26 Avril 2018

# GESTION ÉNERGÉTIQUE DES SYSTÈMES HYBRIDES A ÉNERGIES RENOUVELABLES.

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

# Programme

- **Contexte : - Transition énergétique et intégration des ENR**

  **- Evolution du mix énergétique : systèmes multi-sources**

- **Problématique :** *Gestion énergétique des systèmes hybrides A énergies renouvelables*

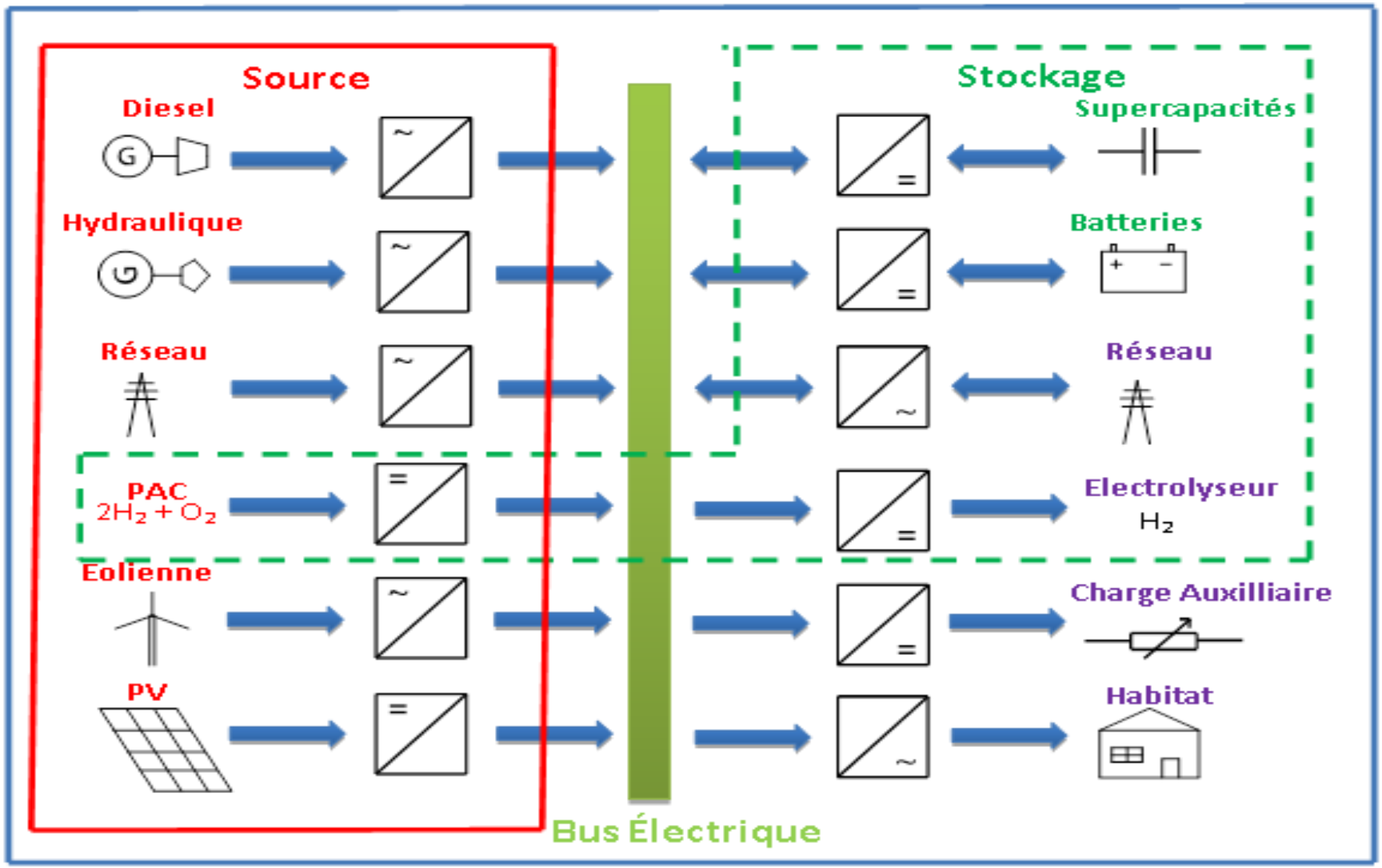
- **Objectifs de cette première partie (3 heures) :**

  - Comprende le principe et les types de supervision énergétique
  - Supervision des systems hybrides autonomes (instllations domestiques)
  - Supervision des systems hybrides connectés au réseau ou micro-réseaux.

# Plan

- Introduction
- Principe et méthodes de supervision énergétique
- Supervision des systems hybrides autonomes (instllations domestiques)
  - Commande en tension
  - Commande en courant
- Supervision des systèmess hybrides connectés au réseau ou micro-réseaux
  - Etude de cas
- Vers des gestions plus intelligentes

# Introduction




**Comment gérer toutes ces sources d'énergie ?**

# Principe et méthodes de supervision énergétique

## ❖ Principe général:

La balance énergétique : assurer à chaque instant l'égalité entre la puissance des sources et la puissance de la charge

## ❖ Méthodes de supervision énergétique :

- Commande tout ou rien : Commande en tension ou en courant

- L'inversion du bilan de puissance (GIC) : Cette méthode consiste à modéliser l'ensemble multisources à l'aide d'un bilan de puissance et de déterminer les puissances de références à l'aide d'une inversion de ce bilan de puissance. Ce type de supervision a l'avantage d'être simple, cependant elle ne prend pas en compte la notion d'énergie.

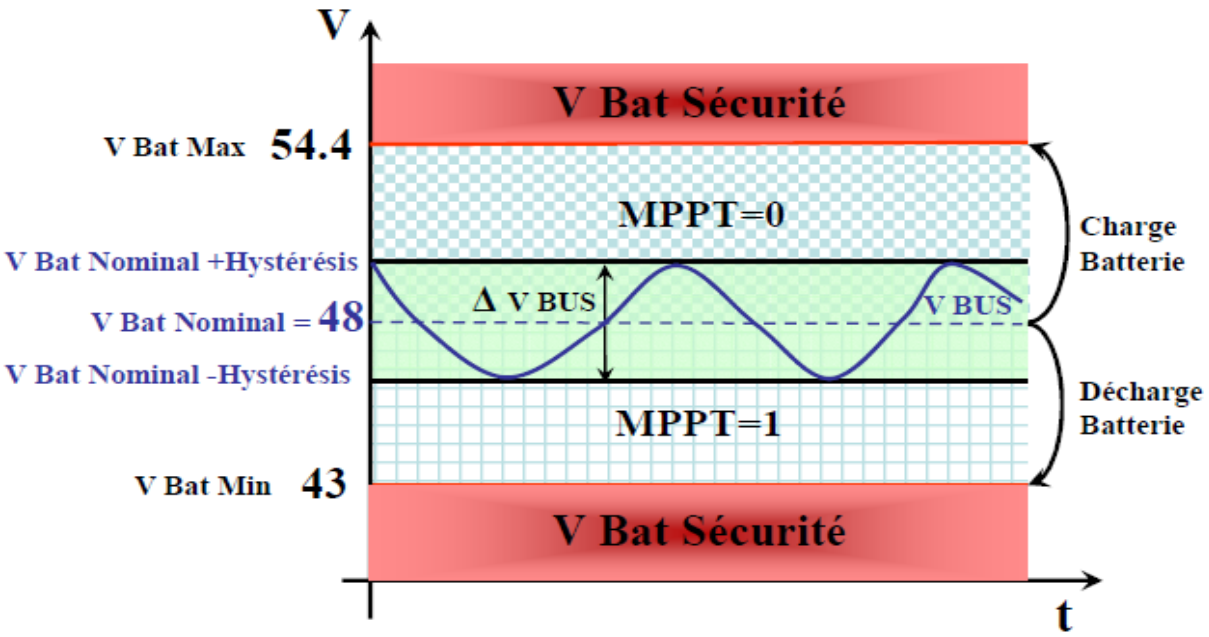
- Algorithme d'optimisation : Prédéterminer (de manière prédictive) la chronique de puissance à envoyer au stockage permettant de garantir la satisfaction de la demande et la bonne exploitation des sources renouvelables (gestion des excès et du déficit des énergies). Difficile à mettre en œuvre en temps réel.

- Intelligence artificielle : systèmes multi-agent ou logique floue. Bien adapté aux systèmes complexes où certains états sont faiblement prévisibles et ne sont donc pas bien connus (vent, éclairage, état du réseau, charge, ...).

# Supervision des systèmes hybrides autonomes (installations domestiques)

| Objectifs | Contraintes | Moyens d'action |
|---|---|---|
| - Satisfaire la demande<br>- Maximiser l'utilisation des sources renouvelables | - Etat de charge des batteries<br>- Excès de production<br>- Déficit de production<br>- Pbat_max & Pbat_min | - Gestion du stockage<br>- Dégradation de la production<br>- Ajout d'une charge de dumping en cas d'excès de production<br>- Délestage<br>- (Démarrer générateur Diesel) |

## ❖ Commande en tension :




Stratégie de régulation de la tension du bus continu

## ❖ Commande en tension :

### Les différents modes de Fonctionnement

MODE BULK sans CHARGE

MODE ABSORPTION sans CHARGE

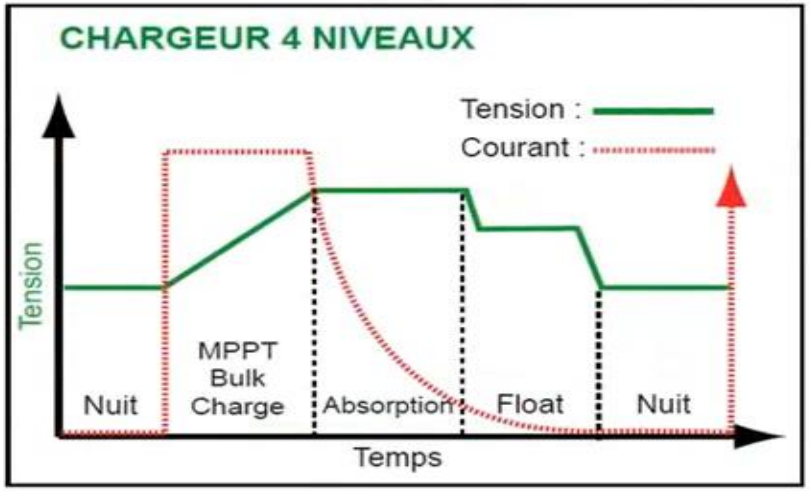
MODE FLOATING sans CHARGE

MODE BULK avec CHARGE

MODE ABSORPTION avec CHARGE

MODE FLOATING avec CHARGE

- **Mode Bulk** = Courant constant (80% de recharge batterie)
- **Mode Absorption** = Tension constante pendant 1 temps donné
- **Mode Float** = Tension constante jusqu'à la recharge complète des batteries (100%)

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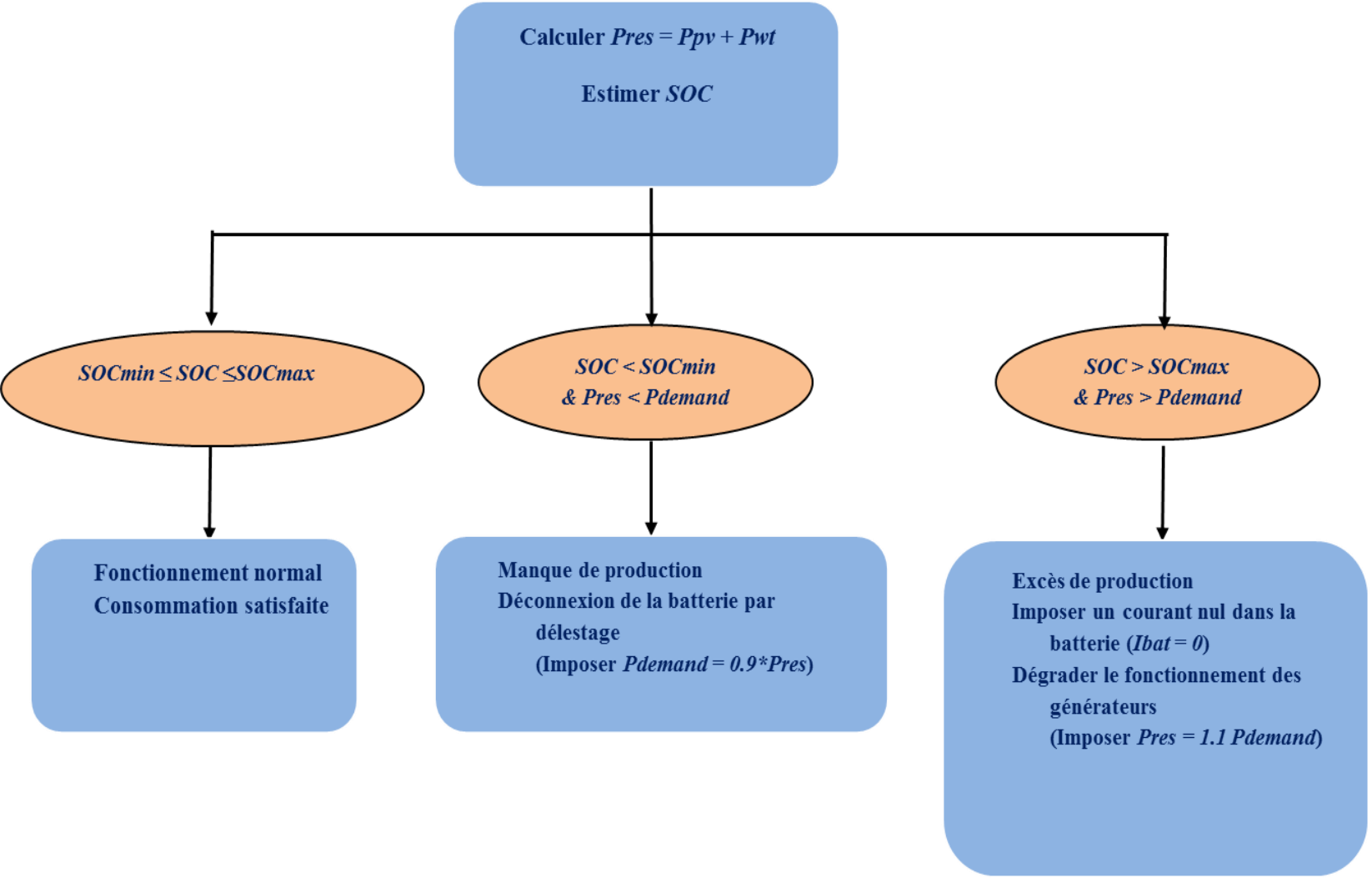
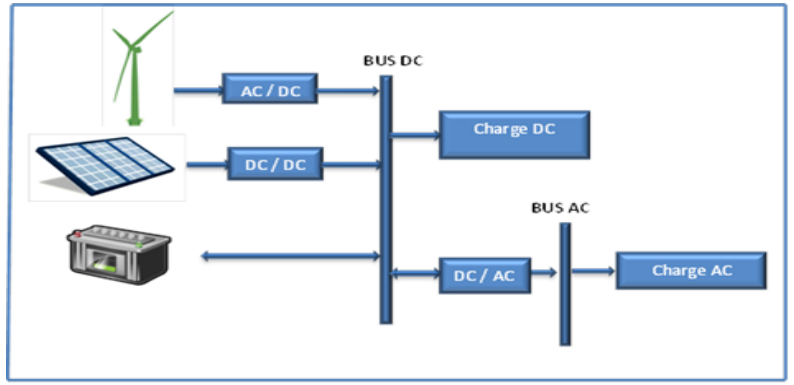
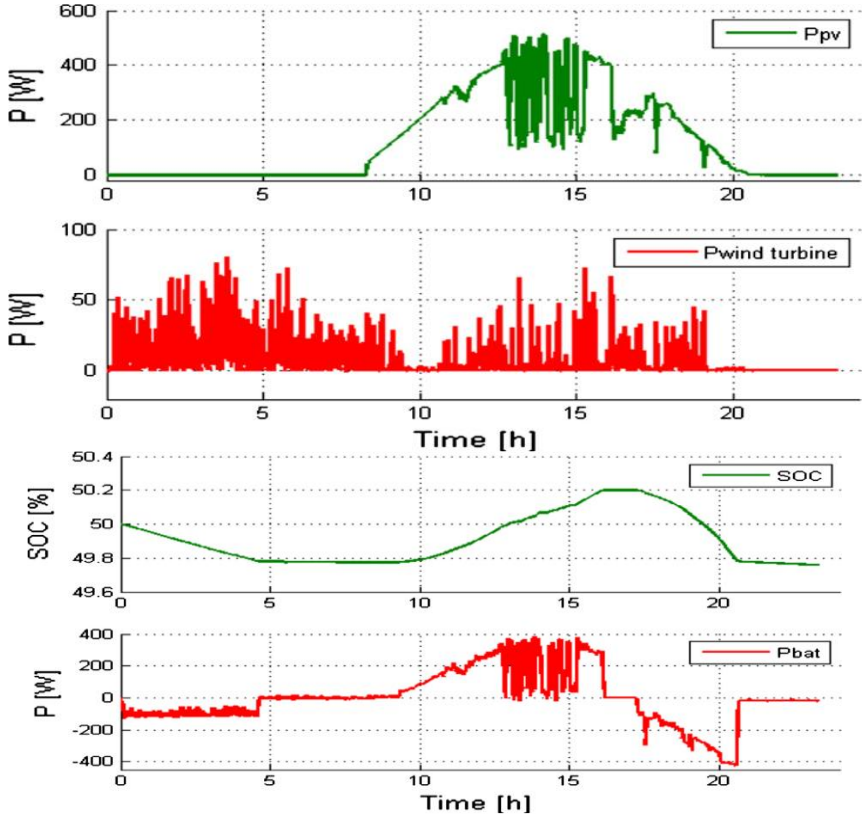
## ❖ Commande en courant (notre proposition en 2012) :




Organigramme de la méthode de supervision proposée

**Configuration du système hybride utilisé**



# ❖ Commande en courant (notre proposition en 2012) :

**Validation de la méthode de supervision sur un banc d'essai**

Description du banc

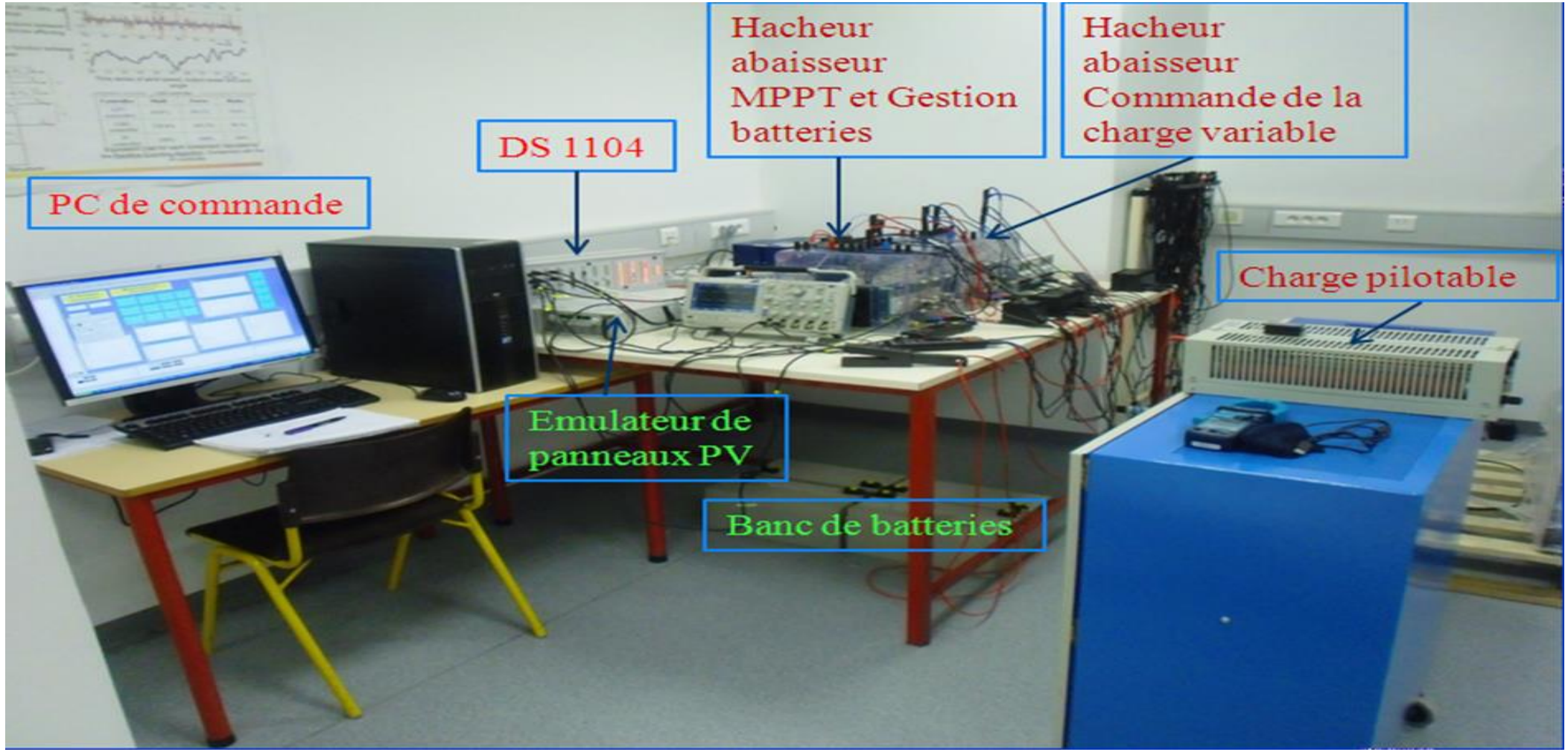
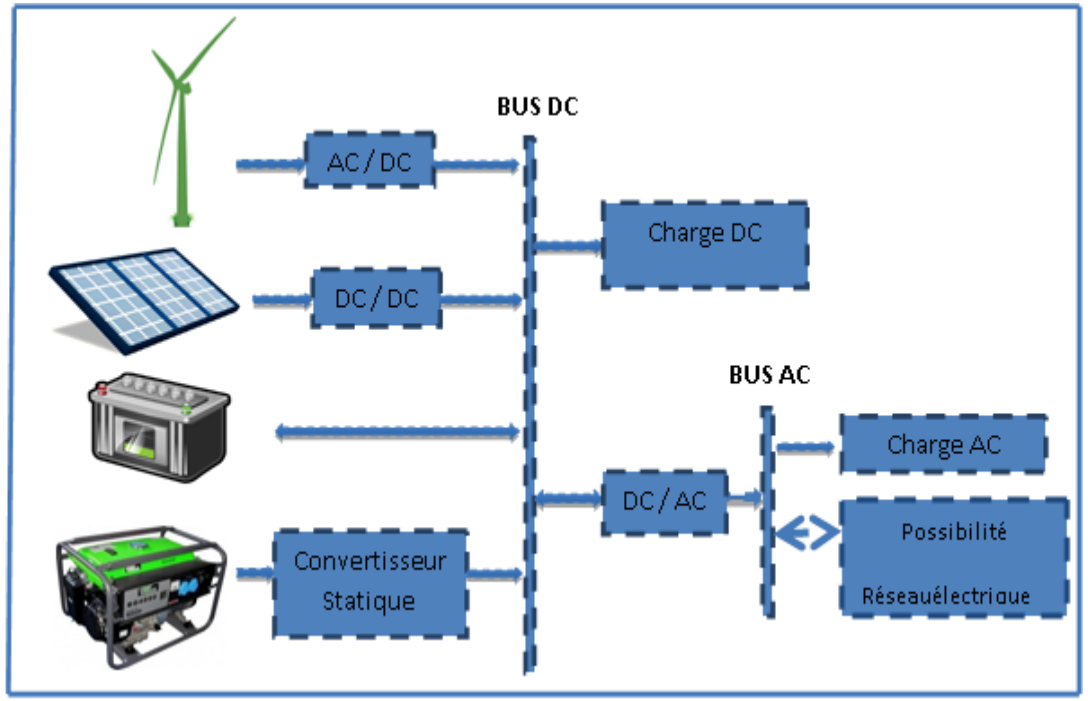
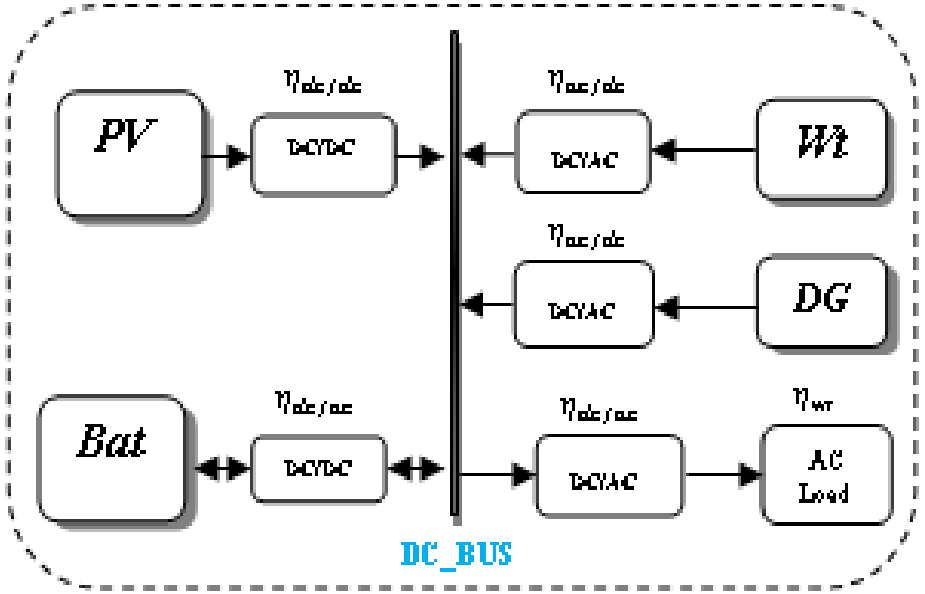



Photo du simulateur solaire photovoltaïque mis en place en laboratoire

# ❖ Commande en courant :

Travaux de Thèse de Toufik Ayadi (Avec LIAS Poitiers)



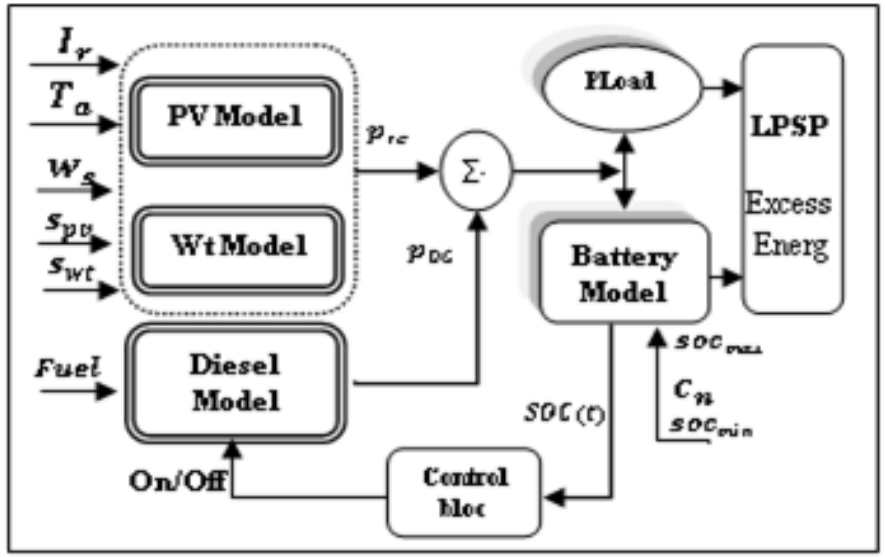




Configuration système multi-source

## ❖ Commande en courant :

Travaux de Thèse de Toufik Ayadi (Avec LIAS Poitiers)

### Principe de supervision




La charge et la décharge de la batterie d'accumulateurs est strictement liée à la différence entre l'énergie totale fournie par le système hybride et l'énergie consommée par la charge notée ΔP (t).

Nous distinguons deux cas:

- ❑ Dans le cas où ΔP (t) ≥ 0, le reste de l'énergie est utilisé pour charger la batterie. Si l'état de charge dépasse le SOC _max un excès d'énergie apparaît.

- ❑ Dans le cas où la différence de l'énergie est négative, la charge sera couverte par la batterie ou le générateur diesel. Ici, le rôle du générateur est la surveillance de l'état de charge de la batterie pour ne pas descendre au-dessous de SOC_Dmin donné.

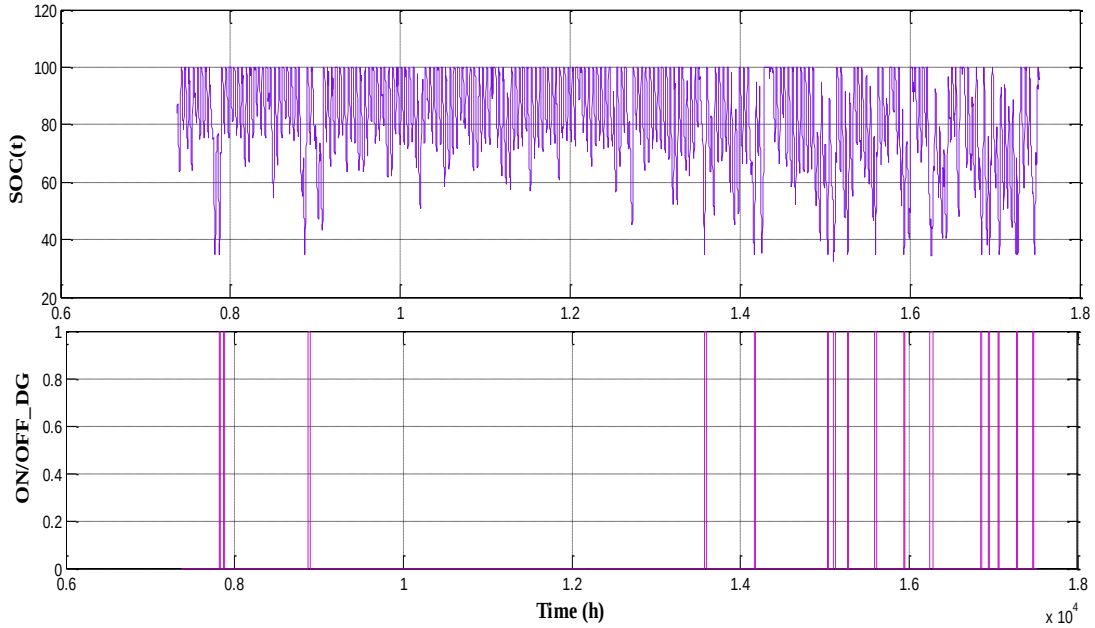
## ❖ Commande en courant :

Travaux de Thèse de Toufik Ayadi (Avec LIAS Poitiers)

### Dimensionnement du groupe Diesel

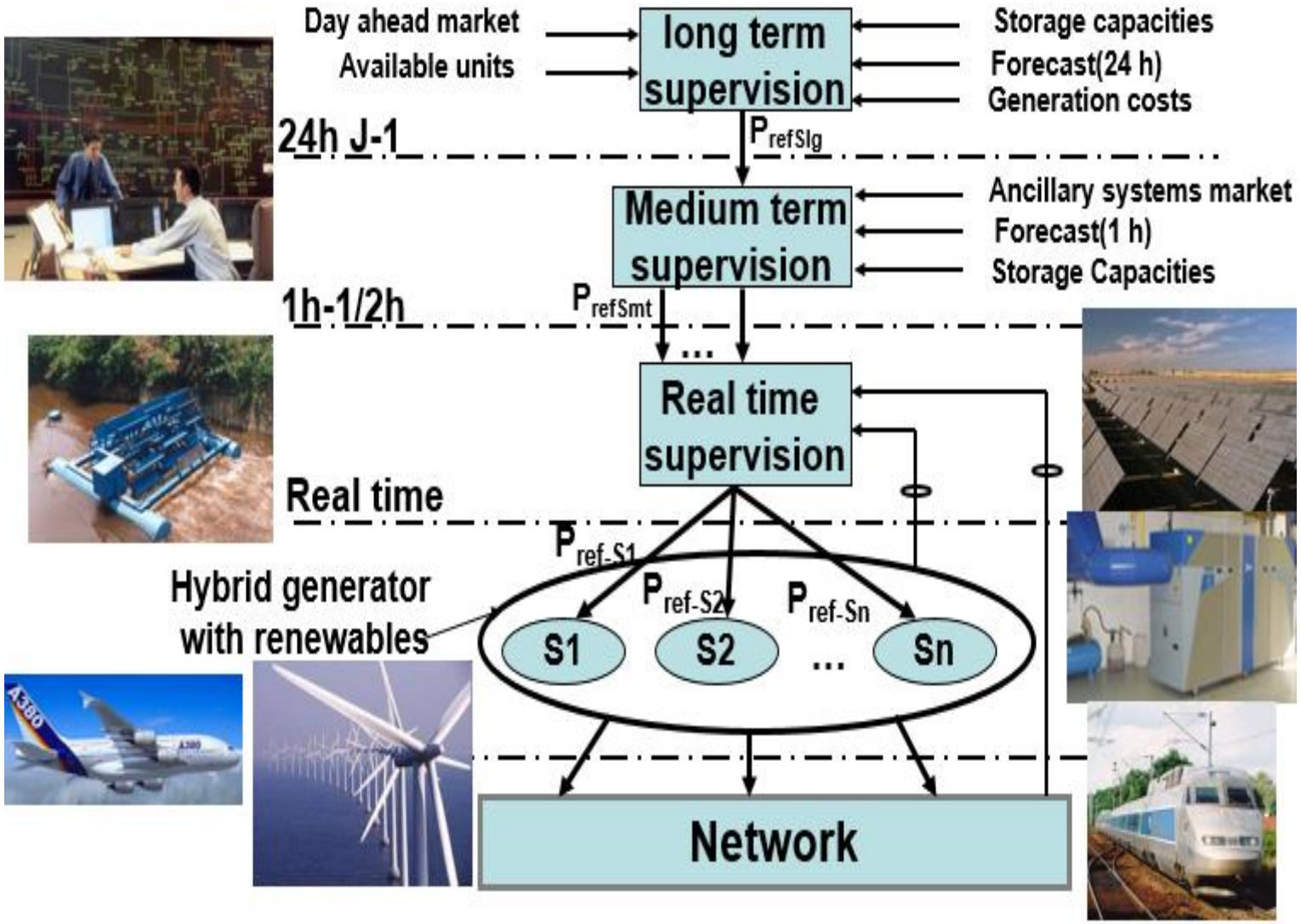
**Simulation for** *SOCDmin=35% et SOCDmax=70%*

| Power of GD (kw) | Excess of energy (Kwh/year) | LPSP(%) | Number On / Off Of DG/year |
|---|---|---|---|
| 0.4204 | 1403 | 0.08425 | 36 |
| 0.5467 | 1413 | 0 | 33 |
| 0.6309 | 1414 | 0 | 32 |
| 0.8417 | 1413 | 0 | 34 |




Opération du générateur diesel en fonction de l'état de charge des batteries.

## ❖ Types de supervision en cas de connexion au réseau ou micro-réseaux:



# Examples and case studies

## Case study : Supervision of a hybrid railway power station

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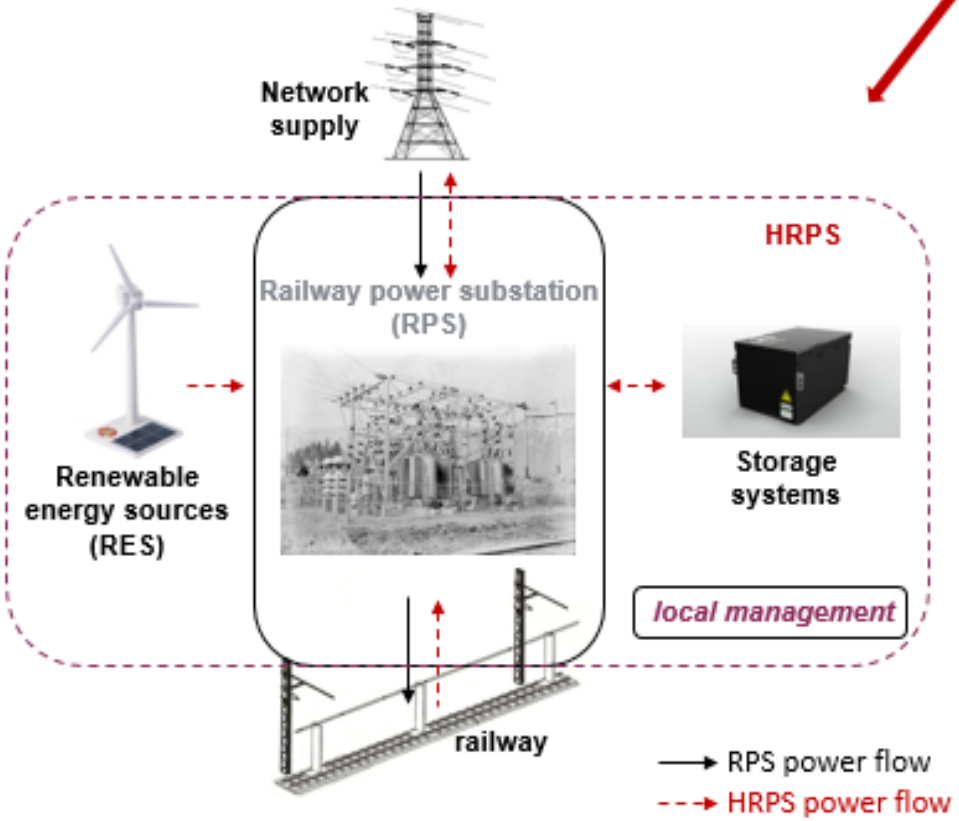
**Context**

- 90% railway traffic ensured by electrified lines (French railway network: 1500VDC & 25kV/50Hz AC)
- railway traffic increasing
- electricity market liberalization

***New solutions to face future energy demand increase (Hybrid Railway Power Substation)***




*Economic issue:*

- HRPS energy bill reduction
- Optimizing the energy purchasing strategy

*In energy terms:*

- Power flow identification in HRPS system
- Energy management objectives definition in order to satisfy energy and economic constraints

## Case study : Supervision of a hybrid railway power station

*Multi-criteria approach for HRPS supervision (with implicit optimization)*

*Energy management services are related to:*

- energetic aspects (reliability, power quality…)
- environmental (favoring renewable consumption)
- economic aspects (electricity bill reduction)

*Energy bill components:*

Wholesale market
*(purchased 24 h in advance)*

Public electricity network user tariff *(10min index)*

Adjustment mechanism
*(gap between purchased power and real consumption)*

*Short-term actions*

- limitation of the exceeding subscribed grid power
- limitation of the adjustment gap

## *Methodology for HRPS energy management*

STEP 1
Work specifications

STEP 2
Design of the supervisor

STEP 3
Chart representation of operating modes
- Functional graphs -

STEP 4
Determination of the membership functions

STEP 5
Chart representation of fuzzy operating modes
- Operational graphs -

STEP 6
Determination of the fuzzy rules

STEP 7
Determination of indicators to measure
the achievement of objectives

## Case study : Design and supervision of a hybrid railway power station

### *Methodology for HRPS energy management (implicit optimization)*

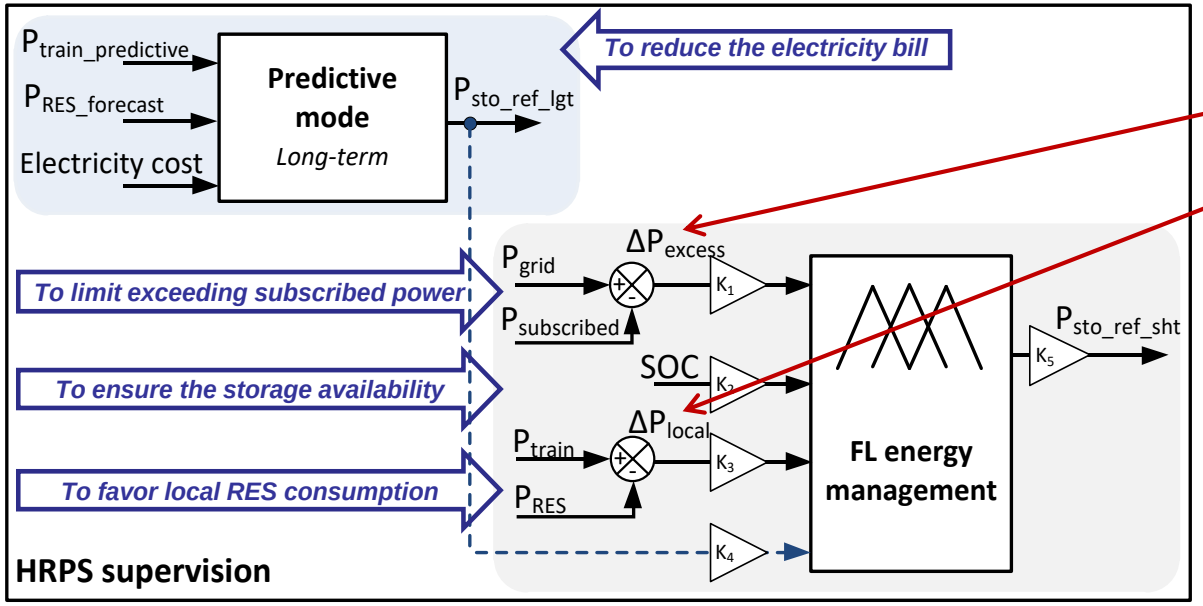
STEP 1
Work specifications

| Objectives | Constraints | Means of actions |
|---|---|---|
| ***Predictive mode – LONGT TERM*** | | |
| Reducing energy bill<br>(regarding short-term trades) | Trains consumption predictions<br>RES forecast<br>Electricity market fluctuations | Storage power ($P_{sto\text{-}ref\text{-}lgt}$)<br>(Predictive reference power) |
| ***Fuzzy Logic energy management – SHORT TERM*** | | |
| Limitation of subscribed power exceeding<br>Favoring local RES consumption<br>Ensuring storage system availability | Subscribed power<br>Storage limits<br>RES availability | Storage power ($P_{sto\text{-}ref\text{-}sht}$)<br>(Predictive mode adjustment) |

## Case study : Design and supervision of a hybrid railway power station

### *Methodology for HRPS energy management (implicit optimization)*

STEP 2
Design of the supervisor



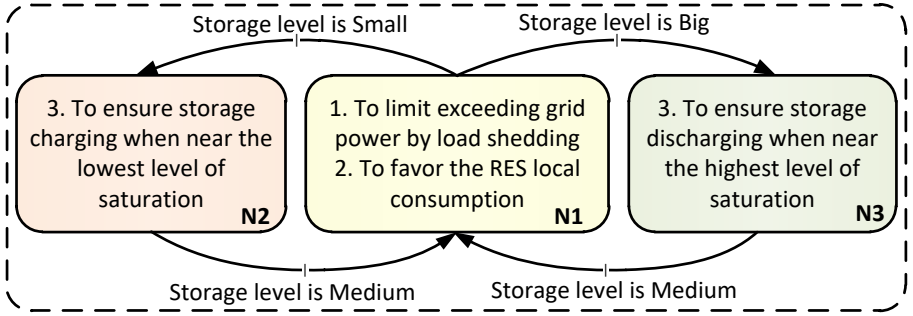

the grid power excess amount

the power difference between train consumption and RES production

$K_1$, $K_2$, $K_3$, $K_4$, $K_5$ = normalisation gains

## Methodology for HRPS energy management

STEP 3
Chart representation of operating modes
- Functional graphs -



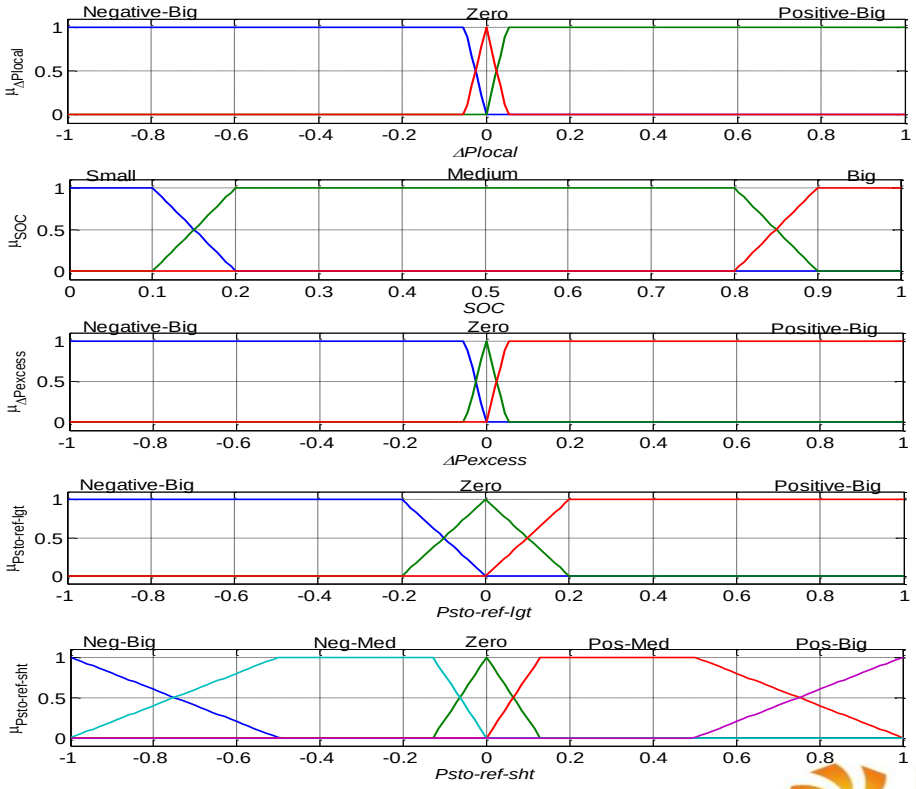

STEP 4
Determination of the membership functions

*Inputs:*

- $\Delta P_{local}$ (Negative-Big, Zero, Positive-Big)
- *SOC* (Small, Medium, Big)
- $\Delta P_{excess}$ (Negative-Big, Zero, Positive-Big)
- $P_{sto\text{-}ref\text{-}lgt}$ (Negative-Big, Zero, Positive-Big)

*Output:*

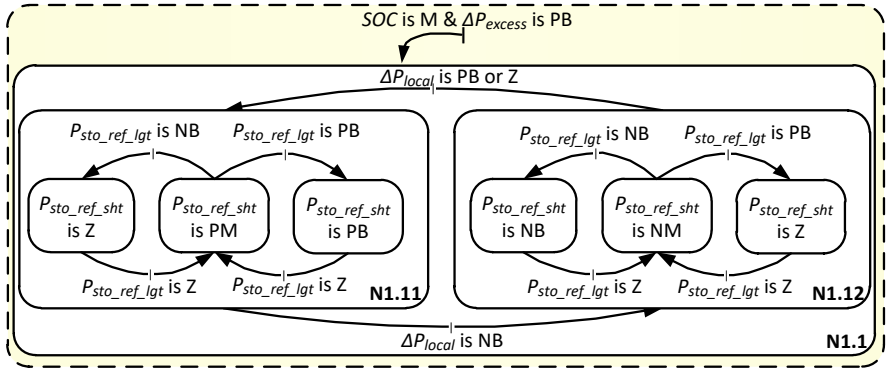
- $P_{sto\text{-}ref\text{-}sht}$ (Negative-Big, Zero, Positive-Big)



## Case study : Supervision of a hybrid railway power station

### *Methodology for HRPS energy management*

STEP 5
Chart representation of fuzzy operating modes
- Operational graphs -




*from 81 possible cases, only 30 fuzzy necessary rules*

STEP 6
Determination of the fuzzy rules

If *SOC* is M
and $\Delta P_{excess_p.u.}$ is NB ($P_{grid}<P_{subscribed}$)
and $\Delta P_{local_p.u.}$ is PB ($P_{train}>P_{RES}$)
and $P_{sto\text{-}ref\text{-}lgt_p.u.}$ is NB *(to charge)*
then $P_{sto\text{-}ref\text{-}sht_p.u.}$ is NB *(charge reference)*

| *Mode* | *Inputs* | | | | *Output* |
|---|---|---|---|---|---|
| | SOC | $\Delta P_{local}$ | $\Delta P_{excess}$ | $P_{sto\text{-}ref\text{-}lgt}$ | $P_{sto\text{-}ref\text{-}sht}$ |
| *N1.11* | M | not NB | PB | PB | Z |
| | M | not NB | PB | Z | PB |
| | M | not NB | PB | PB | PB |
| | M | NB | PB | NB | NB |
| *N1.12* | M | NB | PB | Z | NM |
| | M | NB | PB | PB | Z |
| | … | | | | |

## Case study 2 : Supervision of a hybrid railway power station

### *Methodology for HRPS energy management (implicit optimization)*

STEP 7
Determination of indicators to measure the achievement of objectives

*Economic indicator* (monthly component of the exceeding subscribed power)

$$CMDPS = \sum_{t \in T} \alpha \cdot k_t \sqrt{\sum_{x \in X_t} \Delta P_{excess}^2(x)}$$

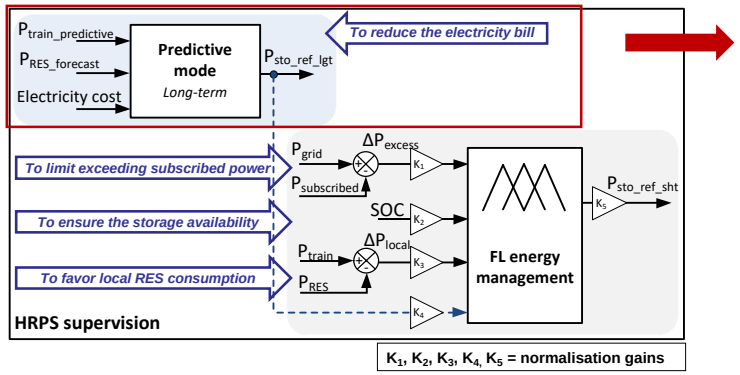
$$\Delta P_{excess} = P_{grid} - P_{subscribed}$$

- five tariff time periods *T*
- *α=0.3584€/kW*
- $k_t$ (%) is a power coefficient for each time tariff period *t*
- $X_t$ represents the index set *x* belonging to each time class *t*).

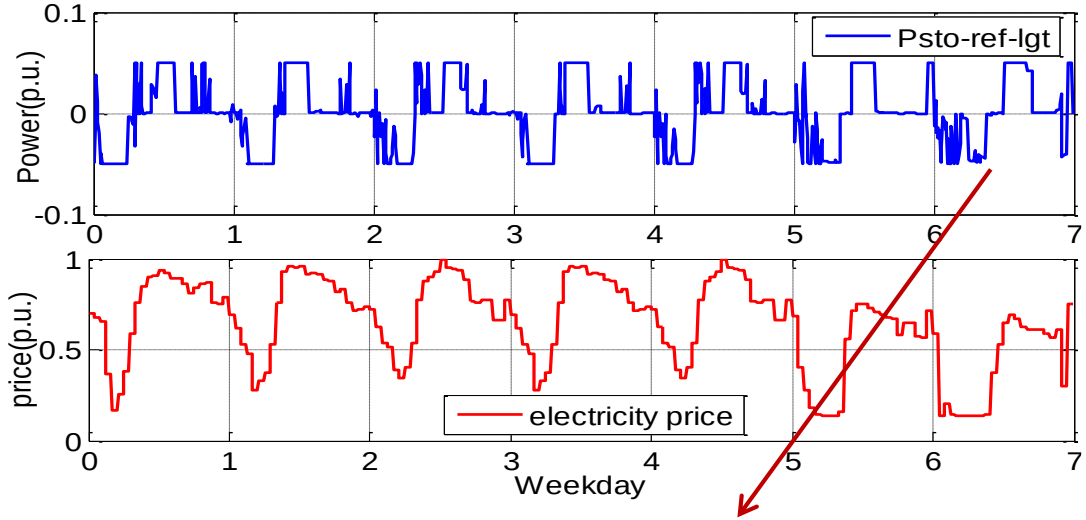
*Energy indicator* (ratio between the locally consumed energy of RES and the produced one)

$$I_{RES}(\%) = \frac{E_{RES} - E_{RES_noncons}}{E_{RES}} \cdot 100$$

## Predictive mode storage reference power



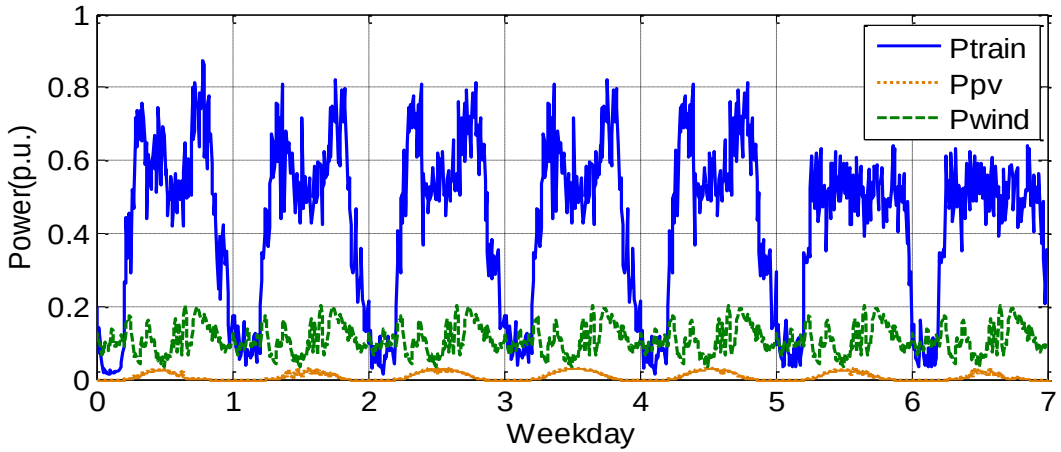

*Depends on electricity price in short term trades*




*Storage system:*

- $C_{sto}$ = 5000 kWh
- $P_{sto\text{-}max}$ = 1MW
- $\eta_{charge}$=90%, $\eta_{discharge}$=90%
- $SOC_{min}$, $SOC_{max}$
- time response constant ($\tau$=0.5s)

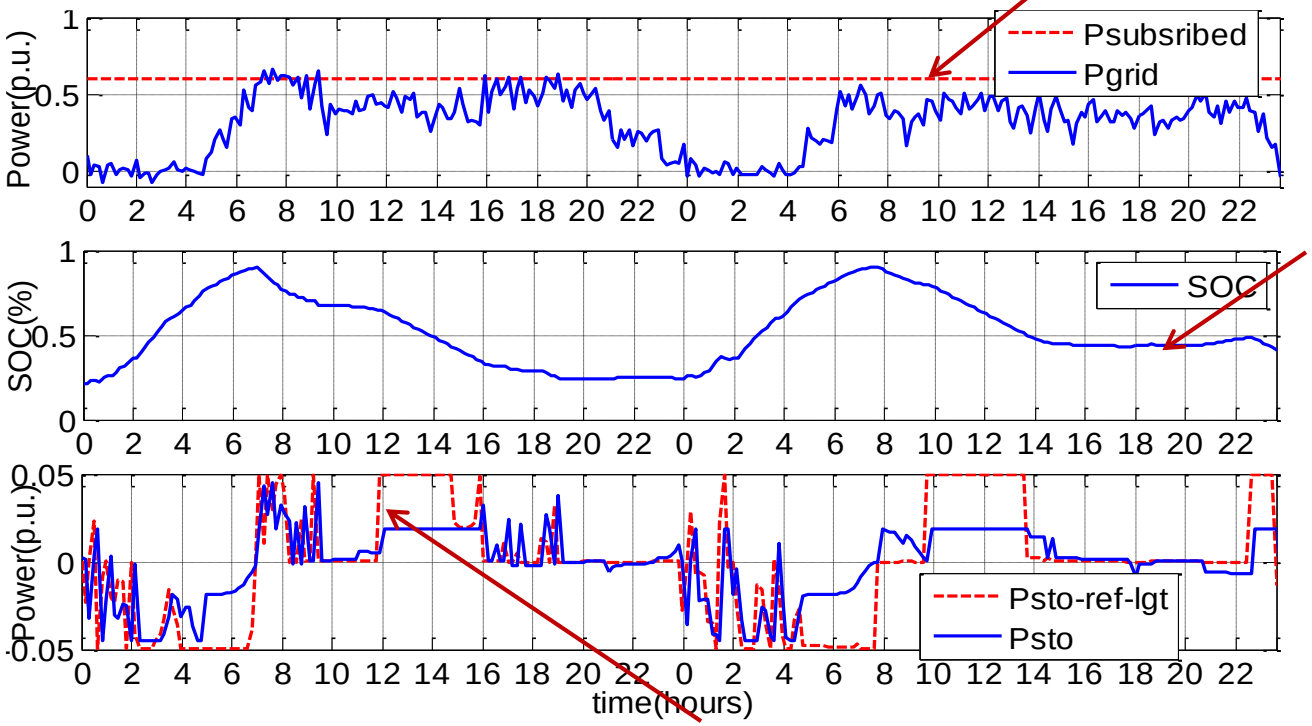
## Production and consumption profiles



## Case study : Supervision of a hybrid railway power station

***storage power adjustment***

the subscribed power is reduced thanks to RES local consumption and storage management




storage system charges when RES exceed train consumption and when economic interesting

adjustment of $P_{sto\text{-}ref\text{-}lgt}$ reference power

## Case study : Supervision of a hybrid railway power station

### *Comparison of different supervision cases*

Subscribed power is reduced five times in HRPS supervision

| *Study case* | *CMDPS* | $I_{RES}$ |
|---|---|---|
| Reference case | 5338 € | 0% |
| Case 1 (Predictive mode) | 1024 € | 96,5% |
| Case 2 (FLEM strategy) | 1036 € | 95,5% |
| Case 3 (Adjustment) | 942 € | 96,9% |

well performance of FLEM strategy compared to predictive mode results

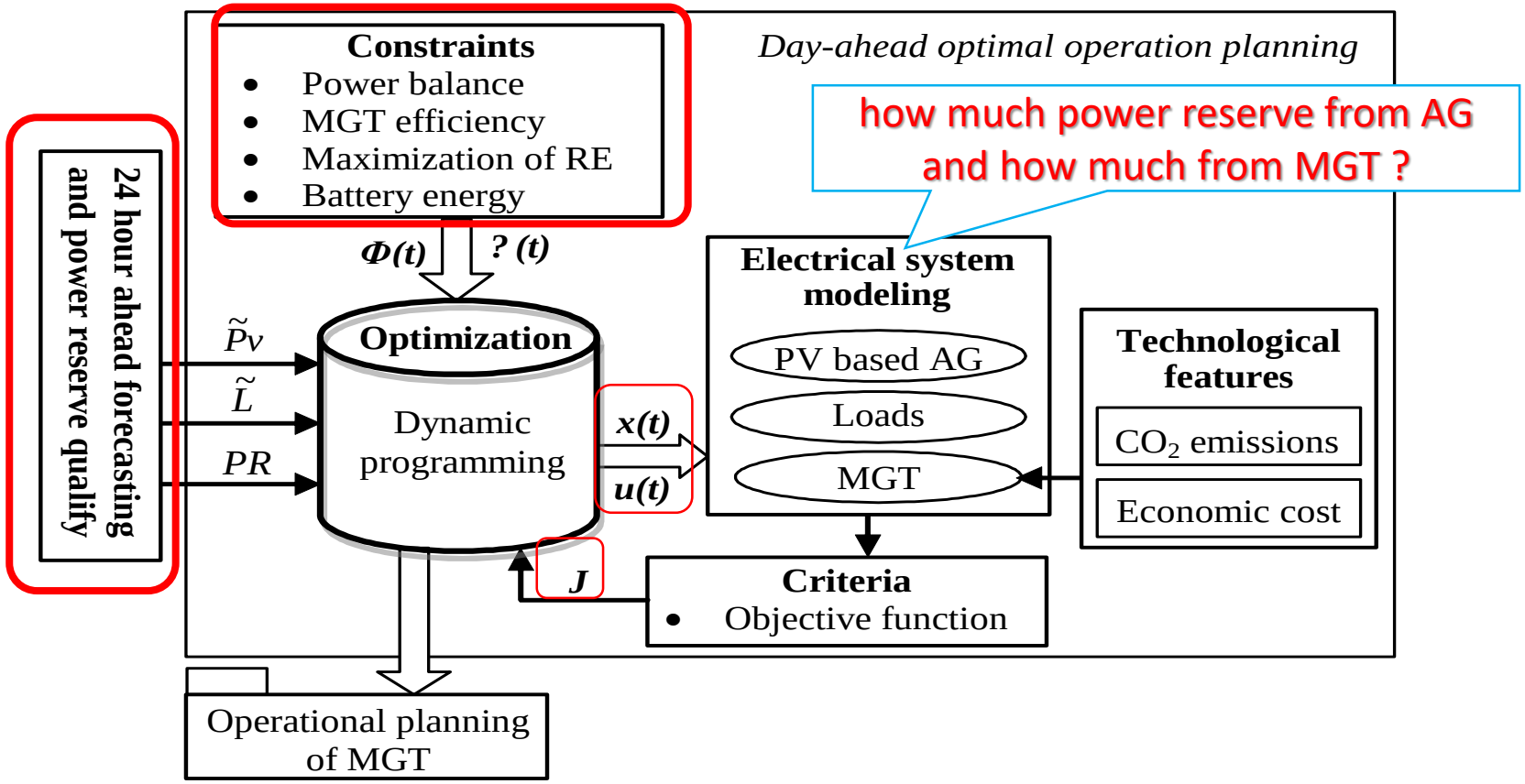
RES is locally consumed almost in totality

Examples and case studies

# Case study 2 : Day-ahead Optimal Operational Planning of Generators

**Case study 2 : Day-ahead Optimal Operational Planning of Generators**

Scheme of Day-ahead Optimal Power Reserve Planning

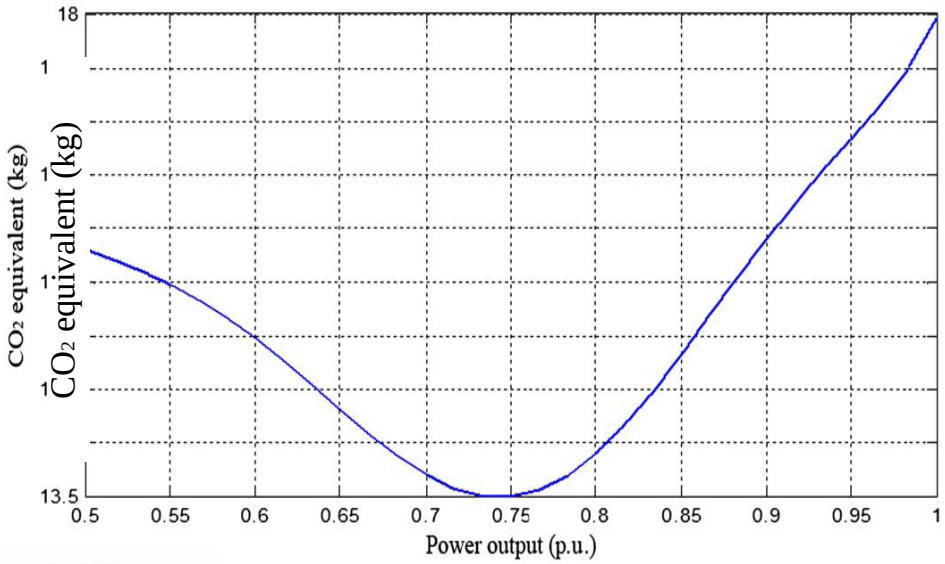



- Focus on the design of the MCEMS under particular constraints.
- Uint commitment problem with dynamic programming is developed in order to reduce the economic cost and/or $CO_2$ equivalent emissions.

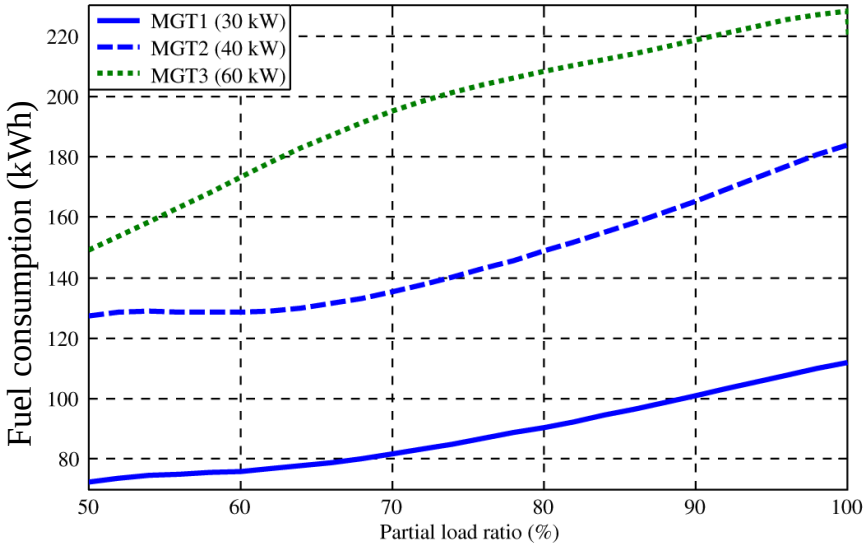
**<u>Case study 2</u> : Day-ahead Optimal Operational Planning of Generators**

## 2. Non-linear Constraints

- Power reserve assessment with *x* % of LOLP;
- Balancing between load demand and power: $\psi(t) = P_L(t) + P_{res}(t) - \sum_{n=1}^{N} P_{AG_n}(t) - \sum_{i=1}^{M} (\delta_i(t) \bullet P_{MGT_i}(t)) = 0$
- Maximization of renewable energy usage: PV power is considered as a prior source;
  - Battery capacity limitation (more PV power, more battery storage !)
  - Different strategies:
    1. During the day (use PV or store energy)
    2. During the night (discharge battery)
- MGT corresponding inequality constraint: $50\% P_{M_max_i}(t) \le P_{M_i}(t) \le 100\% P_{M_max_i}(t)$




Power output (%)




Partial load ratio (%)

**Case study 2 : Day-ahead Optimal Operational Planning of Generators**

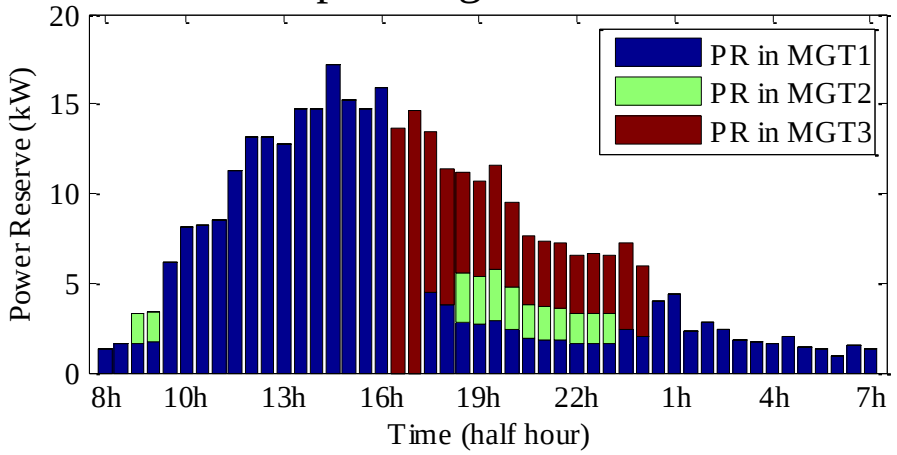
# 3. Operational and Power Reserve Distribution Strategies

- Power reserve needs to be covered by MGTs and/or PV AG:

- Strategy 1:

Power Reserve Covered by only MGT: Classical strategy for passive PV generators;

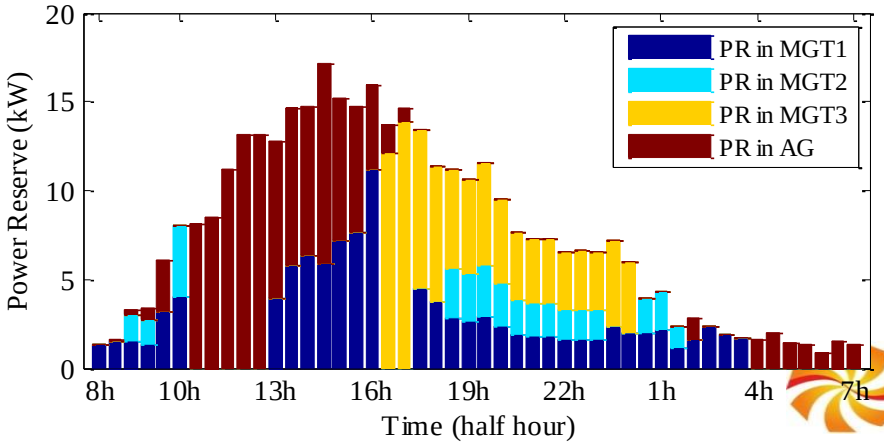
PR Dispatching in three MGT




- Strategy 2:

Power Reserve Covered by both MGT and PV AG: the power reserve is distributed into both MGT and PV AG.

PR Dispatching in three MGT + PV AG



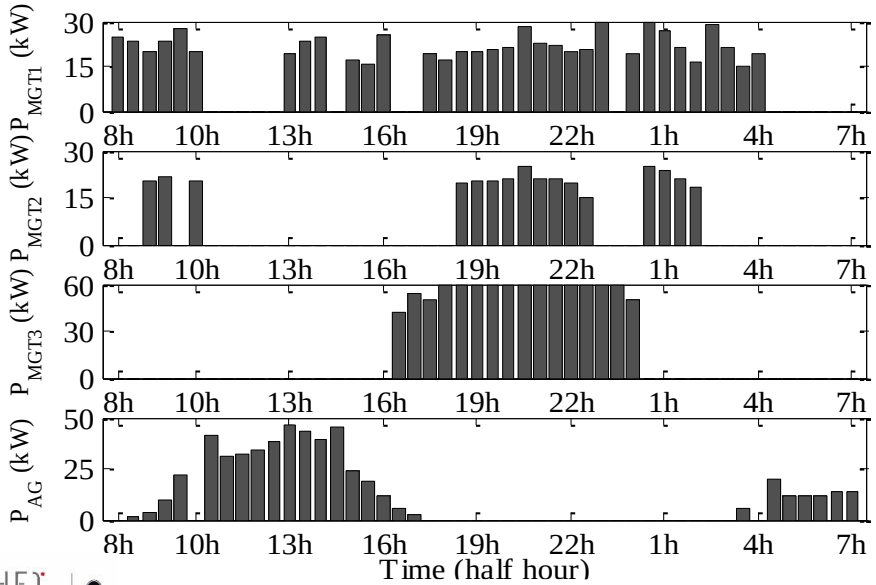
## Case study 2 : Day-ahead Optimal Operational Planning of Generators

# 4. Unit Commitment Problem with Dynamic Programming

- Optimal Operational of a cluster of MGTs (PV power is prior source)
- Formulation of the UCP

$$x(\mathrm{t}) = \left[P_{MGT_1}(t), P_{MGT_2}(t), \ldots, P_{MGT_i}(t)\right]$$

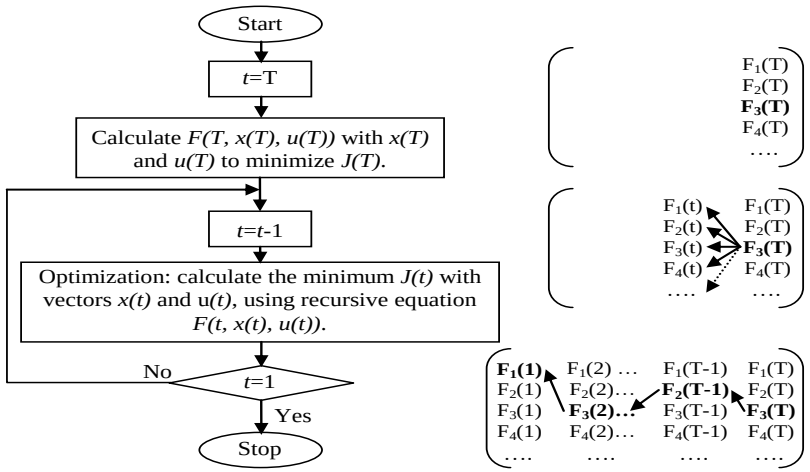
$$u(\mathrm{t}) = \left[\delta_1(t), \delta_2(t), \ldots, \delta_i(t)\right]$$




- Optimization Objectives:

1. Economic criteria: minimize total cost;
2. Environmental criteria: minimize CO2 emission;
3. Best compromise criteria: make a compromise.

- Dynamic Programming



## 5 Simulation Results (1)

**Day-ahead Optimal Operational Planning of Generators**

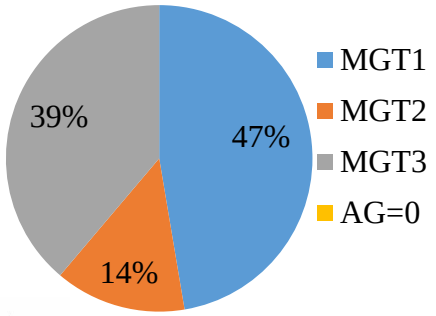
In this case: rated load (110 kW), rated PV power (55 kW) and the power reserve (with 1 % of LOLP) coming from the net demand uncertainty assessment (with second method).

| Scenario | Optimized criteria | Cost (€) | Pollution (kg) | PR on AG (%) | $E_{battery-Max}$ (kWh) |
|---|---|---|---|---|---|
| Without PV power | None | 219 | 1392 | 0 | 0 |
| | Environmental | 212 | 1196 | 0 | 0 |
| | Economic | 210 | 1263 | 0 | 0 |
| Strategy 1: PR from MGT | None | 183 | 1156 | 0 | 80.2 |
| | Environmental | 181 | 1067 | 0 | 80.2 |
| | Economic | 178 | 1120 | 0 | 80.2 |

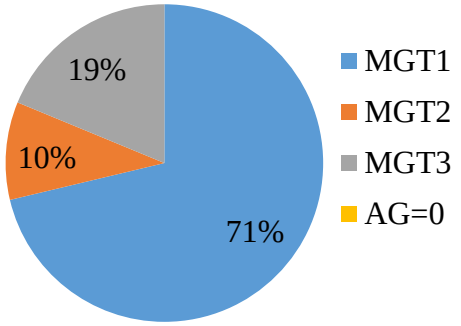
- Power reserve dispatching, one day ahead

**40% of PR is on AG !**

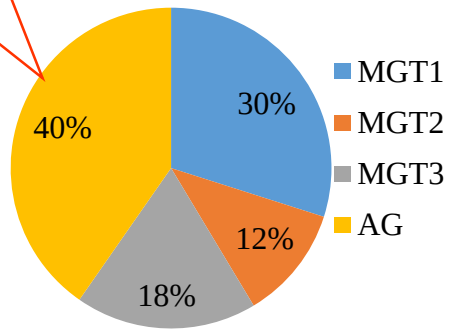
**Without PV power**




**Strategy 1**

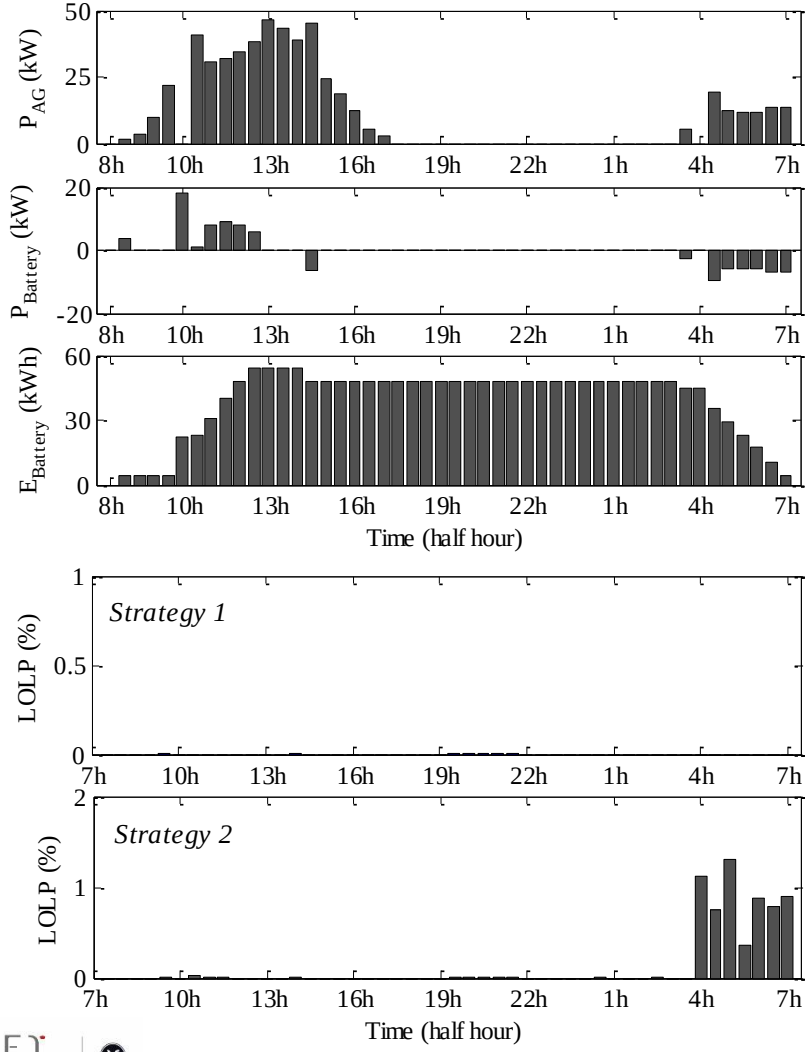



**Strategy 2**

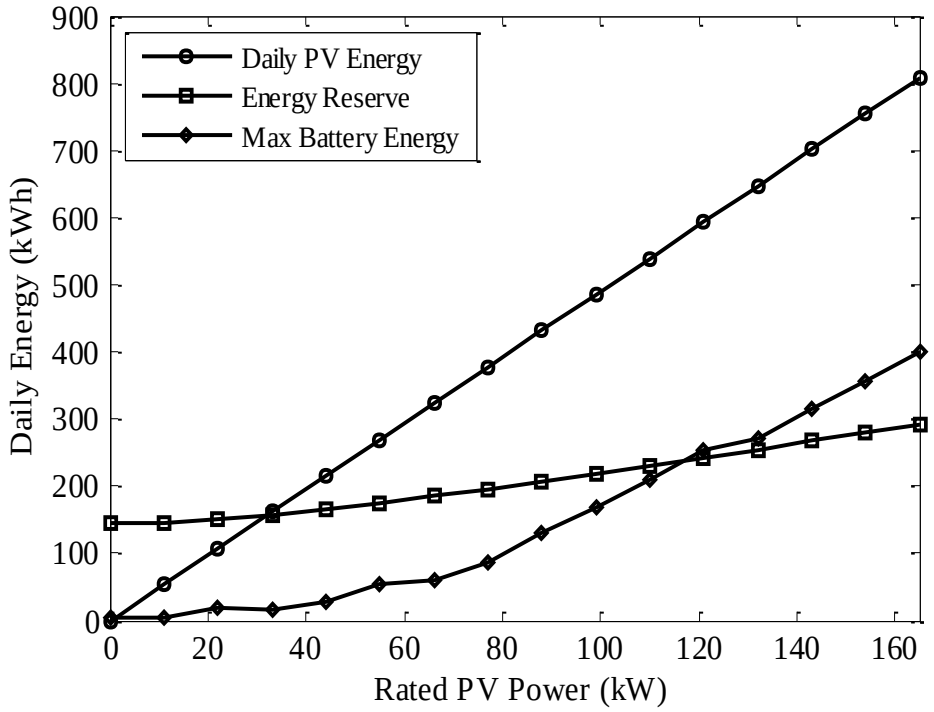


# 5. Simulation Results (2): **Day-ahead Optimal Operational Planning of Generators**

- Battery states and power security

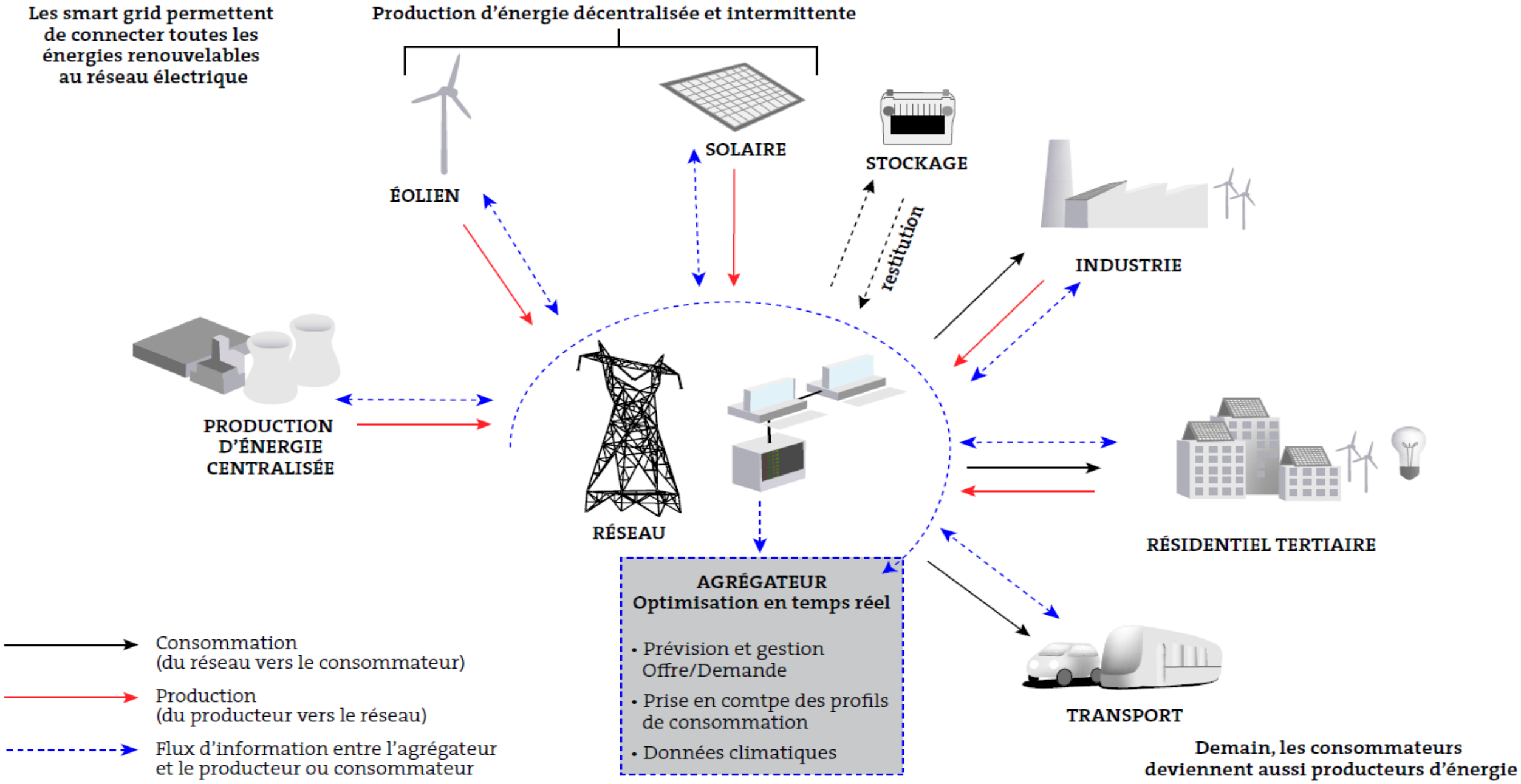



- Increase the PV power Penetration Rate




Daily PV energy and power reserve VS. percentage of PV energy over Load.

# Vers des gestions plus intelligentes



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# Merci

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