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Multi-Microgrids

coordinated voltage and frequency control, emergency functions and ancillary services

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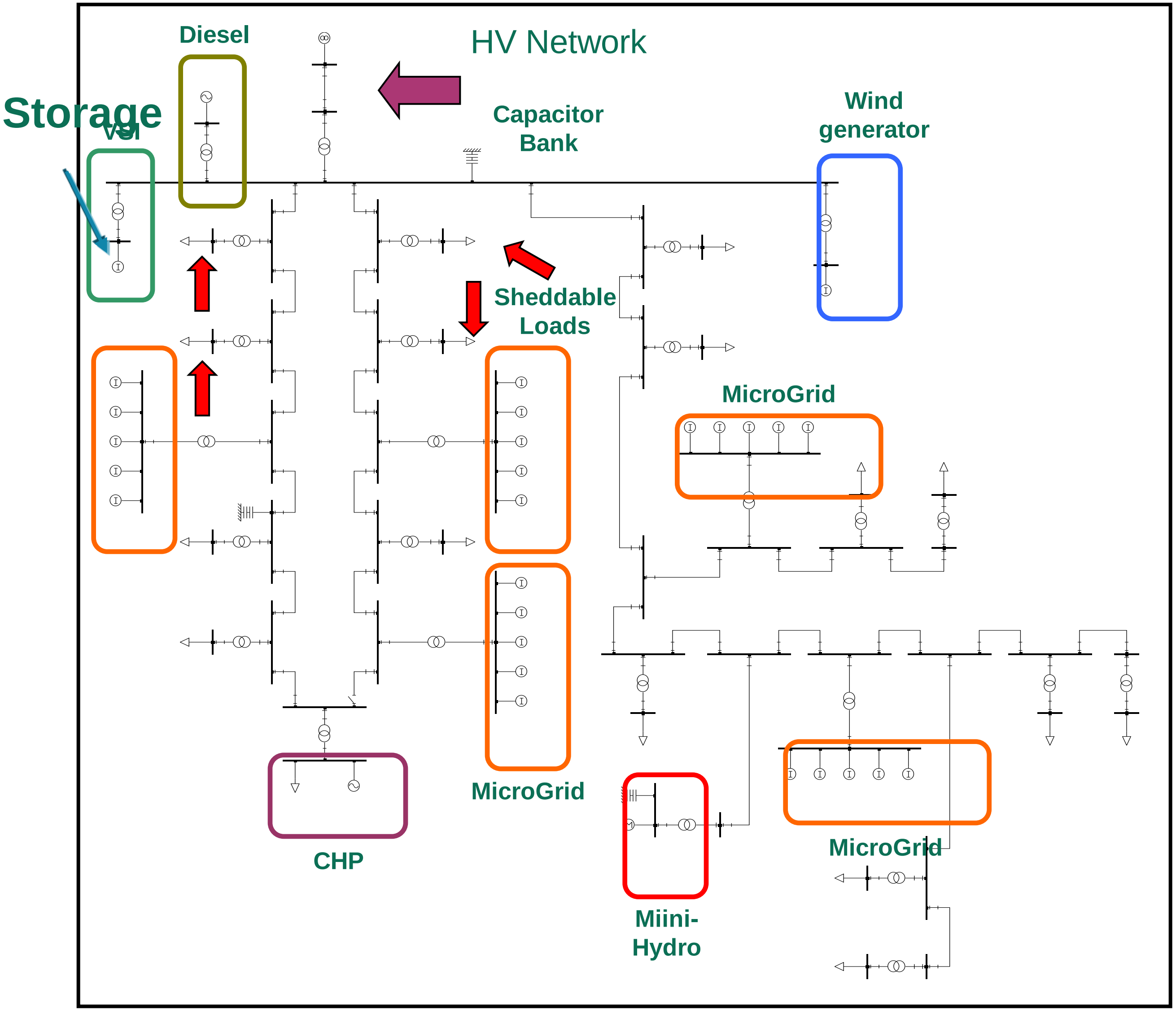
MicroGrid: A Flexible Cell of the Electric Power System

MG Hierarchical Control:

- MGCC, LC, MC
- Communication infrastructure

Multi-microgrids – MV distribution network of the future

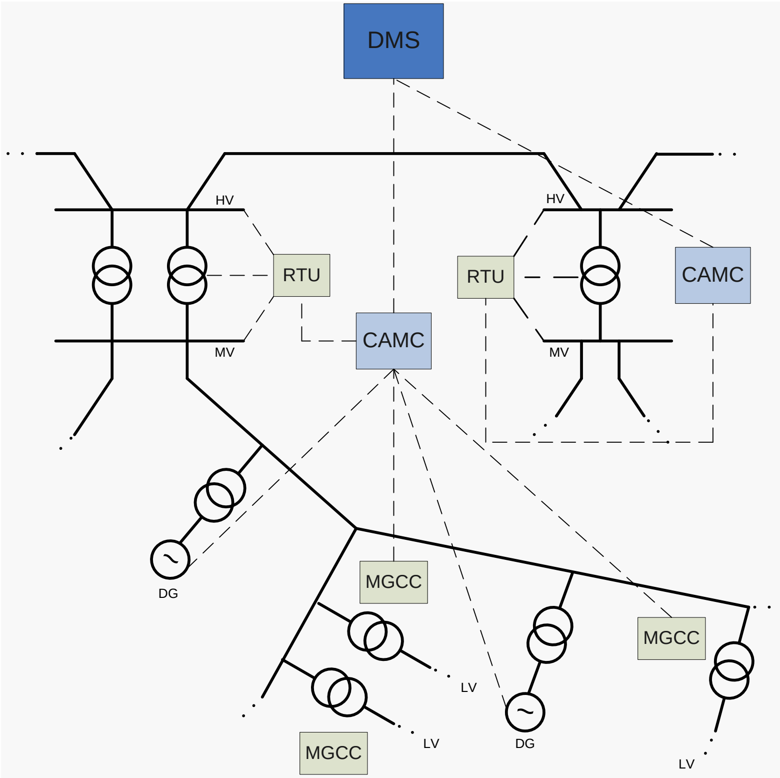
- Microgrids
- Storage device-VSI
- Large DFIM
- Mini-Hydro
- CHP
- Small Diesel
- Sheddable Loads



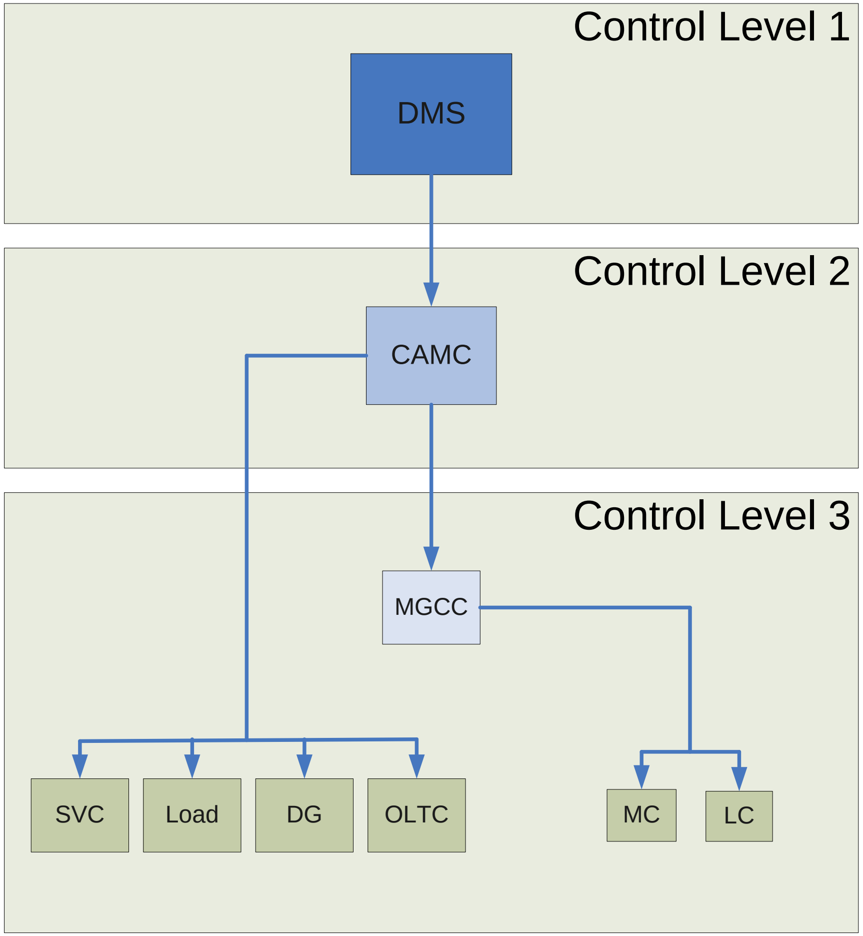
The concept: Multi Microgrids

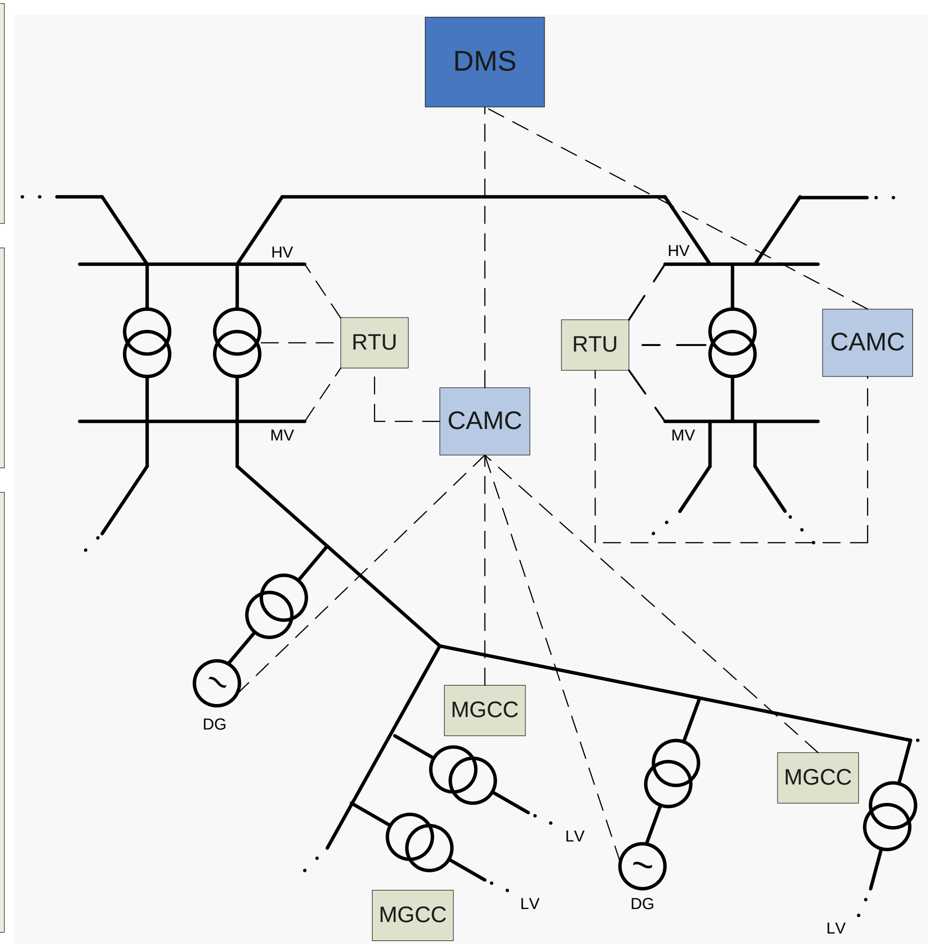
- Integration of several Microgrids in MV networks

- Active Management of microgrids, DG units and loads for
  - Normal Steady-state Operation or
  - Emergency Conditions



Multi-MicroGrids: Interaction of MGCC and DMS





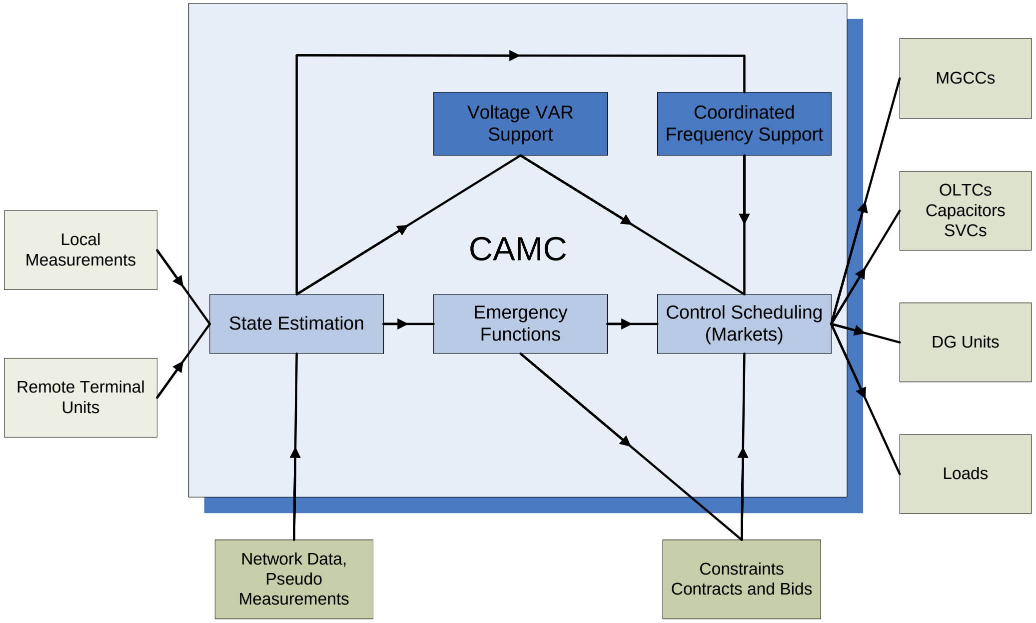
Control Scheme of a Multi-MicroGrid System

- Energy / Services… to be provided in each operating mode (Normal and Emergency)
- Different services can be provided by these agents regarding MicroGrids and Distribution / Transmission Network Operators

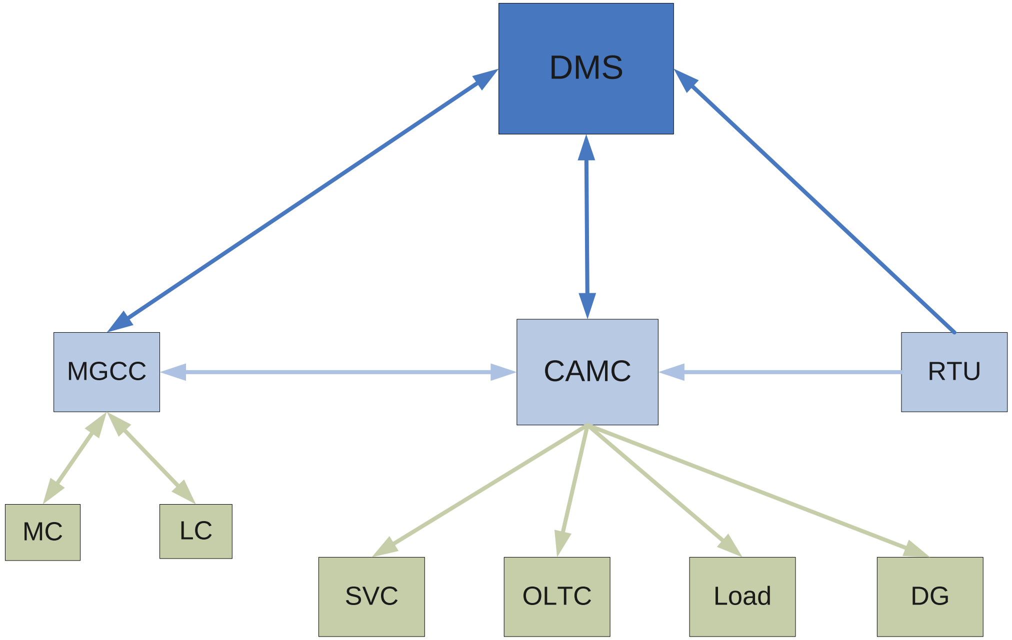
- A list of new DMS functionalities
- List of needed data was identified

Management of the Multi-MicroGrid

- Existing DMS functionalities need to be adapted to Multi-MicroGrid operation
- The management of the Multi-MicroGrid will be performed through the CAMC using an Hierarchical Control Architecture, which requires new functionalities like:
  - Local State Estimation
  - Coordinated Voltage Support and Flow Control
  - Peak shaving
  - Coordinated Frequency Support



- **Communication Scheme of a Multi-MicroGrid System**

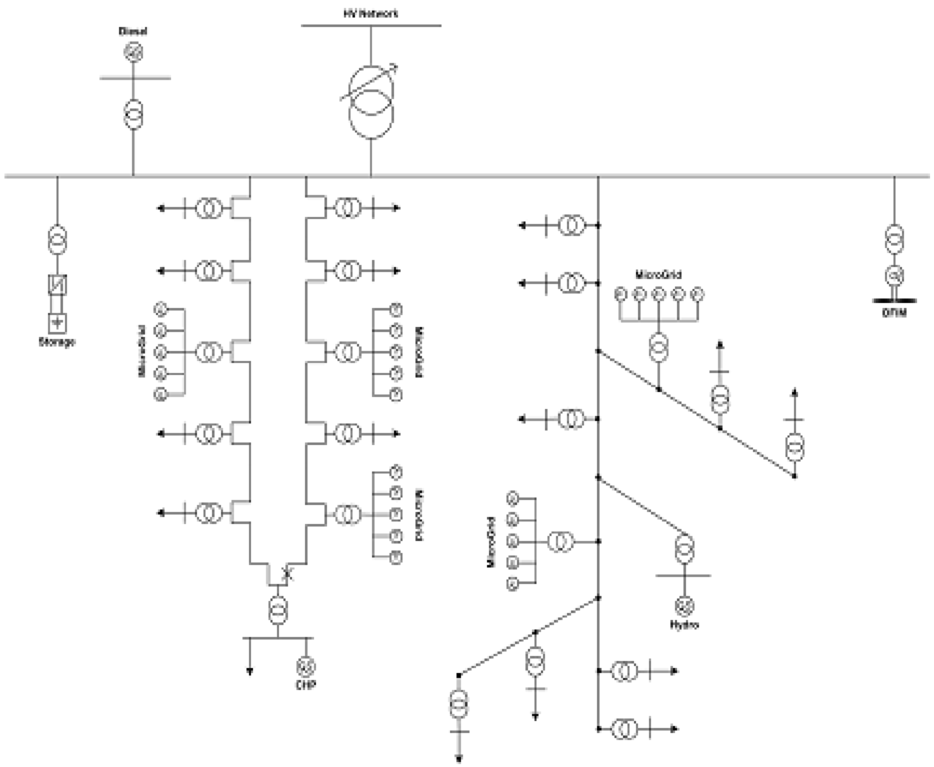


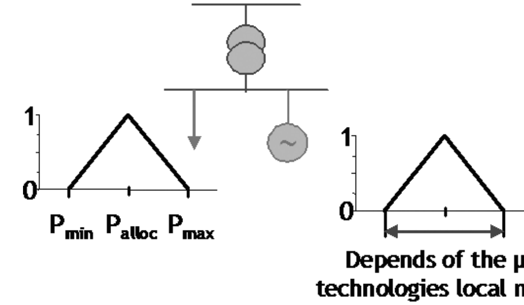
Local State Estimation

- Traditional State Estimation routines for DMS can be adapted to the new paradigm of Multi-MicroGrid systems
  - New algorithms for Distributed State Estimation in order to minimize the amount of data required
  - Fuzzy State Estimation approaches

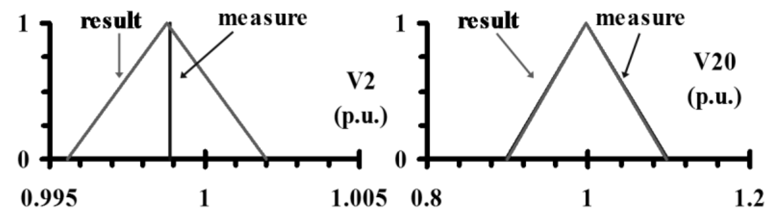
Local State Estimation

FUZZY STATE ESTIMATION

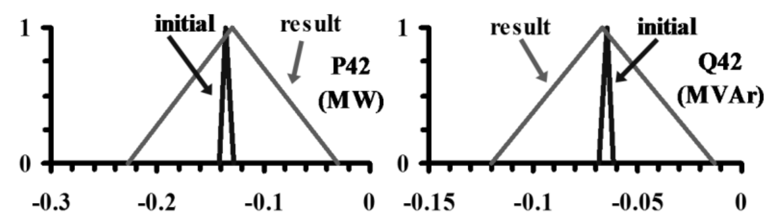




Type of Fuzzy Information considered on the MicroGrids



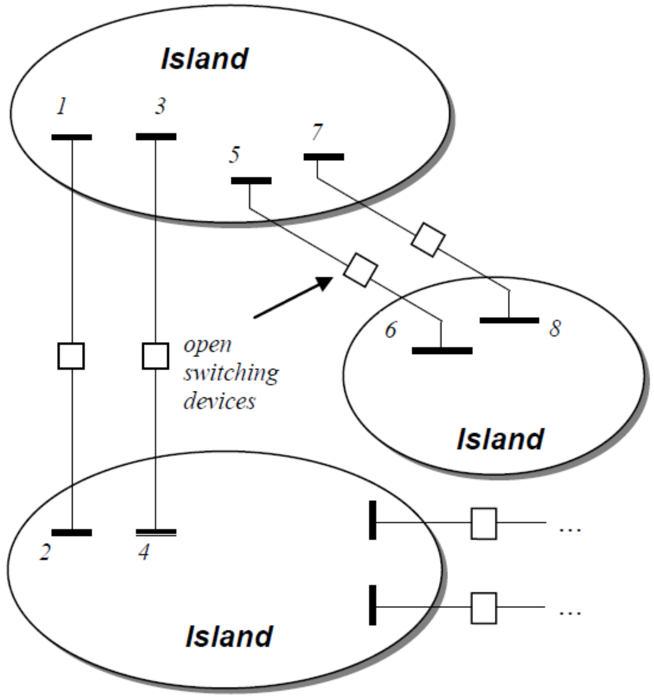
Membership Functions for the Measurements and for the Results of the Voltage Magnitude in the Buses 2 and 20



Membership Functions for the Measurements and for the Results of the Active and Reactive Power injected on Bus 42

Estimation of bus voltages (both module and phase), power injections for each bus and power flows and current in each branch

DISTRIBUTED STATE ESTIMATION



Each area is governed by a *Local State Estimator* that is responsible for estimating its own state

The areas exchange information through communication links to a *Coordination State Estimation*

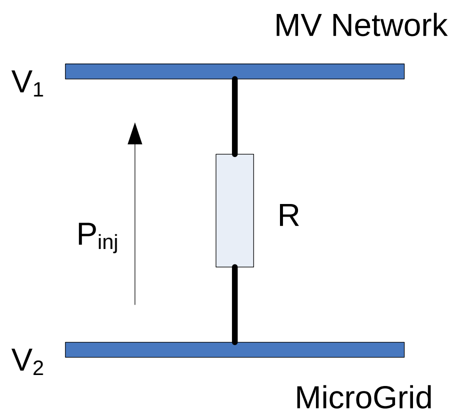
- Two types of tools for the Coordination of Volt/VAR Control:
  - Tools based on a local control approaches (using conventional techniques)
  - Tools based on a global coordinated approach (using meta-heuristics – EPSO)
- The developed approaches make full use of the control capabilities provided by MicroGrids, DG Units, OLTC Transformers and Capacitor Banks

- High DG penetration may cause voltage rise problems, especially in the case of weak distribution networks

- The effects of voltage rise may propagate to the LV side

- From the power flow equations (in LV networks where R<<X does not apply):

$$P_{inj} = \frac{V_2^{\,2}}{R} - \frac{V_2 \cdot V_1}{R} \cdot \cos(\delta)$$



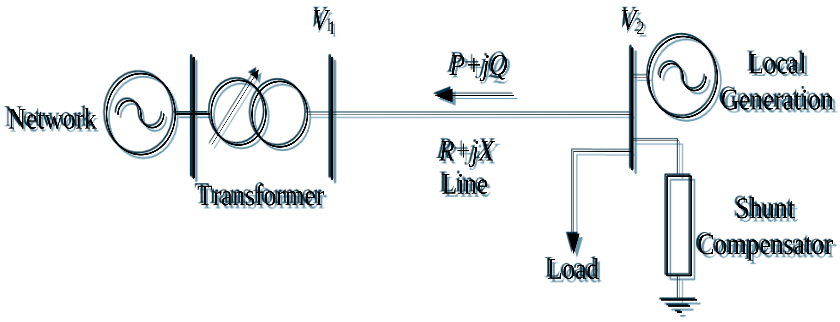
- In conclusion, high DG and microgeneration penetration will require the development of an effective voltage control scheme <u>based on active and reactive power control</u>

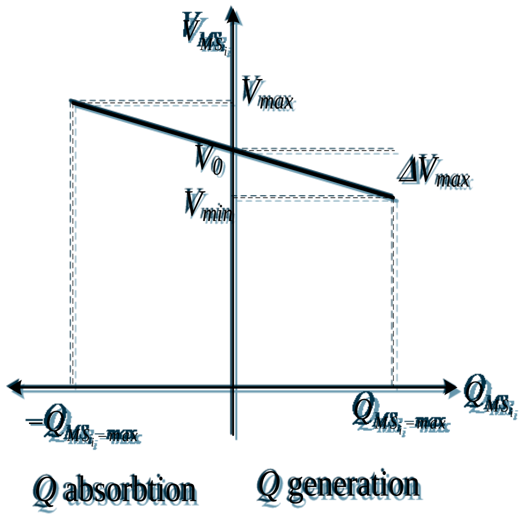
Coordinated Voltage Support and Control

- Voltage/Control in Distribution Systems integrating MicroGrids becomes a hierarchical optimization problem that must be analyzed in a coordinated way between LV and MV levels

- Given the characteristics of the networks, both Active and Reactive Power Control is needed

- **Forms of Control**
  - Generation curtailment
  - Reactive power (Droop control)
  - OLTC





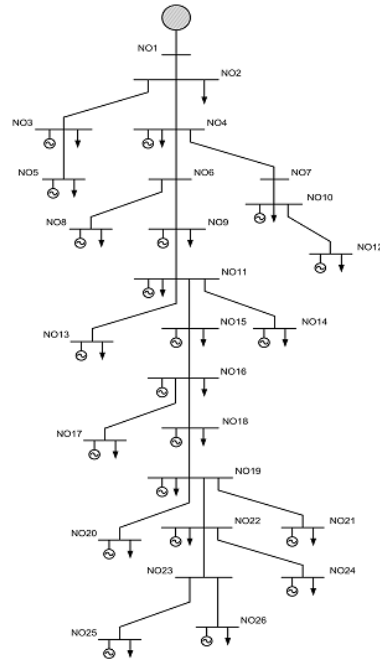
Coordinated Voltage Support and Flow Control

Global Approach

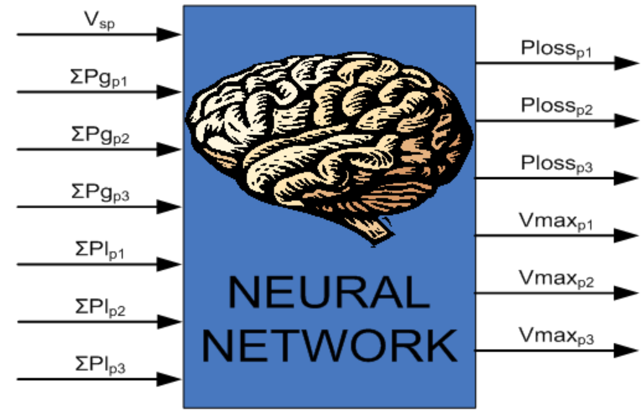
Optimizing distribution network operation in interconnected mode, when dealing simultaneously with DG connected directly to the MV grid and microgeneration installed at the LV side

Controls:

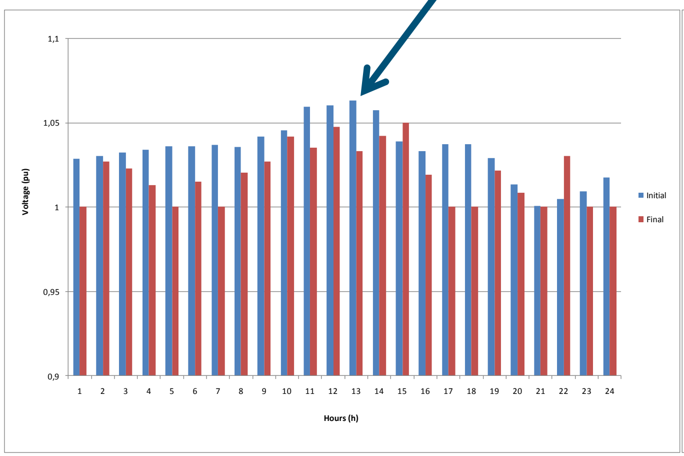
- OLTC Transformer taps
- Reactive power provided by DG Sources and Capacitor Banks
- Active power control at the MicroGrid level in extreme scenarios (using Microgeneration Shedding)

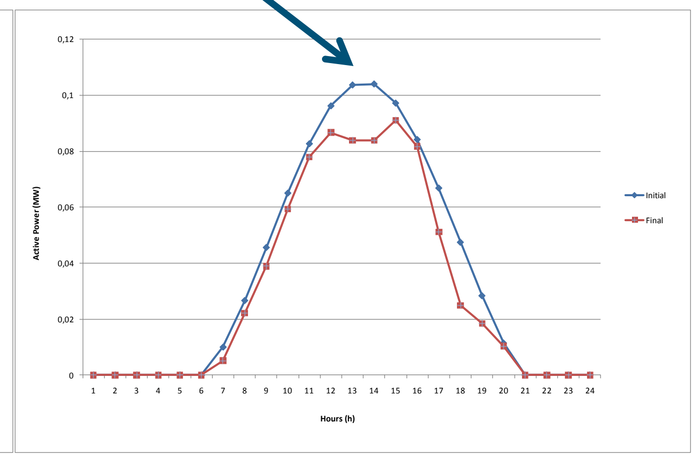


A Neural Network was used to emulate the behavior of the LV MicroGrid



In order to maintain voltage profiles within admissible limits, Microgeneration Shedding was required





Optimization problem within the MMG:

$$P_{G_i} = P_{Gnc_i} + P_{Gc_i}$$

$$P_{L_i} = P_{Lnc_i} + P_{Lc_i}$$

$$\min C_{operation} = \min\left\{\sum_{i=1}^{N} C_{1i} + \sum_{j=1}^{L} C_{2j} + CP_{losses}\right\}$$

$$s.t.$$

$$g(X,U)=0$$

$$I_{ij} \le I_{ij\,\max}$$

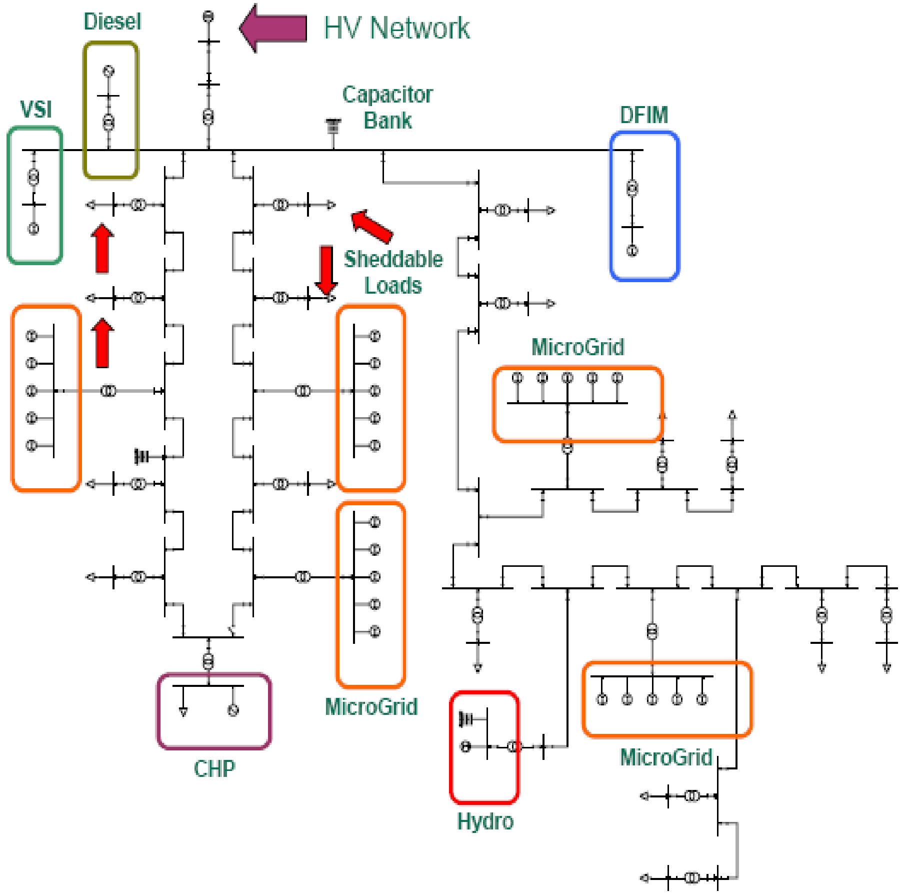
$$U_i \ge U_{\min}$$

$$P^{\min}_{Gc_i} \le P_{Gc_i} \le P^{\max}_{Gc_i}$$

$$0 \le P_{Lc_i} \le P^{\max}_{Lc_i}$$

$$C_{1i} = \left(a_i \cdot P_{Gc_i} + b_i\right) \cdot \Delta t$$

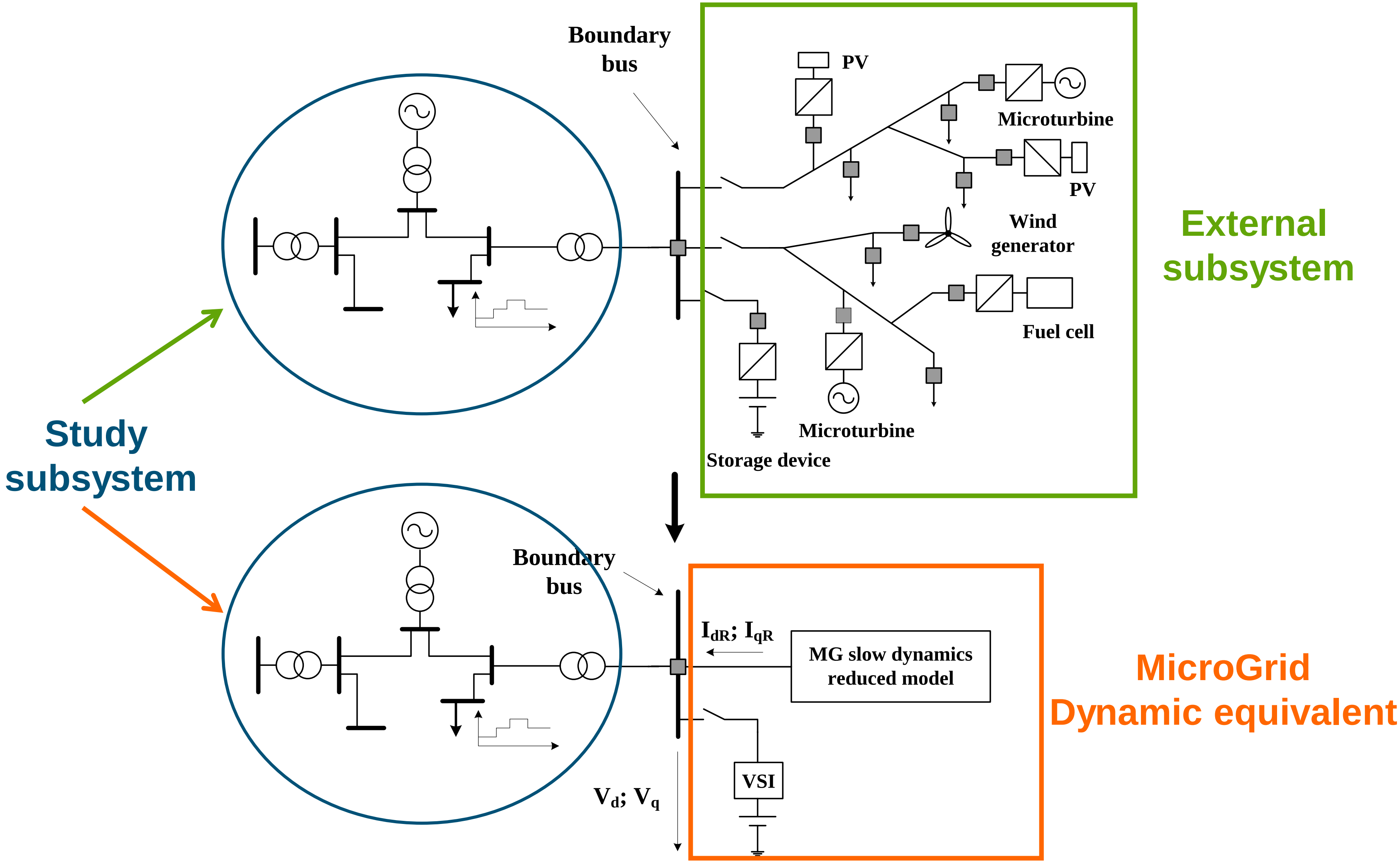
$$C_{2j} = c_j \cdot P_{Lcj} \cdot \Delta t$$



Controlled from the CAMC

Coordinated Frequency Support

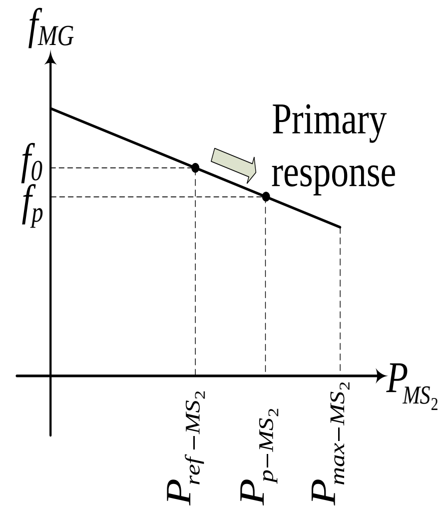
- Effective frequency support can be obtained exploiting decentralized control strategies together with a Hierarchical Approach housed at CAMC and MGCC
- Coordination with Load Curtailment is required
- Dynamic Equivalents of MicroGrids may be needed
- The feasibility and profitability of Ancillary Services provision (namely regarding frequency control) from Multi-MicroGrid should be addressed at different levels:
  - By contributing to general system frequency control (primary and secondary);
  - By allowing islanding operation and black start



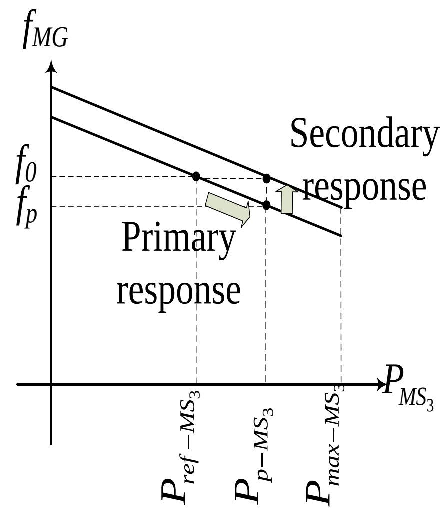
Boundary bus
PV
Microturbine
PV
Wind generator
Fuel cell
Microturbine
Storage device
External subsystem
Study subsystem
Boundary bus
I_{dR}; I_{qR}
MG slow dynamics reduced model
VSI
V_d; V_q
MicroGrid Dynamic equivalent

- MicroSources providing no frequency response

- MicroSources providing primary response using special VSI control solutions

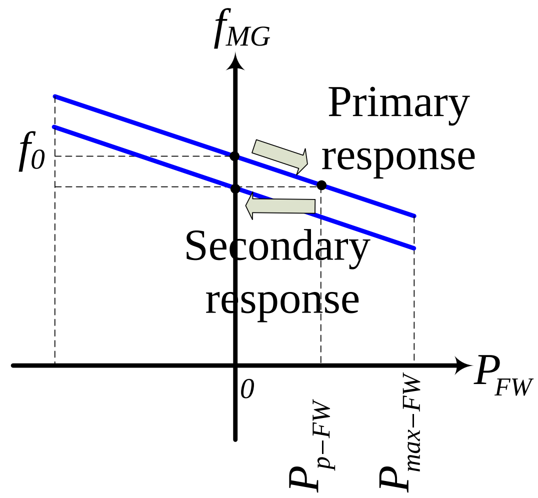


- MicroSources providing primary and secondary responses, exploiting P,Q controlled inverters together with central control

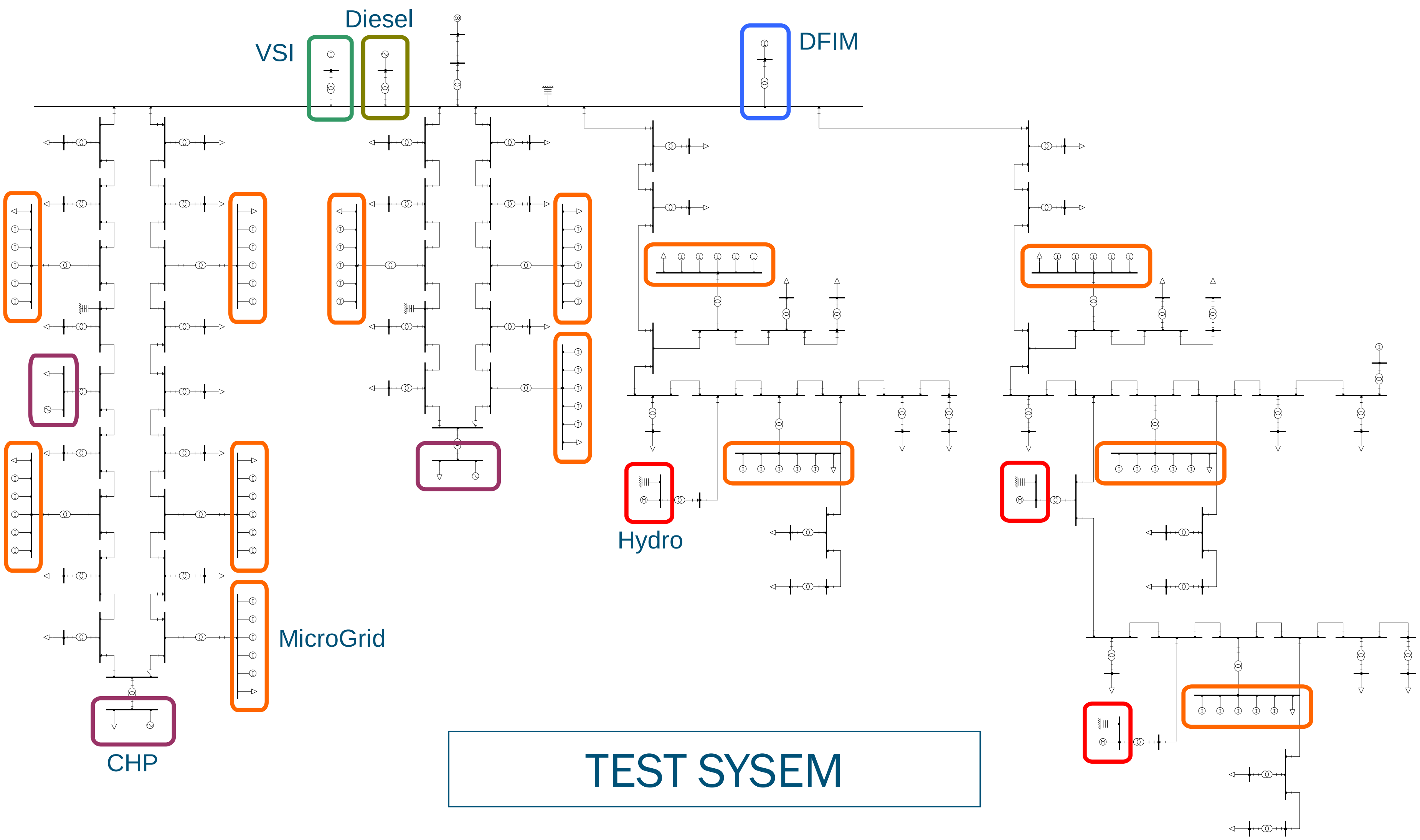


- Flywheel
  - Inertia
  - Short circuit current
  - Initial frequency support

- Frequency target of the flywheel



Coordinated Frequency Support – Multimicrogrid

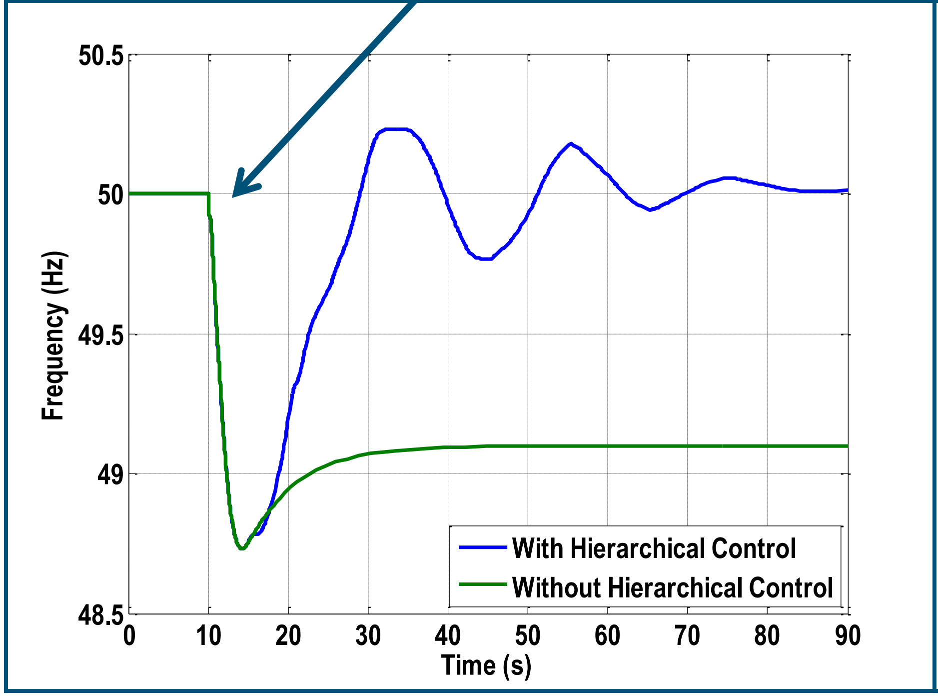


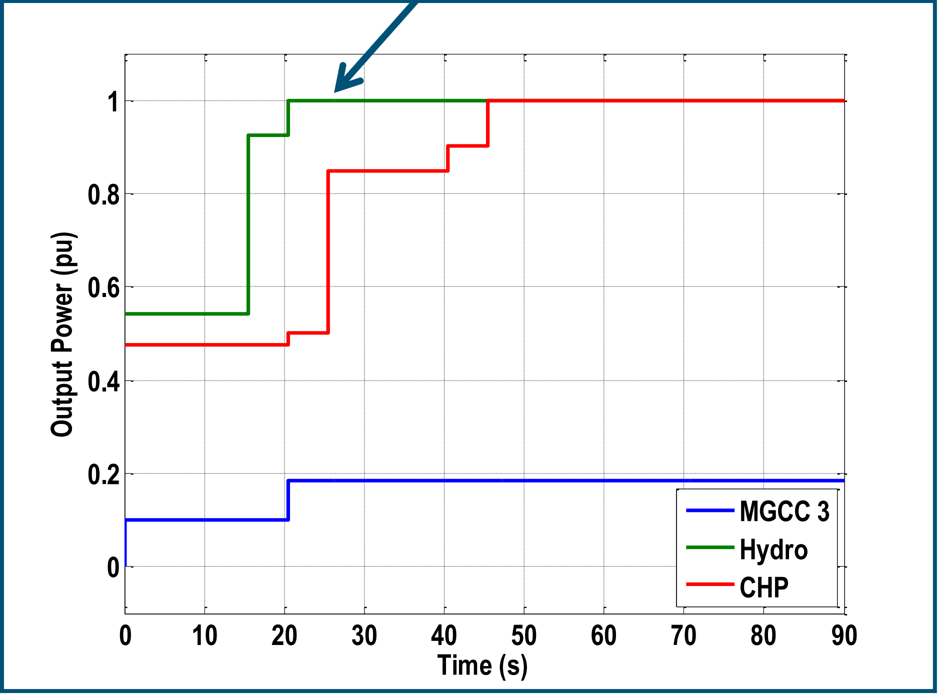
Coordinated Frequency Support

Local secondary frequency control should be designed such that load shedding is also managed

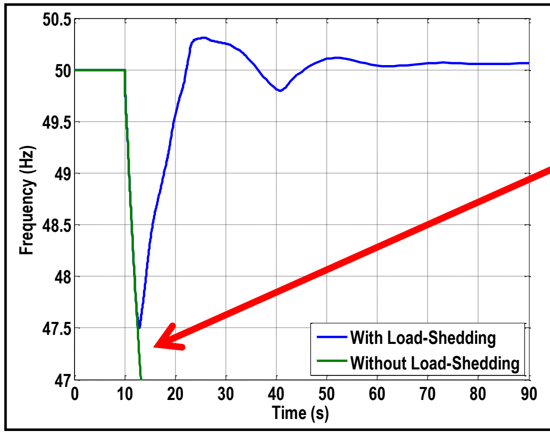
Frequency Deviation following Islanding of the Multi-MicroGrid System

Active Power Set-Points sent by the CAMC to the DG Units and MicroGrids





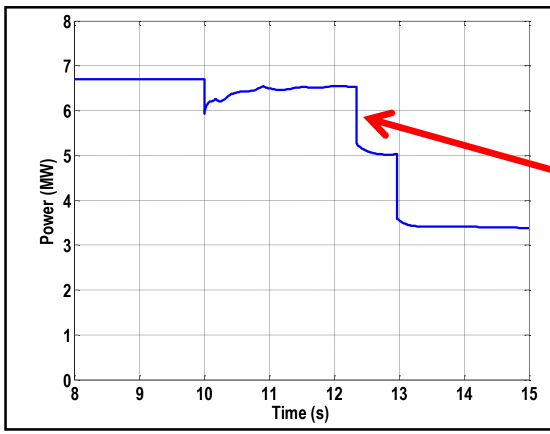
Emergency Functions – Islanding with several MicroGrids



System Collapse

ISLANDING

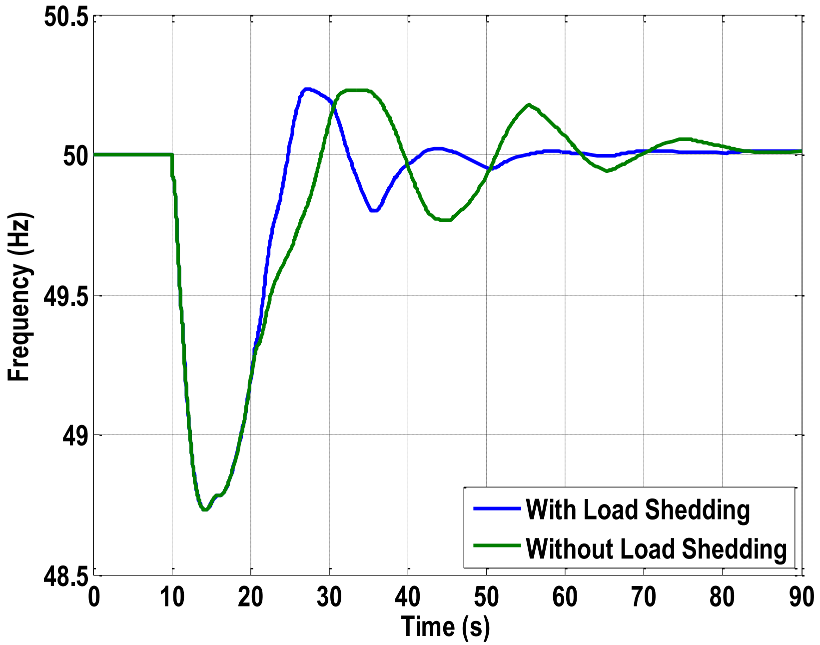
In some extreme situations, Load Shedding may be needed to prevent long frequency excursions and even System Collapse

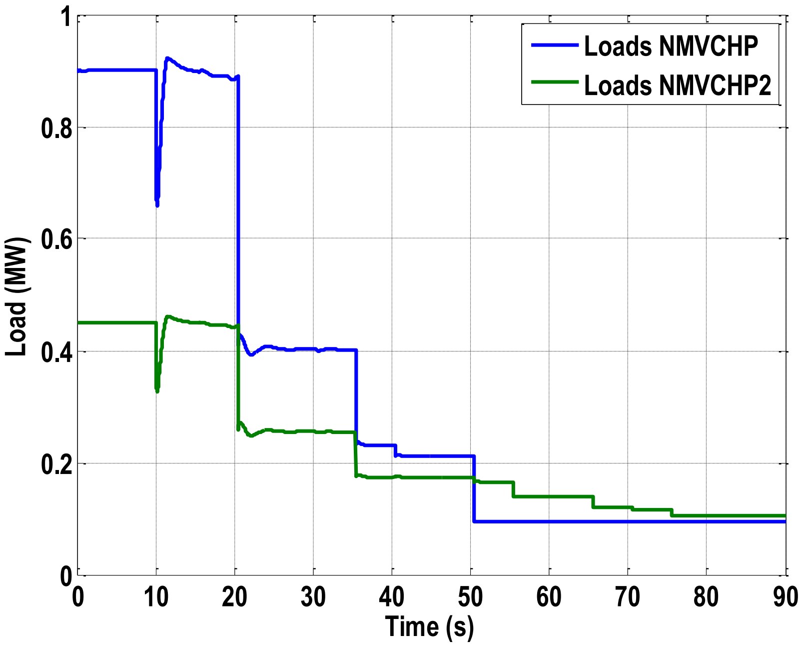


Load Shedding Steps

Centralized Load-Shedding (acting as secondary reserve)

- Controllable loads help to reach rated frequency faster and economically (integrated in an optimal allocation algorithm)
- But are not able to avoid large initial frequency variations.

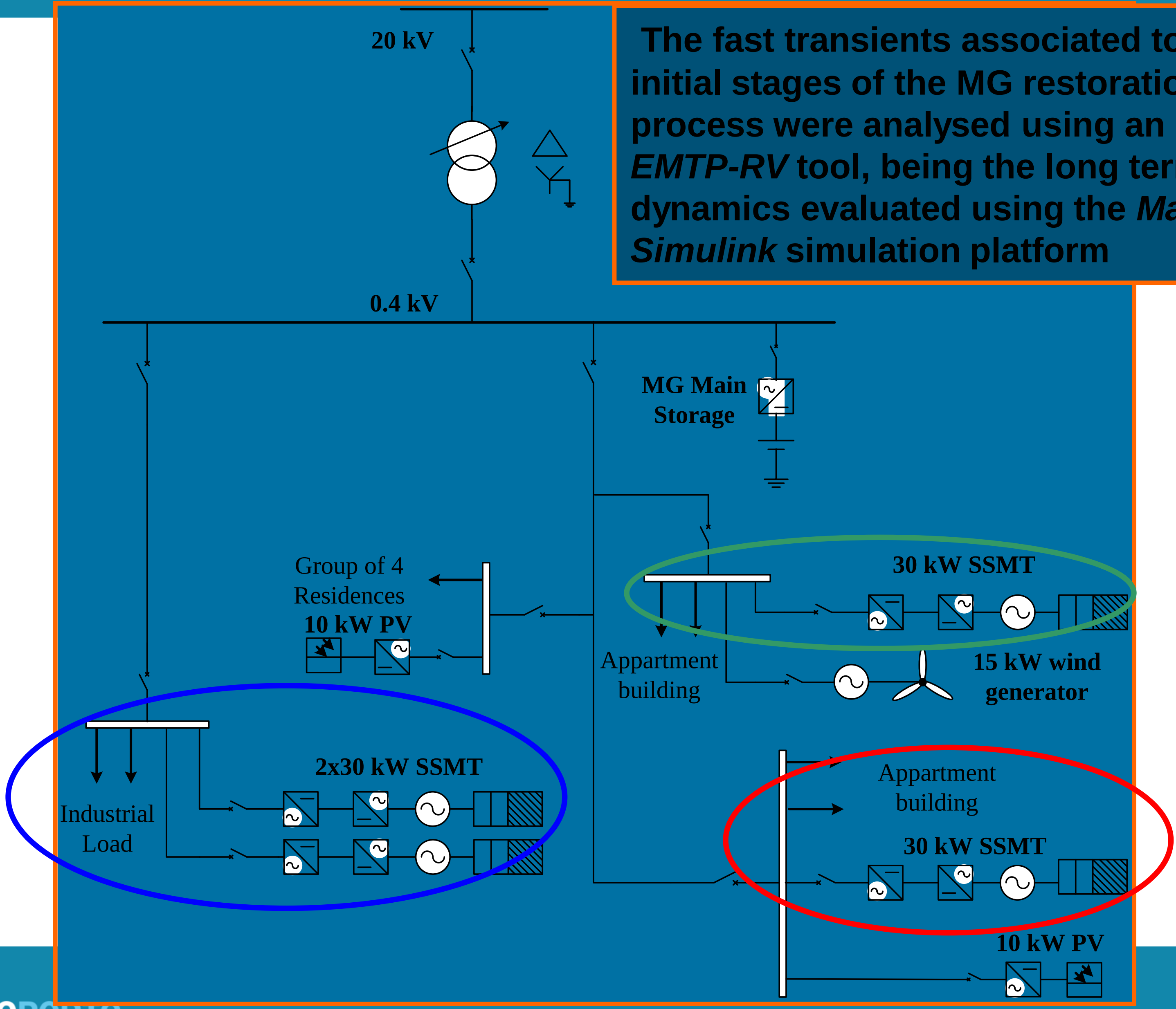




Using MicroGrids for Service Restoration

- Black-Start is a sequence of events controlled by a set of rules
  - A set of rules and conditions are identified in advance and embedded in MGCC software
  - These rules and conditions define a sequence of control actions to be carried out during the restoration stages
  - The electrical problems to be dealt with include:
    - Building LV network
    - Connecting microgenerators
    - Connecting controllable loads
    - Controlling frequency and voltage
    - Synchronization with the MV network (when available)

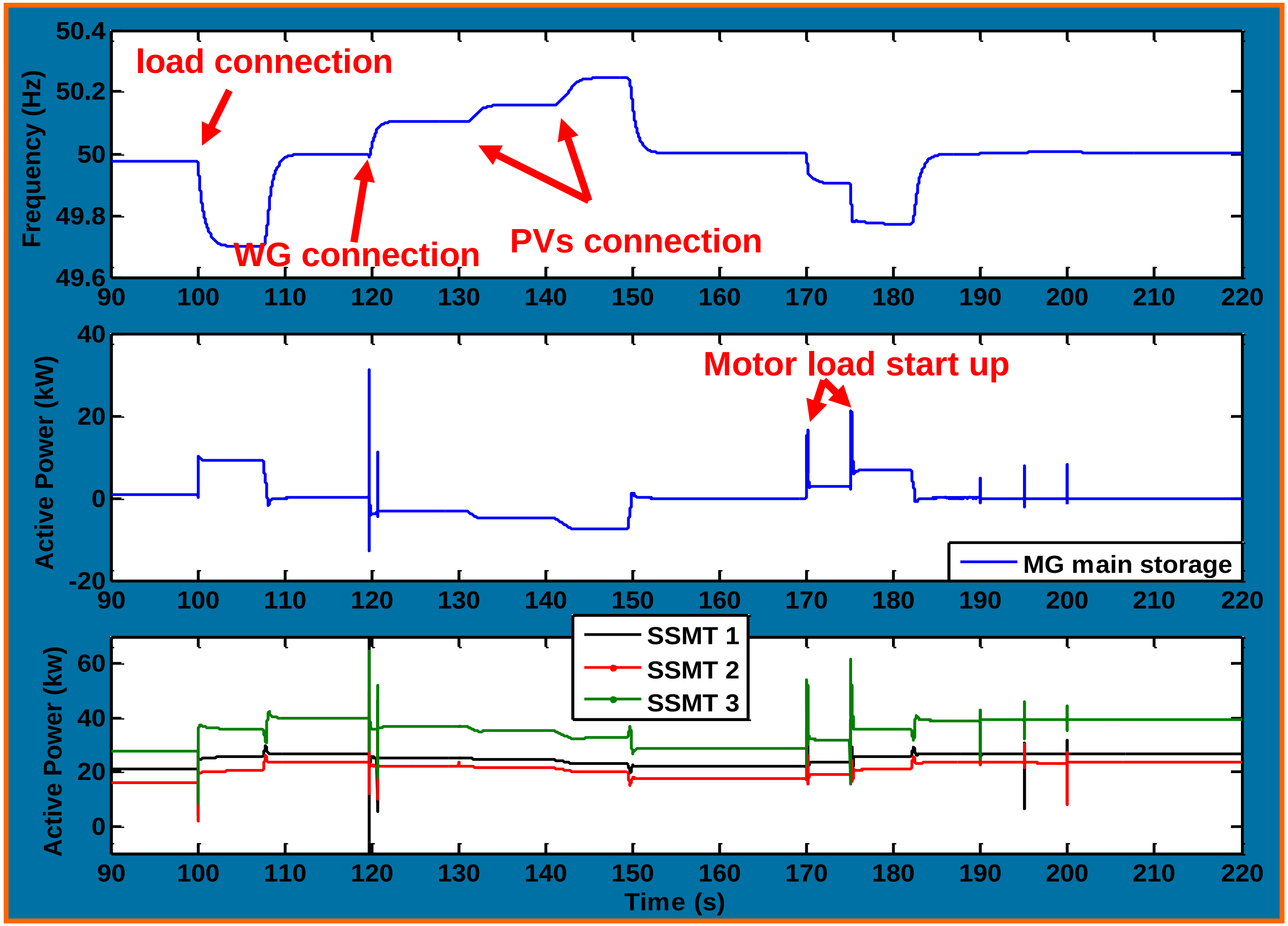
MicroGrid Black Start – Test System



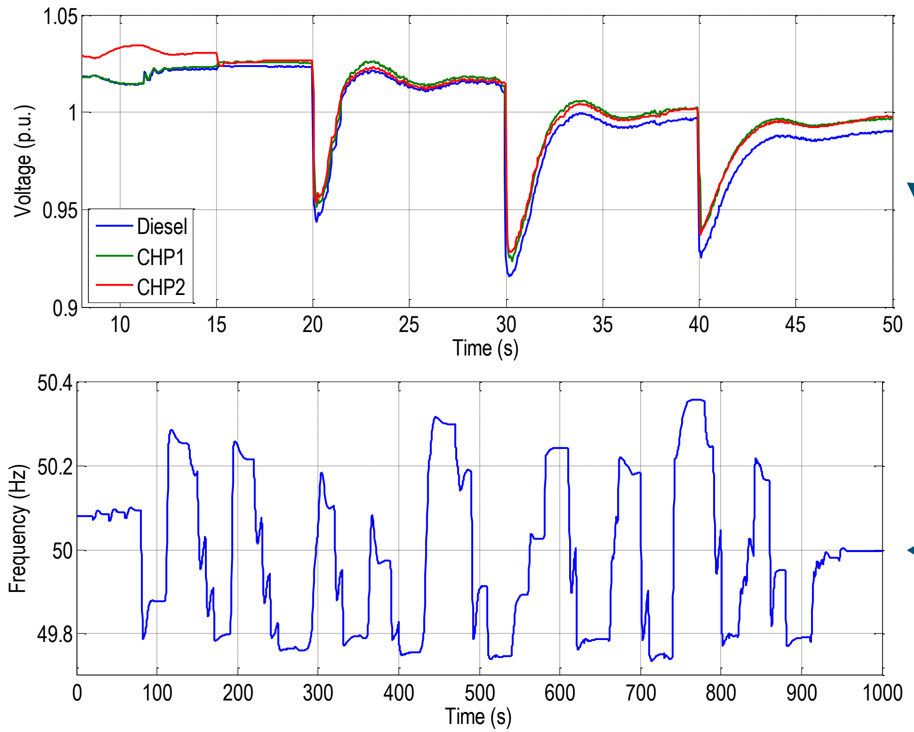
The fast transients associated to the initial stages of the MG restoration process were analysed using an *EMTP-RV* tool, being the long term dynamics evaluated using the *MatLab Simulink* simulation platform

Results from Simulations – Long Term Dynamics

- Development of the Service Restoration Procedure



BLACKSTART



A Bottom-Up Strategy is followed for rebuilding the Multi-MicroGrid network comprising two main stages:

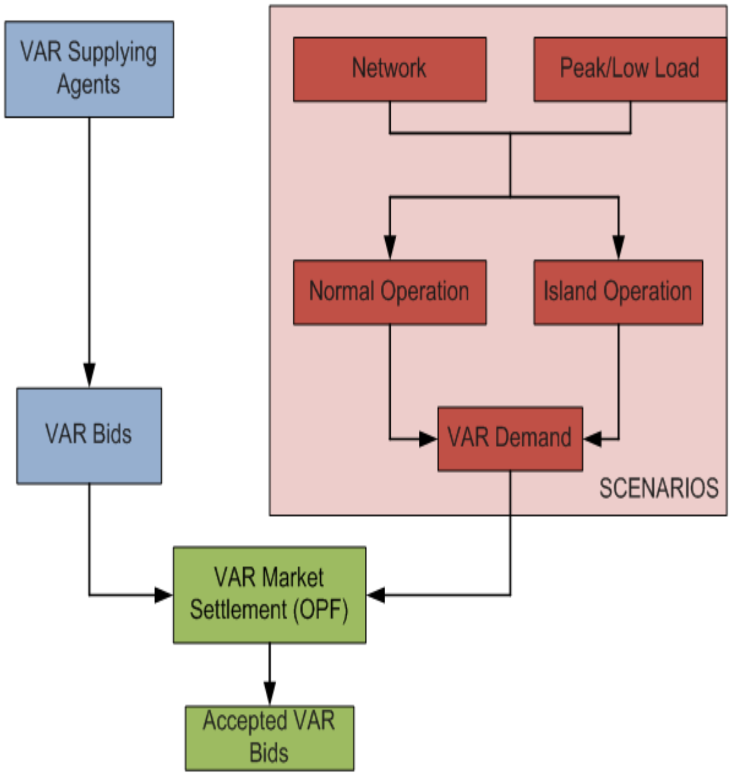
1. MV network energization and synchronization of small islands

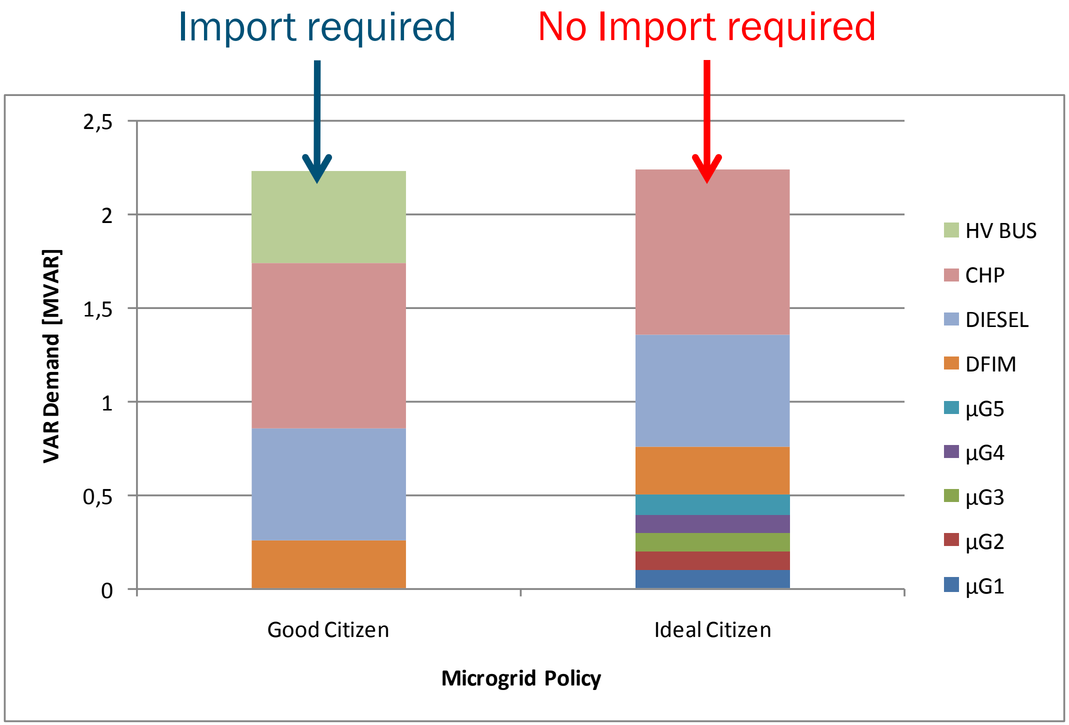
2. Load supply and integration of generation

Ancillary Services Markets

- An Ancillary Services Markets can developed for Voltage Support and Reserves for Normal and Emergency Operation (separated from the main Energy Market)
- An Optimization Algorithm was developed for setting controllers response characteristics in both Energy and Ancillary Services Markets simultaneously
- Functions (existing and new) incorporated in the MGCC and information exchange between CAMC and MGCC regarding Ancillary Services were studied and MicroGrid contribution to voltage violation management has been investigated

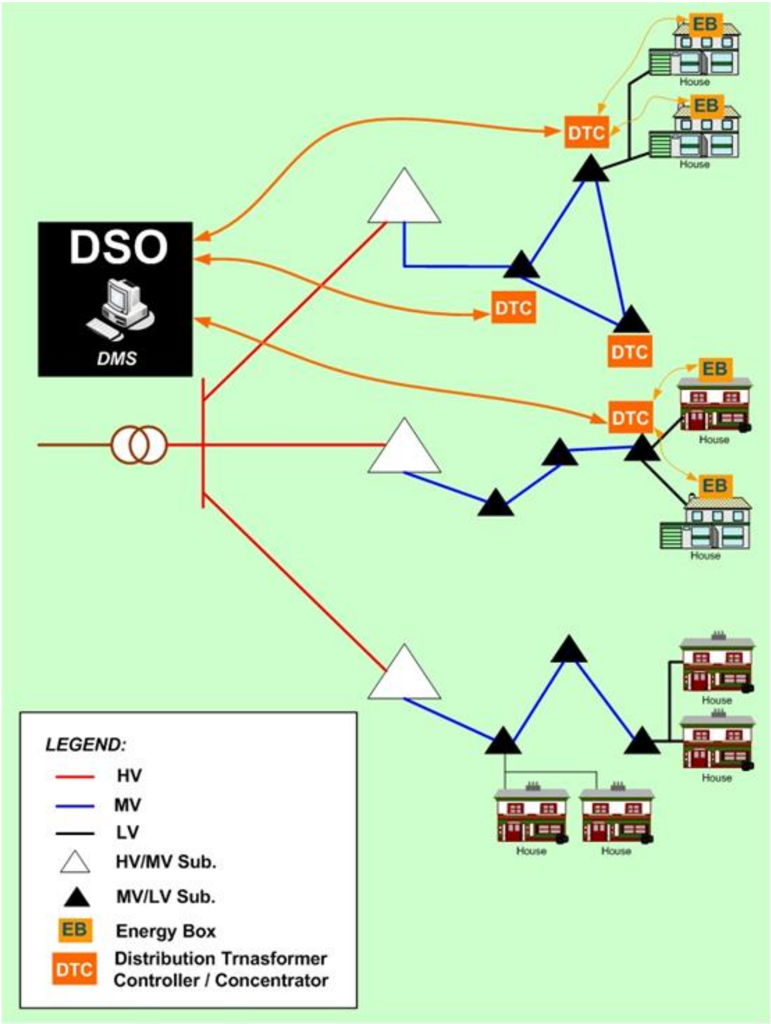
VAR MARKET
Normal and Emergency Mode

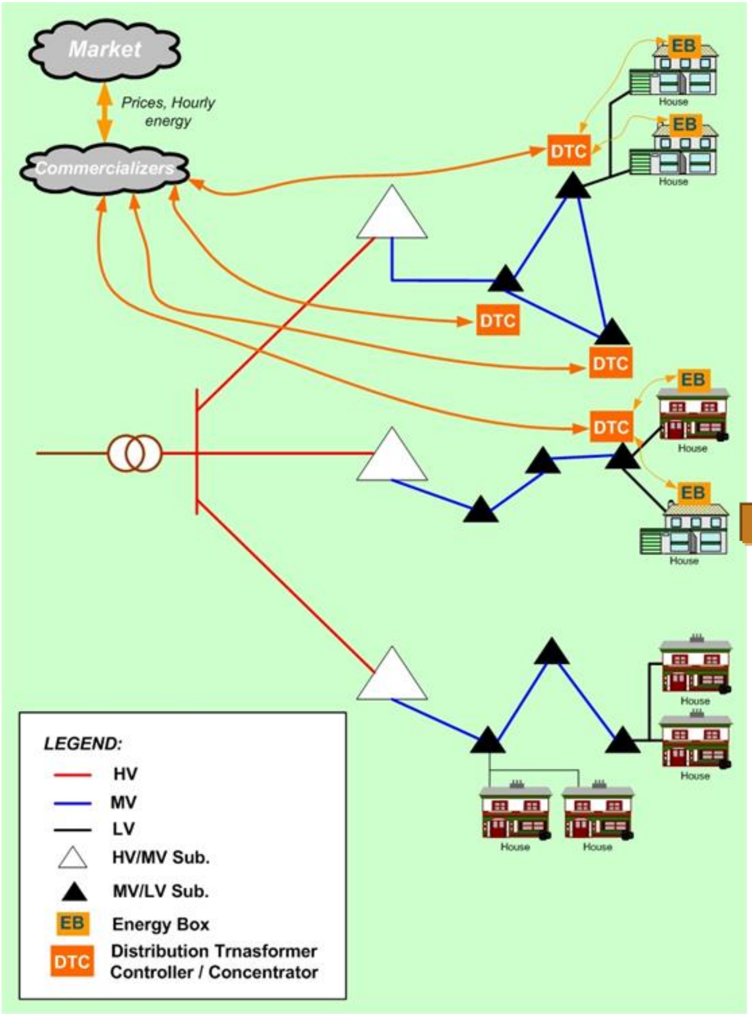




Selected VAR Bids ("Good Citizen" Policy *vs.* "Ideal Citizen" Policy)
Normal Interconnected Operation

SmartMetering infrastructure fostering Microgrids

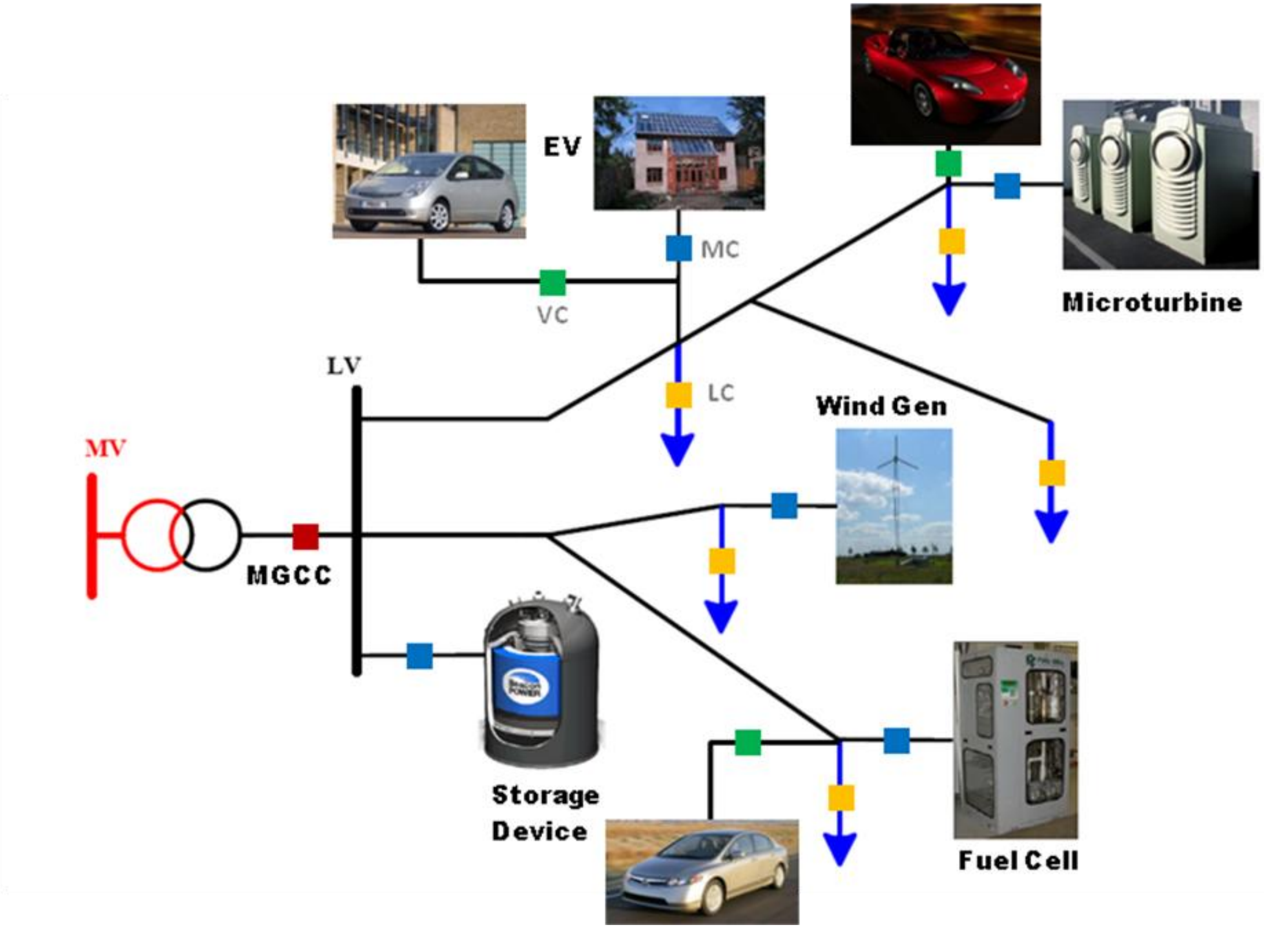




ICTs

Microgrids and Plugged in Electric Vehicles

- **PEV are: controllable charges and mobile storage devices** that **need to be controlled and managed.**



Final Remarks

- The main issues to be dealt with in the future are the deployment of **Smart Metering** as a mean of pushing forward the development of MicroGrids (MG) as an integrated part of the general Smart Grid concept
- **Massive integration of Distributed Storage**, based on mobile storage (Electrical Vehicles) or on stationary storage (fuel cells, regenerative fuel cells, ion-lithium batteries, etc.) needs to be further studied
- A full assessment of **active demand side management** strategies (managed by the DSO) should also be carried out.
- Integrated management of MicroGrids allows the integration of flexible DG, flexible consumption (including EV battery charging – smart charging) and flexible storage. → **Flexibility**
- **Regulatory issues** need to further addressed (quantity of needed flexibility and value of flexibility) for system operation in normal and emergency modes.