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**Smart and Sustainable Electricity Systems**

# *Multi-level Management of Electricity Storage*

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- **The vision of the future**

**Storage is a key issue in this new vision!**


**From the SmartGrids document - EU Commission**

# Introduction

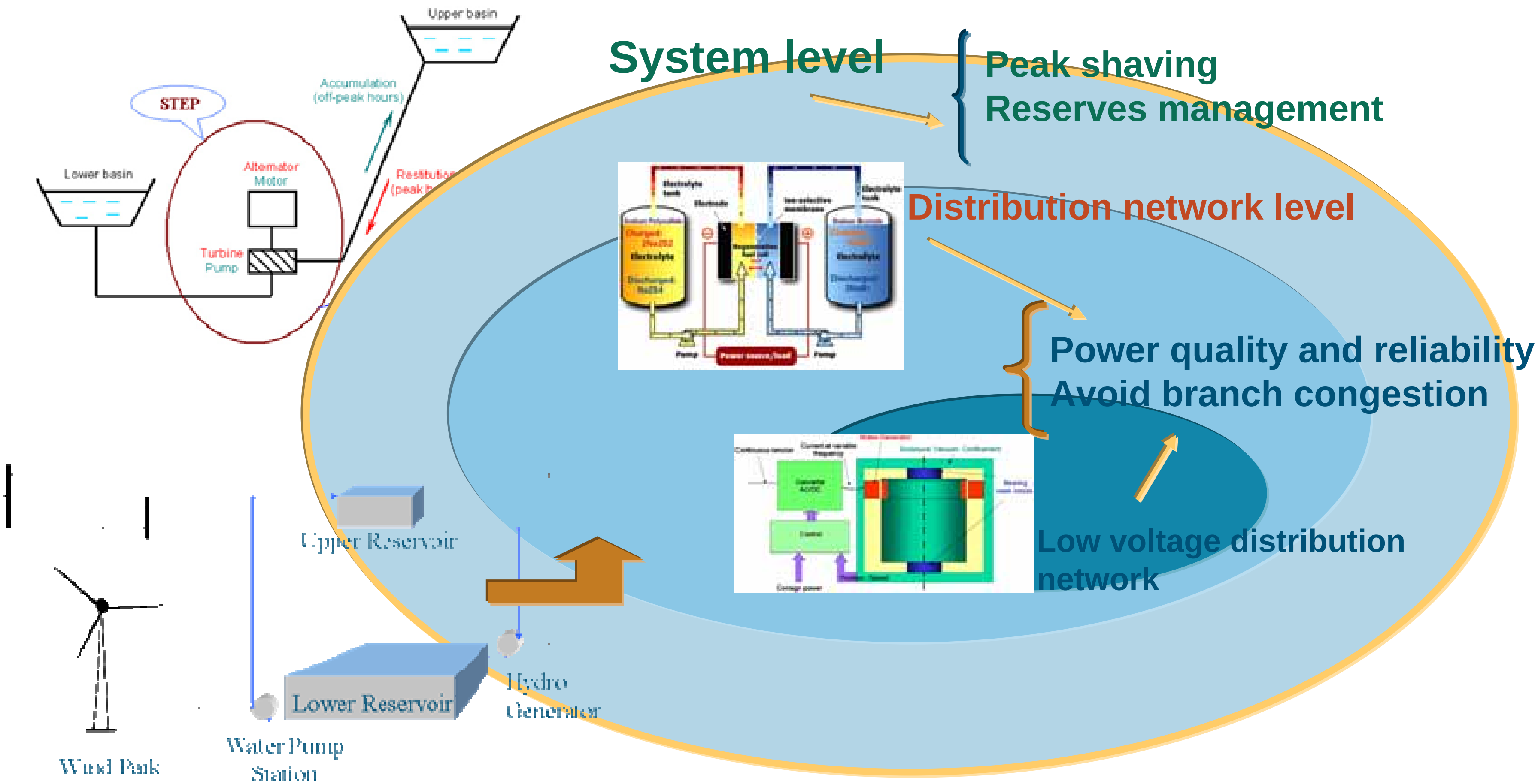
- **Energy storage is a way to transfer energy!**
- **Storage management strategies can be oriented by:**
  - pure economic reasons
  - technical reasons, to cope with global system constraints or network constraints.
- **The most promising technologies are based on:**
  - Electrochemical devices: batteries, Flow batteries; Fuel Cells
  - Mechanical devices: flywheel, pumped hydro, compressed air
  - Electronic devices: super-capacitors, SMES
  - Thermal storage

## Electric storage on a time frame basis

- Short term storage
  - Short-term storage → provides rated power for a few seconds up to a minute. Can be used to provide power quality to energy.
- Medium term storage
  - Medium-term →. Applications for this type of storage capability include renewable energy management, customer energy management, area control/frequency regulation, and rapid reserve management.
- Long term storage
  - Long-term storage → typically bulk energy storage used to take advantage of the energy price difference between peak and off-peak periods.

# Multi-level Storage Management

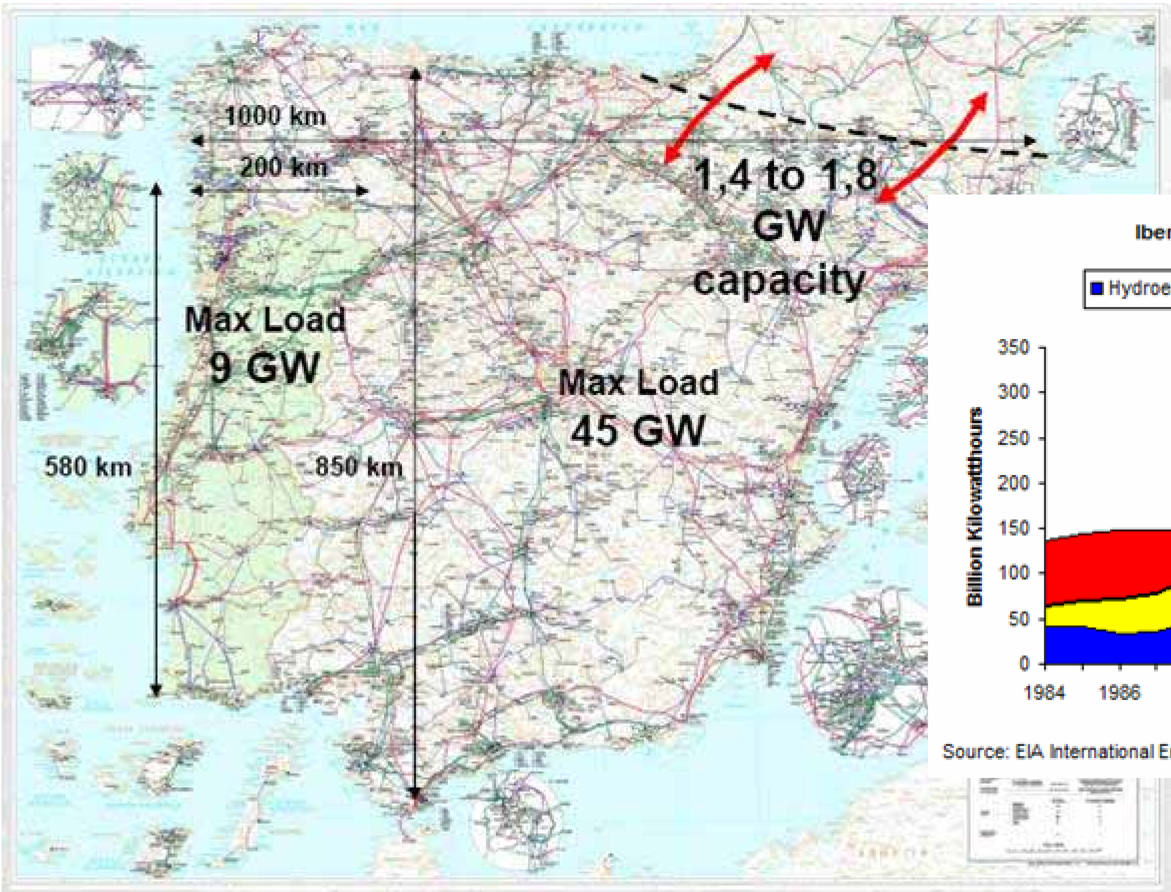
- Storage should be managed at different levels:

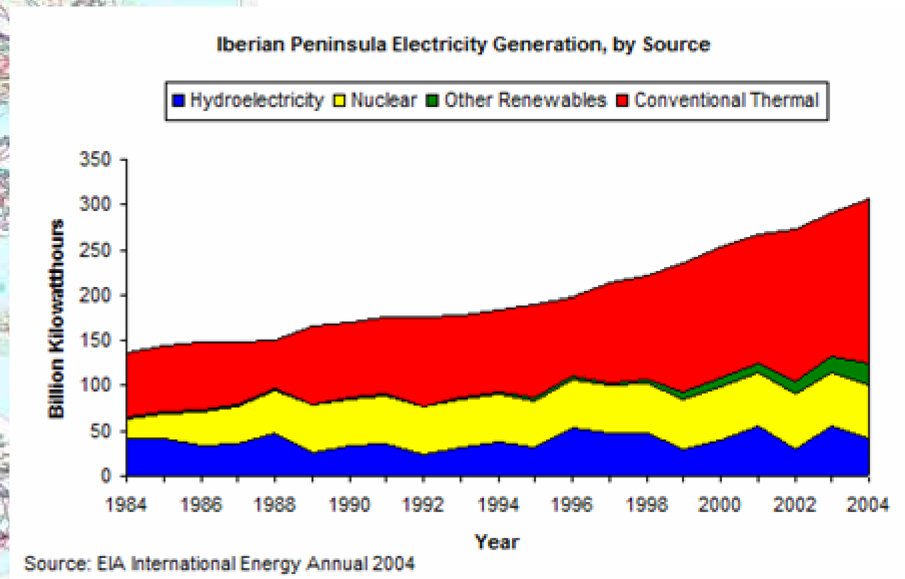



**Generation level → Market participation**

## The need for more centrally managed storage systems

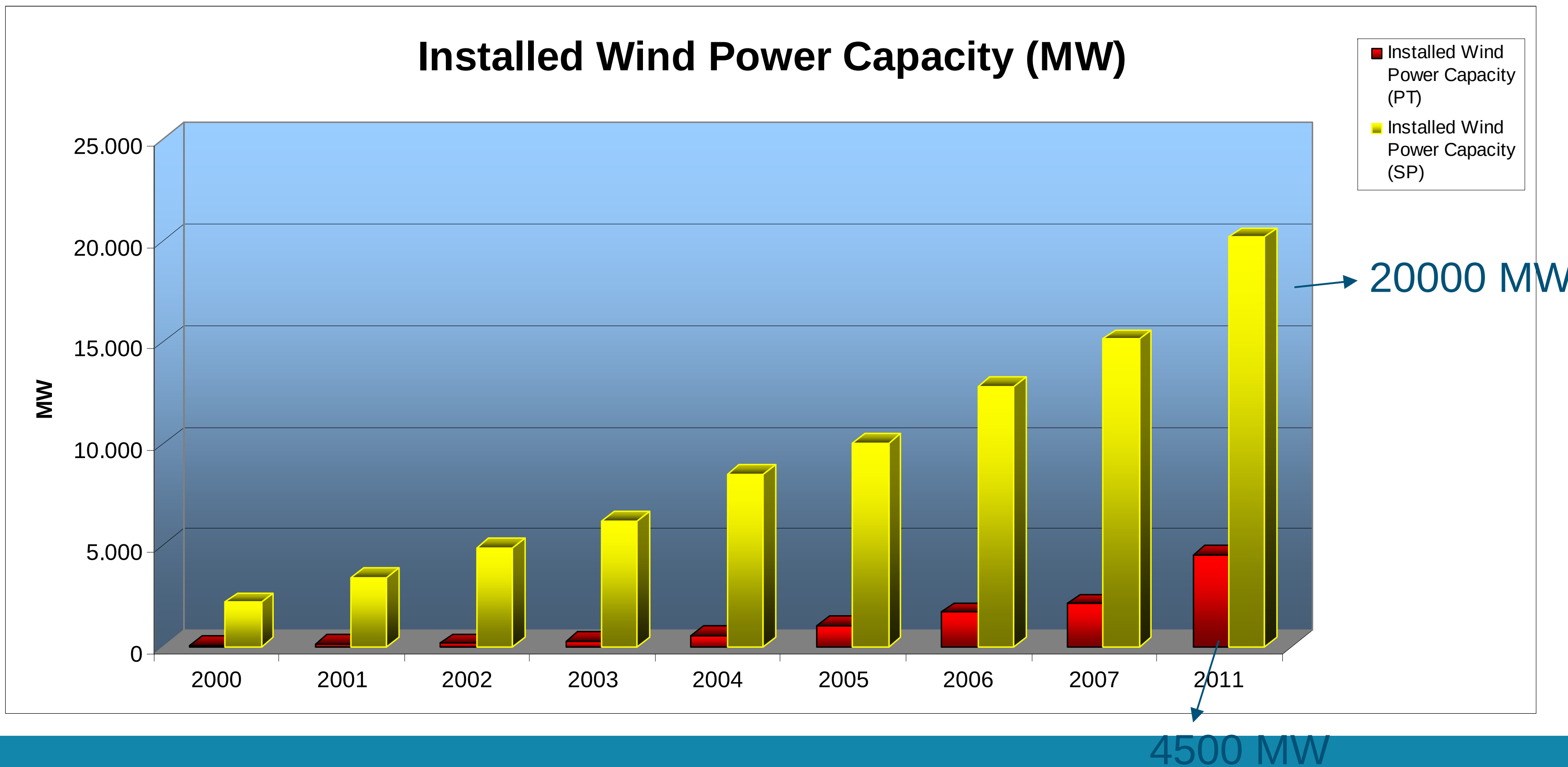
- The Iberian peninsula electric power system



# The need for more centrally managed storage systems

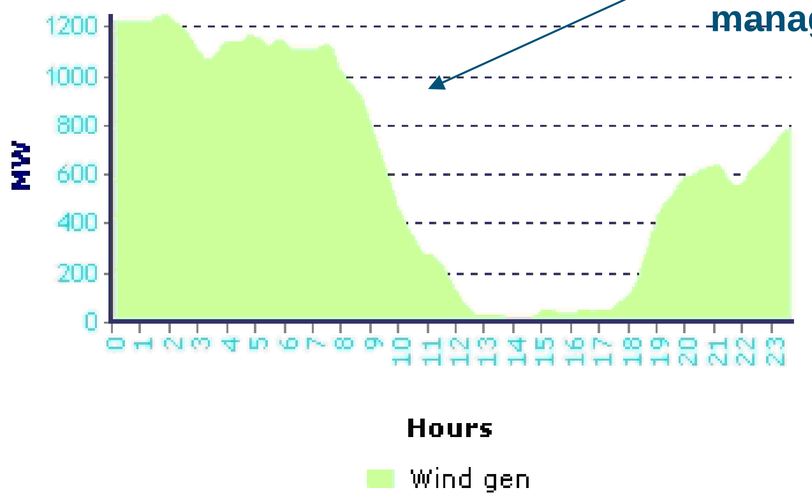
- Deployment of wind generation in the Iberian Peninsula - Evolution of the wind power installed capacity in Spain and Portugal



# The need for more centrally managed storage systems

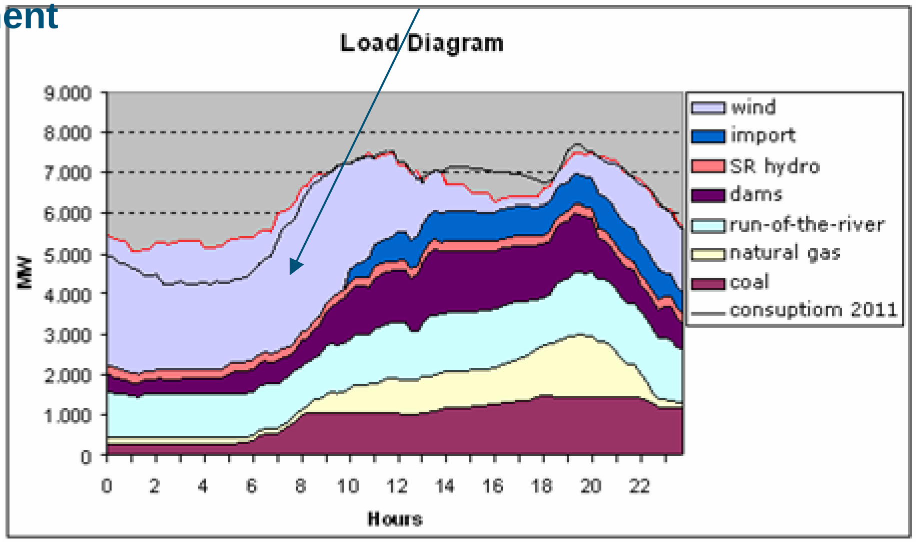
- Large scale wind deployment requires central storage management, involving several storage facilities:
  - **To tranfer renewable energy**
  - **To deal with reserves management**

**Reserve management**



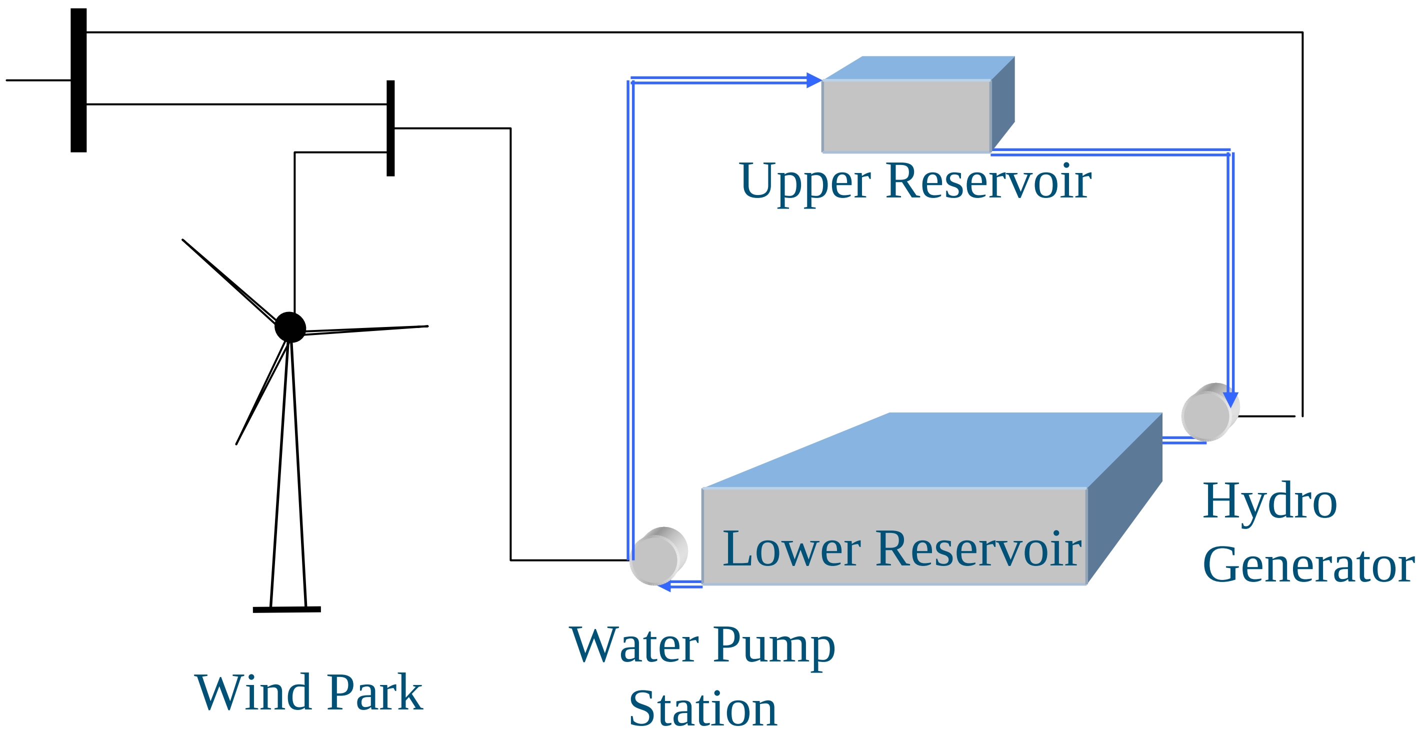

**Wind Generation of 14 th February 2007**
**Source: REN (Portuguese TSO); http://ww.ren.pt**

**Storage is needed**

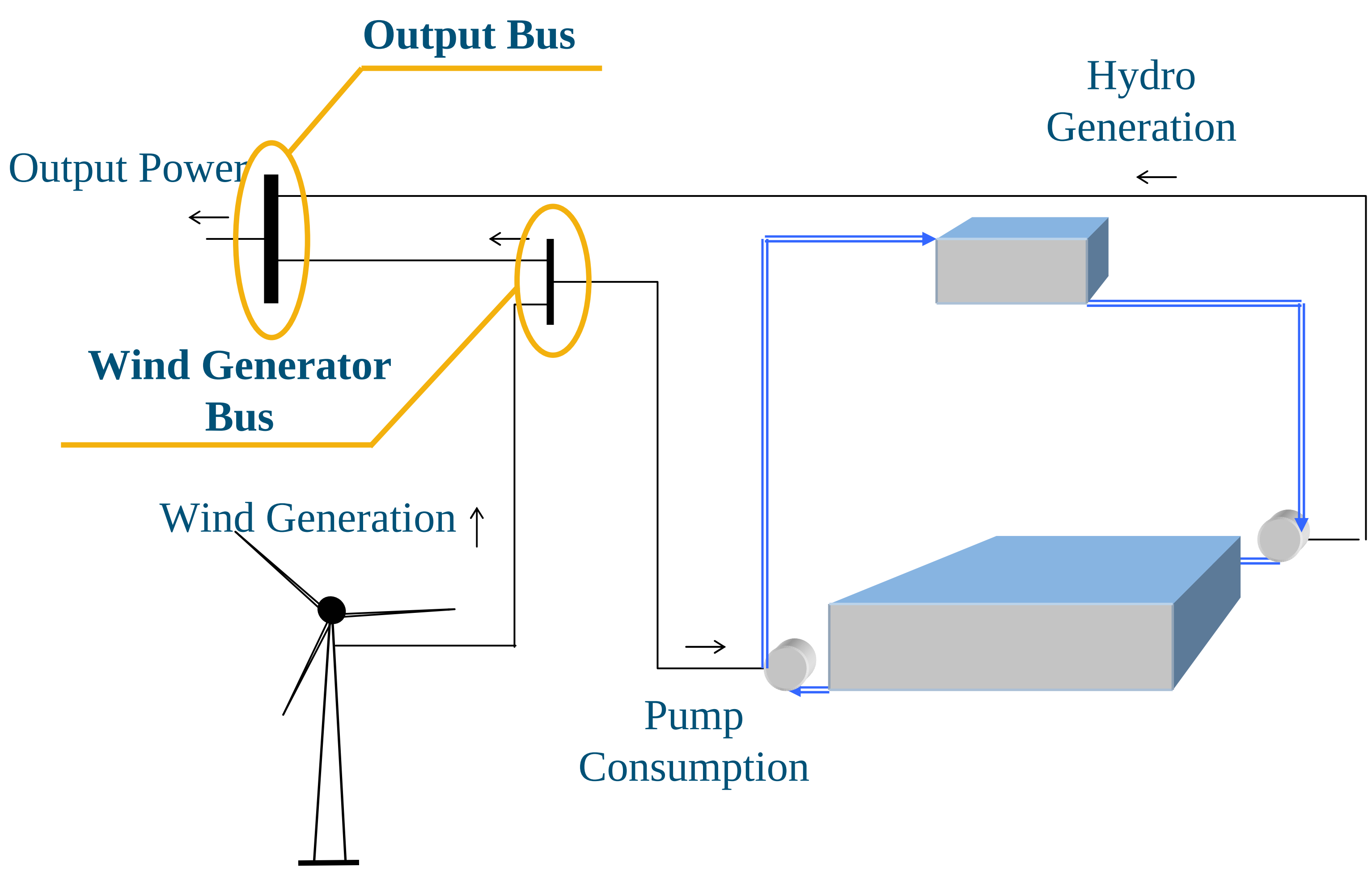



**Prospective generation allocation in a winter windy wet day (2011)**

# Combined storage operation strategies - definition and modelling



# Combined storage operation strategies - definition and modelling



## Combined storage operation strategies - definition and modelling

- **Needed data:**
  - $E^U$ , reservoir storage capacity;
  - $\eta_p$ , efficiency of water pump station and water pipes network;
  - $\eta_h$ , efficiency of the water reservoir and hydro generator;
  - $E_1^{esp}$ and $E_{n+1}^{esp}$, initial and final levels of the reservoir;
  - $Ph^L$ and $Ph^U$ , lower and upper production power limits of the hydro generator;
  - $Pp^L$ and $Pp^U$, lower and upper physical power limits of the pump station, respectively.

data about the remuneration of energy delivered to the grid and costs of storing energy for each time interval of the period under analysis are required.

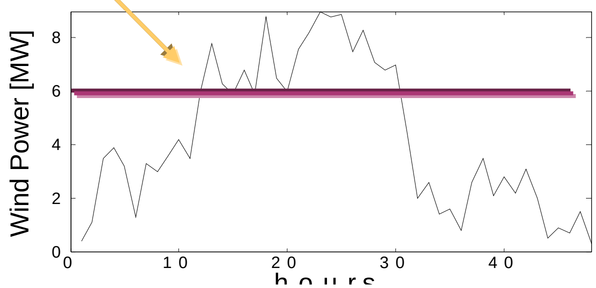
# Combined storage operation strategies - definition and modelling

- An optimization problem for a given time horizon (eg: 24h)
  - Where the inputs of the problem are:
    - the hourly wind power generation forecasts
    - a vector of hourly active power prices
    - a vector of pump operation cost for the same period.
    - Under market environments a forecast of the energy prices for each time step needs to be obtained for the same period.

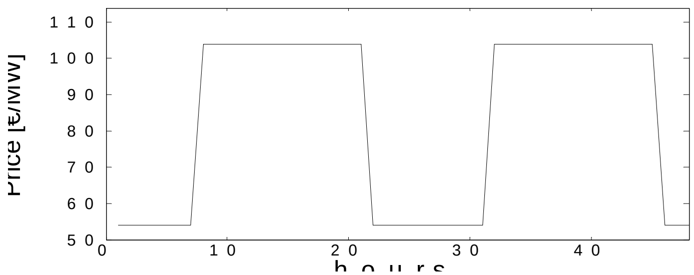
# Combined storage operation strategies - definition and modelling

| | |
|---|---|
| Max. $\sum_i \left( c_i\, P_i - cp\, Pp_i \right)$ | **Output Wind-Hydro Generation and Pump Costs** |
| $P_i = Pw_i + Ph_i$ | **Output Bus Balance** |
| $Pv_i = Pw_i + Pp_i + P_{DLi}$ | **Wind Bus Balance** |
| $E_{i+1} = E_i + t \left( \eta_p\, Pp_i - \dfrac{Ph_i}{\eta_h} \right)$ | **Energy Reservoir Balance** |
| $E_1 = E_1^{esp}$ <br> $E_{n+1} = E_{n+1}^{esp}$ | **Initial and Final Reservoir Conditions** |
| $P_i^L \le P_i \le P_i^U$ | **Output Generation Limits** |
| $Pg^m \le \left( Pw_i + Pp_i \right) \le Pg^M$ | **Wind Park Generation Limits** |
| $Ph^m \le Ph_i \le \min\left( Ph^M, \eta_h \dfrac{E_i}{t} \right)$ | **Hydro Generation Limits** |
| $Pp^m \le Pp_i \le Pp^M$ | **Pump Station Limits** |
| $0 \le E_i \le E^M$ | **Stored Energy Reservoir Limits** |
| $i = 1, \ldots, n$ | |

Network limit




Forecasted Available Wind Power



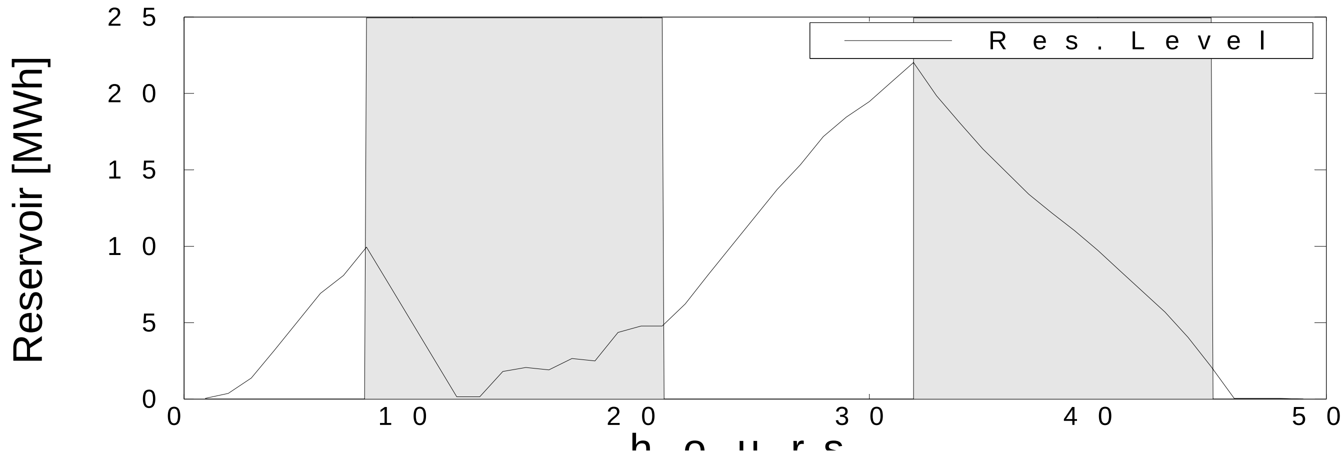

Active Power Price

(Decreto-Lei Nº 168/99 and Decreto-Lei Nº 339-C/2001)

| | | | | |
|---|---|---|---|---|
| $Pg^M$ [MW] | $Ph^M$ [MW] | $Pp^M$ [MW] | $\eta_L$ | $cp$ [€/MWh] |
| 11 | 2 | 2 | 0.75 | 2 |
| $E^M$ [MWh] | $E_1^{esp}$ [MWh] | $E_{n+1}^{esp}$ [MWh] | $P^L$ [MW] | $P^U$ [MW] |
| 22 | 0 | 0 | 0 | 6.0 |

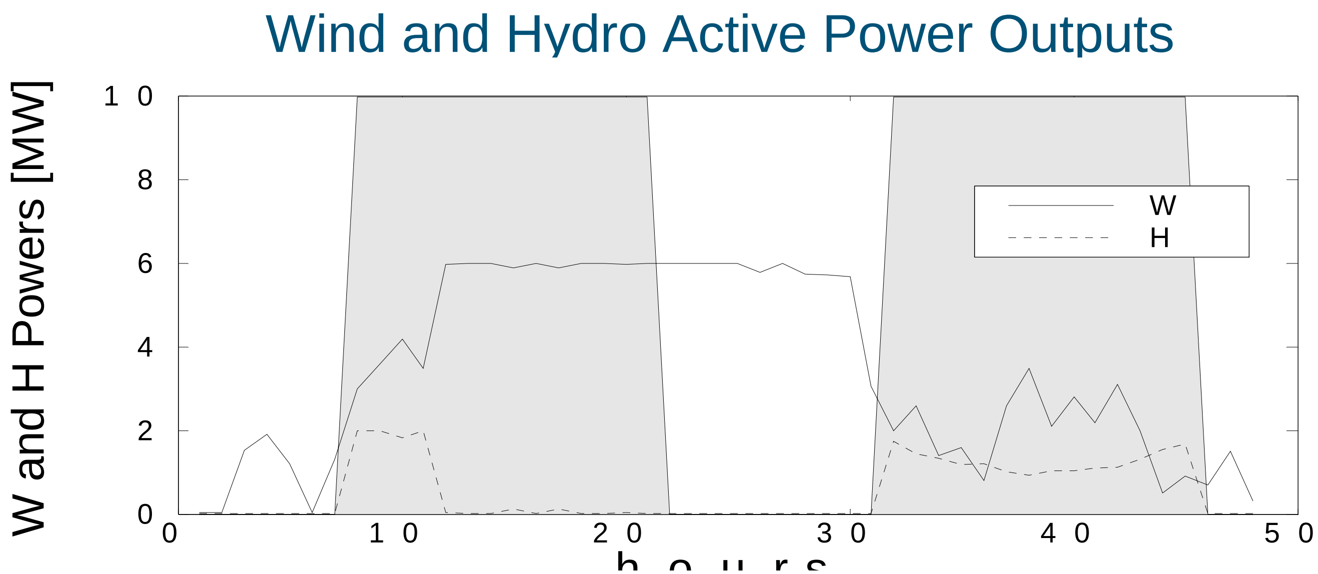
# Combined storage operation strategies - definition and modelling

## Storage Levels in the Upper Reservoir




In low price periods, the upper reservoir always increases its storage level. In the second part of first high price period, the storage can be increased because restrictions in the output generation are reached.

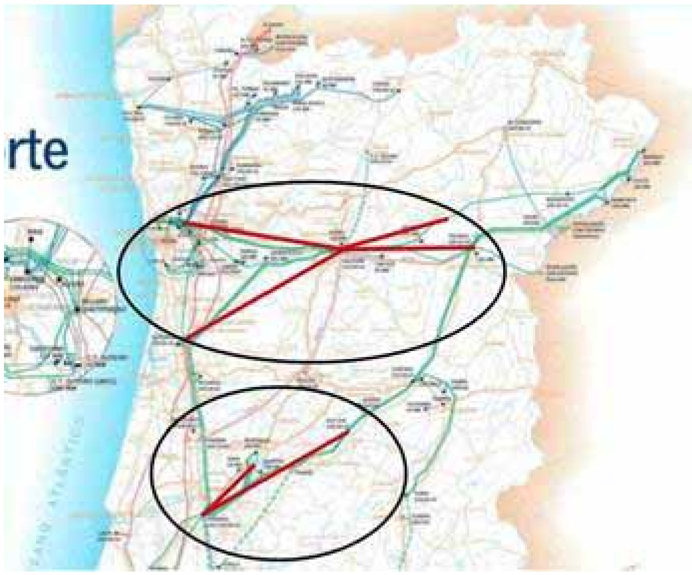
# Combined storage operation strategies - definition and modelling

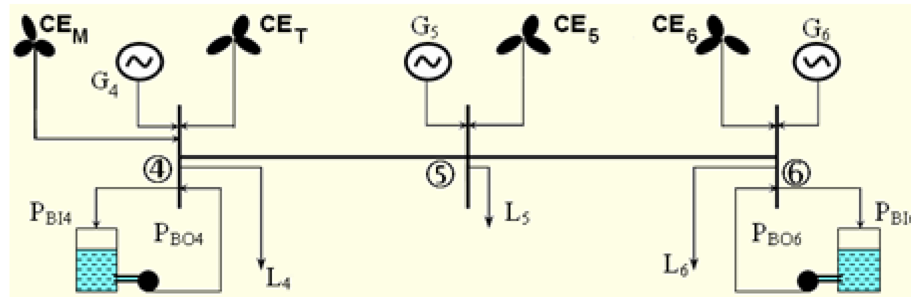


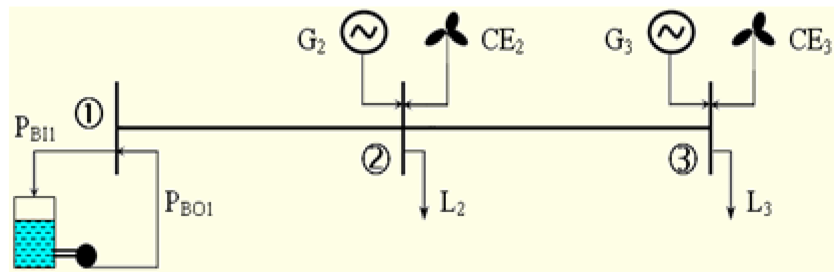

The hydro generator (dotted line) only operates in high price periods.

# Managing Multiple storage systems

**Solve a daily wind-hydro plant operation optimization problem.**



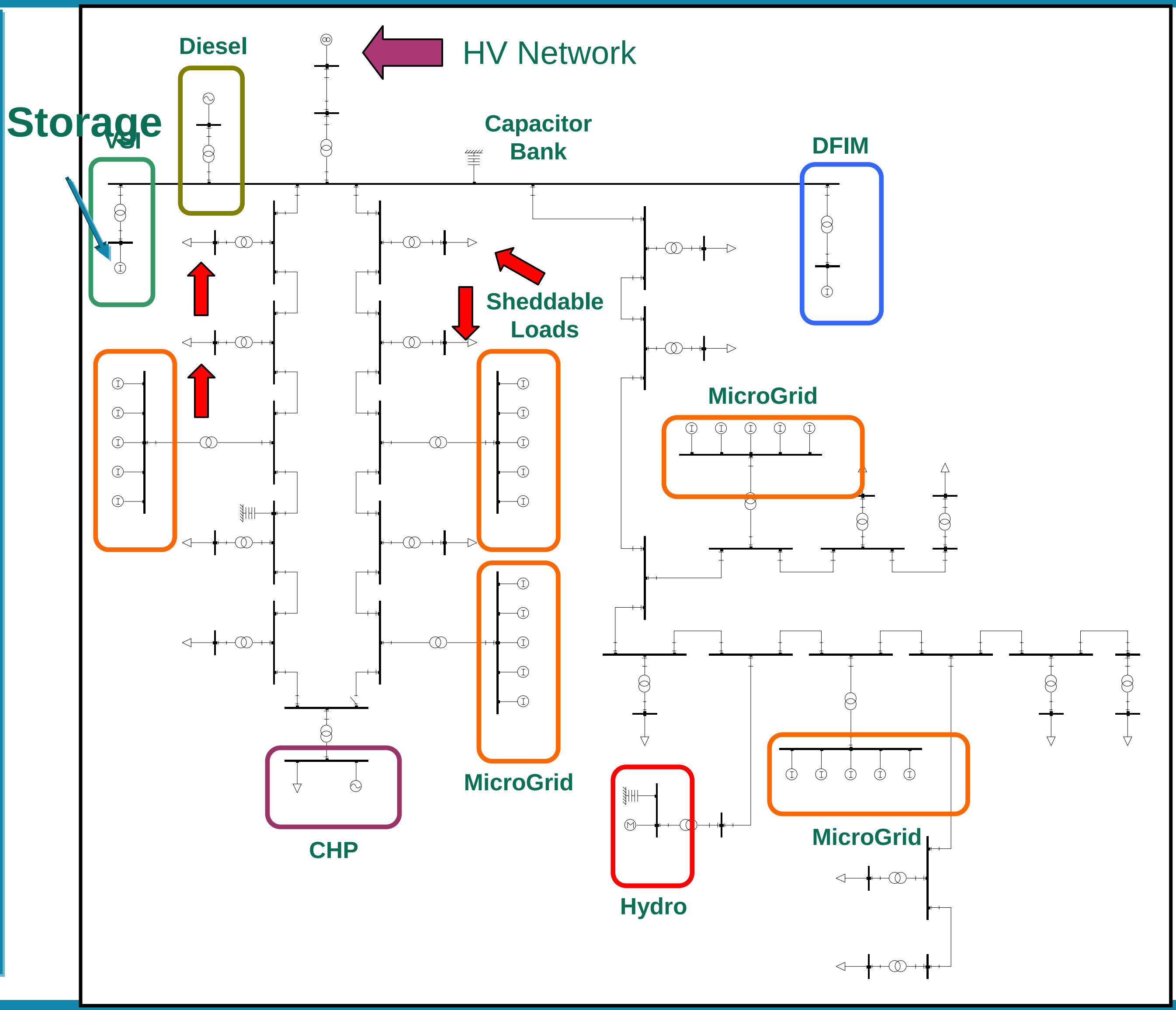




Input data:
- network data
- wind parks power production
- hydro with pumped storage stations data
- market issues

Output data:
- hourly active power to be generated by the hydro and wind generators for 24 h.
- storage levels and the pump operational strategy in the period
- combined wind-hydro economic gains

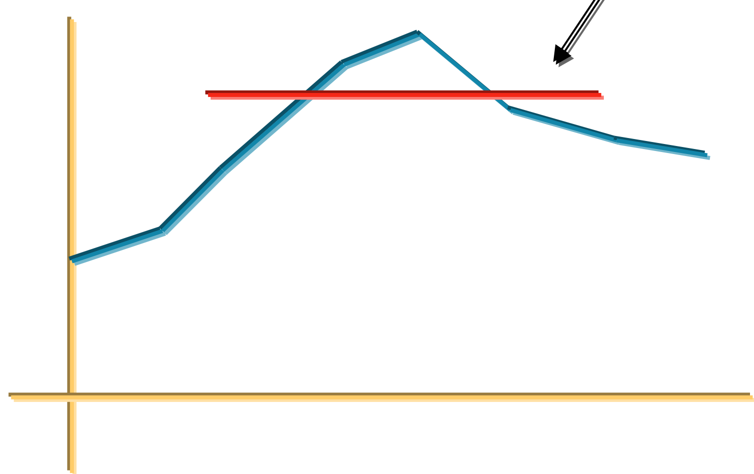
# Multi-microgrids – MV distribution network of the future

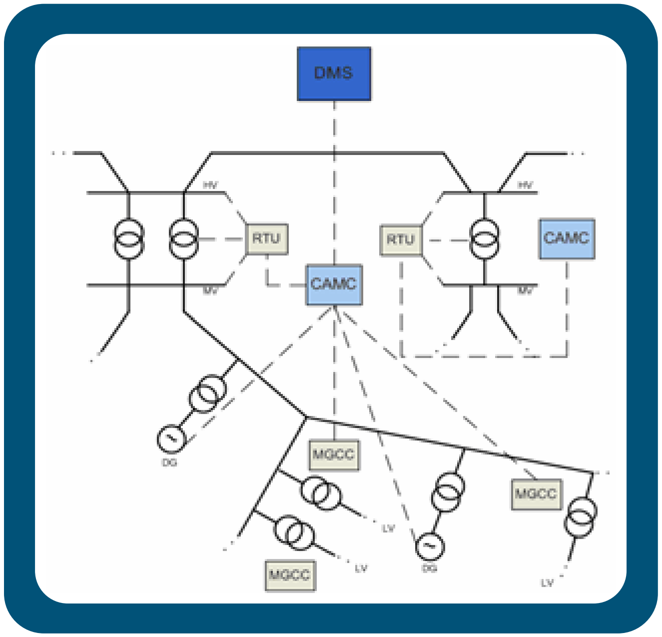
- Microgrids
  - DFIM
  - Fuel Cell
  - Microturbine
  - Storage (VSI)
  - PV
- Storage device-VSI
- Large DFIM
- Hydro
- CHP
- Small Diesel
- Sheddable Loads



## Multi-microgrids – MV distribution network of the future

- Storage devices in MV (and LV) networks can be used for:
  - Peak shaving purposes (controled from a local control structure – CAMC)





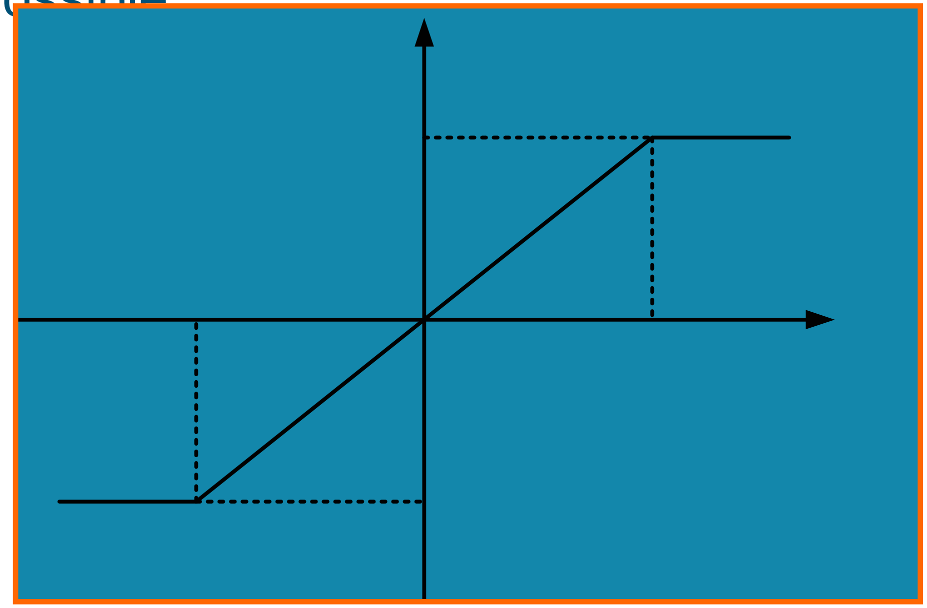
# MicroGrid: A Flexible Cell of the Electric Power System

**MG Hierarchical Control:**

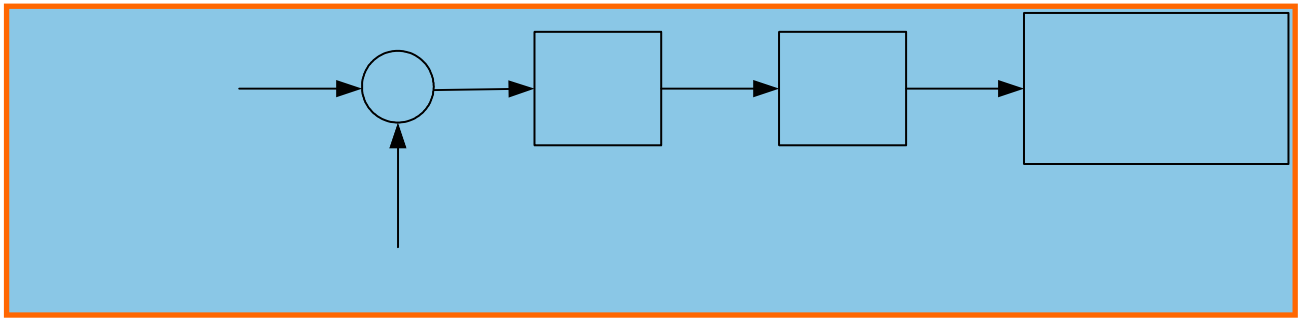
- MGCC, LC, MC
- Communication infrastructure

# MicroGrid and or Multi-Microgrid Operation and Control

- Storage device's active power output is proportional to the MG frequency deviation (droop control) → Islanding operation is possible

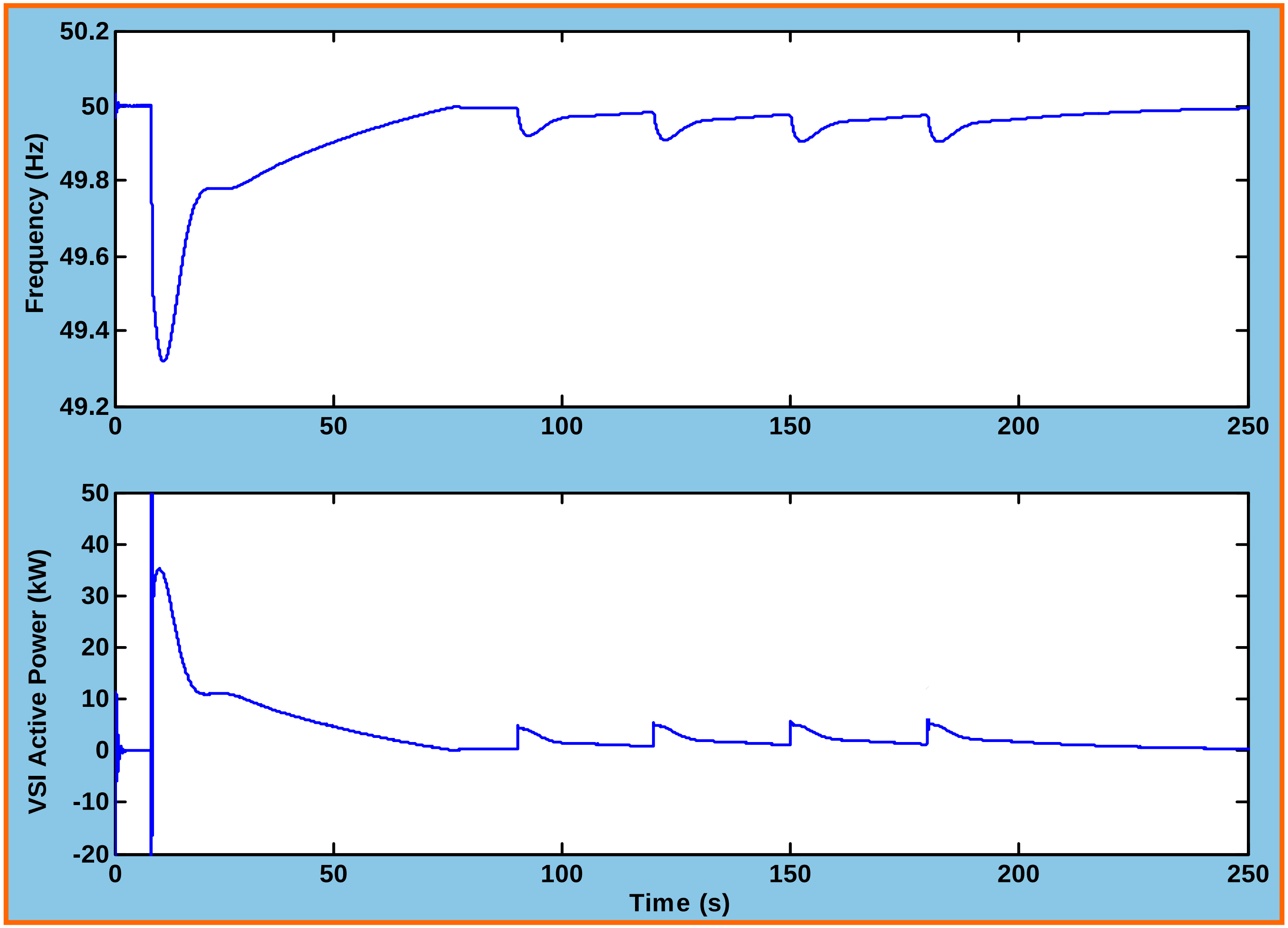


**Correct permanent frequency deviations during islanding operation**



# Results from Simulations (in islanding conditions)

- Frequency and VSI/Storage device Active Power output



# Conclusions

- **Intelligent management of storage** will allow the increase of renewable power sources penetration in the power system;
- **Arbitrage function provided by storage** could annihilate most of extra network reinforcement and reduce balancing expenses;
- **Storage active control** will allow the development of the Microgrids concept and will bring more reliability to final consumers;
- **Plug-in hybrid vehicles** will contribute to management of electricity demand with major impacts on network control.

# Thank you

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