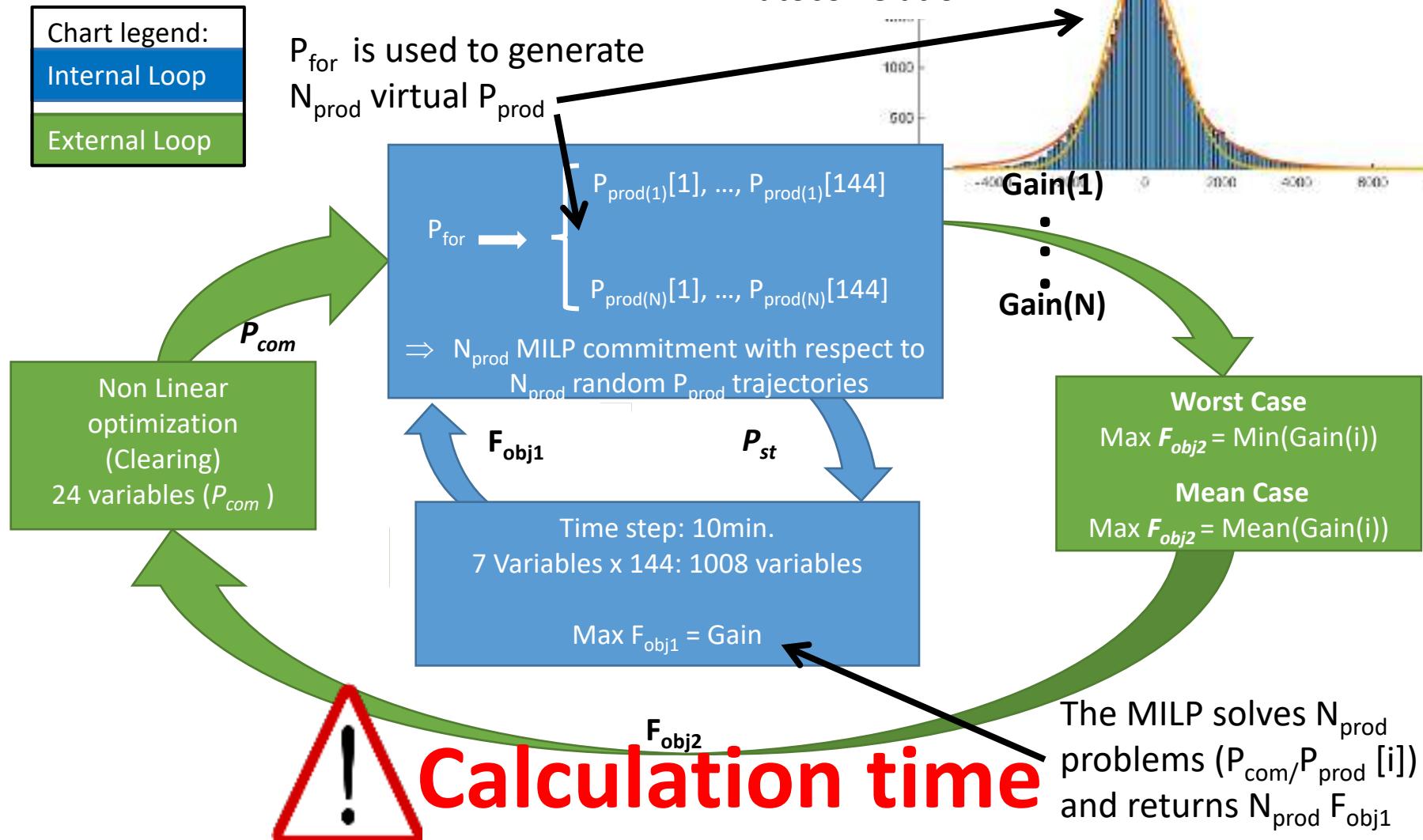
## III. 1 Robust optimization: problem formulation

- Problem setting: variable FIT during the day



- Double goal optimization: commitment respect and grid production => New variable  $P_{com}$
- Gain formulation instead of Cost
$$\text{Gain} = E_{grid} * (1-CF) * \text{FIT} - \text{Cost}_{lifelilon}$$
$$( \text{If FIT constant: } \text{Gain} = E_{prod} * \text{FIT} - \text{Cost}_{tot} )$$

## III. 2 Algorithm



### III. 3 Calculation time

- One MILP Loop (Generation, solving, processing)  
 $\approx 0.27\text{s}$
- External Loop need Niter to converge:
  - $N_{\text{iter}} = N_{\text{pop}} * N_{\text{gene}} + 2 * N_{\text{pop}}$
  - $N_{\text{gene}} = 200 ; N_{\text{pop}} = 100$   
 $\Rightarrow 20\ 200 \text{ iterations}$
- If  $N_{\text{prod}} = 15$ 
  - 303 000 MILP Loops  
 $\Rightarrow 81\ 810\text{s} \quad > 23\text{h for one day...}$

## III. 4 Questions

- Is N big enough?

The bigger the better  Calculation time

- How to evaluate the robustness of the optimization

Evaluate on the actual  $P_{prod}$  for 1 year?  Calculation time

Evaluate on the  $N_{prod}$  generations of  $P_{prod}$ ?

- How the absolute optimization ( $\Rightarrow$  not robust) of the MILP impact the global optimization (external loop?)
- Is the homologue function ( $Min(Gain(i))$  or  $Mean(Gain(i))$ ) a gage of robustness ?

9 Juillet 2018 – Université de Technologie de Compiègne, France

# Hierarchical control of a meshed DC microgrid

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This work is funded by the French Research Agency within the framework of the project ANR-15-CE05-004-02  $C^3\mu$  (Components, Control and Communication)



# Outline

- Introduction
- DC microgrid representation
- Modeling methodology
- Hierarchical optimization based control
- Undergoing work

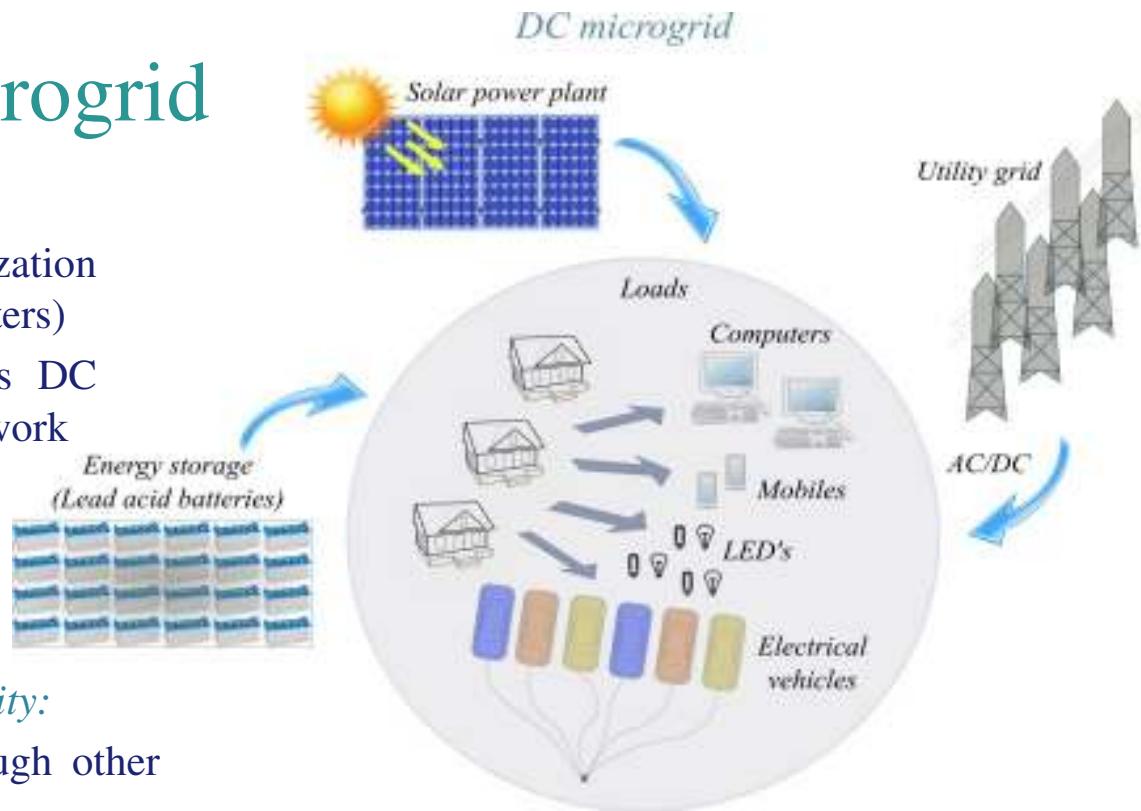
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# Meshed DC microgrid

*DC microgrids:*

- Higher efficiency and minimization of losses (reduction of converters)
- Easier integration of various DC DERs in the transmission network
- More efficient supply of DC loads



*Meshed topology provides reliability:*

- Power can be provided through other sources.
- Power flows through multiple paths among the nodes.

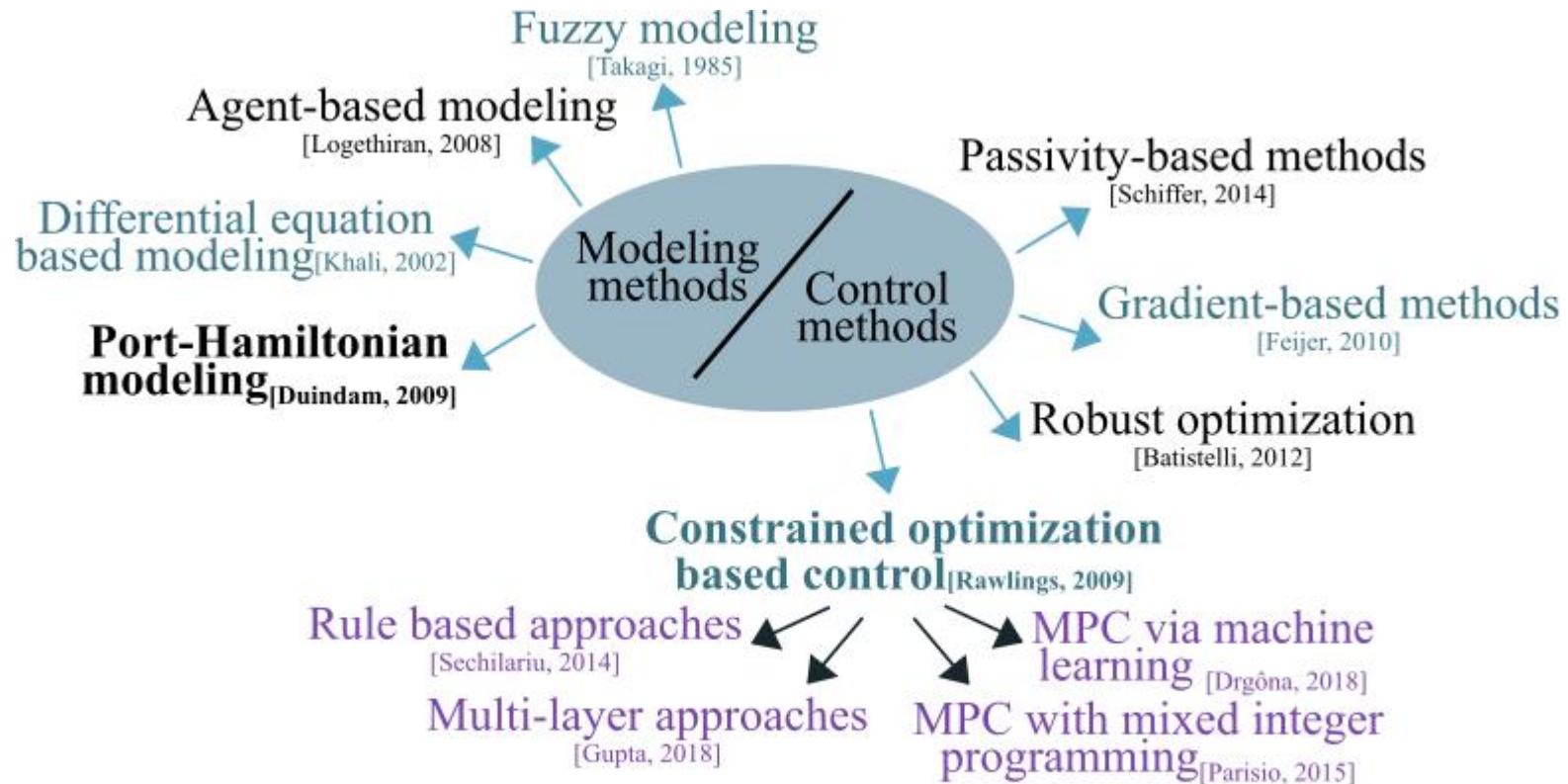
*A faulted line can be isolated:*

- power supply continuity
- power transmission efficiency

*Characteristics:*

- Strongly nonlinear systems
- Distributed in space
- Multiple timescales
- Variable profiles and costs
- Hard constraints

# Modeling and control methods



*Hierarchical control via flatness and MPC*

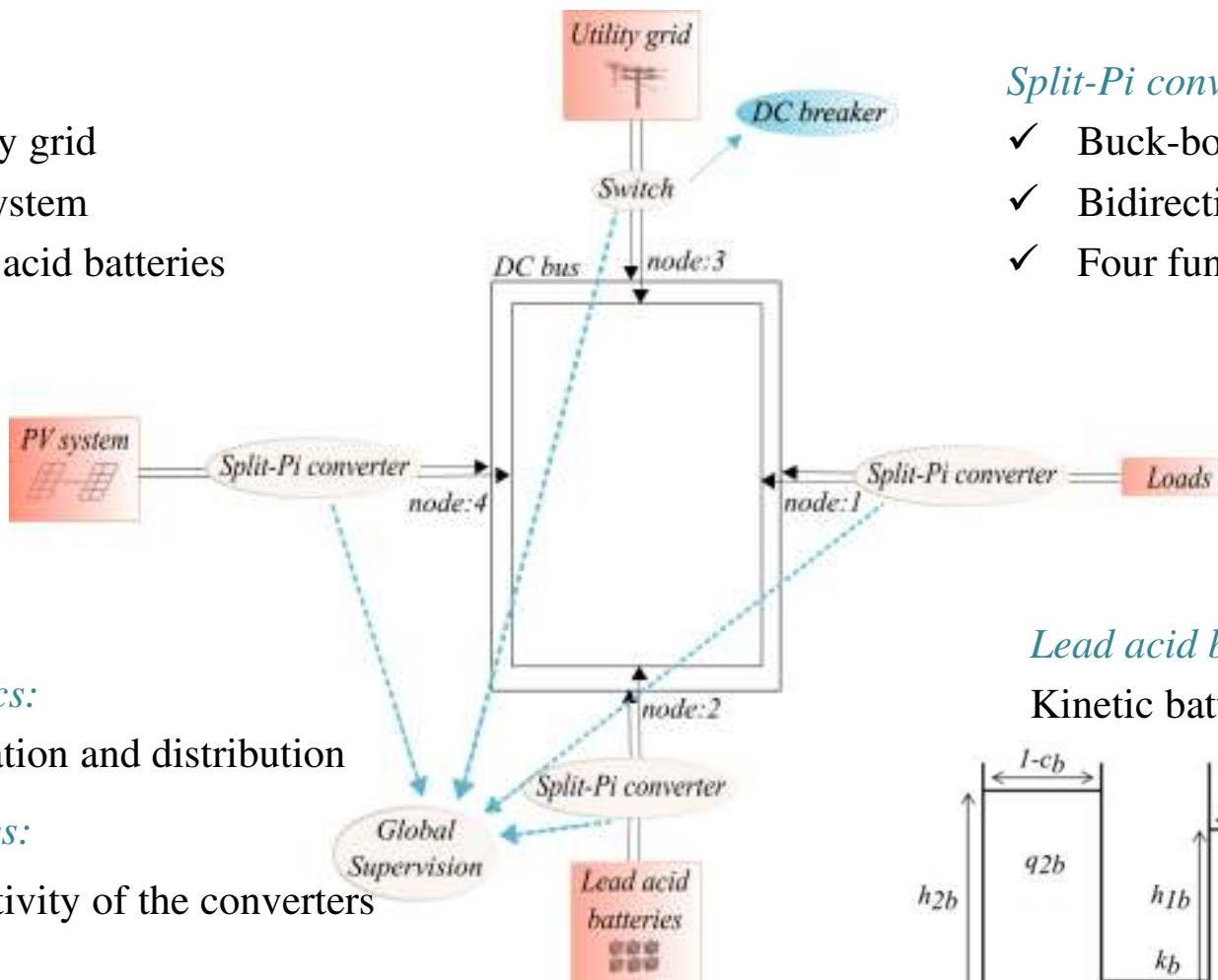
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# DC microgrid representation

## DERs:

- ✓ Utility grid
- ✓ PV system
- ✓ Lead acid batteries



## Slow dynamics:

Power generation and distribution

## Fast dynamics:

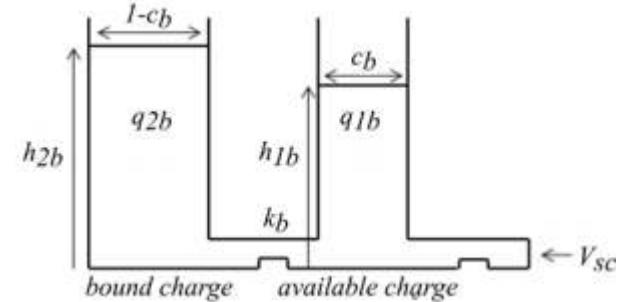
Switching activity of the converters

## Split-Pi converter:

- ✓ Buck-boost converter
- ✓ Bidirectional
- ✓ Four functions

## Lead acid batteries:

Kinetic battery model:

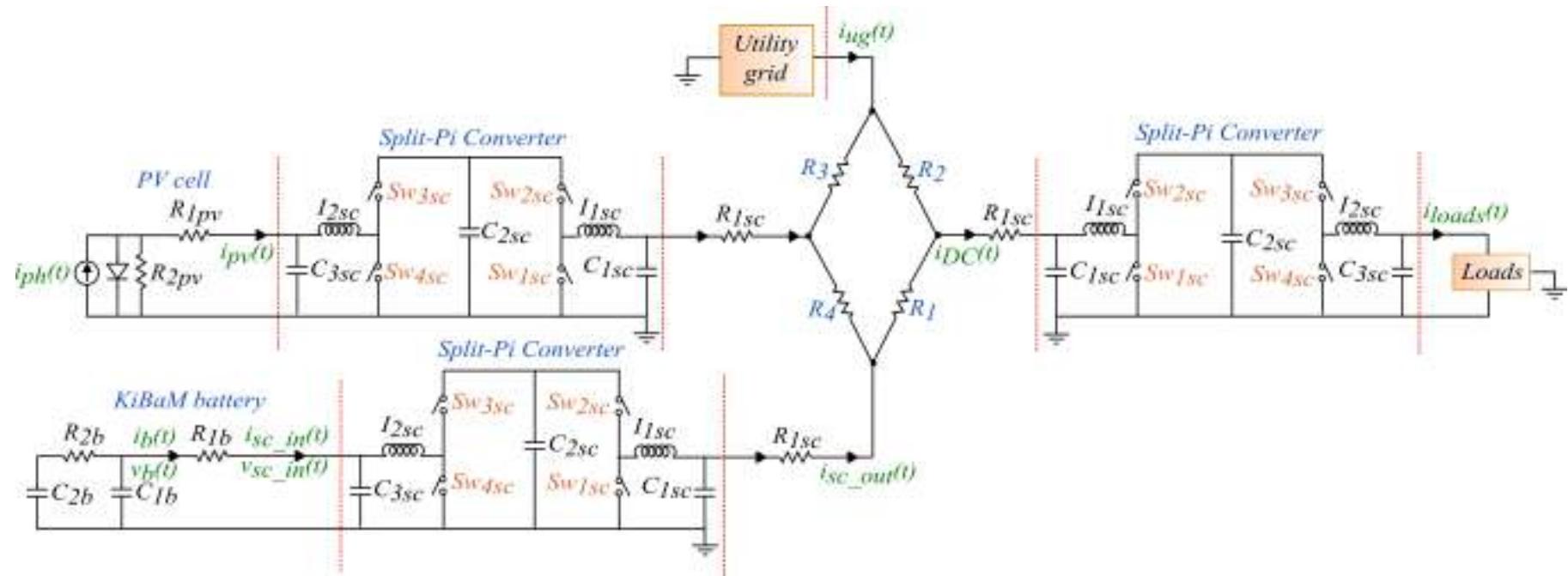


# Objectives

- Minimization of the electricity cost by optimizing the energy consumption.
- Minimization of the power losses within the transmission lines.
- Satisfaction of the consumers demand by forcing the use of the PV and the energy storage.
- Constraints satisfaction concerning the power, the current and the voltage.

# RLC circuit network

The meshed DC microgrid system will be globally represented as an RLC electrical circuit for proceeding to the modeling part.

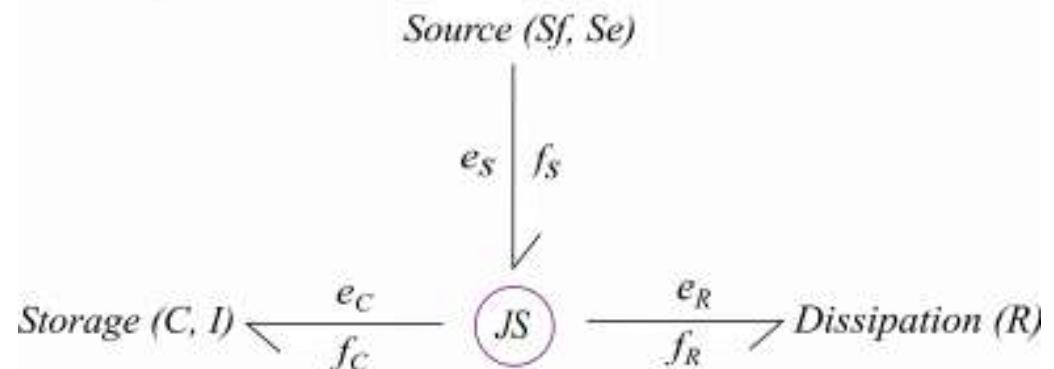


# Outline

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# DC microgrid modeling

- Bond Graph [Schiffer, 2014]



- Port-Hamiltonian formulation

$$\dot{x} = [J - R]Qx - Gu$$

$$y = G^T Qx + Du$$

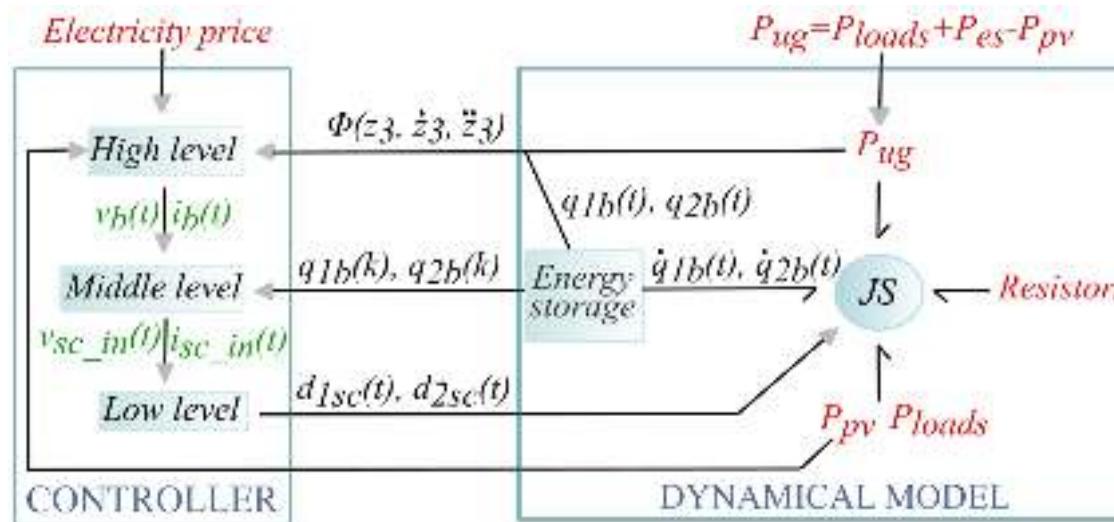
*Main advantage:*

The power exchange, the dissipation and the energy storage are given explicitly.

# Outline

- Introduction
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# Hierarchical optimization based control



- *Dynamical models:*
  - PV cell
  - Lead acid batteries (KiBaM)
  - Split-Pi converter
- *Reference profiles:*
  - External temperature and solar irradiation
  - Users demand
  - Electricity price
- *Control variables within the DC microgrid:*
  - Duty cycles of the Split-Pi converters
  - Power on the nodes of the central transmission network

# High level control

- Goal
  - Generate optimal profiles related to the battery charges and discharges while minimizing the electricity purchase from the utility grid.
- Method
  - Flatness representation of the battery's model [Fliess, 1955] :
    - Generation of optimal profiles

Flat outputs of the system Split-Pi/Battery:

$$\begin{aligned}z_1(t) &= \frac{1}{I_{1sc}} \frac{p_{1sc}(t)^2}{2} + \frac{1}{I_{2sc}} \frac{p_{2sc}(t)^2}{2} + \frac{1}{C_{2sc}} \frac{q_{2sc}(t)^2}{2} \\z_2(t) &= q_{3sc}(t) + q_{1b}(t) \\z_3(t) &= q_{2b}(t) \\z_4(t) &= q_{2sc}(t)\end{aligned}$$

# High level control

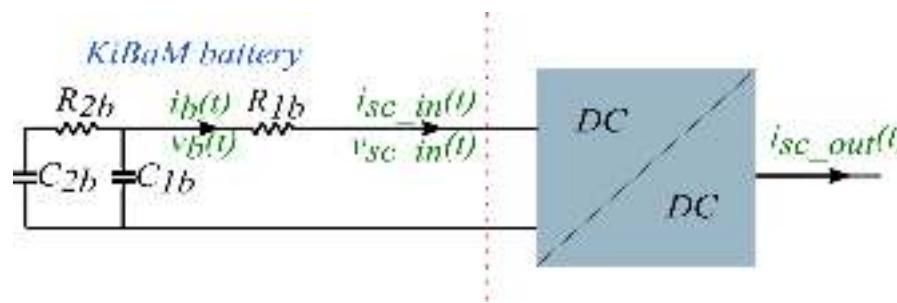
- Flat representation of the battery:

We consider the current and the voltage of the battery in function of the flat outputs and their derivatives

$$i_b(t) = C_{1b}R_{2b}\ddot{z}_3(t) + \left(\frac{C_{1b}}{C_{2b}} + 1\right)\dot{z}_3(t)$$

$$v_b(t) = R_{2b}\dot{z}_3(t) + \frac{1}{C_{2b}}z_3(t)$$

- B-splines parametrization [Stoican, 2017] for calculating the flat output derivatives.



# High level control

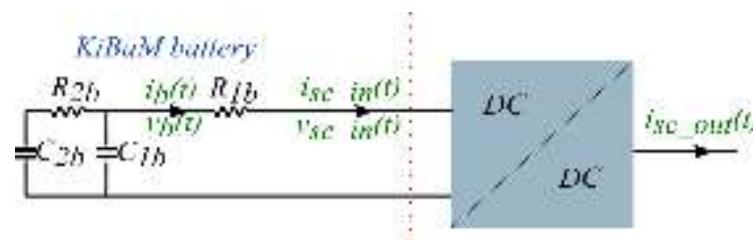
- Obtain optimal reference trajectories by minimizing the cost function:

$$\begin{aligned}\mathcal{J}_h &= \int_{t_0}^{t_f} e(t)(P_{es}(t) + P_{loads}(t) - P_{pv}(t))dt = \\ &= \int_{t_0}^{t_f} e(t)(i_b(t)v_b(t) + P_{loads}(t) - P_{pv}(t))dt,\end{aligned}$$

where  $P_{es}(t) + P_{loads}(t) - P_{pv}(t) = P_{ug}$

## Constraints:

$$\begin{aligned}12.1V &\leq v_b(t) \leq 12.9V \\ -14.5A &\leq i_b(t) \leq 19.5A \\ 72.6Ah &\leq q_{2b}(t) \leq 77.4Ah \\ -2000W &\leq P_{ug}(t) \leq 4100W\end{aligned}$$

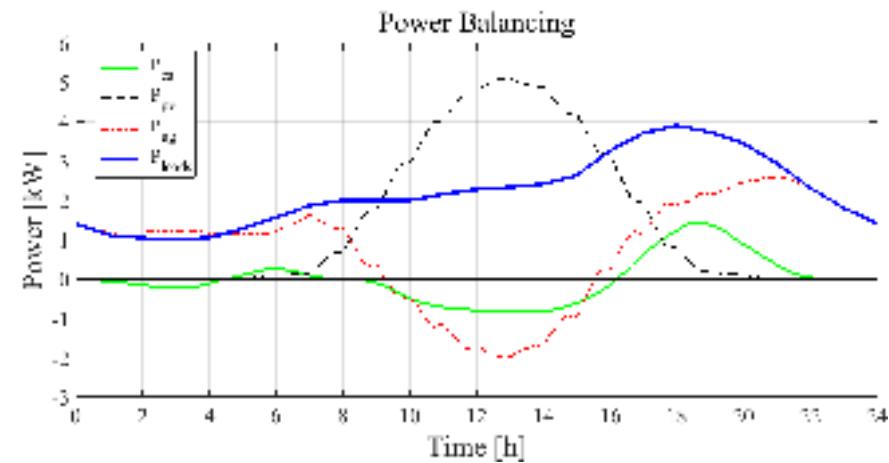
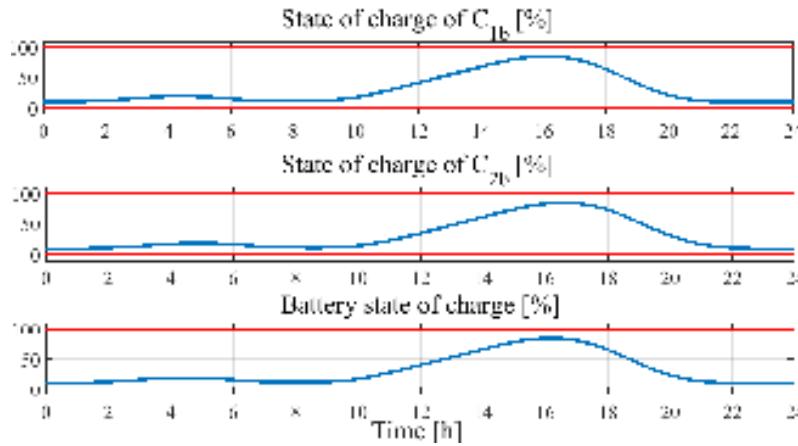


# Simulation results

The flat output  $z(t)$  is projected over  $N$  B-splines of order  $d$  :  $z(t) = \sum_{i=1}^N p_i \cdot b_{i,d}(t) = \mathcal{PB}_d(t)$

$N$	20	25	30	35	40
$d$	4	4	4	4	4
Electricity cost [euros]	2.514	2.427	2.448	2.396	2.125
Calculation time [s]	134	197	309	444	535
Number of charge/discharge	4	6	5	9	11

The cost with using the battery is equal to 2.818 euros.



# Middle level control

- Goal
  - Solve a tracking reference problem according to the reference trajectories obtained in the high level for the voltage and the current.

Reference profile of the Split-Pi output voltage:

$$v_{sc\_in}^{ref}(t) = v_b^{ref}(t) + i_b^{ref}(t)R_{1b}$$

- Method
    - Discrete-Time Model Predictive Control (MPC)
- Constraints:
- $$12V \leq v_b(t) \leq 13V$$
- $$-15A \leq i_b(t) \leq 20A$$
- $$72Ah \leq q_{2b}(t) \leq 78Ah$$
- $$-2100W \leq P_{ug}(t) \leq 4200W$$

Optimization problem over a receding prediction horizon  $N_p$ :

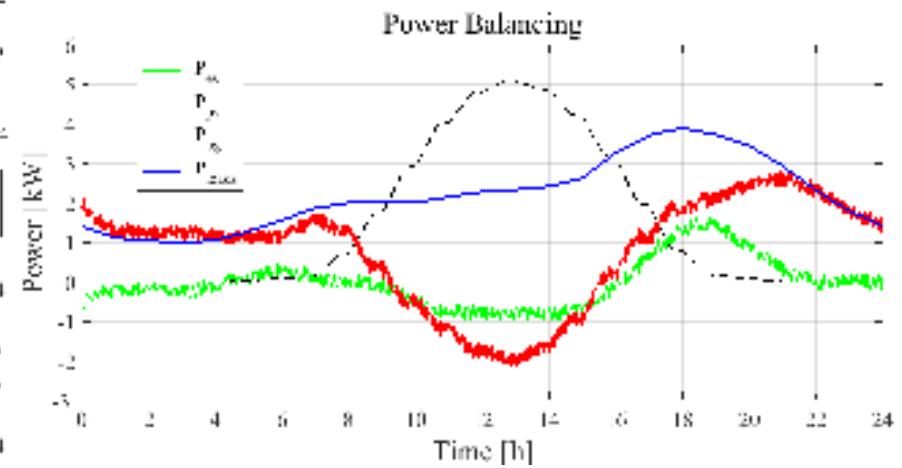
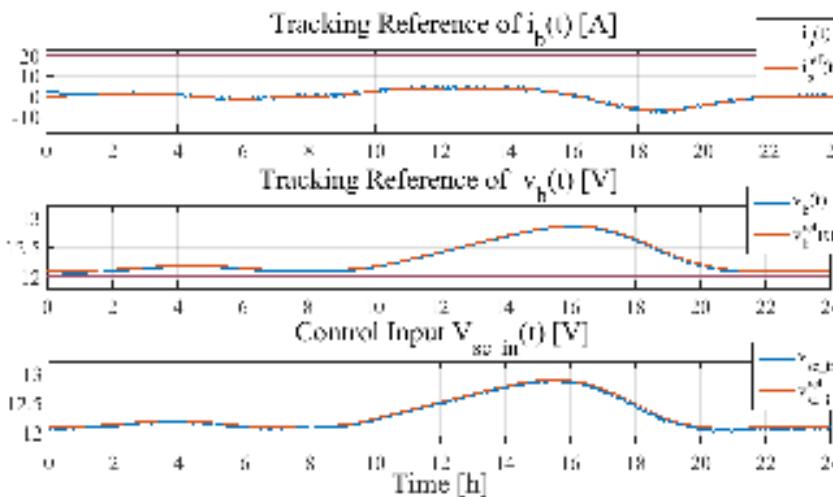
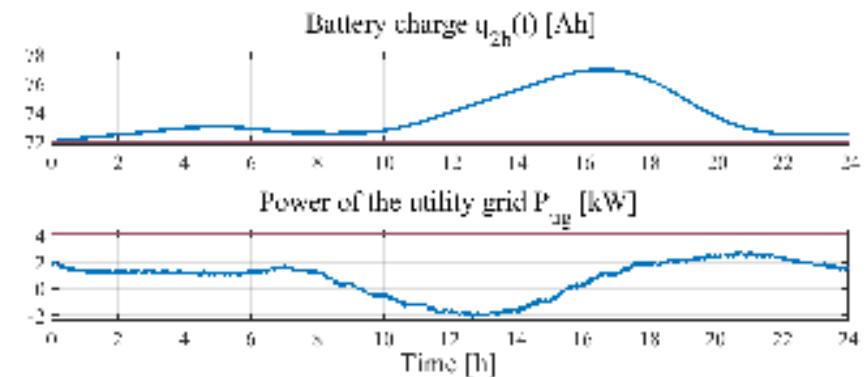
$$\min_{\tilde{u}(k)} \sum_{i=k}^{k+N_p-1} (\tilde{y}(i) - \tilde{y}^{ref}(i))^T Q_{\tilde{y}} (\tilde{y}(i) - \tilde{y}^{ref}(i)) + (\tilde{u}(i) - \tilde{u}^{ref}(i))^T R_{\tilde{u}} (\tilde{u}(i) - \tilde{u}^{ref}(i))$$

# Simulation results

## Solver

- IPOPT with YALMIP + MATLAB

$N_p$	10
$T_s$	60 [s]
$Q_y$	$diag(1, 1)$
$R_u$	800

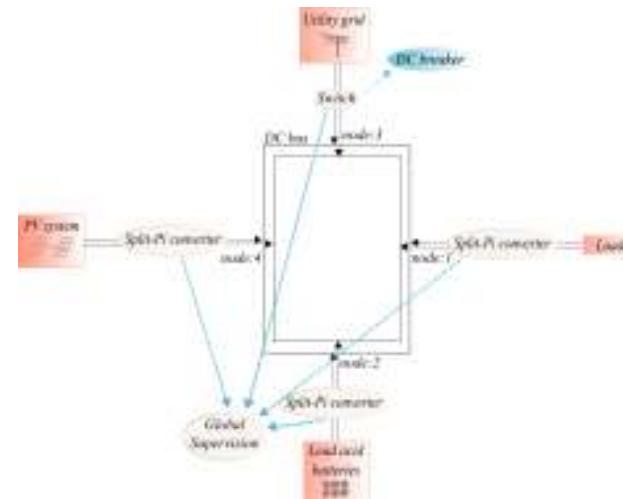


# Outline

- Introduction
- DC microgrid representation
- Modeling methodology
- Hierarchical optimization based control
- Undergoing work

# Undergoing work

- Low level control problem formulation
- Consider the power losses
- Fault mitigation and reconfiguration
- Theory combination of differential flatness, Bond Graph and port-Hamiltonian formalism



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*Thank you!*



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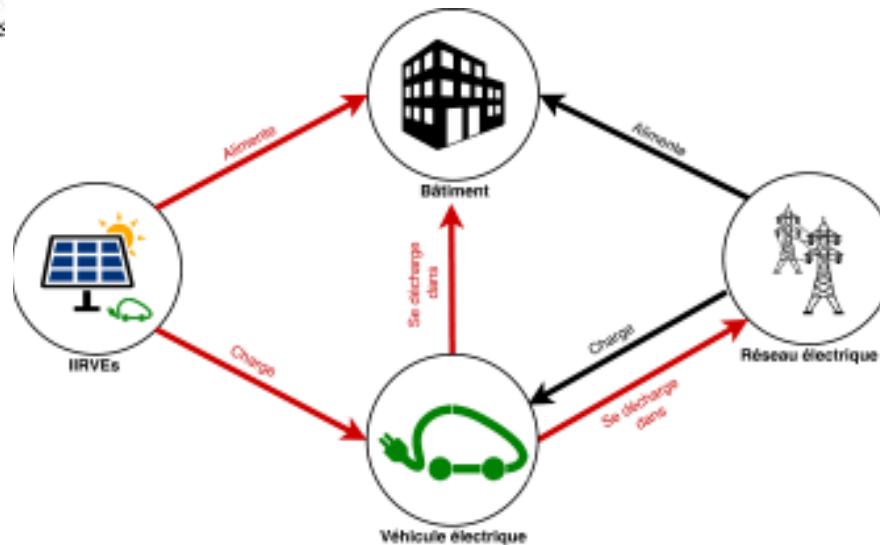
# SOCIAL ACCEPTABILITY OF MICROGRIDS DEDICATED TO ELECTRIC VEHICLE CHARGING STATIONS

***M. Sechilariu<sup>1</sup>, F. Locment<sup>1</sup>, N. Darene<sup>2</sup>***

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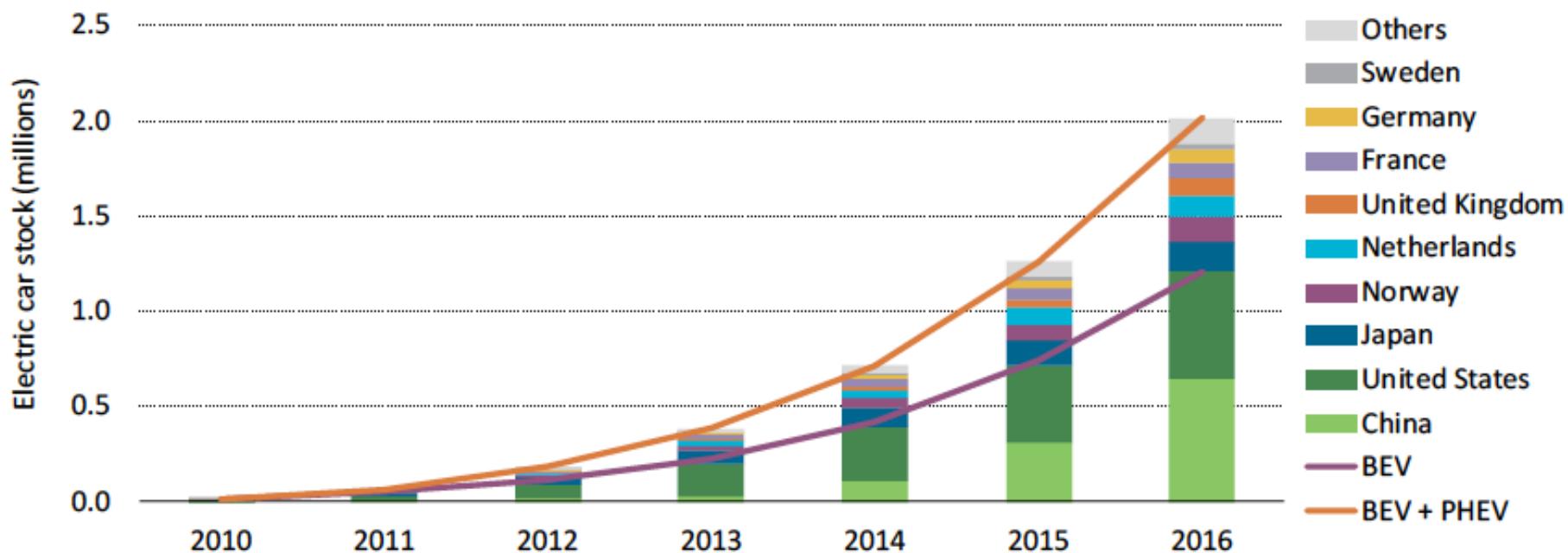


# PLAN DE L'EXPOSE

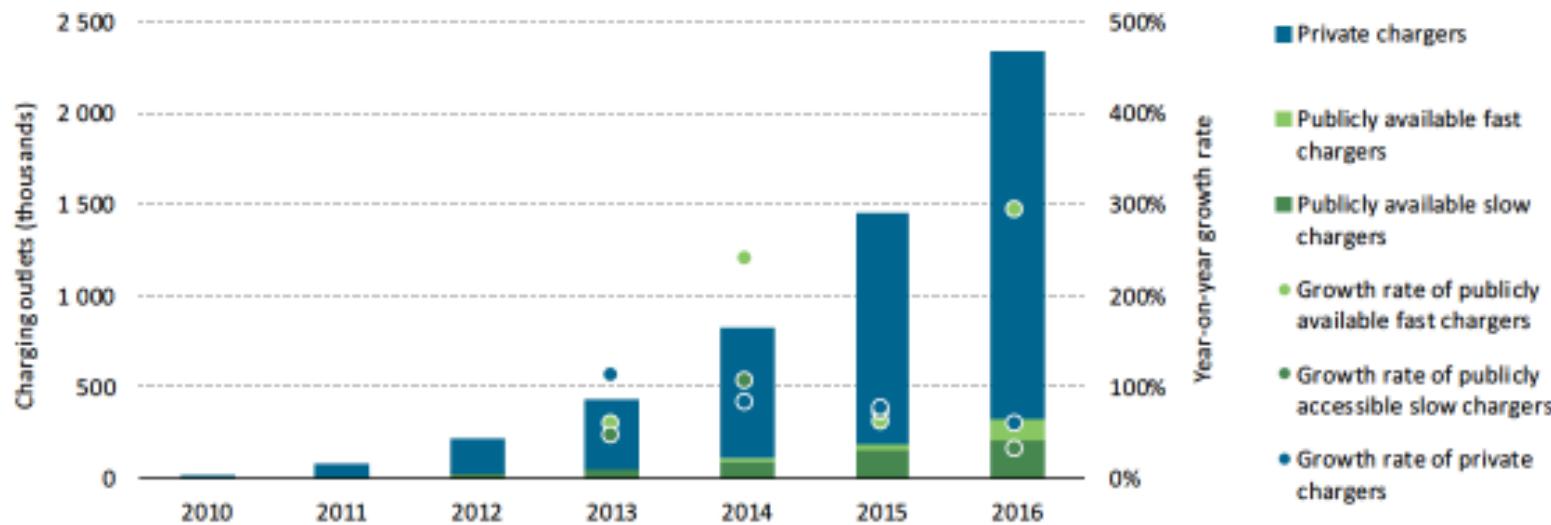
1. Contexte du projet Infrastructure Intelligente pour la Recharges des Véhicules Électriques (IIRVEs)
2. IIRVEs alimenté et piloté par un micro-réseau
3. Étude d'acceptabilité sociale
  - 3.1. Approche marketing et sociétale
  - 3.2. Etude qualitative
  - 3.3. Etude quantitative
4. Plan d'actions pour le projet IIRVEs
5. Conclusion

# 1. Contexte du projet IIRVEs

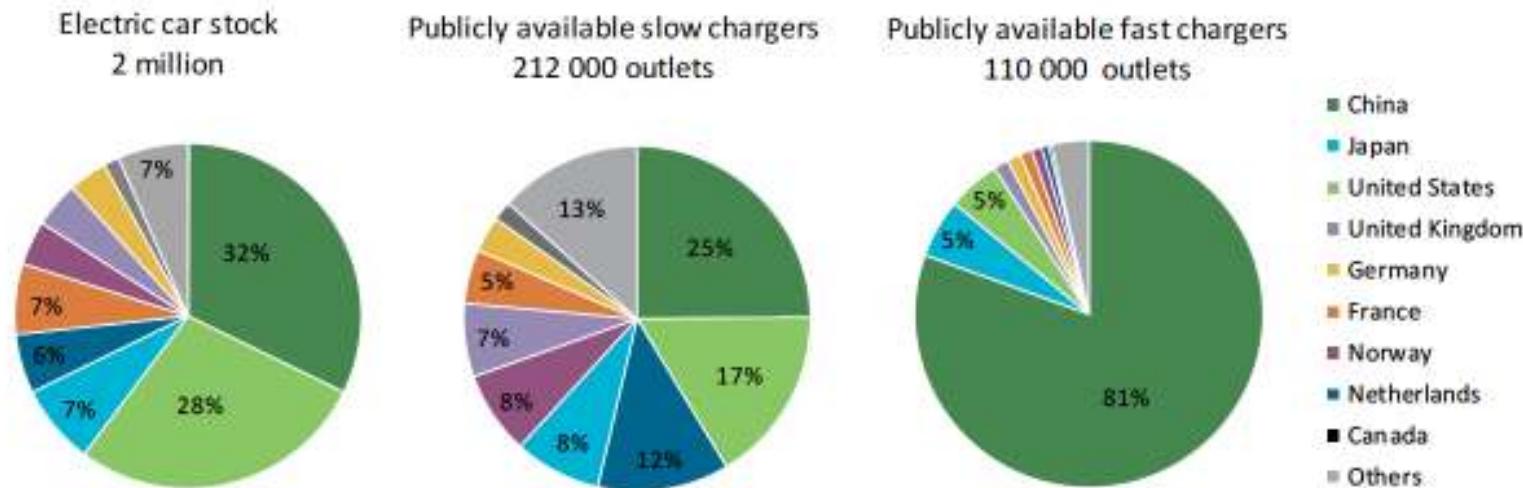
- Électromobilité et véhicules électriques
- Croissance du stock des VEs (BEV et PHE)



# 1. Contexte du projet IIRVEs

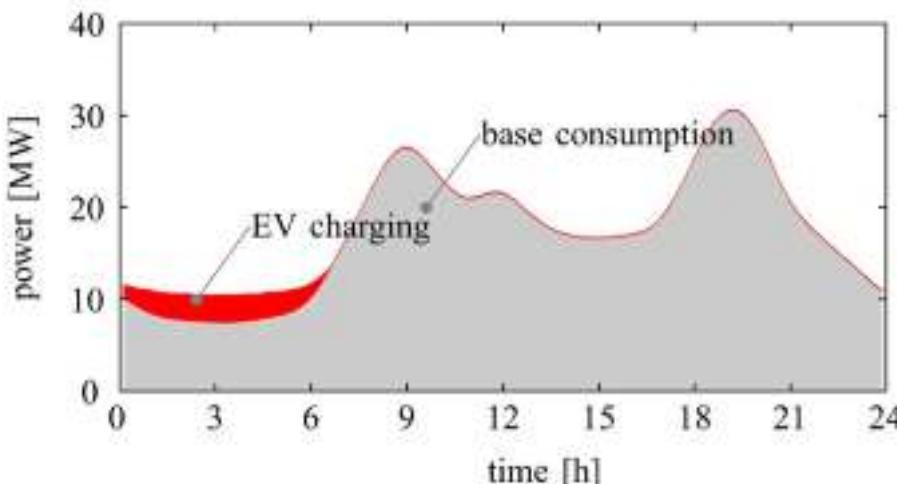
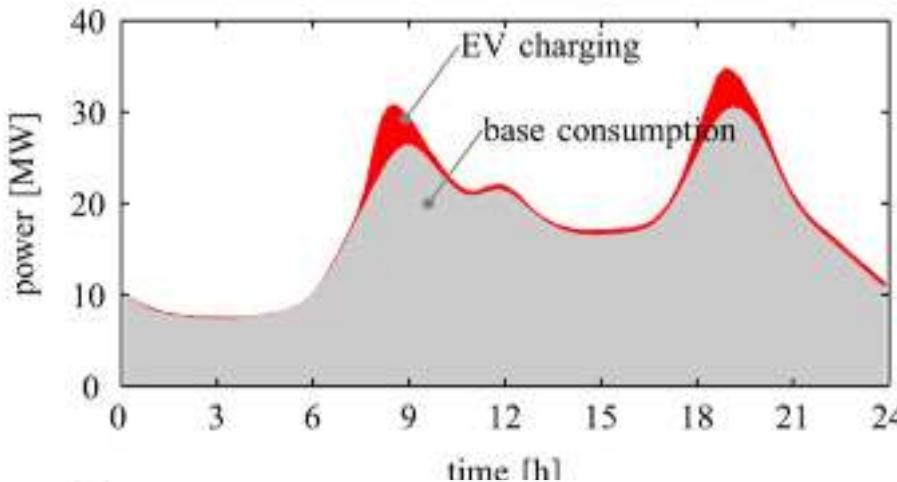


Source : International Energy Agency



# 1. Contexte du projet IIRVEs

- Consommation d'électricité et pointe de puissance électrique



Source : E. Sortomme, M. a. El-Sharkawi. "Optimal scheduling of vehicle-to-grid energy and ancillary services". IEEE Transactions on Smart Grid, 3(1), 351–359. 2012.

# 1. Contexte du projet IIRVEs

## PROJET MOBEL\_CITY



- Micro-réseau intelligent, implantation urbaine et régulation locale pour la mobilité électrique en ville



- Partenaires



**SYSTRA**

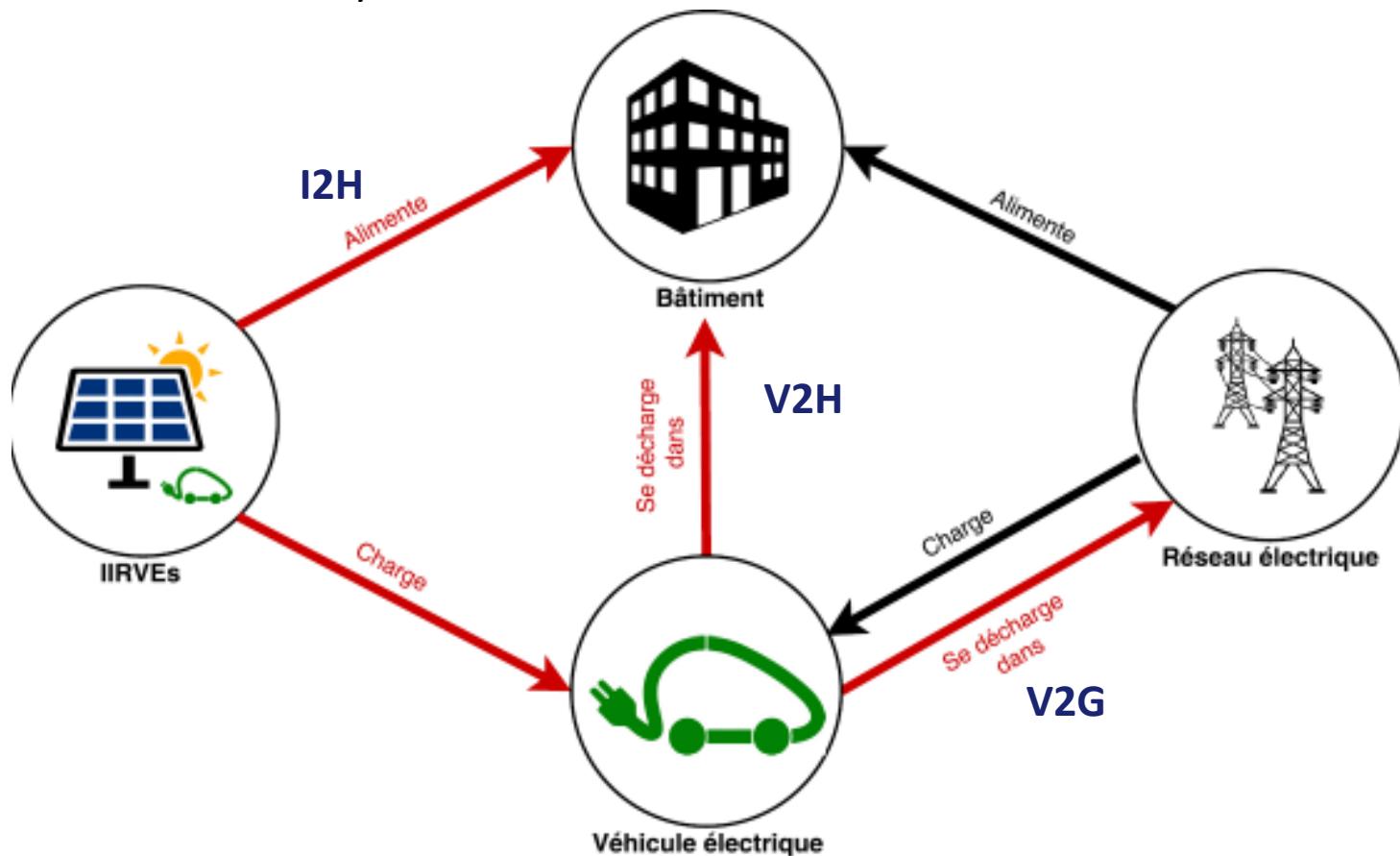
- Labellisations



- Projet interdisciplinaire
  - énergie-micro-réseau, mobilité, transport, urbanisme
- Forte dimension sociétale

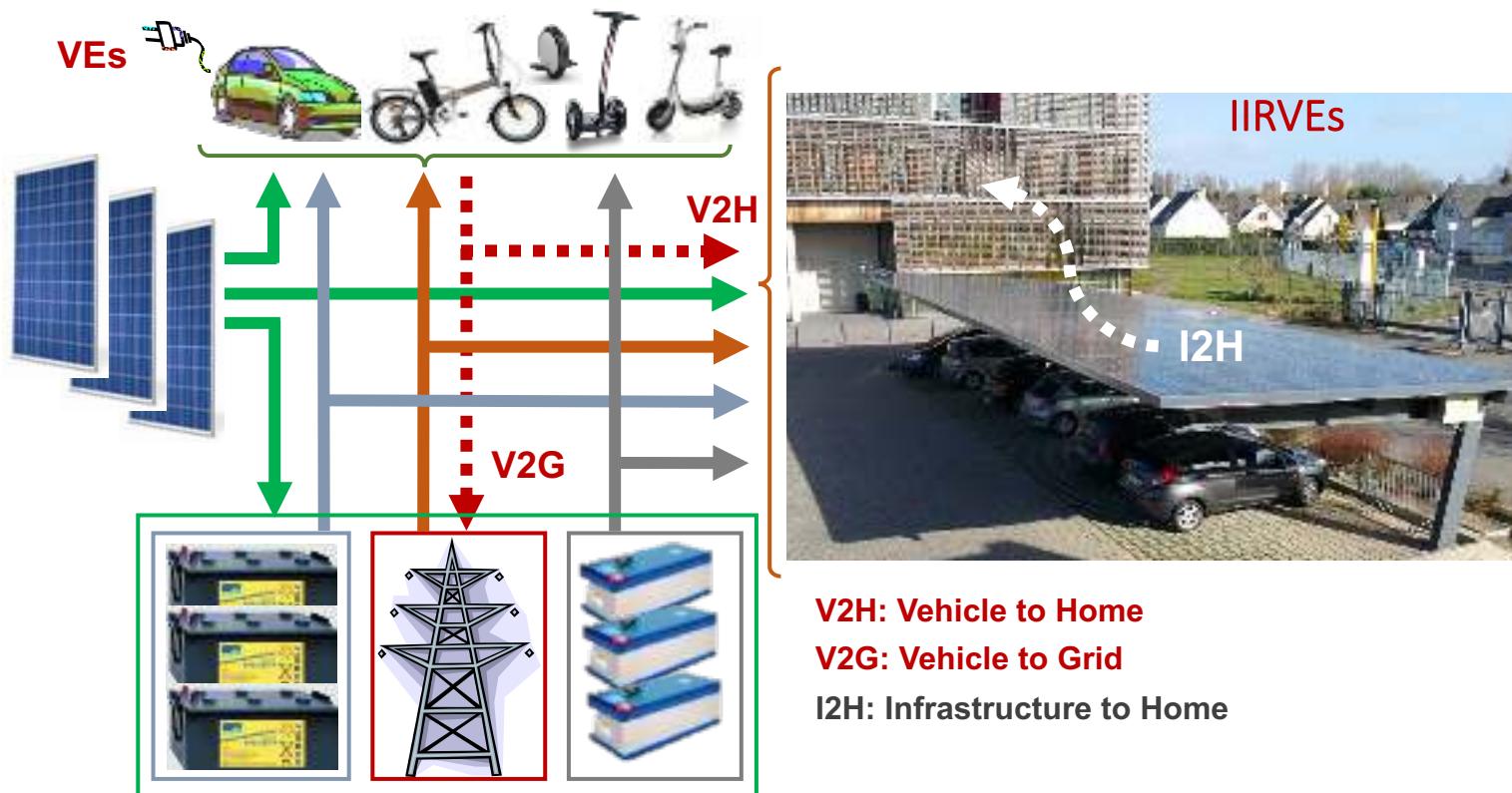
## 2. IIRVEs alimenté et piloté par un micro-réseau

- Système énergétique innovant et son implantation dans un espace urbain
  - une IIRVEs (infrastructure intelligente dédiée à la recharge des VEs)
  - une flotte hétérogène de véhicules électriques (VEs)
  - un bâtiment ayant une connexion à l'IIRVEs



## 2. IIRVEs alimenté et piloté par un micro-réseau

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# 3. Étude d'acceptabilité sociale

- **Méthodologie**

Travail interdisciplinaire SPI et SHS

Approche marketing et sociétale

Étude qualitative

Étude quantitative

# 3. Étude d'acceptabilité sociale

## 3.1. Approche marketing et sociétale

- Typologie de l'innovation des IIREVs
  - Innovation incrémentale : recharge par énergie renouvelable (ombrières PV déjà existantes)
  - Innovation de rupture : stratégies V2G / V2H
- Système impliquant multiple acteurs
  - Relations entre les acteurs
  - Notion de services, besoin de *Business Model*
- Existence d'un consommateur triple
  - Utilisateur VE (charge-décharge)
  - Maître d'ouvrage (bâtiment) (V2H, I2H)
  - Opérateur du réseau public (charge, V2G)

# 3. Étude d'acceptabilité sociale

## 3.2. Étude qualitative

- *Objectif* : questionnaire ouvert dont les résultats aident à la rédaction du questionnaire quantitatif
- 67 réponses avec un échantillon représentatif
- Attentes de la population par rapport aux bornes de recharge  
Rapidité, bien localisées, accessibles, bien intégrées dans l'environnement urbain
- Quelques incertitudes sur le projet, son utilité et son efficacité
  - Incompréhension sur le principe de décharge-recharge (V2G, V2H)
  - Incompréhension du *Business Model* (V2G)
  - Inquiétude sur le niveau de batterie restant après la décharge (V2G, V2H)
- Favorables à la recharge par une source d'énergie renouvelable malgré des incertitudes sur l'intermittence, le rendement, le cycle de vie et la pollution
- Réserves sur l'emplacement des ombrières dans la ville

# 3. Étude d'acceptabilité sociale

## 3.3. Étude quantitative

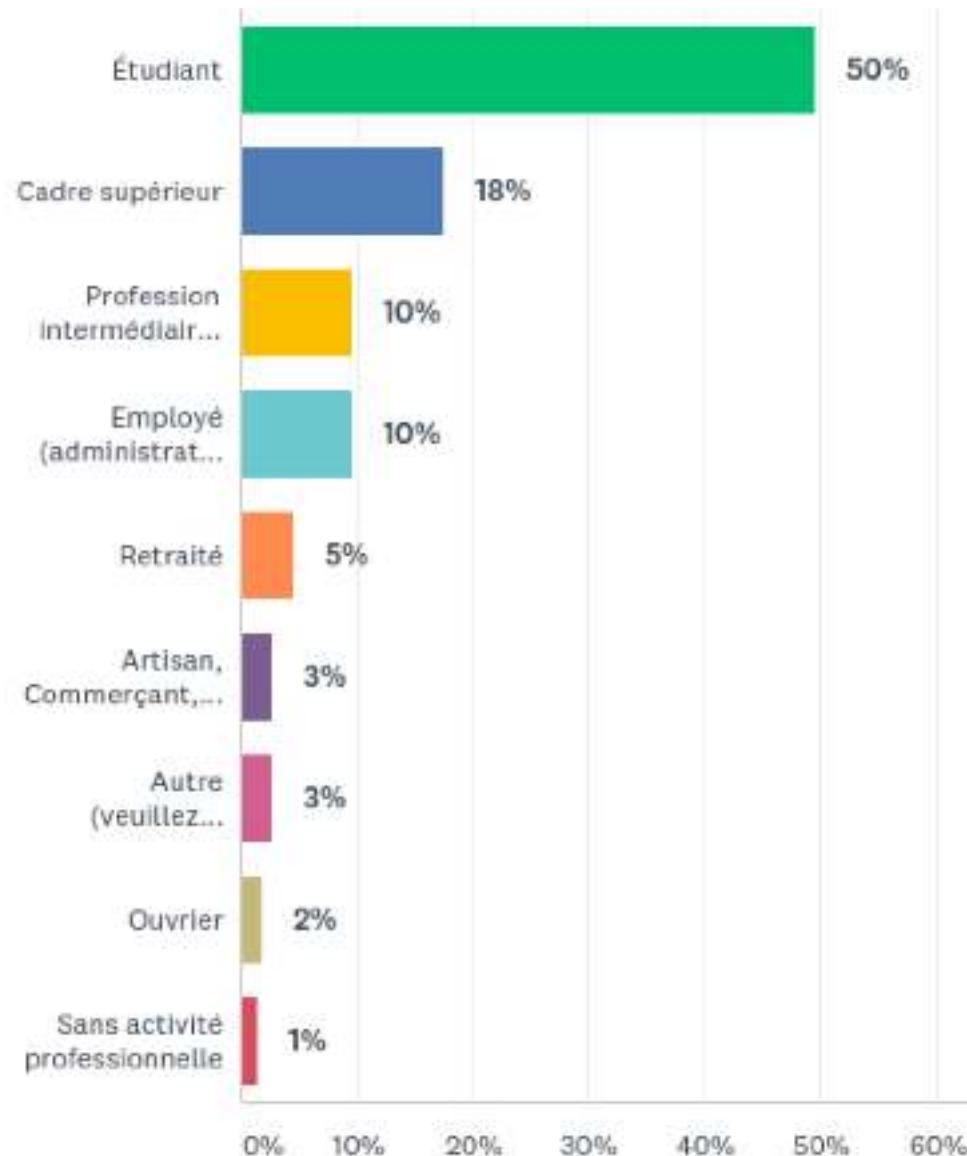
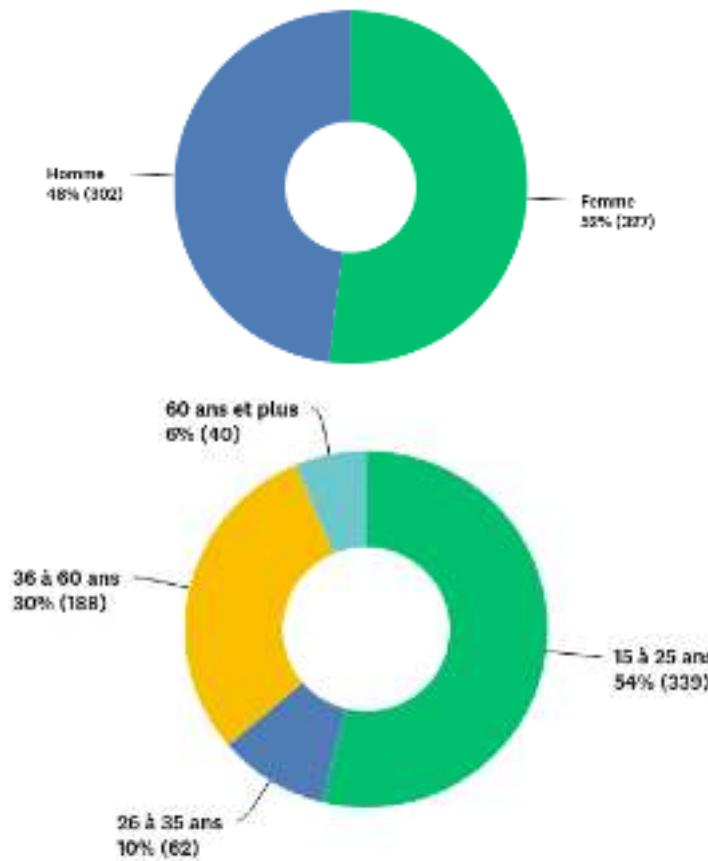
- Questionnaire rédigé sur la base de
  - Approche marketing
  - Étude qualitative
- Questionnaire à choix multiples : 33 questions
  - Profil de l'usager
  - Borne de recharge et système de décharge-recharge
  - Recharge par PV et ombrières
- 629 réponses : vision positive du projet avec quelques doutes



# 3. Étude d'acceptabilité sociale

## 3.3. Étude quantitative

- Profil de l'usager



# 3. Étude d'acceptabilité sociale

## 3.3. Étude quantitative

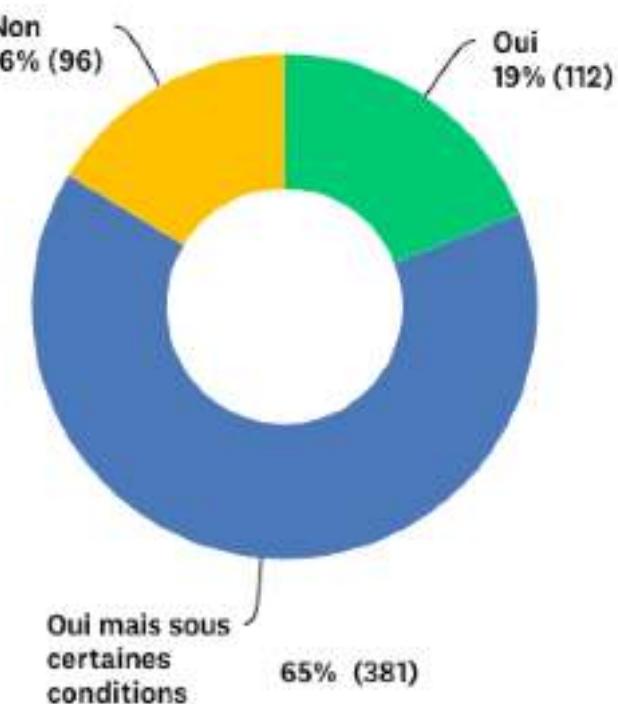
- Borne de recharge et système de décharge-recharge

→ 5 thématiques

- Caractéristiques et implantation
- Tendance générale à l'acceptabilité
- Modalités de la décharge-recharge
- Intention lucrative
- Destination de l'énergie



Acceptabilité de la décharge partielle de la batterie :



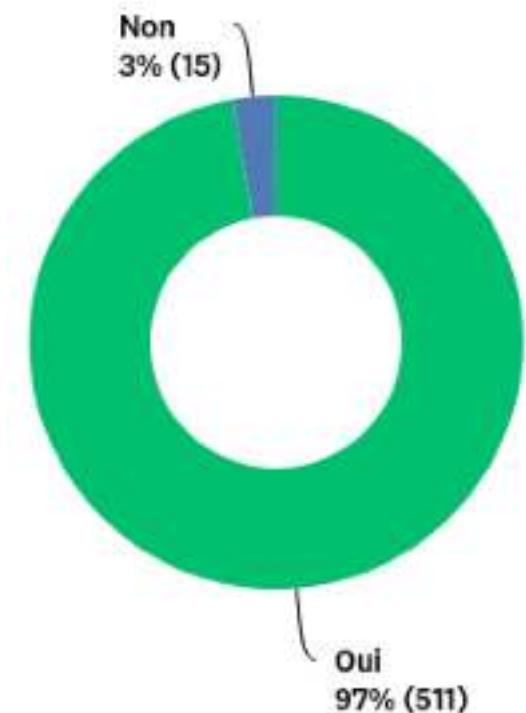
# 3. Étude d'acceptabilité sociale

## 3.3. Étude quantitative

- Recharge par PV et ombrières

*Acceptabilité de la recharge par PV et ombrères :*

- 97% des sondés ont répondu qu'ils ne considéraient pas l'ombrière PV comme un frein au projet
- MAIS 54% des sondés sont réellement indifférents au lieu d'implantation de l'ombrière PV
- 58% des sondés seraient plus favorables à l'implantation des ombrières PV s'ils sont consultés



# 3. Étude d'acceptabilité sociale

## 3.3. Étude quantitative

- Tendances globale : **FAVORABLE**

- Recharge par panneaux photovoltaïques : 97%
- Ombrières : 96%
- Décharge-recharge : 84%
  - dont 64% sous certaines **CONDITIONS**



## 4. Plan d'actions pour le projet IIRVEs

- Améliorer l'acceptation du projet

### *Borne de recharge*

- Appréhension sur la mise en place du système décharge-recharge
- Suivi en temps réel et à distance l'autonomie de la batterie
- Transparence des informations de décharge-recharge
- Facilité d'utilisation et d'une liberté d'interaction avec la borne

### *Panneaux photovoltaïques (PV)*

- Communication sur les améliorations du rendement des PV
- Communication sur les efforts effectués pour minimiser la pollution engendrée par leur production et leur recyclage
- Consultation de la population locale pour la mise en place d'ombrières PV

## 5. Conclusion

- Micro-réseau intelligent, implantation urbaine et régulation locale pour la mobilité électrique en ville
  - Électromobilité
  - Système énergétique innovant
  - Interdisciplinarité
- Transition énergétique
- Transition numérique
- Transition environnementale
- Dimension sociétale
- L'humain au centre des préoccupations et des études

# Merci pour votre attention !

- Questions, remarques, commentaires ??



**GT  
Micro-réseaux  
JSN - 2018**

Systèmes d'Énergie Électrique dans leurs Dimensions Sociétales  
GDR 2994